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The Skadar/Shkodra Lake Environment

Springer

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Volume 80

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With contributions by

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ISSN 1867-979X   ISSN 1616-864X (electronic)
The Handbook of Environmental Chemistry
ISBN 978-3-319-99249-5   ISBN 978-3-319-99250-1 (eBook)
https://doi.org/10.1007/978-3-319-99250-1

Library of Congress Control Number: 2018956296

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geoecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Contents

Introduction

Vladimir Pešić, Gordan S. Karaman, and Andrey G. Kostianoy

Contents

Abstract In this volume, for the first time, the current knowledge on the environment of the Lake Skadar/Shkodra ecosystem has been brought together in one overview of this unique ecosystem. The last similar book on Lake Skadar/Shkodra was published in 1981. Over the last four decades, a lot of new knowledge about Lake Skadar/Shkodra has been accumulated in various fields of science. Altogether, this book includes 23 chapters and brings together researchers of many disciplines synthesizing the fragmented knowledge on Lake Skadar/Shkodra and its basin in a book which will improve our understanding of this ecosystem and the path toward sustainable and science-based ecosystem management. This book is a basic tool for all scientists interested in the environment of Lake Skadar/Shkodra – in particular for scientists investigating the interaction between the land and the water, between limnology and biota, and between natural and cultural resources. This book is intended for a wider audience as well as for decision-makers, in order to emphasize the necessity of protecting this unique ecosystem, which today is exposed to various forms of anthropogenic impact.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 1–10, DOI 10.1007/698_2018_258,
© Springer International Publishing AG 2018, Published online: 27 April 2018

Keywords Albania, Ecology, Environment, Lake Skadar/Shkodra basin, Montenegro, Natural resources

Lake Skadar/Shkodra is located in the western Balkans, south of the Dinaric Alps, in the northern Mediterranean region. This is the largest lake in the Balkan Peninsula with a surface area that fluctuates seasonally between 353 and 500 km^2. It is a transboundary lake, and approximately 65% of its surface belongs to Montenegro and around 35% to Albania (Fig. 1). The lake extends in a NW-SE direction, parallel to the current shore of the Adriatic Sea coast, and it is approximately 44 km long (Table 1).

The southern and southwestern sides of the lake are rocky, barren, and steep, having bays in which sublacustrine springs are usually to be found [2, 3]. The northern and northeastern shore (Fig. 2) is less steep, and at times of high-water levels, it represents an enormous inundated area, the boundaries of which change as the water levels fluctuate. The largest inflow is from the Morača River, which provides about 63% of the lake's water [4]. Moreover, the Morača River provides the most of the sediments and nutrients that enter the lake, for example, total input to the lake for 2008 were calculated approximately to 50,000 tons of suspended particulate matter, 165 tons of total phosphorus, and 3,200 tons of total nitrogen [5].

The most important tributaries of Lake Skadar/Shkodra enter the lake from the north: the Morača, the Crnojevića (Fig. 3), the Orahovštica, the Karatuna and the Plavnica in Montenegro, and the Rjolska and the Vraka in Albania. As a result of heavy rain over several months, the lower parts of the inflowing rivers fall below the water level of the lake.

The River Buna/Bojana with an outflow on average of 304 m^3/s connects the lake with the Adriatic Sea [4]. The River Bojana is connected to the River Drin (and consequently Lake Ohrid) by the 11-km-long River Drinasa, which represents the major channel of the lower River Drin. The lake's water level fluctuates seasonally from 4.5 to 10.4 m above sea level as a result of the precipitation/evaporation regime over the lake and over its catchment area and lake bathymetry [1]. The monthly mean water levels of Lake Skadar/Shkodra for period 1943–2002 fluctuated as much as 4 m and were highest in the spring and lowest during the late summer [5]. The water in Lake Skadar/Shkodra is renewed 3.5 times a year what corresponds to a water residence time of about 100 days [5].

A characteristic feature of Lake Skadar's water balance is the high inflow from a number of temporary and permanent karstic springs, some of which are sublacustrine in cryptodepressians (the so-called oko). The best known sublacustrine springs are Raduš and Karuč (Fig. 4).

The climate of Lake Skadar/Shkodra basin is Mediterranean. The annual rainfall on the lake is between 1,750 and 3,250 mm [1]. The temperatures in summer are high, giving a high evaporation, while in winter the temperature is low but remains above freezing point [1].

Fig. 1 Map of the Lake Skadar catchment area (modified after [1]). Map prepared by P. Glöer

The exceptional natural values characterized by Lake Skadar/Shkodra represent the basis for the protection of this unique ecosystem. In Montenegro, Lake Skadar/Shkodra has been a National Park (IUCN Management Category II) since 1983, with a surface area of 40,000 ha. The Albanian government (Council of Ministers' Decision, No. 684 dated 02.11.2005) proclaimed the Albanian part of Lake Skadar/Shkodra a "Managed Natural Reserve" (IUCN Category IV). At the international level, since 1995, the Lake Skadar/Shkodra National Park has been included on the Ramsar List (as a wetland area of international significance).

Table 1 Summarized geographical, physiographical, and hydrological characteristics of Lake Skadar/Shkodra (data from [1, 4])

Location	42°03′–42°21′N, 19°03′–19°30′E
Average level of the lake, m a.s.l	6.52
Length (maximum), km	44
Width (maximum), km	14
Depth (maximum), m	8.3
Depth (mean), m	5.01
Volume, km^3	1.75–4.25
Total catchment area, km^2	5,631
Total catchment area in Montenegro, %	81
Total catchment area in Albania, %	19
Catchment area, the mean annual precipitation, mm	2,500
Catchment area, the mean annual air temperature, °C	4–12
Total length of coastline (including islands), km	207
Approximate length of lake outflow (Bojana River), km	42
Climate type	Csa (Koppen)

Fig. 2 The northern shore of Lake Skadar/Shkodra (Photo by S. Popović)

The combination of the abiotic and biotic factors of the Lake Skadar/Shkodra environment and its position in a karst terrain in the outer part of Dinaric Alps resulted in the unique ecological conditions of the Lake Skadar/Shkodra basin,

Fig. 3 The River Crnojevića: the view from "Pavlove strane" (Photo by V. Pešić)

whose value has been recognized beyond national boundaries. These values represent a symbiosis of the natural and cultural values that Lake Skadar/Shkodra has had through history. More than 20 monastery complexes, churches, and other cultural monuments such as the remains of the fortresses from the Middle Ages (at Žabljak Crnojevića) and individual military fortifications (at Grmožur, Lesendro, Besac, and others) indicate the burning history of this area and the importance that it had for the development of society in both Montenegro and Albania.

In the historical sources, Lake Skadar/Shkodra is hardly spoken of as a lake until the fifteenth century. The lake was first mentioned by the Italian humanist Merula [6] who described it as recently formed. Based on historical sources, it can be assumed that in the location occupied by the lake there was a marshland until at least the fifth century A.D. [6]. The Greek geographer Ptolemy does not mention the lake in his description of ancient Illyria, while the Roman geographer Titus Livius mentions a swamp on the site of the modern-day lake. A recent micropaleontological study conducted by Mazzini et al. [7] showed that around 1,200 cal yr. BP (calibrated years before the present), the marshland was transformed into a permanent shallow lake. This process of forming the lake was linked with the continuous sea level rise along

Fig. 4 The Karuč sublacustrine spring (Photo by V. Pešić)

the coastline where the Bojana and Drin rivers flow into the Adriatic Sea [8]. Another process that influenced the formation of the lake was the shifting of the course of the River Drin from its own riverbed. This was the result of repeated flooding events in 1848, 1858, and 1896, which caused the River Drin to breakthrough to the River Bojana, most likely after 1867 [7].

The natural resources and especially the outstanding biodiversity value of Lake Skadar/Shkodra have been exposed to various forms of human activities over the entire history of the lake and its basin. The impact of these activities on the Lake Skadar/Shkodra ecosystem is related to the importance that certain economic activities have had for the development of the local community. On the Montenegrin side of the lake, there are about 40 settlements located within the border of the National Park. Among them, Virpazar and Rijeka Crnojevića are the largest settlements with a population which represents only 4% of the total number of 12,474 inhabitants (according to the Census from 2003) who inhabit the area of the National Park [9]. On the Albanian side, there are about 20 villages, and around half of them are located closer to the lake. The largest city in the lake area is Shkoder, which is also the main economic center in the area with a population of 110,000 [9]. In recent decades, a trend of emigration from rural areas and migration to urban areas, especially to Shkoder and Podgorica, has been evident.

The main economic activities in the area of Lake Skadar/Shkodra include agriculture, fishing (Fig. 5), and tourism. Industrial activity is not very important as a

Fig. 5 Fishing in Lake Skadar/Shkodra in 1974 using a commercial beach-seine net called a "grib" (Photo by O. Vizi)

result of the transition changes in the economies of both Montenegro and Albania after the 1990s. The only factory that has been working for decades within the territory of the National Park on the Montenegrin side of the lake is the fish processing plant in Rijeka Crnojevića. On the Albanian side, the city of Shkoder had various well-developed industrial activities, especially in the processing of tobacco and the production of cigarettes. However, after the events of the 1990s, this industry has been completely destroyed [9].

The situation of fishing, which has historically been one of the most important economic activities in the area of Lake Skadar, has also significantly changed. Fishing was the basic source of subsistence for some settlements around the lake (including Dodoši – Fig. 6, Žabljak and Vranjina on the Montenegrin side and Zogaj and Shiroka on the Albanian side). Lopičić [10] mentioned that in the middle of the eighteenth century, about 2 million kg of fish was caught annually. The Ceklinjani (a historical tribe that inhabited the village of Ceklin) fished up to half a million kilograms of bleak each year, bringing them an annual income of 30–60,000 ducats, which was often the cause of bloody conflicts between the Montenegrins and the Turks around Lake Skadar/Shkodra [11]. The main causes that led to the loss of fishing as the main source of subsistence lie in changes to the working engagement of the local community as well as in the reduction of the fish stock of Lake Skadar/Shkodra.

In recent times, the development of tourism has become an increasingly important form of economic activity and especially the development of excursion tourism –

Fig. 6 Village Dodoši (Photo by S. Popović)

most notably boat rides on the lake [9]. According to a National Park report, the number of tourists who visited NP Lake Skadar increased from about 7,000 in 2004 to 40,242 in 2010.

According to the Strategic Action Plan (SAP) for Lake Skadar/Shkodra [9], the main threats to the environment of Lake Skadar/Shkodra and its basin are (1) pollution (including industrial, municipal, solid, and liquid waste), (2) hunting and fishing, (3) lakeshore development, and (4) water management measures. Additional challenges that face Lake Skadar/Shkodra include [5] (1) increased expansion of tourism, (2) intensification of the agricultural sector, (3) use of the sublacustrine springs of Lake Skadar/Shkodra for the regional water supply of the Montenegrin coastal area, (4) hydropower development of the Drin River in Albania and the Morača Valley in Montenegro [12], and (5) dredging of the Bojana/Buna River to reduce flooding problems.

Numerous multidisciplinary studies that have been undertaken in recent years (see [13] for a review) have highlighted the need to establish an integrated approach to protect the ecosystem of Lake Skadar/Shkodra. This approach, inter alia, requires the establishment of a long-term monitoring system as well as the recognition of the obligations and responsibilities of the key stakeholders involved in the implementation of the measures planned for the protection of Lake Skadar/Shkodra and its basin.

The first continuous studies of Lake Skadar/Shkodra started in 1952 when the Fishing Station of the People's Republic of Montenegro was founded in Titograd (today Podgorica) with the aim of monitoring and scientifically studying waters in

Montenegro and especially Lake Skadar/Shkodra. The fishing station operated until 1965 when it was transformed into the biological station, which worked within the Institute for Biological and Medical Research (from 1973) as part of “Veljko Vlahović” University in Titograd. In the 1990s, the Institute transformed itself into the Department of Biology of the University of Montenegro, and in addition to its scientific work, it took on a role in the education of young biologists and ecologists in Montenegro.

This is the first book in which all the information on scientific research on the Lake Skadar/Shkodra ecosystem is systematized. The last similar book on Lake Skadar, entitled *The Biota and Limnology of Lake Skadar*, was published in 1981 [14]. The latter book summarized the results obtained from 1972 to 1977 within the framework of the project “Limnological Investigations of Lake Skadar” conducted between the Institute for Biological and Medical Research in Titograd and the Smithsonian Institute (USA).

Over the almost four decades since then, a lot of new knowledge has been accumulated in various fields of science about Lake Skadar/Shkodra. This induced a need to bring together the present knowledge about the environment of Lake Skadar/Shkodra and its basin in one overview of this unique ecosystem. Moreover, producing such a comprehensive book has to emphasize the need to protect this unique ecosystem, which today is exposed to various forms of anthropogenic impact.

To achieve this goal, we have brought together hydrologists, chemists, biologists, ecologists, and social science researchers in order to synthase the fragmented knowledge on the Lake Skadar/Shkodra environment in one book which will improve our understanding of this ecosystem, moving toward a sustainable and science-based management approach. As we stated in the abstract, this book is intended as a basic tool for all scientists interested in the Lake Skadar/Shkodra environment – in particular for scientists investigating the interaction between the land and the water, between limnology and biota, and between natural and cultural resources. We would like to thank all our colleagues who took part in the writing and compiling of this book.

Acknowledgments A. G. Kostianoy was partially supported within the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2018-0003). We thank Peter Glöer for preparing Fig. 1 and Saša Popović and Ondrej Vizi for their permission to use their photos.

References

1. Lasca NP, Radulović V, Ristić RJ, Cherkauer DS (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, D.C., USA, pp 17–38

2. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
3. Jacobi GZ (1981) Zoobenthos from sublacustrine springs in Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, D.C., USA, pp 251–263
4. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82
5. Skarbøvik E, Perović A, Shumka S, Nagothu US (2014) Nutrient inputs, trophic status and water management challenges in the transboundary Lake Skadar/Shkodra, Western Balkans. Arch Biol Sci 66(2):667–681
6. Merula G (1474) Bellum scodrense. Gabriele di Pietro, Venezia, 24 pp
7. Mazzini I, Gliozzi E, Koci R et al (2015) Historical evolution and middle to late Holocene environmental changes in Lake Shkodra (Albania): new evidences from micropaleontological analysis. Palaeogeogr Palaeoclimatol Palaeoecol 419:47–59
8. Uncu L (2012) Holocene landscape changes of the Lezha region: a contribution to the palaeogeographies of coastal Albania and the geoarchaeology of ancient Lissos. Marburger Geographische Gesellschaft, Marburg, Lahn
9. APAWA and CETI (2007) The strategic action plan (SAP) for Skadar/Shkodra Lake. GEF, World Bank, LSIEMP Shkodra-Tirana-Podgorica, Tirana, Podgorica, 72 pp
10. Lopičić S (1931) Ceklinski ribolovi, Ilustrovani zvanični Almanah–Šematizam Zetske banovine, 84 pp
11. Jovićević A (1909) Skadarsko jezero i ribolov na njemu. Srpski etnografski zbornik 13:157–257
12. COWI (2009) Strategic environmental impact assessment for detailed spatial plan for hydro power projects (HPPs) on the Morača River. Norwegian Water Resources and Energy Directorate on Behalf of the Ministry of Economy, Podgorica
13. Vukašinović-Pešić V, Blagojević N (2018) Metal pollution: evidences from plants, aquatic invertebrates and fishes from the Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra environment. Springer International Publishing AG, Cham, Switzerland
14. Karaman GS, Beeton A (eds) (1981) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, D.C., USA

The Physical and Geographical Characteristics of the Lake Skadar Basin

Goran Barović, Velibor Spalević, Vladimir Pešić, and Duško Vujačić

Contents

Abstract Lake Skadar/Shkodra is the largest lake in the Balkan Peninsula, located in the Western Balkans with approximately 65% of its surface belonging to Montenegro and around 35% to Albania. The lake consists of two parts which correspond to the two circulation systems within the lake: the smaller part, Vučko blato, in the northwest and the larger, main part of the lake called Velje blato to the southeast – these two parts are connected by a narrow opening (of about 50 m in width) at the south end of the causeway at Vranjina.

The Lake Skadar basin is unique in its physical and geographical characteristics due to its position in the karst terrain of the *Visoki Krš* tectonic zone in the outer part of the Dinaric Alps. This region is characterized by a high degree of karstification, including various underground karst forms, among which the caves belonging to the so-called system of the Cetinje Caves (Cetinje, Obod, and Lipa Caves) and the Trnovska Caves (Grbočica, Bobotuša, and Spila) are the most famous. The Lake Skadar transboundary area is home to around half a million people, and it is economically the most important part of Montenegro that is home to around one third of the

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 11–24, DOI 10.1007/698_2018_276,
© Springer International Publishing AG 2018, Published online: 27 April 2018

total population. Today this region faces a number of environmental problems related to inappropriate spatial planning, pollution, and regional climate change.

Keywords Geogenesis, Geographical features, Geomorphology, Lake Skadar/Shkodra basin, Speleological objects

1 Introduction

Lake Skadar/Shkodra is the largest lake in the Balkan Peninsula. It is a trans-border lake, the surface area of which fluctuates from 350 to 500 km^2, with approximately 65% belonging to Montenegro and around 35% to Albania [1]. The lake is located south of the Dinaric Alps, in the northern Mediterranean region, and it is a key geomorphological and hydrological element of the Inland Depression geomorphological zone [2] (Fig. 1a). The Lake Skadar catchment area covers 5,631 km^2, of which around 81% belongs to the territory of Montenegro, while the rest belongs to Albania [3]. Lake Skadar has several tributaries that flow into the lake, of which the River Morača is the most important and contributes 63% of the total water inflow to the lake [3]. The lake has one outlet, the River Bojana, which after a few kilometers receives water from the River Drinasa/Drinjača which in turn represents the major channel of the lower River Drin/Drim.

The lake has a Dinaric direction, being oriented northwest-southeast, and is elongated with an amorphous appearance, whose longer axis reaches a length of about 44 km, while the lake's width is about 14 km [1]. Its coastline including the islands is 207 km long, with a shoreline development index value of about 3.0 [4]. Parts of its bottom, which is a continuation of the Zeta Plain, in some places descend below sea level and represent a crypto-depression. The southern and southwestern sides of the lake are rocky and steep, having bays along the coast of Rumija (near Štitar, Bobovište, Bljac, Murići, and Raduša). The largest bay is Hotski Bay, in the northeastern part of the lake, which is almost symmetrically shared between Albania and Montenegro. Many of these bays contain sublacustrine springs (okos) [3, 4]. The northern and northeastern shore is less steep, and at times of high water levels, it represents an enormous inundated area [1].

The part of Lake Skadar, which extends from the mouth of the River Crnojevića toward the southeast to the line connecting Cape Tanki Rt to Lesendro Island and the Kralj plate on the island of Vranjina, is called Fučko (or Vučko) blato (named after Mount Fučka). The rest of the lake from the mentioned line toward the southeast is called Velje blato. The northeast part of the lake around Hum Bay is called Humsko blato, after the hill of Hum, to which it stretches [5]. Malo blato, with a shore length of about 10 km [6], was formed from a river transformed into a lake next to Lake Skadar [7]. During a high water level, Malo blato represents a bay of Lake Skadar, while during a low water level period, it is an isolated water body which is connected to Lake Skadar by the River Karatuna.

Biogeographically, Lake Skadar belongs to the Mediterranean region which is primarily characterized by the Mediterranean climate, with hot, dry summers and humid, cool winters [8]. The Mediterranean region harbors more than half of the habitat types listed in the Habitats Directive. At the level of Lake Skadar, there

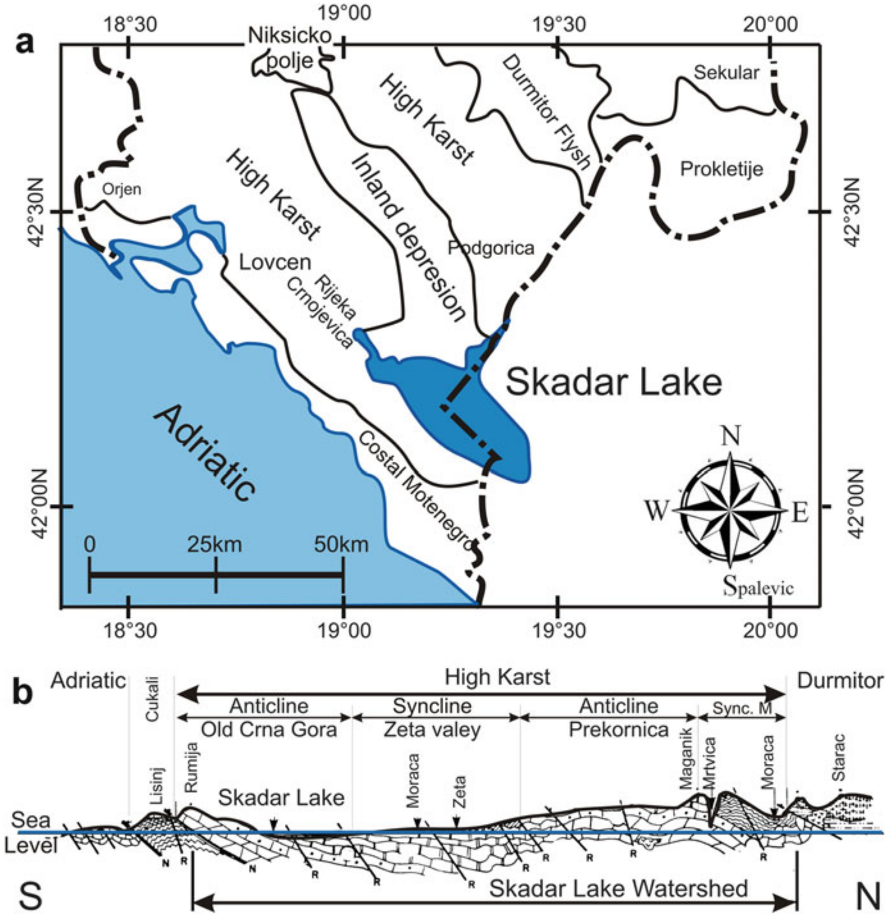

Fig. 1 (**a**) Geomorphological regionalization of the Lake Skadar catchment area (modified after [2]); (**b**) geological cross section of the Lake Skadar watershed (modified after [4])

are 23 habitats listed by the Annex I of the Habitats Directive including two priority habitat types: 6220 (pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*) and 91AA (Eastern white oak woods) that are in danger of disappearing at the level of the EU as a whole [9].

2 Geomorphological Characteristics of the Lake Skadar Basin

Geomorphologically, Montenegro can be divided in seven regions [2]. Lake Skadar is located in the Inland Depression which includes four zones starting from the high polje of Nikšić (1), the valley of River Zeta (2), the plain of Podgorica formed on the debris fan of the River Morača (3) and Lake Skadar (4) [2]. Lake Skadar is located in the lowest part of the Inland Depression zone (Fig. 1). This geomorphological zone represents one of the largest karst depressions in the area of the Dinaric Alps and includes the system of the karst depressions forming the Skadar basin – the Zeta valley, the Bjelopavlići valley, the Nikšić polje, and the Duga gorge [3]. The Inland Depression zone is surrounded by the High Karst zone, geomorphologically the largest region in Montenegro which consists mainly of Cretaceous limestone [10]. This region is characterized by phenomena, processes, and shapes that are characteristic for holokarst and includes the most typical forms of karst relief – karrens, clefts, sinkholes (dolines), uvalas, poljes, pits, and caves. The famous Serbian geographer Jovan Cvijić [11] wrote: "There is no deeper or more entire karst in the world than the Herzegovinian–Montenegrin karst between the valley of the Neretva, the Skadar mud flats, and the Adriatic Sea. Not a drop of water drains off from its surface, all water instead sinking into pits, ponors, blowholes, and fissures." Indeed, despite the high precipitation which reaches 2,000 mm/year [12], water bodies such as springs and rivers are extremely rare in this zone, and most of them are intermittent and/or ephemeral in character. This is especially true for the karst plateau, which extends southwest from the Inland Depression zone.

Along the boundary of the High Karst zone with the coastal region, there is a chain of mountains composed of Mts. Orjen (1,895 m), Lovćen (1,749 m), Sutorman (1,180 m), and Rumija (1,595 m). This area is characterized by the formation of various underground karst forms (see below under Speleological Objects). On the other hand, the characteristic features of the part of the karst plateau that extends northeast include the canyons of the Rivers Morača, Mrtvica, Mala Rijeka, and Cijevna in the Montenegrin part of the Lake Skadar catchment and the Rivers Thata and Rrjoli in the Albanian part of the catchment.

2.1 Speleological Objects

Lake Skadar is located in marked karst zones, which are characterized by the formation of underground karst forms. Among the numerous speleological objects located in the area of the Lake Skadar basin, the Cetinje, Obod, and Lipa Caves stand out. They are part of the so-called system of Cetinje Caves [13]. A second group of caves that are characterized by their significance are those of Grbočica, Bobotuša, and Spila that are located in the western part of Lake Skadar basin in the hamlet of Trnovo and near the village of Komarno between Virpazar and Rijeka Crnojevića.

2.1.1 Cetinje Cave

Cetinje Cave (Montenegrin: Cetinjska pećina) is located in the heart of Cetinje between the Cetinje Monastery and Bogoslovija High School. It belongs to a group of complex speleological objects, with more than 1,700 m of cave channels that have so far been explored with four main and many secondary channels that are interconnected, located above and below the bottom of Cetinje field.

The formation of the Cetinje Cave included three phases [13]: in the first phase, the upper gallery was formed, connected to the surface by the cave channels. In the second phase, there was a period of further evolution of the cave when the lower gallery was formed, the main channel was formed and expanded, and the connection with the upper gallery was made. The third phase of the formation of the Cetinje Cave represents the period of the filling of the Cetinje field bottom, lowering the flow of the River Cetinje to even lower levels and the formation of the lowest parts of the cave channel that extend toward the southeast. The lowest parts of the Cetinje Cavern descend to about 50 m below ground level [13]. The origin of the Cetinje Cave system coincides with the stepwise descent of the River Cetinje deeper into the earth. Petrović [13] stated that the River Cetinje was formed by two main source branches: the River Lovćen and the River Cev. According to this author, the process of the disappearance of surface flows followed by the valley's karstification occurred at the end of the Pliocene [13].

The chemical sediments indicate that the galleries of the Cetinje Caves are at different stages of development [13]. The presence of powerful beryllium and calcite-frozen cascades, in addition to mechanical sediments, indicates that the upper gallery is in the final phase of fossilization. Some of its channels are completely filled with chemical sediments, and the frozen cascades and columns are separated from the other rooms. In the lower gallery, through which occasional streams still flow, the process of the excretion of chemical sediments is only in the initial phase, while in the lowest gallery, there are no such sediments [13]. Based on this, it has been concluded that most of the Cetinje Cave galleries are at the stage of filling and the lowest is at the stage of an intense erosion process.

The Cetinje Cave has been arranged for tourist visits, but unfortunately the local community did not persist in the realization of this project. Today, the Cetinje Cave complex is in a very bad condition with ruined infrastructure and broken jewelry (Fig. 2), while the cave entrance is filled with waste material. To improve the

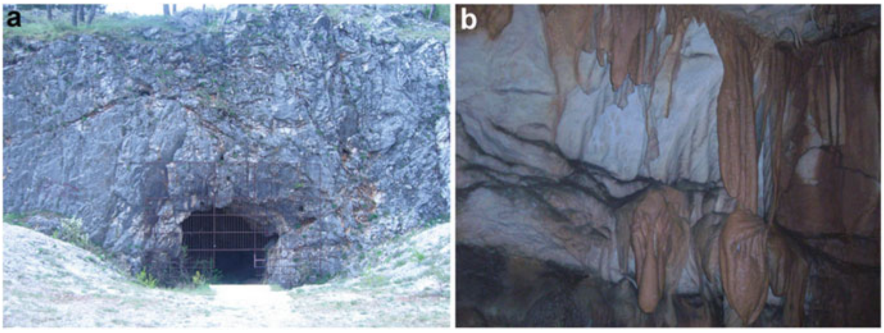

Fig. 2 (**a**) Entrance of the Cetinje Cave; (**b**) broken jewelry in the Cetinje Cave. Photos by G. Barović

situation, it is necessary to close the cave in order to further protect the facility itself and start restoration activities that will return the cave to its original state.

2.1.2 Lipa Cave

Lipa Cave (Montenegrin: Lipska pećina) is located in the hamlet of Lipa in the vicinity of Dobrsko, about 5 km from Cetinje. This is the first cave in Montenegro which was permanently opened (from 13 July 2015) to tourists (Fig. 3). The first written mention of the cave was made by Austen Henry Layard, an English researcher who visited the cave in 1839 [14]. The cave was formed in the rock mass between Cetinje field and the Dobrska ravine [13]. It can be classified among floor speleological objects because the channel's web is very well developed. The main channel through which used to run a large amount of water has lost its basic function, i.e., the water has found a second, "lower" level or floor, and moved its current somewhat lower creating new channels. So far, the length of the cave channels that have been explored is over 3.5 km, while the vertical distance between the highest and the lowest point in the cave system is over 300 m [13]. The basic orientation of the whole system is southeast-northwest, which corresponds to the

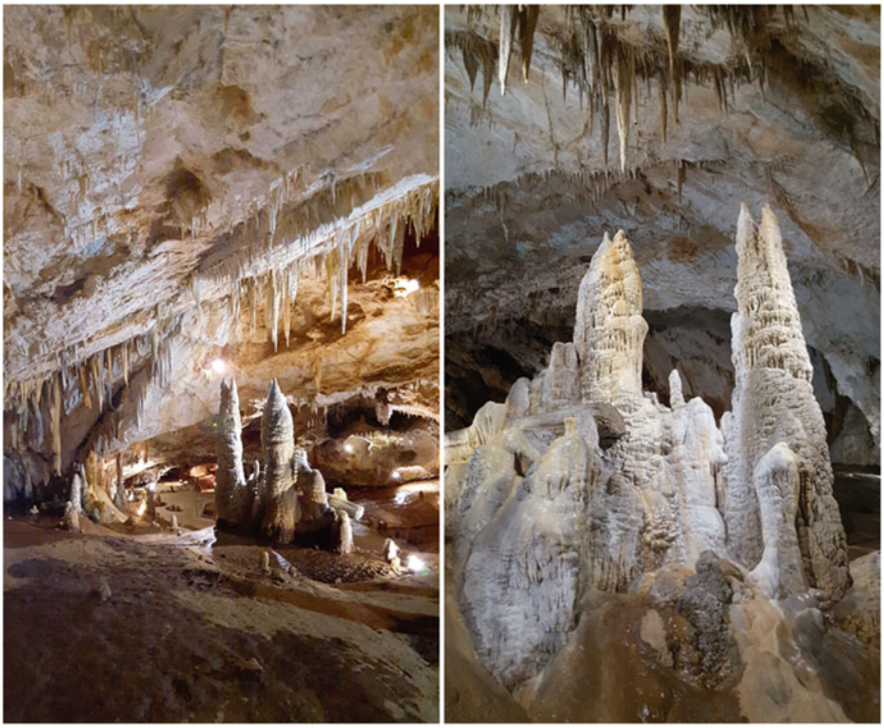

Fig. 3 Lipa Cave. Photos by V. Pešić

direction of the rock mass in which it was created but also the direction of the water coming from Cetinje field that created it. Several units have been distinguished in the cave: entrance channels, the Njegos Hall, the Crystal Hall, corridors with stone blocks, and others.

Lipa Cave, as part of the system of Cetinje Caves, was created by the flow of the River Cetinje [13]. In spring and autumn, whenever there is more precipitation in the zone of Cetinje field, in the Njegos Hall, there are lakes with tributaries and an underground island each year. Today's channels of the Lipa Cave flood only on occasions when the water flow is very significant and the underground stream of the river cannot receive all the amount of water that comes in. In the cave there is plenty of ornamentation represented by frozen cascades, bigren tubs, lakes, and so on (Fig. 3). Lipa Cave is a *locus typicus* for several endemic species of invertebrates [15], e.g., *Bogidiella montenigrina* (Amphipoda), *Neobisium umbratile* (Pseudoscorpiones), *Folkia mrazeki* (Aranea), *Anthroherpon absoloni*, and *Hadesia zetae* (Coleoptera).

2.1.3 Obod Cave

Obod Cave (Montenegrin: Obodska pećina), situated in the spring zone of Rijeka Crnojevića, belongs to a group of simple speleological objects with a simple 340 m long channel. The cave entrance (Fig. 4) has a height of 14 m and a width of 12 m [13]. The main channel, along its entire length, has larger dimensions than the entrance part. The direction of the channel is southeast-northwest. At the end of the channel, there is a hollow-shaped hall in which Lake Obod is located. The length of the lake is about 50 m and the width is about 20 m [13]. In the period when less

Fig. 4 Entrance of Obod Cave. Photo by G. Barović

water flow is poured from the lake, it is lost among the large blocks of rocks that cover the floor of the main channel, while in periods of greater water flow, it flows from the cave to the riverbed. There is connection between Lake Obod in the cave and the spring. The cave is characterized by a very variable flow that ranges from a minimum (which occurs in November or December) of 0.24 m^3/s to a maximum (which occurs in March or April or rarely in February) of 46 m^3/s [16]. Moreover, the water from Lake Obod also reaches spring Suvodoliki, on the right side of the valley, and is located in the same hydrological system [17]. Fascinatingly, there is almost no cave ornamentation. The appearance of stalagmites in the cracks and cavities has been recorded in several places [13].

Obod Cave is a *locus typicus* for several endemic species of invertebrates [15], e.g., *Metohia carinata*, *Typhlogammarus mrazeki* (Amphipoda), *Sphaeromides virei montenegrina* (Isopoda), *Chaetonotus antrumus* (Gastrotricha), *Plagigeyeria montenigrina*, *Saxurinator hadzii*, and *Spelaeodiscus obodensis* (Gastropoda).

2.1.4 Grbočica Cave

Grbočica Cave belongs to the group of floor speleological objects because the channels are provided on several levels. The cave entrance is rectangularly shaped, about 8 m in width and up to 2 m in height [18]. The total length of the explored channels exceeds 2.5 km. Characteristically, the upper levels of the channel are completely dry, and without any hydrological function, the middle channel level, during heavy precipitation, has an occasional current, while the lowest level has a constant flow with variable volumes. At the higher levels, there is almost no ornamentation, while at the lower levels, the ornamentation is plentiful and of various shapes and sizes. In the second part of the main channel, the columns are especially beautiful and 12–15 m high [18]. There are also a number of frozen cascades, stalactites, and other features. Almost all the channels are covered with stone blocks, of different dimensions, that can slow down movement. The vertical difference in the object is about −120 m, while the highest recorded channel width is 35 m and the ceiling height is 28 m [18].

2.1.5 Bobotuša Cave

Bobotuša Cave is much smaller than Grbočica Cave. The length of the explored channels is about 470 m. The entrance to the cave is easier to locate because it is lower and less masked by vegetation than is the case with Grbočica Cave. The cave entrance is rectangular in shape although somewhat wider than that of the latter cave. The entrance is about 2.5 m in height and 15 m in width [18]. The entire channel has a general direction of delivery toward the west and is of larger dimensions. In the middle of the channel, there is a round-shaped hall with a length of 40 m and a width of 30 m which continues leading to another 15–20 m wide channel. The maximum width of the channel is 32 m, and the height is 16 m; its bottom is covered by large blocks or large quantities of clay [18]. The entrance of the cave is completely dry, the central part has an occasional hydrological function, while at the very end, several ponds are present [18].

2.1.6 Spila Cave

The lowest and youngest among the Trnovo Caves is Spila Cave [18]. It is a hydrologically active cave because a constant flow comes out of it. During the year, the level of water is variable, so at times of the greatest flow, it can cause problems for the local population. Water from the cave is used by the local population as a drinking source and for the irrigation of the agricultural areas at lower levels. The length of the explored channel is about 270 m, with a height difference of 11 m, a maximum channel width of 5 m, and a height of 4 m, while the altitude difference is 11 m [18]. The cave channel is hydrologically active all along its length and functions as a spring almost year-round.

3 The Geological Characteristics of the Lake Skadar Basin

Based on the available literature [3, 4, 17] in the wider area of Lake Skadar, four geotectonic zones can be distinguished: (1) the Paraautochton (Adriatic–Ionian) zone which extends along the coast of the Adriatic Sea; (2) the Budva–Cukali zone, situated between the Paraautochton and *Visoki Krš* zones; (3) the Dinaric zone of High Karst (the *Visoki Krš* zone) which lies between the Budva–Cukali zone and internal zone of the Dinaric Alps; and (4) the Durmitor zone (or internal zone of the Dinaric Alps) which lies to the northeast of the *Visoki Krš* zone and occupies the northern part of the territory of Montenegro and Albania [4, 19]. Lake Skadar lies in the *Visoki Krš* zone which is the largest geotectonic unit, composed of Mesozoic (Triassic, Jurassic, and chalk) sediments (dolomite and limestone), and characterized by a high degree of karstification [20].

The southwestern parts of the Lake Skadar basin belong to the anticlinorium of the Katun Karst (Old Montenegro), whose continuation is Mount Rumija, which, toward the northeast, passes into the central synclinorium [20]. Further to the northeast, on the synclinorium of the central part, is the anticlinorium of Žijova, Prekornica, Vojnik, and Golija (Fig. 1b). Along the southwestern anticlinorium, the dolomite zone extends along the coastal sides, and Paleozoic shales, water-resistant rocks, which form a considerable part of the deep karst, orientate the water toward Lake Skadar [20]. The northeastern edge of the basin is a considerable area of the sediments of the Durmitor flysch, which, being less permeable, also orientate the waters toward Lake Skadar. The structure of the stone caused the layers of rocks to fall toward the northeast, which, with the gradual slope of the central valley toward the southeast, significantly influenced the underground and surface circulation of the water to be oriented in that direction, i.e., toward Lake Skadar [20]. Since Neogene sediments (clays, sandstones, and marls) are found only in the deepest parts of the basin (e.g., in the well in the village of Gostilj in the Lower Zeta region [21]), the largest part of the basin, as well as the surrounding sides, is built from limestone and chalk [20]. At the contact of limestone with less permeable rocks (dolomites, paleogenic flysch, and Durmitor flysch), from which the rivers deposited small-scale material and created inundation levels, and in the presence favorable climatic conditions, as was the case at the end of the Neogene (i.e., high temperatures and abundant precipitation), an intense process of marginal corrosion and expansion of the plateau took place. On the plateau, the back parts are constructed of less clear limestone or dolomite, which still runs from the plain as hills and hummocks [20]. In the largest part of the Podgorica-Skadar basin over the limestone ravine, there lie the fluvioglacial deposits of the Pleistocene [20].

Based on recent studies, the Lake Skadar basin and Zeta-Skadar depression were formed due to the complex folding and faulting within the northeastern wing of the Old Montenegro anticlinorium (the *Visoki Krš* zone) during the Cenozoic period [21]. On the other hand, the Lake basin was formed as the result of sinking blocks in the Neogene period or even the Paleogene [21]. During the younger Pliocene, the connection between Lake Skadar and the sea was interrupted. As stated by Radulovic [21], the basic contours of the Zeta-Skadar depression are the results of endogenic factors during the Mesozoic and particularly the Cenozoic. However, in addition to orogenic and epirogenic processes (endogenic factors), it is worth highlighting the impact of exogenic forces on shaping the present contours of the Zeta-Skadar depression and the lake basin [21].

4 The Bathymetric Characteristics of Lake Skadar

The main bathymetric characteristic of Lake Skadar is the presence of two circulation systems within the lake [4]. This is the result of the disruption of the natural pattern of the lake-water circulation by the causeway at Vranjina which divides the lake into two separate water parts, the smaller part (Vučko blato) to the northwest and the larger, main part of the lake to the southeast [4]. These two parts are connected by a narrow opening at the south end of the causeway of about 50 m in width [4].

Lake Skadar is a shallow lake with a mean depth of around 5 m, while the maximum depth (without the sublacustrine springs) is 8.3 m [4]. It is worth mentioning that over an area that covers 44.3% of the lake surface (165 km^2), the lake's depth extends below sea level and represents a crypto-depression [4]. The greatest depths in Lake Skadar were recorded at the sublacustrine springs (called "oko," Eng. "eye") which are underwater dolines (depressions) whose bottom extends deep below the general lake floor. The deepest sublacustrine spring, at Raduš, extends 72.5 m below the average lake level [22].

Lasca et al. [4] proposed the classification of the sublacustrine springs of Lake Skadar into three groups. The first group includes numerous sublacustrine springs along the southwestern shore (i.e., Raduš, Krnjice, the springs near the island of Starčevo, Mrčiluka, Bobovište, Gradac, Smokvica, Tophansko oko, Moračnik, Bisag, and Ckla) that lie on the fault line along the tectonic graben which runs at the base of Mount Rumija and Mount Sutorman. The second group includes the springs of Malo blato and Podhum Bay (Vitoja, Tonudoko, Ploče) that lie in the direct vicinity of the littoral area of the flooded area. The third group includes the springs which are located in the bed of the lake's main tributaries, the Morača and the Crnojevića. This spring group includes the "Manastirsko oko" sublacustrine spring in the bed of the River Morača below the monastery on Vranjina and the spring called "Grab" in the bed of the River Crnojevića located below the village of the same name.

Sublacustrine springs are of great importance for commercial fishing [23]. Based on their ichthyofaunal characteristics, Marić and Kažić [24] provided a more traditional division, and in the first group of "okos," they include the springs in the northwestern part (towards the mouth of Rijeka Crnojevića) called the "Ceklin Fishing" (Montenegrin: Ceklinski ribolovi); among them the Karuč spring stands out, while the second group consists of the springs around Malo blato, and the third group includes the springs that lie along the southwestern part of Lake Skadar.

5 The Socioeconomical Characteristics of the Lake Skadar Basin

The Lake Skadar transboundary area is home to about 500,000 people who mainly live in the Montenegrin cities of Podgorica, Nikšić, and Cetinje and in Shkodra in Albania [7]. This is, economically speaking, the most important part of Montenegro, home to about one third of the national population, most of whom live in the two largest cities, the capital Podgorica and Nikšić. The region shows a permanent increase of population in each census conducted after World War II [25]. At the level of Lake Skadar, more than 100,000 people live presently around the Albanian side of the lake, most of them in Shkodra. On the other hand, according to the census from 2003, the total number of inhabitants in settlements belonging to Lake Skadar National Park in the Montenegrin part of the lake was 12,474 [7]. Only a small proportion of around 4% of this population prefers to remain in the urban settlements such as Virpazar and Rijeka Crnojevića, and most people live in rural settlements [7]. The population showed a decline in size in the park area in the 1990s, but after 2005 there has been a reversal in the trend, mainly as a result of the development of tourist activities [26].

The city of Shkodra is the main economic and industrial center of this region of Albania, situated on the southeastern shore of the lake, with a surface area of about 30 km^2 and a population of 110,000 [26]. The city possesses various industries which include food processing, textiles and clothing, lumber, oil refineries, cement, chemicals, and basic metals. However after the 1990s, most of the industries, especially the processing of tobacco and the production of cigarettes, went into significant decline [26]. Shkodra is also an important fishing center. The most important activities in the Albanian part of the lake, apart from industrial processes, include agriculture, stockbreeding, fishing, and tourism [26].

The two main economic activities within the Lake Skadar National Park are tourism and agriculture with fisheries [26]. Agriculture dominates on the periphery of the lake, especially in the Zeta Plain, which is also the most populated part of the region. The alluvial soil, which is the highest-quality agricultural area, covers about 17,000 ha on the flat hinterland part in the Zeta Valley region [26]. Fishing is another major activity around the shores of Lake Skadar, but in recent times it has lost significance in comparison with tourism, which is becoming an increasingly important form of economic activity, especially on the Montenegrin side of the lake [1].

The region of Lake Skadar faces a number of environmental challenges. Most of these issues are related to inappropriate spatial planning, especially around the Albanian part of the lake, the impact of pollution, overfishing, and other types of anthropogenic pressure that affect local biodiversity (as is discussed in [27]). These pollutants mainly originate from industrial waste in the Montenegrin part and the sewage of the city of Shkodra in the Albanian part of the lake [28]. On the Montenegrin side, there are no polluting industries within the Lake Skadar National Park, and the only industrial impact is provided by the fish processing plant in Rijeka Crnojevića. However there are some heavy industries outside the border of the national park such as the KAP (an aluminum factory) in Podgorica and the steelworks in Nikšić, which are the main industrial sources of pollutants in the lake.

References

1. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
2. Frankl A, Lenaerts T, Radusinović S, Spalević V, Nyssen J (2016) The regional geomorphology of Montenegro mapped using land surface parameters. Z Geomorphol 60(1):1–14
3. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82
4. Lasca NP, Radulović V, Ristić RJ, Cherkauer DS (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian Institution, Washington, pp 17–38
5. Radojičić B (2005) The waters of Montenegro. Faculty of Philosophy, Institute of Geography, Nikšić
6. Burić M, Radulović M (1983) Skadarsko jezero – najveći hidrografski objekat kopna SR Crne Gore. Skadarsko jezero. In: Zbornik radova, CANU–Naučni skupovi, Titograd, vol 9, pp 37–44
7. Keukelaar F, De Goffau A, Pradhan T, Sutmuller G, Mišurović A, Ivanović S, Uskokovic B, Hetoja A, Haxhimihali E, Prifti A, Kapidani E, Kashta L, Gulan A (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515, Podgorica. Royal Haskoning, Nijmegen, 111 pp

8. EEA (2015) European Environment Agency – biogeographical regions. http://www.eea.europa.eu/data-and-maps/data/biogeographicalregions-europe. Assessed 15 Dec 2017
9. Hadžiablahović S (2018) The diversity of the flora and vegetation of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
10. Živaljević M (1989) Explanation for geological map of SR Montenegro, scale 1: 200.000. The Institute for Geological Exploration of SR Montenegro
11. Cvijić J (1926) Geomorfologija II. Srpska Akademija Nauka i Umetnosti, Beograd, 506 pp
12. Kilibarda Z (2001) Unusual floods in high karst plateau of Montenegro, Yugoslavia. In: Geological Society of America annual meeting, Geological Society of America abstracts with programs, Boston, 5–8 Nov 2001
13. Petrović J (1982) Cetinjska cave. Institute of Geography, PMF, Novi Sad, 37 pp
14. Lipska Pecina – Lipska Cave. Show caves. http://www.showcaves.com/english/misc/caves/Lipska.html. Accessed 13 Jan 2018
15. Pešić V, Karaman G, Sket B (2018) The diversity and endemism of aquatic subterranean fauna of the Lake Skadar basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
16. Kolicka M, Gadawski P, Dabert M (2017) A new species of freshwater Chaetonotidae (Gastrotricha, Chaetonotida) from Obodska Cave (Montenegro) based on morphological and molecular characters. Eur J Taxon 354:1–30
17. Bešić Z (1969) Geology of Montenegro, book II, karst of Montenegro Institute of Geological Research of Montenegro, Titograd, 109 pp
18. Lješević M (1981) Report on research of Trnovo Cave. Association of Speleological Organizations of Serbia, Belgrade
19. Mirković M, Živaljevicć M, Đokić V, Perović Z, Kalezić M, Pajović M (1985) Geological map of Montenegro 1:200,000. The Republic Self Managing Community of Interest for Geological Exploration of Montenegro, Titograd
20. Radojičić B (1996) Geography of Montenegro – natural basis. University of Montenegro, Nikšić
21. Radulović V (2007) Geogenesis of the Skadar Lake. In: Mijušković M (ed), Prirodne vrijednosti i zaštita Skadarskog jezera. CANU, Naučni skupovi, vol 44, pp 77–92
22. Radulović M (2018) Hydrogeology of the Skadar Lake basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
23. Marić D (2018) The ichthyofauna of Lake Skadar/Shkodra: diversity, economic significance, condition and conservation status. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
24. Marić D, Kažić D (1990) Kvalitativno – kvantitativni sastav ihtiofaune sublakustričnih izvora Skadarskog jezera u zimskom periodu. Glasnik republ zavoda zašt Prirode-Prirodnjačkog muz 23:85–96
25. Mugoša R (2008) Spatial plan of Montenegro until 2020. Ministry of Economic Development, Podgorica
26. APAWA & CETI (2007) The strategic action plan (SAP) for Skadar/Shkodra Lake Albania & Montenegro. GEF, World Bank, LSIEMP, Shkodra, Tirana, Podgorica, 72 pp
27. Pešić V, Karaman GS, Kostianoy AG, Vukašinović-Pešić V (2018) Conclusions: recent advances and the future prospects of the Lake Skadar/Shkodra environment. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
28. Vukašinović-Pešić V, Blagojević N (2018) Metal pollution: evidences from plants, aquatic invertebrates and fishes from the Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham

Hydrogeology of the Skadar Lake Basin

Milan M. Radulović

Contents

Abstract The Skadar Lake basin belongs to the Dinarides mountain chain, which is well-known for classical karst terrains. In this area, we find a variety of karst phenomenon, from minor landforms (karren) to large karst depressions (poljes) on the surface, as well as networks of various karst conduits and caves underground. Also, almost all hydrogeological phenomena are present in this area (typical karst springs, sublacustrine springs, intermittent springs, swallow holes and estavelles). In addition to the inflow of surface water, Skadar Lake is also recharged directly by groundwater. It flows out through numerous sublacustrine springs distributed along the littoral zone. The assessed inflow of groundwater to the lake amounts to around 55 m^3/s (17% of the total water budget). If we take the mean specific yield as a comparison parameter, the Skadar Lake basin represents one of the richest basins of fresh water in the world (54 l/s/ km^2). However, because of the karst regime of flow characterized by large fluctuations, in summer numerous karst springs dry up, and the inflow from rivers decreases significantly. At this time of year, the importance of the lake is particularly evident, because it still retains a considerable amount of fresh water. Special attention should be paid to the protection of this water as it represents one of the most valuable natural resources in the region.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 25–46, DOI 10.1007/698_2017_231,
© Springer International Publishing AG 2018, Published online: 27 April 2018

Keywords Groundwater, Karst aquifer, Skadar Lake, Sublacustrine springs

1 Introduction

The Skadar Lake basin represents a typical karst terrain with very interesting hydrogeology. There are cases where one stream sinks into the ground and appears again on the surface several times along its course. Some sinking waters never see the light of day again, but flow out only from the lake floor in the form of cold sublacustrine springs, which are precious for the aquatic biota.

The karst terrains of the Skadar Lake basin belong to the Dinaric system (Dinarides), more precisely to its south-eastern part. The whole basin covers 5,631 km^2, of which 81% belongs to Montenegro and the rest to the Albania [1] (Fig. 1). The largest amount of water comes to the lake by the Morača River. The lake water flows out by the Bojana River which connects the Skadar Lake and the Adriatic Sea.

This chapter gives an overview of the geology, geomorphology, tectonics and hydrogeology of the Skadar Lake basin, with special emphasis on the sublacustrine springs which recharge the lake with a significant amount of groundwater.

2 Geology

The geological characteristics of this area have been researched by many authors since the end of the nineteenth century [2–12].

2.1 Geomorphology

The Skadar Lake basin represents the classic karst of the Dinarides (Fig. 2) where almost all karst landforms are developed, but the following are particularly widespread: karren fields, sinkholes (dolines), uvalas, poljes and caves.

According to Radulović [13], there are three regional geomorphological units in the Skadar Lake basin, i.e. two karst plateaus and one system of karst depressions between them (Figs. 1 and 3).

Karst plateaus represent the highland with an average altitude of around 1,000 m asl. Some mountain peaks rising from the plateaus reach over 2,000 m asl (Vojnik, Žurim and Žijovo mountains). The plateaus are elongated along two regional anticlines (Fig. 1). There are numerous surface and subsurface karst landforms in these areas. Dolines are often densely arranged in the form of *polygonal karst*. There are two karst poljes, Nikšić and Cetinje, with fully developed hydrography (springs are located along the northern and western edges of the poljes and ponors along the southern and eastern edges). There is a well-developed system of caves in the area from Lovćen Mountain to Skadar Lake, consisting of three main caves: Cetinjska, Lipska and Obodska caves [14]. The deepest

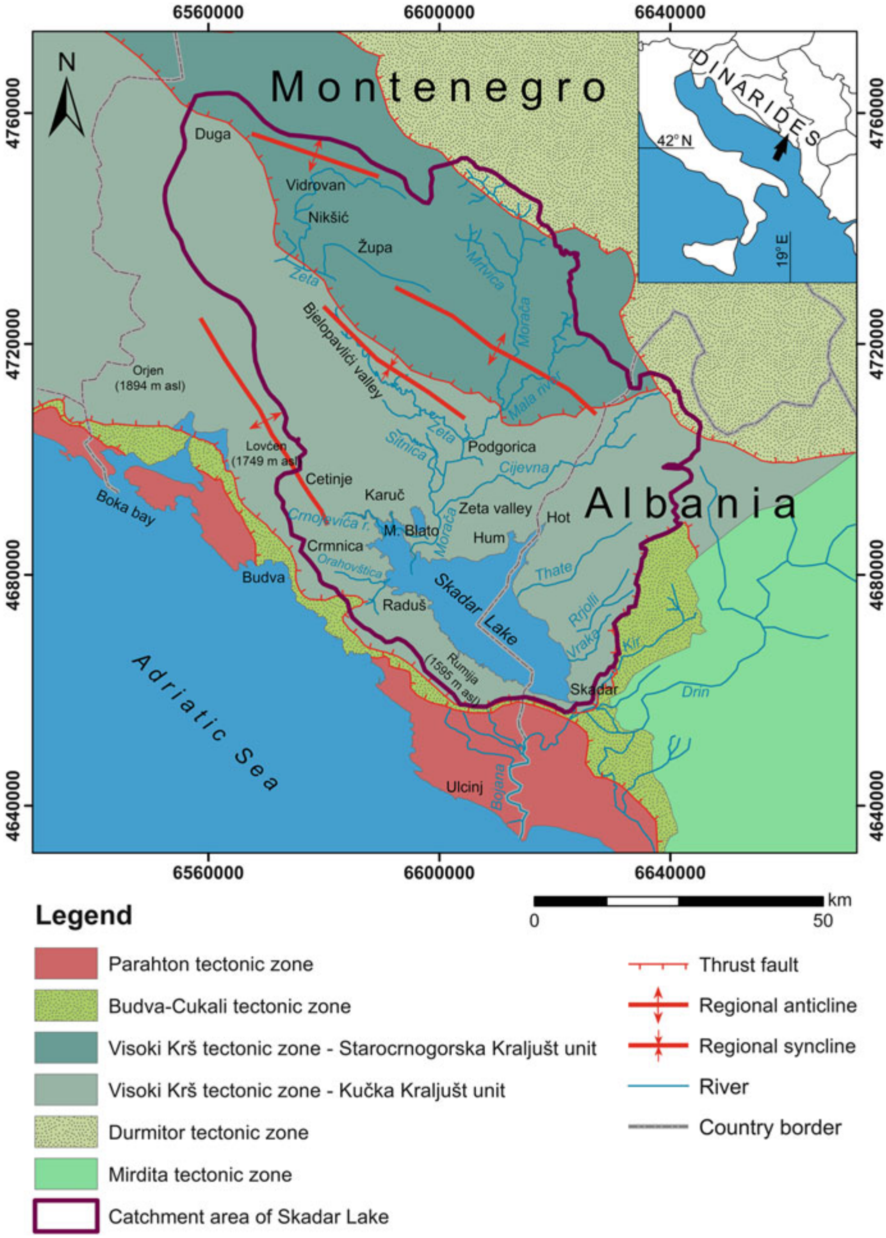

Fig. 1 Position of the Skadar Lake catchment area on the regional tectonic map [1]. Environmental Earth Sciences, 74, 2015, 71–82, Radulović et al., Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow, Fig. 1, Copyright 2015. With permission of Springer

Fig. 2 Typical karst terrains of the Skadar Lake basin (photo by Milan Radulović)

cave of the Skadar Lake basin is the Iron Cave (1,162 m deep) located on Maganik Mountain [15]. The north-eastern plateau is cut by the deep canyons of the Morača River, Mrtvica River, Mala Rijeka River and Cijevna River, which represent the discharge zone in this part of the Skadar Lake basin (Figs. 1 and 3).

The system of karst depressions, consisting of Nikšić, Bjelopavlići, Zeta and Skadar Valley, is elongated along the regional syncline (Fig. 1). The altitudes of the valleys generally decrease from north to south, so the southernmost part represents a cryptodepression. This lowest part is flooded by lake water. The lake floor in the south-western part is around 2 m below sea level, and at the locations of the sublacustrine springs, it reaches several tens of metres lower (with an average depth of 72.5 m).

2.2 *Geology and Tectonics*

Karstified carbonate rocks (limestone and dolomite) have dominant distribution in the Skadar Lake basin. The flysch (claystone, marlstone, sandstone) has just a limited distribution in the northern part of the basin, but due to the low hydraulic conductivity of the flysch, it has a very important hydrological role. In contrast to the permeable karst areas, which are generally characterized by the absence of surface water, there are many streams in the flysch terrains.

Valleys and karst depressions are mainly covered by fluvioglacial and lacustrine sediments, the thickness of which ranges up to 100 m.

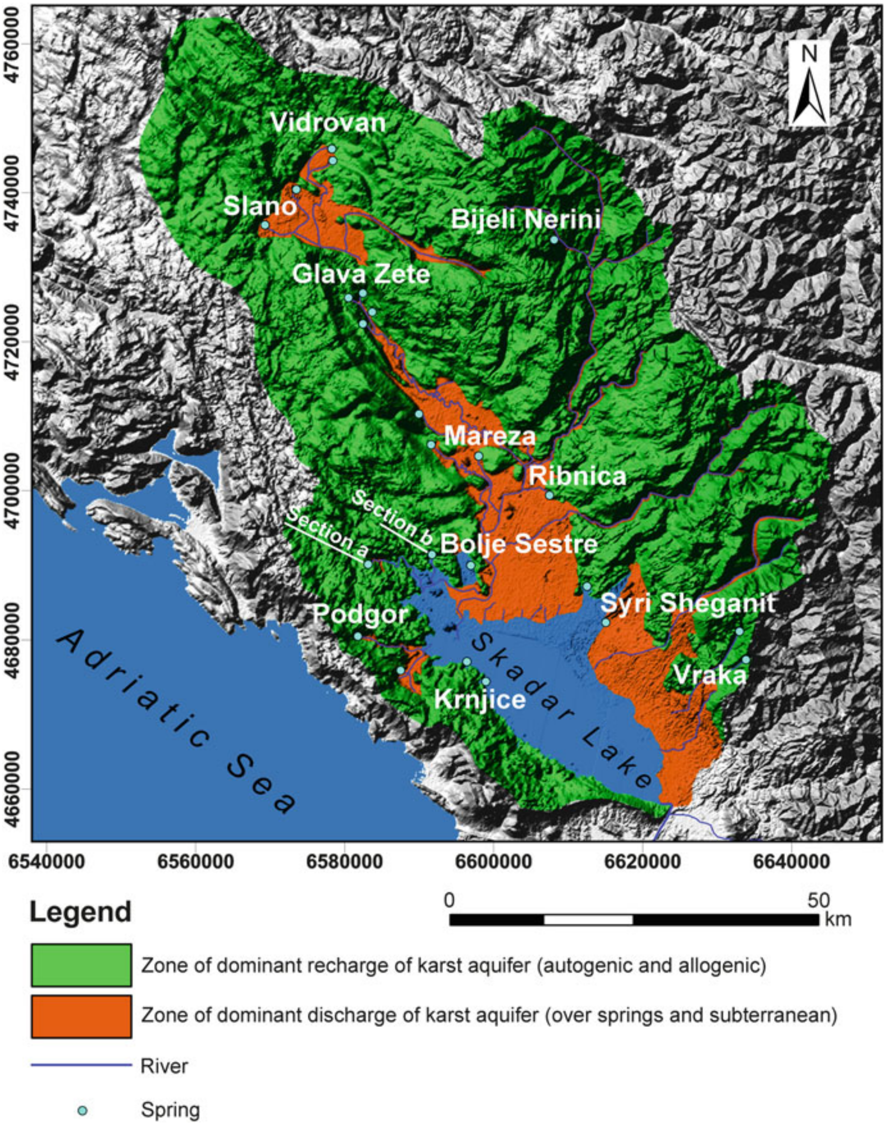

Fig. 3 Map of recharge and discharge areas of the karst aquifer in the Skadar Lake catchment area [1]. Environmental Earth Sciences, 74, 2015, 71–82, Radulović et al., Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow, Fig. 2, Copyright 2015. With permission of Springer

According to the authors of the Geological Map of Montenegro 1:200,000 [12], there are four tectonic zones in the wider area of the Skadar Lake basin (Fig. 1):

- *Paraautohton* (Adriatic-Ionian)
- *Budva-Cukali*
- *Visoki Krš*
- *Durmitor*

The Skadar Lake basin is mainly distributed within the Visoki Krš tectonic zone. Two tectonic units are distinguished in this zone: *Starocrnogorska Kraljušt* and *Kučka Kraljušt*. These two units are separated by a system of reverse faults.

The *Starocrnogorska Kraljušt* unit is mostly represented by limestone and dolomite, but along its northern boundary, a narrow flysch zone is present. It is distributed from the Budva-Cukali zone to the northern edge of the Nikšić, Bjelopavlići, Zeta and Skadar depressions. This unit contains one regional anticline and one regional syncline (Fig. 1) with Dinaric orientation (NW-SE).

The *Kučka Kraljušt* unit consists of carbonate rocks and flysch sediments. There is one regional anticline elongated along this tectonic unit from which high mountains rise, such as Golija, Vojnik, Žurim, Lola, Maganik, Prekornica, Vjeternik and Žijovo.

According to dating represented on the Geological Map of Montenegro 1:200,000 [12], the rocks are mainly from Mesozoic (limestone and dolomite), Paleogene (flysch sediments) and Quaternary (gravel, sand, conglomerate, debris and clay).

2.3 Genesis of Skadar Lake and the Surrounding Area

Geologists and geographers have long been drawn to Skadar Lake, lying as it does in the lowest part of one of the largest karst depressions in the Dinarides. Numerous explanations regarding the genesis of Skadar Lake have been put forward, but to date, the issue has not been solved.

One world-famous geomorphologist (recognized as the father of karstology), Jovan Cvijić [5], believed that the Zeta-Skadar depression represents a polje (large karst depression). According to him, this polje is created by merging dolines and uvalas which were previously formed by the dissolving action of rainwater.

Bešić [16] did not believe that the Zeta-Skadar depression represents a polje. He stated (1983) that the area was initially lowered by tectonics, followed by strong glacial and fluvial erosion. According to him, that erosion shaped the sides of the depression. Today, the depression is filled by thick glacial-fluvial, alluvial and lacustrine deposits.

Radulović [13] stated: “At the end of the Pliocene, finally the sea withdrew from the area that today belongs to the Skadar Lake basin… During the Quaternary the north-eastern part of the Zeta-Skadar depression was uplifted, and at the same time the south-western and western part was lowered”. Today, that lower part of the Zeta-Skadar depression is filled by the fresh water of Skadar Lake.

Miladinović [17] stated that Skadar Lake represents the relict of a sea from the Pliocene epoch.

A new view on karst genesis [18] allows the possibility that the karst depressions were formed under the sea. According to the same author [18], the Zeta-Skadar depression represents a large karst polje, the genesis of which was just initiated by tectonics. The depression was formed at great depths beneath sea level (below the lysocline), where the dissolution of carbonates was dramatically increased. Thereafter, rapid seawater regression and the action of strong fluvial and glacial erosion shaped the sides of the depression and broke a south-eastern crest of the polje, which had divided this area from the sea. The current geomorphological and hydrological characteristics of the area have influenced fresh water accumulation in the south-western part of the depression, i.e. the formation of Skadar Lake.

In order to clarify this issue, extensive future geological and geomorphological research should be carried out.

3 Hydrogeology

The hydrogeology of the Skadar Lake basin has been studied by many researchers, especially after World War II [1, 13, 19–31].

3.1 Hydrogeological Characteristics of the Basin

Since carbonate rocks (limestone and dolomite) have a dominant distribution on the Skadar Lake basin, most groundwater resources are accumulated within the *karst aquifer*. Also, the shallow *intergranular aquifer* of the Zeta and Skadar Valleys plays a very important role, especially during the dry season when karst spring discharge decreases significantly. *Impervious rocks* have limited distribution on the Skadar Lake basin. Mostly they are represented by impervious flysch sediments, volcano-sedimentary formations and lacustrine sediments.

3.1.1 Karst Aquifer

Permeable limestone and dolomite occupy around 73% of the basin surface. They are also distributed below the other rocks, i.e. below the impermeable flysch and clastic sediments of the karst depressions.

The karst aquifer mostly receives water from precipitation reaching permeable karst plateaus (Fig. 3). The mean annual precipitation rate for the recharge zone is relatively high (around 2,500 mm/year), but in spite of that, there is no surface water on this area. Almost all rainwater infiltrates rapidly into the permeable ground. Infiltrated water percolates vertically down until it reaches the water table. The average depth to the saturated zone of the karst aquifer from which groundwater can be abstracted is around 800 m, so the settlements distributed along the karst plateau remain "thirsty" throughout the year. Drilling wells and pumping groundwater from such a depth are not sustainable.

From the recharge zones, the groundwater flows to karst depressions and canyons mainly through karst conduits and caves. Subsurface karst landforms are generally developed along the faults. Also, the orientation of the main folds (synclines and anticlines) has an influence on the direction of groundwater flow.

The karst aquifer has high hydraulic conductivity, especially along karstified zones. According to the results of tracer tests performed in the Skadar Lake basin, the average tracer velocity amounts to 3.41 cm/s (3 km/day). Uranine (fluorescein sodium salt) was used as the tracer. The proven hydraulic connections between shallow holes and springs [13, 20, 28, 29] are presented in Table 1 and Fig. 4. The results of the tests contributed to the delineating of the groundwater divides of Skadar Lake basin.

The groundwater of the karst aquifer flows out through numerous springs, mostly distributed along the edges of karst depressions and canyons (Fig. 3). Some springs appear at contact points between permeable carbonate rocks and impermeable flysch sediments. There are around 200 known karst springs within the Skadar Lake basin. The following springs have the highest yields (from southeast to the northwest; Fig. 3): Krnjice Spring, Raduš Spring, Velji Spring, Podgor Spring, Vitoja Spring, Crnojevića Spring (Fig. 5a), Karuč Spring (Fig. 5b), Bolje Sestre Spring, Ribnica Spring, Mareza Spring, Vučji Studenci Spring, Bijeli Nerini Spring, Oraš Spring, Milojevći Spring, Dobropolje Spring, Glava Zete Spring, Obošnica Spring, Slano Spring, Poklonci Spring, Rastovac Spring, Vidrovan Spring (located on Montenegrin territory), Vraka Spring, Rrjolli Spring and Syri i Sheganit Spring (located on Albanian territory) [1].

The karst aquifer also discharges directly to surface flows such as the Morača River, Zeta River, Cijevna River, Mala Rijeka River and Sitnica River. At the beginning of the dry season, the groundwater level of the karst aquifer descends below the beds of the rivers, so that the rivers then start to sink and feed the karst aquifer. Due to intensive sinking, the smaller rivers (the Cijevna, Mala Rijeka and Sitnica) dry up during the summer.

Besides the typical karst springs distributed within the discharge zone (Fig. 3), there are also other hydrogeological phenomena such as estavelles, intermittent springs and sublacustrine springs (*vrulja* or *oko*). Estavelles are hydrogeological phenomena with a dual role. In the rainy season, they function as springs and during the dry season as swallow holes (ponors). There are many sublacustrine springs distributed along the Skadar Lake coast through which the karst aquifer discharges below lake level. They are represented by underwater dolines (depressions) whose bottoms descend deep below the general lake floor. The deepest such doline is located in Raduš Bay. Its bottom descends as low as 66 m below sea level, i.e. 72.5 m below the average lake level. The largest sublacustrine springs are described in the next section (see Sect. 3.2).

Also, groundwater from the karst aquifer partly feeds the intergranular aquifer of Zeta-Skadar Valley. This transfer of groundwater between aquifers is very useful because the intergranular aquifer can store water longer than the karst aquifer. Therefore, a significant

Table 1 Hydraulic connections between swallow holes and springs confirmed by artificial tracer tests [13, 20, 22–24, 28, 29]

Tracer injection point	Date of tracer injection	Tracer appearance point	Date of tracer appearance	Difference in elevation (m)	Distance (m)	Tracer velocity (cm/s)
Swallow hole in Ljevačko (Sozina)	16.12.1971	Pod Kapom Spring (Sozina)	02.12.1971	600	3,000	0.82
Swallow hole in Bijelo Polje	23.09.1969	Modro Spring, Velji Spring, Okrugli Spring	06.11.1969	592.5	4,000	0.11
Swallow hole in Obzovica	07.01.1970	Podgor Spring	08.01.1970	657	6,965	13.82
Swallow hole in Seoštik (Seoca)	24.01.1969	Podgor Spring	26.11.1969	632	7,000	5.21
Swallow hole in Ugnji	16.09.1969	Crnojevića Spring	19.09.1969	640	6,990	2.75
Swallow hole in Cetinje	15.03.1934	Crnojevića Spring	17.03.1934	598	7,000	4.05
Swallow hole in Cetinje	23.10.1935	Crnojevića Spring	25.10.1935	598	7,000	4.74
Borehole C-4 (Cetinje)	09.07.1973	Crnojevića Spring	28.07.1973	614.98	8,550	0.52
Borehole C-2 (Cetinje)	15.03.1970	Crnojevića Spring	29.06.1970	622.5	8,850	0.25
Swallow hole in Cetinje	02.10.1987	Crnojevića Spring	05.10.1987	598	7,000	5.50
Swallow hole in Cetinje	18.11.1987	Crnojevića Spring	21.11.1987	598	7,000	4.50
Swallow hole in Cetinje	20.01.1988	Crnojevića Spring	23.01.1988	598	7,000	4.20
Swallow hole below Grabova Glavica (Štitari)	02.12.1977	Volač Spring (Karuč Bay)	05.12.1977	510	12,875	5.40
Swallow hole Lainje (Župa Dobrska)	10.12.1977	Djurov Spring, Karuč Spring, Volač Spring (Karuč Bay)	29.12.1997	300	6,200	0.65–0.67
Swallow hole Brežine (Lješanska Nahija)	18.12.1978	Kaluđerov Spring (Malo Blato)	20.12.1978	230	3,950	2.30
Borehole IBG-2 (Grbavci)	07.03.2007	Čkanjak Spring (Malo Blato)	08.03.2007	5.5	1,522	2.50
Cijevna River (Dinoši)	16.09.1965	Mileš Spring, Krvenica Spring, Vitoja Spring	17.09.1965–21.09.1965	33–80	2,755–8,500	2.05–3.07
Cijevna River (Dinoši)	06.11.1965	Ribnica Spring	13.11.1965	37	5,125	0.87
Swallow hole in Ostros (Rumija)	–	Van I Šitarit Spring	–	215	1,818	0.42

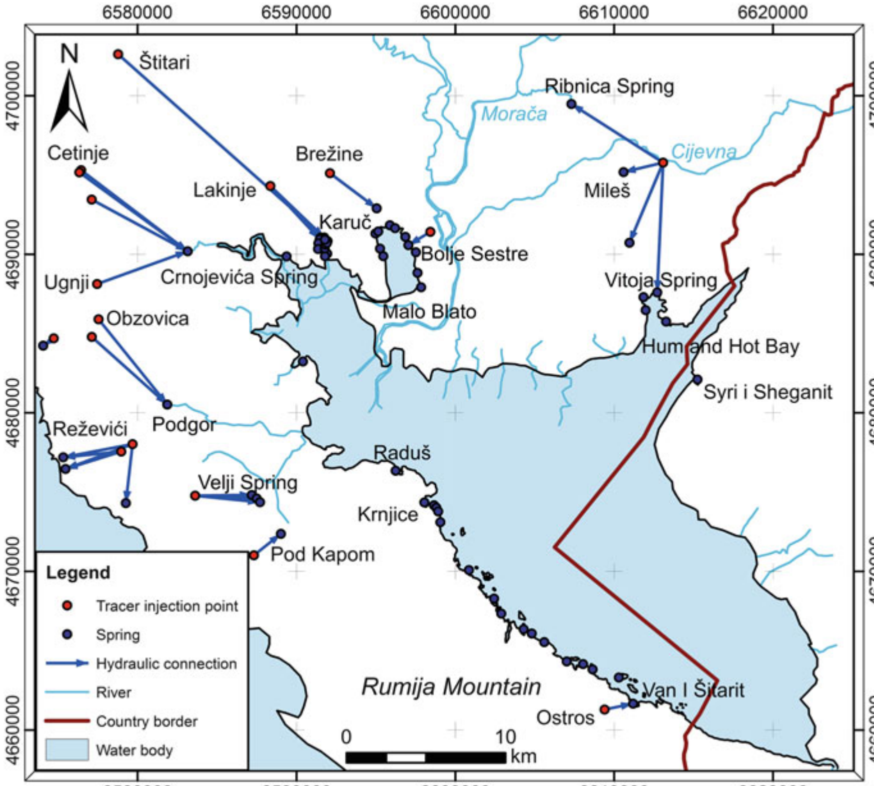

Fig. 4 Map of hydraulic connections between swallow holes and springs confirmed by artificial tracer tests

amount of groundwater is available from the intergranular aquifer, even in the driest period of the year.

The karst springs react rapidly to rainfall impulses. That is manifested by pronounced fluctuations in the water table and discharge. Fluctuations of the water table on the area of karst poljes can amount to as much as 200 m [20, 32]. Such karst aquifer behaviour can be seen clearly from the hydrograph on Fig. 6.

Groundwater from the karst aquifer is of good quality throughout the year, except after extreme rainfall events when turbidity increases. Water has low TDS (generally around 300 mg/l), with a higher concentration of HCO_3^{2-}, Ca^{2+} and Mg^{2+} ions. The pH value of groundwater amounts to 6.95–7.80 [30].

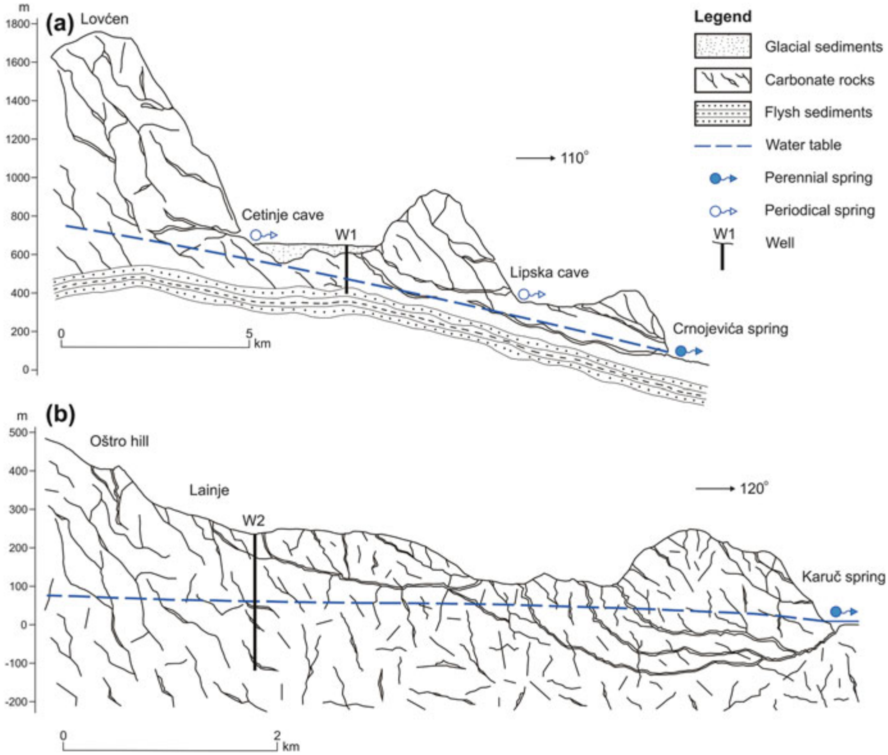

Fig. 5 (**a**) Hydrogeological section Lovćen-Crnojevića spring, (**b**) hydrogeological section Oštro hill-Karuč [1]. Environmental Earth Sciences, 74, 2015, 71–82, Radulović et al., Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow, Fig. 3, Copyright 2015. With permission of Springer

3.1.2 Intergranular Aquifer

The main intergranular aquifer is distributed along Zeta Valley. Also, this type of aquifer is presented in Skadar Valley, Crmnica Valley, Cetinje and Nikšić.

The shallow intergranular aquifer of Zeta Valley is represented by alluvial and fluvioglacial sediments. These sediments consist of gravel, sand and conglomerates. The thickness of the sediments is up to 100 m. They lie over the limestone and dolomite in the northern and central part of the valley and over impermeable claystone and siltstone in the southern part.

Recharge of the intergranular aquifer of Zeta Valley occurs through the infiltration of atmospheric water and surface water, as well as by subterranean inflow from the bottom karst aquifer. The general direction of groundwater flow is north-south. The hydraulic conductivity of the intergranular aquifer is relatively high ($K \approx 0.005$ m/s) except for the southern part, where lacustrine sediments (clay, mud and silt) are present.

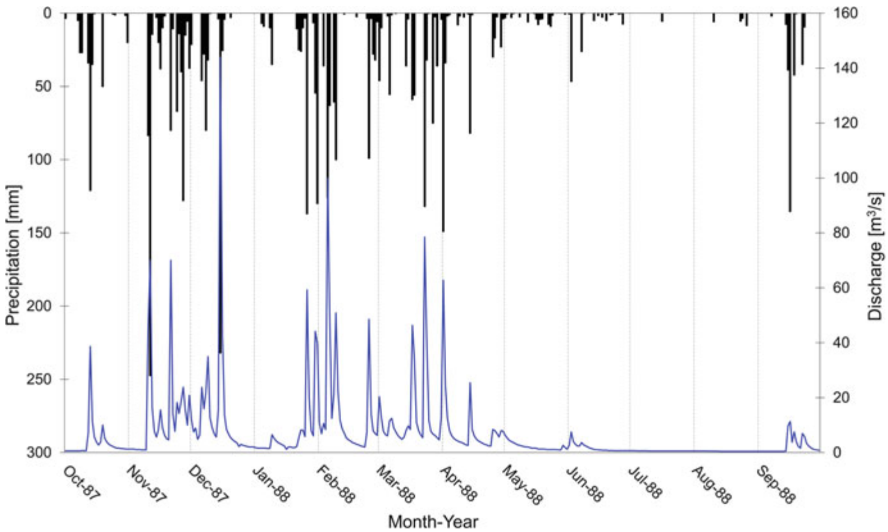

Fig. 6 Hydrograph of Crnojevića spring discharge (hydrometric station "Brodska Njiva") with precipitation bar graph (climatological station "Cetinje") (after Živaljević [33]) [1]. Environmental Earth Sciences, 74, 2015, 71–82, Radulović et al., Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow, Fig. 4, Copyright 2015. With permission of Springer

The northern littoral belt of Skadar Lake represents the discharge zone of the Zeta Valley intergranular aquifer. In that zone, there are numerous diffuse springs and short streams through which groundwater from the intergranular aquifer flows out. In that zone, the following short streams flow into Skadar Lake: Plavnica, Zetica, Gostiljska River, Svinješ, Pjavnik, Velika Mrka, Mala Mrka and many other nameless streams (Figs. 1 and 4). According to the numerical groundwater flow model (MODFLOW), the outflow of groundwater from the Zeta Valley intergranular aquifer amounts to 11.62 m^3/s [1].

Also, artificial discharge of the intergranular aquifer takes place by means of abstraction wells distributed along the valley. The pumped groundwater is used for the water supply, irrigation and industry (Aluminium Plant Podgorica). The drawdown of the water table in the wells is very limited (just a few metres) despite the fact that over 100 l/s is pumped from some wells.

The quality of groundwater is satisfactory in the northern part of Zeta Valley, but it is often disturbed in the area south of Aluminium Plant Podgorica, as well as south of some larger settlements and agricultural areas. The front of pollution spreads south from the polluters, but pollutant concentrations decrease after a few kilometres. Given that a contaminant transport through porous media (affected by dispersion, sorption, biodegradation and dissolution) decreases concentrations, Skadar Lake ultimately receives good-quality water from the intergranular aquifer.

The Skadar Valley intergranular aquifer behaves in a similar way to the Zeta Valley aquifer, but it has a lesser distribution. It consists of gravel and sand. This intergranular aquifer receives water from precipitation, the bottom karst aquifer and surface water (Thate River, Rrjoli River and Vraka River), and it discharges into Skadar Lake. The groundwater is mostly used for the water supply and irrigation.

3.2 Sublacustrine Springs of Skadar Lake

There are numerous sublacustrine springs in Skadar Lake, but most of them are located in the following areas: south-western coast, Karuč Bay, Malo Blato Bay, Hum Bay and Hot Bay (Fig. 4).

3.2.1 Sublacustrine Springs of the South-Western Coast

The karst aquifer of the south-western edge of Skadar Lake is discharged by sublacustrine springs distributed along the coast (Fig. 4). There are around twenty known springs, but besides the concentrated outflows of groundwater, there are also zones where diffuse discharge of the karst aquifer occurs. The main sublacustrine springs in this area are Raduš Spring and Krnjice Spring.

Raduš Spring

This is a spring on the south-western coast that first emerges on the line from the north-west to the south-east. It is located in Raduš Bay, where there is a small fishing village. The spring is positioned near the south-western edge of Raduš Bay (Fig. 7). The discharge of groundwater occurs through the bottom of a 70-m-deep underwater doline. The diameter of the funnel-shaped doline is around 130 m. The discharge point is also defined according to tectonics, i.e. according to the fault which transmits groundwater towards the spring (the orientation of this fault is north-south).

At the end of the 1980s, this spring was a potential source for the regional water supply system of the Adriatic coast, and a detailed investigation of the spring area was carried out [34]. The conclusion of the investigations was that the yield of the spring in the driest period of the year ($Q_{\mathrm{min}} = 60$ l/s) could not meet the demands of the water supply system. According to findings, the average yield of Raduš Spring amounts to 1.27 m^3/s, and the maximum is around 50 m^3/s. Therefore, the maximum yield is almost a thousand times greater than the minimum yield. This indicates that a well-developed network of karst conduits is present, so that the retention capabilities of the karst aquifer are very low within the catchment area of Raduš Spring. The highly fractured and karstified limestone of the spring background cannot accumulate water for long periods, but almost all of the infiltrated water transmits rapidly to the discharge point. The assessed size of this catchment area is around 25 km^2 [34].

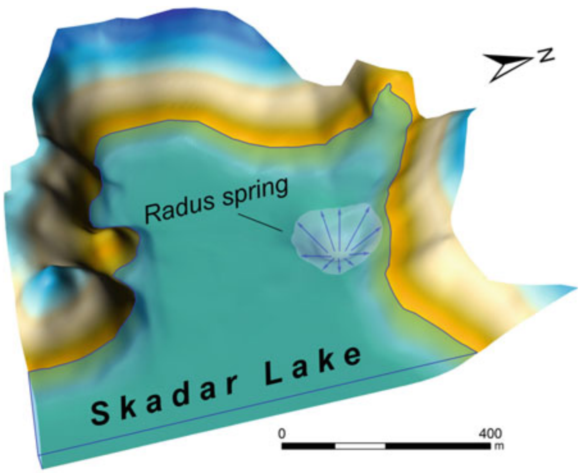

Fig. 7 Morphology of the lake floor in the area of Raduš Bay

The spring water has low TDS, with an increased concentration of hydrocarbonate and calcium ions. According to systematic measurements [34], quality parameters were within threshold limits.

Krnjice Spring

Moving south-east, the next spring to appear after Raduš is Krnjice Spring. It is located in Luke Bay, where there is another fishing village, named Krnjice. This sublacustrine spring is also represented by an underwater doline. The depth of the lake at this location is 24.6 m [13]. Aquifer discharge occurs from the bottom of the doline. Since the catchment area of Krnjice Spring also consists of highly karstified limestone and dolomite, the discharge regime is similar to that at Raduš Spring. After intensive rainfall events, the spring reacts quickly with a high yield, but in the dry season, the discharge decreases significantly. In the immediate backdrop to Krnjice Spring, there is a fault with orientation north-south. The groundwater probably flows along this fault towards the bottom of the underwater doline, where it flows out to the lake.

Other Sublacustrine Springs on the South-Western Coast

Further to the south-east, there are many nameless sublacustrine springs. Their locations are presented on Fig. 4. Many of these springs dry up during the summer. According to a performed tracer test (Table 1), a hydraulic connection between a swallow hole in Ostros and the sublacustrine spring in Van I Šitarit Bay was established. The detected tracer velocity was 0.36 km/day [23, 24].

3.2.2 Sublacustrine Springs of Karuč Bay

Karuč Bay also represents one of the discharge zones where karst aquifer groundwater flows directly out to the lake. There are numerous sublacustrine springs in Karuč Bay (Fig. 4), such as Karuč Spring, Volač Spring, Đurov Spring, Studenac Spring, Radišev Spring, Žabin Spring, Grivo Spring and Bazagurska Spring.

The main discharge point is Karuč Spring. The minimum yield of this spring is around 1 m^3/s [25]. At the location of the spring, there is an underwater doline, the bottom of which is around 20 m below lake level. Measured spring water temperature at the discharge point is 11.7°C [25], which is much lower than the temperature of lake water in summer. This temperature anomaly (the zone of colder water) is detected by thermal infrared camera, which is a very useful tool for the detection of sublacustrine springs (Fig. 8).

Right next to Karuč Spring is Volač Spring, which flows out from the cave. The channels of the cave descend deep below spring level (around 50 m lower), so there is an ascending outflow of groundwater to the spring (Fig. 5b).

The size of the Karuč Bay catchment area covers around 116 km^2 [21, 35]. Results of tracer tests represented the main base for the delineation of the groundwater divides in these highly karstified terrains (Fig. 4, Table 1), because surface topography plays no role in water separation. One of the most interesting facts is that sinking water from the Lainje swallow hole flows towards three different springs. Therefore, there is an underground water bifurcation through the branched network of karst channels. Other tracer tests helped in the delimitation of this catchment area, from the catchment areas of the Crnojevića River, Malo Blato Springs and springs along the south-western edge of Bjelopavlići Valley (Fig. 4, Table 1).

When planners ruled out Raduš Spring as the source for the regional water supply system, detailed investigations of Karuč Spring were conducted, but the spring was not selected.

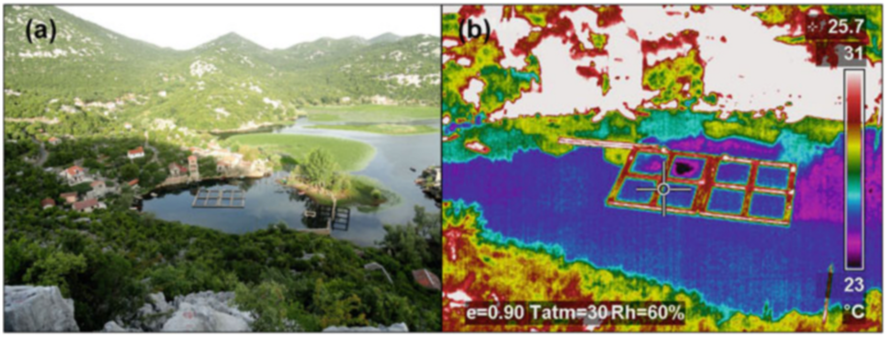

Fig. 8 (**a**) Photo of Karuč Bay captured in the visible spectrum; (**b**) photo of Karuč Bay captured in thermal infrared spectrum, from which a temperature anomaly can be seen (purple tones), i.e. the main location of groundwater discharge [1]. Environmental Earth Sciences, 74, 2015, 71–82, Radulović et al., Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow, Fig. 6, Copyright 2015. With permission of Springer

3.2.3 Sublacustrine Springs of Malo Blato Bay

Malo Blato Bay is located at the north-western part of Skadar Lake, between Karuč Bay and Zeta Valley. Water flows into Malo Blato by way of the Sinjačka River and numerous sublacustrine springs (Fig. 4), such as Velja Suica Spring, Mala Suica Spring, Krakala Spring, Bivo Spring, Crni Spring, Bolje Sestre Spring, Brodić Spring, Biot Spring, Bobovine Spring and Krstat Spring. The stream of the Sinjačka River begins with the Kaludjerovo Spring in the northern edge of Malo Blato Bay and flows just 1 km to the lake. Outflow of water from Malo Blato Bay occurs through the Biševina River, which connects this bay to the main body of Skadar Lake. The mean annual discharge of the Biševina River is 11.75 m^3/s [22].

The main point of groundwater discharge is the Bolje Sestre Spring. It is located in the eastern part of Malo Blato Bay, at the foot of Kolozub Hill. The groundwater discharges at two points, one at the level of the lake and another at the lake floor a few metres away from the coast (Fig. 9). The depth of the lake at the location of the sublacustrine spring is around 7–8 m [22]. The spring background consists of bedded limestone and dolomite. Groundwater flow direction is predisposed according to faults and bedding planes. The general orientation of faults is southeast-northwest. The bedding planes dip towards the northwest at an angle of 28° [36]. The minimum yield of the Bolje Sestre Spring is around 2 m^3/s. The temperature of spring water in summer is 14.8°C [37].

Fig. 9 Water source “Bolje Sestre” during construction (photo by Milan Radulović)

When Raduš Spring and then Karuč Spring were rejected as potential water sources for the regional water supply system, detailed hydrogeological investigations were conducted in the area of Bolje Sestre Spring [28, 36, 38–40]. Numerous hydrogeological methods were applied at this area (geophysical investigations, remote sensing, drilling, pumping tests, tracer tests, hydrological and hydrochemical methods), and based on all obtained results, Bolje Sestre Spring was chosen as the best source for the regional water supply system. Nowadays, water from this source is tapped and transported by means of a 150-km-long pipeline to almost every settlement along the Montenegrin part of the Adriatic coast.

In Malo Blato Bay, there are also springs which discharge from the bottom of underwater dolines. Typical of such springs are Kaludjerovo Spring and Biot Spring.

3.2.4 Springs of Hum and Hot Bay

Hum Bay and Hot Bay represent another important zone of groundwater discharge. There are a few karst springs here, such as Ploče Spring, Vitoja Spring, Funija Spring and Syri i Sheganit Spring.

When it goes along Hum Bay towards the Montenegro-Albania border, the *zone of minor springs* first appears at the very beginning of the bay. There are some small springs which discharge at the level of the lake.

The next spring that comes up is *Ploče Spring*, which is located in Sunji Ploč Cove. It is a sublacustrine spring that flows out from a depth of around 6 m.

The main discharge point at Hum Bay is *Vitoja Spring* (Fig. 10) located in the northern part. In fact, it is a discharge zone that consists of two land springs and three sublacustrine springs. The land springs are located just below the limestone slope. They are around 30 m away from each other. At hydrological maximum, these springs are also flooded by lake water. There is another group of sublacustrine springs around 30–50 m away from the terrestrial springs. They flow out from a depth of around 5 m. The temperature of spring water in summertime was 11°C [41]. According to tracer test results [13], there is a connection between the swallow holes of the Cijevna riverbed (near the Trgaj Village) and Vitoja Spring. It was very interesting that tracer injected into the sinking zone of the Cijevna River (at the exit of the limestone canyon) appeared at four different springs: Ribnica Spring, Mileš Spring, Krvenica Spring and Vitoja Spring. So, there is an underground bifurcation of sinking water in four directions (Fig. 4).

At the bend between Hum and Hot Bays, there is one typical sublacustrine spring (*Funija Spring*) that flows out from a depth of 10 m. It is located around 300 m from the lake coast.

Syri i Sheganit is one of the largest springs in the Skadar Lake area. It is located at the south-eastern part of Hot Bay, near Gashaj Village. The minimum yield of the Syri i Sheganit Spring amounts to around 300 l/s, and the maximal yield is around 6.9 m^3/s [42]. The mean annual yield is around 1.4 m^3/s [31]. Groundwater flows out from the cave, the channels of which have been explored up to a depth of 52 m and up to 160 m in length [43]. This karst spring probably drains the south-western slopes of Prokletije Mountain. The catchment area of the spring covers around 30 km^2.

Fig. 10 Vitoja Spring (photo by Milan Radulović)

The assessed groundwater inflow to the Montenegrin side of Hum and Hot Bays is 2.5 m^3/s [44]. The total inflow into the bay (Montenegrin and Albanian sides) is around 4 m^3/s.

3.2.5 Other Springs

Besides the mentioned groups of sublacustrine springs, there are also individual discharge points such as Modro Spring (western coast), Grab Spring and Vranjina Spring (north-western coast) and many other nameless sublacustrine springs.

4 Conclusion

The Skadar Lake basin represents one of the richest basins of fresh water in the world, measured by mean specific yield, which amounts to as much as 54 $l/s/km^2$ [1]. On this karst area, almost all natural factors (precipitation, land cover, the permeability of rocks, geomorphology) have a favourable effect on such a large outflow of water. However, problems with insufficient quantity of water can be expected in summer, a fact which is characteristic of such karst terrains. The minimum yield from springs might be as much as a thousand times lower than the maximum yield (e.g. Raduš Spring). Some springs with high yields in the rainy period dry up completely in summer (e.g. Ribnica Spring). With this in mind, the significance of the lake is seen as even greater, because it plays the role of reservoir, where a considerable amount of fresh water is gathered, even in the driest period of the year.

The inflow of groundwater represents a very important constituent of the lake water budget. The assessed groundwater inflow amounts to around 55 m^3/s, accounting for 17% of the total lake budget [1].

Bearing in mind the significance of sublacustrine springs at Skadar Lake, additional efforts are needed in order to establish adequate groundwater protection, since it represents one of the most valuable natural resources in the area.

Acknowledgements I would like to express my sincere gratitude to all hydrogeologists who researched the Skadar Lake basin. Also, I would like to thank my friend Jonathan Griffiths, who helped me a great deal with proofreading this paper.

References

1. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82. https://doi.org/10.1007/s12665-015-4090-7
2. Tietze E (1884) Geologische Uebersicht von Montenegro. Hölder, Vienna
3. Baldacci L (1886) Ricognizione geologico-minerariadel Montenegro. Boll R Comit Geol Ital Boll 17:9–10
4. Hassert K (1895) Beiträgezurphysischen Geographie von Montenegro. Petermanns Mitteilungen Ergänzungsheft, Gotha
5. Cvijić J (1899) Glacial and morphological studies of the mountains of Bosnia, Herzegovina and Montenegro (in Serbian). Voice Serbian R Acad Sci 57:1–196
6. Nopcsa F (1916) Begleitwortzur geol. Karten von Nordalbanien, Rasien und Ostmontenegro. Földtani Közlöny 46:7–12
7. Bourcart J (1926) Nouvelles observations sur la structure des Dinarides adriatiques. In: Actasdel XIV Congreso Geológico Internacional, Madrid, pp 1899–1941
8. Waisse JG (1948) Les bauxites de l'Europecentrale (Province dinariqueet Hongrie). Dissertation, University of Lausanne, Lausanne
9. Milovanović B (1965) Epeirogenic and orogenic dynamics in the area of External Dinarides and the problems of paleokarstification and geological evolution of holokarst (in Serbian). J Geol Surv Serbia 4(5):5–44
10. Bešić Z (1969) Geology of Monetenegro–Karst of Monetenegro (in Serbian). Geological Survey of Montenegro, Podgorica
11. Grubić A (1975) Tectonics of Yugoslavia. Acta Geol 41:365–384
12. Mirković M, Žvaljević M, Đokić V, Perović Z, Kalezić M, Pajović M (1985) Geological map of Montenegro 1:200,000. The Republic Self Managing Community of Interest for Geological Exploration of Montenegro, Titograd
13. Radulović V (1989) Hydrogeology of Skadar Lake watershed (in Serbian). Geological Survey of Montenegro, Titograd
14. Petrović J (1980) Development of system of Cetinje caves (in Serbian). In: Proceeding of 7th Yugoslovenian speleological congress, Herceg Novi, 9–14 October 1976, pp 343–353

15. Djurović P, Djurović M (2016) Physical geographic characteristics and sustainable development of the mountain area in Montenegro. In: Zhelezov G (ed) Sustainable development in mountain regions, 2nd edn. Springer, Zurich, pp 93–111
16. Bešić Z (1983) Geomorphology and geology of the Zeta Valley and Skadar Lake area (in Serbian). In: Ivanović B (ed) Skadar Lake, Book 9 of scientific meetings. Montenegrin Academy of Sciences and Arts, Titograd, pp 13–23
17. Miladinović M (1964) Geology and tectonics of the Rumija Mountain area along the Montenegrin coast (in Serbian). Dissertation, University of Belgrade
18. Radulović MM (2013) A new view on karst genesis. Carbonates Evaporites 28:383–397. https://doi.org/10.1007/c13146-012-0125-2
19. Torbarov K, Radulović V (1966) Regional hydrogeological research of Montenegro and Eastern Herzegovina (in Serbian). Geological Survey of Montenegro, Titograd
20. Radulović M (2000) Karst hydrogeology of Montenegro (in Serbian). Geological Survey of Montenegro, Podgorica
21. Radulović MM (2012) Multi-parameter analysis of groundwater recharge in karstic aquifers-case examples from Skadar Lake basin (in Serbian). Dissertation, University of Belgrade
22. Radulović M, Radulović V, Popović Z (1979) Final report on the task of preparation for the basic hydrogeological map of SRY 1:100,000, “Titograd” sheet (in Serbian). Geological Survey of Montenegro, Titograd
23. Radulović M, Popović Z, Vujisić M, Novaković D (1989) Basic hydrogeological map of SRY 1:100,000, “Bar” sheet (in Serbian). Geological Survey of Montenegro, Titograd
24. Radulović M, Popović Z, Vujisić M, Novaković D (1998) Guide book for the Basic hydrogeological map of SRY 1:100,000, “Bar” sheet (in Serbian). Geological Survey of Montenegro, Titograd
25. Zogović D (1992) Final report of hydrogeological exploration of Karuč source (in Serbian). Energoprojekt, Beograd
26. Burić M (1993) Water supply of tourist settlements of the Montenegrin coast (in Serbian). Dissertation, University of Belgrade
27. Radulović M, Radulović V (2004) Hydrogeological map of Montenegro 1:200,000 (in Serbian). Geological Survey of Montenegro, Podgorica
28. Stevanović Z, Radulović M, Puri S, Radulović MM (2008) Karstic source “Boljesestre”: optimal solution for regional water supply of the Montenegro coastal area (in Serbian). In: Proceeding of board for karst and speleology, vol 9. Serbian Academy of Science and Arts, Belgrade, pp 33–64
29. Djordjević B, Sekulić G, Radulović M, Šaranović M, Jaćimović M (eds) (2010) Water potentials of Montenegro (in Serbian). Montenegrin Academy of Sciences and Arts, Podgorica
30. Dević N (2011) Geochemical-environmental properties of the catchment area of the Moraca River, upstream of its mouth to the Zeta River (in Serbian). MSc thesis, University of Montenegro
31. Sekulić G, Bushati S (eds) (2013) Development of hydrogeological and hydraulic study of regulation of Skadar Lake and Bojana river water regime (IPA Project), vol 1. Montenegrin Academy of Science and Arts, Podgorica
32. Vlahović V (1975) Karst of Niksic polje and its hydrogeology (in Serbian). The Society of Sciences and Arts of Montenegro, Titograd
33. Živaljević R (1991) Hydrological analysis of karst water flow-Crnojevića River case study (in Serbian). Dissertation, University of Montenegro
34. Avdagić I, Filipović S, Mišurović A (1989) Skadar Lake as a water source for water supply. In: Proceeding “Ecological topicality in Montenegro”. Montenegrin Academy of Science and Arts, Podgorica, pp 30–59
35. Radulović MM, Stevanović Z, Radulović M (2012) A new approach in assessing recharge of highly karstified terrains-Montenegro case studies. Environ Earth Sci 65(8):2221–2230
36. Radulović M, Radulović MM, Sretenović A (2005) Report about results of hydrogeological investigations of terrain between Grbavci and Bolje Sestre Spring (Malo Blato Bay). Geoprojekt Ltd., Podgorica

37. Radulović M, Radulović V, Popović Z (1982) Guide book for the Basic hydrogeological map of SRY 1:100,000, “Titograd” sheet (in Serbian). Geological Survey of Montenegro, Titograd
38. Stevanović Z, Balatov A, Petrović B (2007) Report about Bolje Sestre Spring-results of additional hydrogeological investigations of Bolje Sestre Spring (Malo Blato Bay, Skadar Lake), studies to solve the problem of water supply of Montenegrin coast. IK Konsalting Ltd., Beograd
39. Stevanović Z, Radulović M (2007) Report about additional hydrogeological investigations of Bolje Sestre Spring (Malo Blato Bay, Skadar Lake) for the water supply of Montenegrin coast for the level of Main Design. IK Konsalting Ltd., Beograd
40. Radulović M, Stevanović Z, Tucović A, Radulović MM, Balatov A, Žikić M (2007) Report about delineation and maintenance of protection zones around the Bolje Sestre Spring. IK Konsalting Ltd., Beograd
41. Szerszen A (2008) Karst springs of Skadar Lake-expedition report. Grupa Nurków Jaskiniowych, Warsaw
42. Hoti M (1990) Physical-geographical characteristics of the Mbishkodres field (in Albanian). Studime Gjeografike 4:159–173
43. Zhalov (2017) Results of Bulgarian–Albanian speleological researches in Albania (1991–2005). https://www.researchgate.net/publication/22854451612. Accessed 12 Jan 2017
44. Radulović MM, Novaković D, Sekulić G (2013) Geological and hydrogeological characteristics of the Montenegrin part of the Skadar Lake catchment area. In: Sekulić G, Bushati S (eds) Development of hydrogeological and hydraulic study of regulation of Skadar lake and Bojana river water regime (IPA Project), vol 1. Montenegrin Academy of Science and Arts, Podgorica, pp 9–115

The Obscure History of the Lake Skadar and Its Biota: A Perspective for Future Research

Michał Grabowski, Aleksandra Jabłońska, Anna Wysocka, and Vladimir Pešić

Contents

Abstract The Lake Skadar and its basin, representing the classic karst of the Dinarides with a very complex hydrogeology, are unique areas with high landscape heterogeneity and rich species diversity, including numerous endemic species from various taxonomic groups. However, the geological history of the Lake Skadar basin remains poorly understood, with several hypotheses on its origins. Also, the evolutionary history of local biodiversity and its link with the palaeogeography of the area are largely unknown. However, recent accumulation of studies upon some model taxa, such as crustaceans, molluscs or fish, provides space for at least some generalisation.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 47–62, DOI 10.1007/698_2018_349,
© Springer International Publishing AG, part of Springer Nature 2018,
Published online: 20 June 2018

Keywords Aquatic fauna, Endemic species, Geological history, Phylogeny, Phylogeography, Lake Skadar basin

1 Introduction

The Lake Skadar (Shkodra, Scutari) is located in the northern Mediterranean Region, western Balkans, and extending in a NW-SE direction, parallel to the coastline of the Adriatic Sea. It occupies a large karst field between two mountain chains dominating the Balkan Peninsula, namely, the Dinarides (Dinaric Alps) and the Hellenides (Fig. 1). This is the largest lake in the Balkan Peninsula, approximately 44 km long and up to 18–20 km wide, with a surface area fluctuating seasonally from 353 to 500 km^2 [1]. The whole Lake Skadar basin covers an area of 5,631 km^2. The lake is generally shallow with the average depth of 5 m and the maximum depth of 8.3 m; however, while the average altitude of the lake surface is 6.5 m asl (4.7–9.8 m asl), it is a cryptodepression which means that in some parts the lake bottom is below sea level. Such places are usually occupied by a number of deep sublacustrine springs, the so-called oko, that provide a substantial share of the inflow [2]. The deepest oko, Raduš, is at least 60 m deep. The lake is fed by several rivers, of which the largest is the Morača, which provides about 62% of the lake's water [1]. The Drim River links the Skadar with the ancient Lake Ohrid, while the 41 km stretch of the Bojana (Buna) River drains the Lake Skadar to the Adriatic. The climate of Lake Skadar/Shkodra basin is Mediterranean with hot summers and winter temperatures rarely going down below freezing point. Thus, the Lake Skadar is referred to as a subtropical water body [3] and is known for its high landscape heterogeneity and lush vegetation. Since the nineteenth century, the lake and its basin have attracted interest of scientists, who evidenced rich species diversity in various taxonomic groups including numerous endemic species.

Surprisingly, the origins of this spectacular lake as well as the history of its environment and biota remain very obscure. In this chapter we will present the current knowledge and hypotheses upon the development of Lake Skadar basin and evolutionary history of associated organisms.

2 The Uncertain Palaeogeography of the Lake Skadar Basin

Geologically, the Lake Skadar basin represents a typical Dinaric karst with carbonate rocks (limestones and dolomites) mostly of Mesozoic and, to a lesser extent, of Cenozoic age and a diversity of landforms, such as karren fields, sinkholes (dolines), uvalas, poljes and caves. There are three geomorphological units in the basin, i.e. two karst plateaus with numerous springs and one system of karst depressions

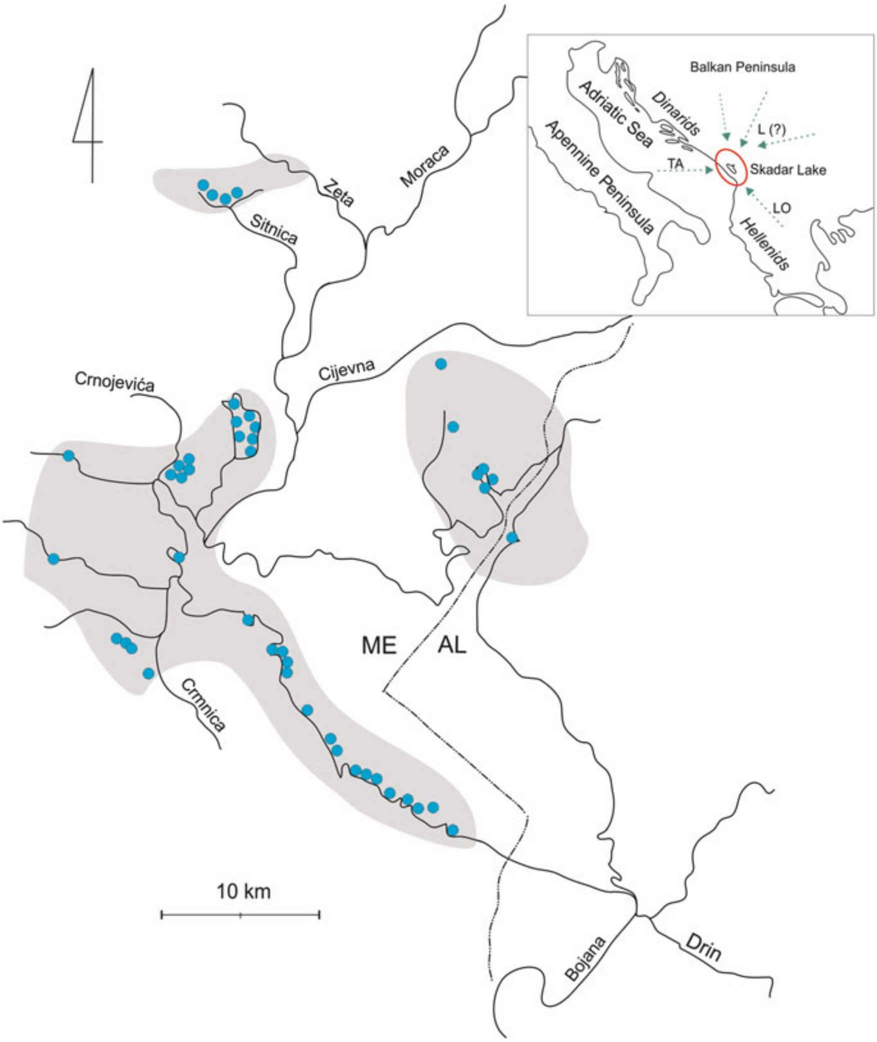

Fig. 1 The map of Lake Skadar basin and major karst springs (blue dots). Grey shades indicate areas of high endemic diversity. Arrows in the general map mark possible directions of the basin colonisation in the past (*L* local, *TA* trans-Adriatic, *LO* Lake Ohrid)

between them, filled with thick fluvioglacial and lacustrine sediments, the present lake but also including the deep sublacustrine springs [4–6].

Generally, as in the case of most sedimentary rocks in southern Europe, the formations in Dinarides and northern Hellenides accumulated in the vast, relatively stable shallow area of the ancient Tethys Ocean that separated Laurasia from Gondwana since ca. 150 Ma, in Jurassic [7]. Tethys occupied most of the present Mediterranean Region even longer, for over 250 Ma, shrinking with time until its final closure and desiccation at ca. 5.96 Ma, in late Miocene, due to the collision of the African and Eurasian tectonic plates. After a short episode of predominantly terrestrial conditions with some hypersaline lakes, known as Messinian Salinity Crisis, and at least one intrusion of brackish or even freshwaters from the Paratethys Sea, the former Tethys basin was refilled by the Atlantic waters at ca. 5.33 Ma, an event known as Zanclean flood, marking the beginning of Pliocene and of the Mediterranean Sea as we know it today (Fig. 2) [4, 8–10].

The Dinaric area started to emerge in Cretaceous as a result of the Alpine orogeny, and already in Palaeogene it was a large uplifted terrain, followed soon by the emergence of Hellenides. According to Radoman [11], many of the river valleys of the Adriatic tributaries in both Dinarides and Hellenides, including at least some of the present drainages, originated at least 30 Ma and passed also through lacustrine phase until some 10 Ma, when the presently known rivers finally formed. Curiously this overlaps with the estimated time of divergence of cyprinid fish *Telestes montenegrinus* (Vuković, 1965), endemic to the rivers of the Skadar basin, from its closest relative, *T. muticellus* (Bonaparte, 1837), widely distributed in the Apennine Peninsula and northern Adriatic drainages and also to divergence times of other Balkan species of *Telestes* (from ca. 16 to ca. 5 Ma) [12].

It is known that the two above-mentioned land platforms, Dinarides and Hellenides, were separated by a marine strait until middle Miocene, when they eventually merged. Between the two uplifted landmasses remained a large depression in which freshwater, presumably lacustrine, conditions prevailed. These waterbodies were part of the extensive, most probably at least partially interconnected, system of Neogene lakes that occupied large areas of the present

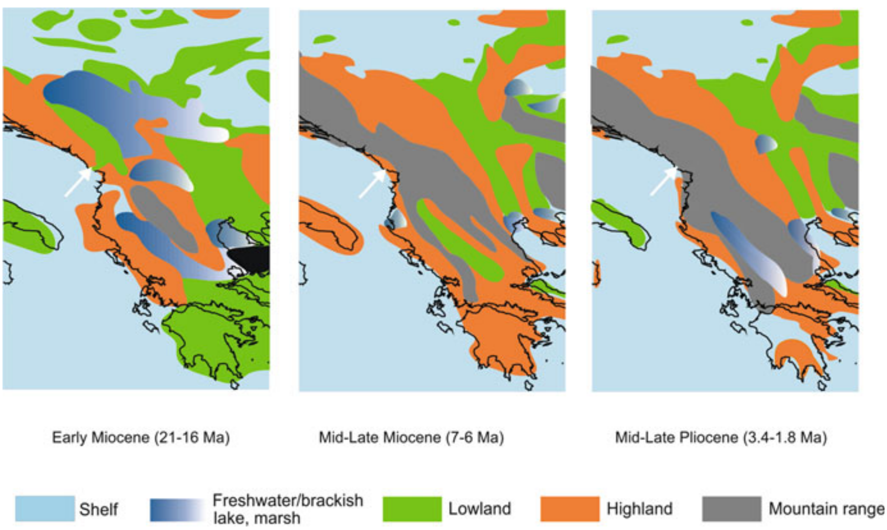

Fig. 2 Palaeogeographical changes of Periadriatic area in Miocene and Pliocene based on the reconstruction made by Popov et al. [14]. White arrows indicate the position of the Lake Skadar

Balkan Peninsula [13–15]. The Balkan lakes such as Ohrid, Prespa, Ioannina, Kastoria, Vegoritis, Doiran, Trichonis and Skadar are believed to be relicts of this ancient palaeolacustrine system [16]. Some of them, such as Ohrid or Trichonis, may indeed be classified as ancient, i.e. maintaining freshwater conditions for at least 1 Ma [17, 18]. Among them, only the Lake Ohrid has been thoroughly studied and unequivocally proven with geological data to be more than 2 Ma [19]. Most are presumably much younger waterbodies, such as Lake Prespa, that have desiccated once or several times during their history or only recently filled the depressions representing old lake beds [20]. Some others, such as the Lake Skadar, have probably very complex and yet unresolved geological and environmental history with, partially, conflicting hypotheses.

Apparently, Lake Skadar, the associated spring systems, and the Zeta River valley lies on the westernmost edge of the former Miocene depression. However, it is not obvious what the origins of the present lake basin and the lake itself were. The earliest hypothesis by Cvijić [21] assumed that the Skadar-Zeta depression is simply a polje consisting of dolines (sinkholes) and uvalas (larger closed concavities) formed during the classical karstification process through dissolving carbonate rocks by rainwater. In contrary, according to Bešić [22], the depression was originally formed by tectonic processes, followed by further erosion and deepening due to both fluvial and glacial processes, what resulted in the observed accumulation of thick glacial-fluvial, alluvial and lacustrine deposits. Another set of hypotheses considered the Skadar-Zeta depression as a former, Neogene, sea gulf. Baldacci [23] considered that it was progressively filled with the alluvial sediments of the River Bojana and evolved into a marshland and then to a lake. Miladinović [24] and Radulović et al. [5] hypothesised that the marine waters retreated from the gulf only recently, during the last 2.5 Ma, due to the eustatic sea regression associated with Pleistocene glaciations. According to Boskovic et al. [25], the sea gulf had been ca. 600 m deep and was progressively filled by the deposits and overflown with waters of the Morača, Drin and Bojana Rivers until, during the Last Glacial Maximum at ca. 26 ka BP (before present), it finally drained completely to the Adriatic due to its low level (by ca. 180 m) at that time. Radoman [11] mentioned that some geologists believed, although without providing any literature sources, that in Miocene the Adriatic covered the area past Ulcinj to, more or less, Vladimir and Pistola, while in Pliocene it penetrated through Plavnica as far inland as present Podgorica. Lately, Radulović [26, 27] proposed a novel and very controversial hypothesis on formation of the Dinaric karst in the deep sea and its very recent and rapid emergence in Holocene (even less than 5 ka), what stands in opposition to the commonly accepted knowledge based on the solid geological evidence (e.g. [28, 29]). According to this hypothesis, the large polje was exposed due to the rapid seawater regression and furtherly shaped by strong fluvial and glacial erosion, finalising with accumulation of freshwater in the southwestern part of the depression, i.e. in the present Lake Skadar. Taking into account the several, partially mutually exclusive, hypotheses, the further geological and geomorphological research should be carried out to clarify this issue.

Much more reliable is the knowledge on the Holocene history of the Skadar basin, from 16.5 ka BP till now. A recent study by Mazzini et al. [30] aimed at reconstruction of Middle-Late Holocene palaeoenvironmental and palaeoclimatic changes based on micropalaeontological evidence including subfossil Ostracoda and Characeae, compared with palynological data and stable isotope curves. The study showed that, at least from 4,560 to 1,200 cal year BP (calibrated years before present), the Skadar basin was occupied by a vast freshwater marshland, apparently fed mainly with the numerous springs, particularly in the north-western part of the basin, and by the few rivers, such as Morača, Crnojevića and Crmnica. The water accumulating in marshland discharged from the Bojana (Buna) River directly to the Adriatic. It is hard to say with confidence why the marshland changed, apparently quite abruptly, to the large shallow lake that we know today. The palaeoclimatic data, obtained from the δ^{18}O curve, provided no definite answer that could relate this environmental change to a wetter climate change [31]. Instead, it was probably caused by a combination of several factors, such as the progressive sea level rise along the eastern Adriatic coastline [32] and, possibly, changed course of the Drim River that contributed to overflowing of the Skadar depression. Such river course changes are not unusual in the Balkans, where the tectonics is extremely dynamic. For example, it is known that the Drim River has periodically changed its course over the last five centuries, deviating it into the Bojana River and causing flood events [33]. The reconstruction of environmental conditions by Mazzini et al. [30] copes well with historical records – neither Ptolemy and Strabo nor Titus Livius mentioned the lake in their description of this region, while the latter geographer reported a large swamp and River Moraca on the site of the modern-day lake. The Italian historician, Georgius Merula [34], was the first to account for the presence of Lake Skadar, on the occasion of his description of an Ottoman siege of the Venetian-controlled Shkodra, and described the waterbody as recently formed and already large and navigable for ca. 40 km, so the Montenegrin Ivan Crnojević, the Lord of Zeta, could sent his forces to sail on galleys through the lake from Žabljak Crnojevića to Shkodra, to help the Venetians.

These recent views on the Holocene history of Lake Skadar bring a general conclusion, crucial for the further discussion of the history of local aquatic biota. Namely, whatever were the deep origins of the lake basin, it has undergone a series of profound environmental changes over the probable several millions of years of its existence. Even if in the more distant past the lacustrine conditions prevailed in the basin, they were not permanent and have not continued until the present. At the moment there are no available geological data that would allow to estimate if and for how long the lacustrine conditions dominated in the basin in the past as well as how many times and for how long there were interluded with more terrestrial environments – marshlands or spring systems. Yet, undoubtedly, the large system of karstic springs is much older and has existed much longer than the present lake.

3 The Obscure History of Fauna Inhabiting Lake Skadar and the Associated Spring System

Already Radoman [11], in his thorough biogeographical analysis of the freshwater hydrobioid snails of the Balkan Peninsula, noticed that the endemic species inhabiting Lake Skadar belong to genera chiefly associated with running waters, and particularly with springs, not with lakes. He regarded only two endemics, *Radomaniola* (=*Orientalina*) *lacustris* Radoman, 1983, and *Vinodolia* (=*Anagastina*) *scutarica* Radoman, 1973, as typically lacustrine forms (but see [35, 36] for a discussion). Glöer et al. [37] indicated that the absence of major hydrobioid radiation in Lake Skadar could have triggered diversification of other snail groups, especially bithyniids. With five species of *Bithynia*, Lake Skadar is a hot spot of evolution of this genus. However, none of endemics that occur in Lake Skadar including bithyniids are typically lacustrine species (see [36] for a discussion on the endemism of gastropods in Lake Skadar).

This is certainly not what would be expected from an ancient lake. For comparison, the Lake Ohrid basin, estimated to be at least 2 Ma old [19], is inhabited by more than 40 endemic species of hydrobioids, of which the majority occurs in the lake itself and only some species, apparently derived from the lacustrine taxa, thrive in the associated springs [11, 38]. Such poverty of endemic lacustrine species in Lake Skadar is coherent with the extremely young age of the present waterbody, estimated by Mazzini et al. [30], leaving no time for adaptive radiation. On the other hand, the presence of even two lacustrine endemics in this lake demands consideration. Radoman [11] argued that it is far more probable, from the evolutionary point of view, to derive stenothermic species inhabiting springs from the rather eurythermic and euryoecious lacustrine form, than reverse. Thus, if the Lake Skadar is a relatively young waterbody derived from a marine gulf, evolution of these species from spring-inhabiting forms has been unlikely. On the other side, it was recently shown that in case of the nearby ancient Lake Ohrid, the lacustrine endemic *Gammarus* species flock (Malacostraca, Amphipoda) derives from one of the local lineages inhabiting surrounding springs and headwaters [39].

As an alternative scenario, Radoman [11] assumed that both, *R. lacustris* and *V. scutarica*, are relicts from the much older lacustrine phases, possibly related to the Neogene system palaeolakes covering vast area of the Balkan Peninsula. They could survive in the marshlands or larger limnocrenes left behind the palaeolakes in the karst terrain. In such setting, the numerous spring-inhabiting endemics of the Skadar basin would be derived from the now extinct lacustrine forms. However, it is worth to be mentioned that the recent studies by Pešić and Glöer [35, 36] have questioned *R. lacustris* and *V. scutarica* as typically lacustrine, for they found both species only in environment associated with sublacustrine springs. It would either put in doubts the impossibility of lacustrine forms to adapt to spring conditions or, more probable in this particular case, leave the Skadar Lake without any typically lacustrine endemics. Surely before drawing any definitive conclusions, the local distribution of snails should be thoroughly studied. Additionally, there is already some evidence for the local lineage divergence and endemism in case of some widely distributed European gastropods, such as *Lymnaea* [40] and even within some of the Skadar basin endemics [41]. Much less is known about freshwater mussels. A study upon molecular identity and demography of Balkan endemic species of *Dreissena*, which is a genus typically occurring in lakes and large lowland rivers, clearly indicates that Lake Skadar was only recently colonised from Lake Ohrid by *D. carinata* (Dunker, 1853) (syn. *D. stankovici* Lvova and Starobogatov, 1982) [18]. This could have happened via the Drim River, connecting Lake Ohrid and Skadar – particularly that the ontogeny of *Dreissena* is characterised by the presence of planktonic dispersal stage that can easily be carried with the river current. The earliest possible date of the population expansion was estimated at ca. 300 ka; however this could be the initial expansion in the Lake Ohrid, while the colonisation of Lake Skadar may be much later or even recurrent event associated with the already mentioned alteration of local hydrological networks. Noticeably, an important role of Lake Ohrid for the colonisation of the Skadar basin, as well as shared Prespa/Ohrid/Skadar endemism, was also underlined in several studies upon fish (e.g. [42, 43]) and, recently, some amphipods [44].

Very interesting are the results of ongoing studies upon various malacostracan crustaceans inhabiting the Lake Skadar basin. After gastropods, it is the second known animal group with respect to the number of local endemics at the morphological species level. The definitive majority of this endemic diversity is associated with the subterranean karst habitats and represented by various *Niphargus* species. Recently, McInerney et al. [45] provided a thorough time-calibrated reconstruction of *Niphargus* intrageneric phylogeny in Europe including two species, *Niphargus* cf. *aquilex* and *N. polymorphus*, from the Skadar basin. The authors evidenced that first members of the genus colonised the Dinaric karst, and started to diversify, in Late Oligocene (ca. 25 Ma), while their major diversification occurred in Miocene (23–5 Ma). It is worth to be mentioned that the latter coincides well with the suggested time of the intensification of karstification processes in the Mediterranean area [46–48] and stands in opposition to the Radulović's [26, 27] hypothesis of the marine and, very recent, Holocene, origin of karst, given that *Niphargus* is a strictly freshwater genus and could not occur in marine conditions. According to McInerney et al. [45], the divergence of lineages in the Skadar basin initiated some time in Pliocene (5–2.5 Ma), what suggests the freshwater conditions at that time.

The epigean taxa follow, in principle, the above pattern; however more endemism is observed at the level of divergent lineages (possibly cryptic species) within the conventionally described morphospecies. For example, our recent studies ([49, 50]; Wysocka et al. unpublished data) upon the common European freshwater isopod *Asellus aquaticus* (Linnaeus, 1758) indicated that, in early Pleistocene/latest Pliocene, the Skadar basin was colonised by members of a local south-eastern European mtDNA clade. It was apparently a singular event that gave rise to an endemic mtDNA lineage that has subsequently expanded and diversified in the whole Skadar basin. Similar is the situation of *Laurogammarus scutarensis* (Schäferna 1922), which is the Skadar basin endemic, inhabiting sublacustrine springs and streams (Fig. 3) [51]. In case of this species, divergence of local lineages

Fig. 3 Habitat of the local endemic *Laurogammarus scutarensis* in the Sitnica River, Skadar Basin. Photo by M. Grabowski

has most probably started in Pliocene and continued through Pleistocene, with connectivity/isolation patterns between populations from different springs suggesting that the spring system existed for a prolonged time prior to the lake (Jabłońska et al. unpublished).

Our very preliminary data suggest also that the common Balkan amphipod, *Gammarus roeselii*, Gervais, 1835, is represented by two lineages in the Skadar basin – one of presumably Pliocene origin and another one which is an apparent case of colonisation from Lake Ohrid, most likely through the Drim River ([44]; Wysocka et al. unpublished data). In case of a few other currently studied malacostracans, such as the mysid *Diamysis lacustris* Băcescu, 1940; *Palaemon antennarius* H. Milne Edwards, 1837; *Atyaephyra vladoi* [52] (Fig. 4); and *Cryptorchestia* sp. nov., the molecular data suggest even later, Pleistocene, colonisation and/or diversification in the Skadar basin ([52]; Grabowski et al. unpublished data). Interestingly, among the malacostracan crustaceans inhabiting the Skadar basin, there are no typically lacustrine species, and almost all of them seem to be associated predominantly with the spring systems and adjacent parts of the lake. Only *D. lacustris* was found by us to occur massively in typically lacustrine habitats; however it was present also in some of the sublacustrine springs ([53]; Grabowski et al. unpublished data). The other Mediterranean species of the genus *Diamysis* inhabit both the coastal lagoons and lowland rivers [54], so we can hypothesise it could colonise the Skadar basin during one of the eustatic sea regressions caused by the Pleistocene glaciations and prevalence of fresh- and brackish water conditions in northern, and presumably also

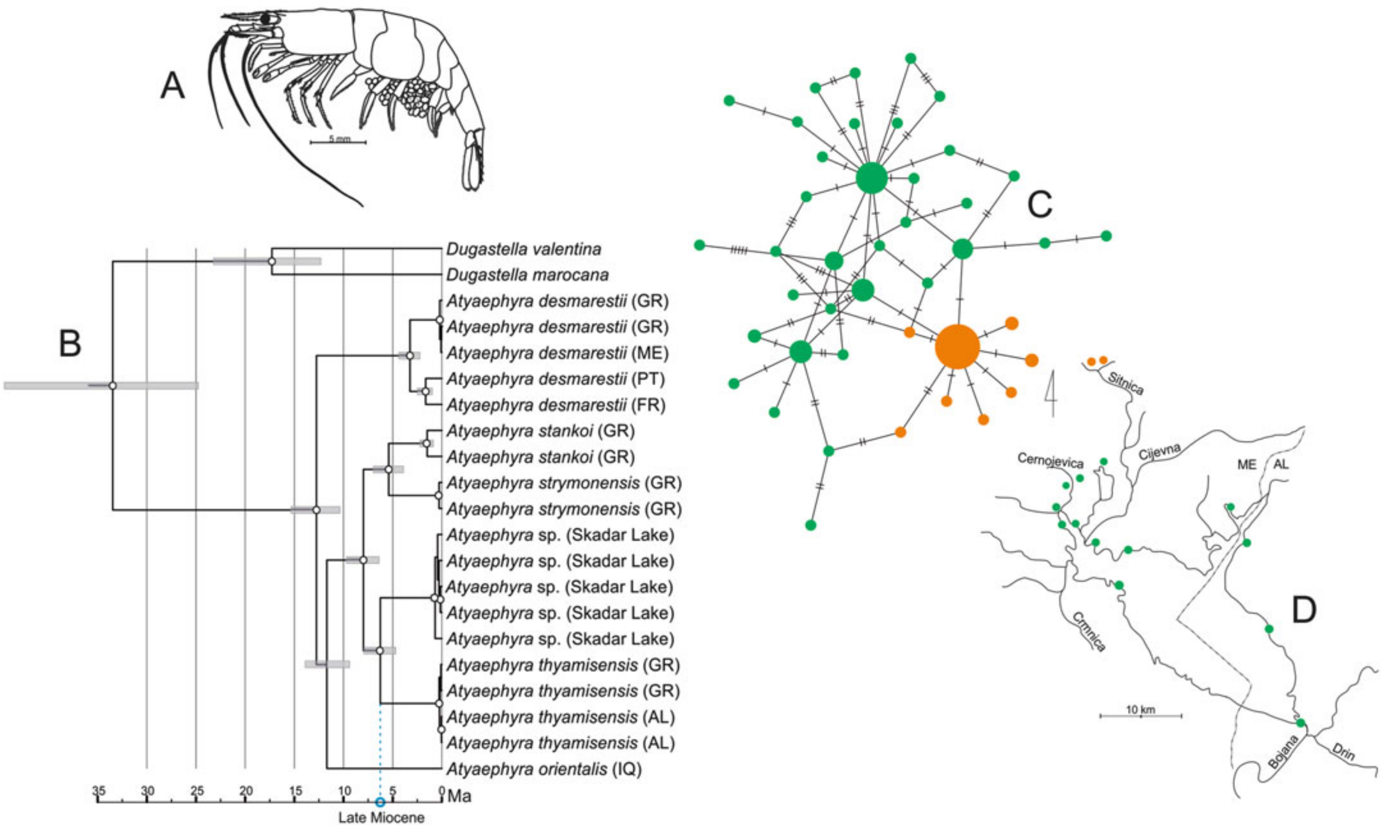

Fig. 4 Recently described *Atyaephyra vladoi* shrimp from Lake Skadar basin. (**a**) Habitus, (**b**) time-calibrated phylogeny, (**c**) median-joining network of haplotypes and their distribution (**d**) in the basin. Modified after [52]

central, part of the Adriatic Sea [55]. The same could be valid also for the *P. antennarius* and the yet-undescribed species of *Cryptorchestia*, whose closest relatives were found in other, now disjunct, lacustrine and riverine ecosystems, around the Adriatic (Jabłońska and Grabowski unpublished data). These findings also suggest the Late Neogene origin of the freshwater conditions in the Skadar basin and also some episodes of trans-Adriatic hydrological connections during its history.

4 Conclusion and Perspective for Future Research

As it may be clearly seen, the research upon the history of the fauna in Lake Skadar and its basin is still rather scarce, with in-detail studies concerning only few taxa. However, for now, it may be concluded that the largely preliminary results generally conform to the hypothesis that the Skadar basin is a former Neogene sea gulf (e.g. [11]), pointing to Pliocene as the time frame during which the freshwater conditions prevailed in the basin and continued until now. Another conclusion may be that, indeed, the Lake Skadar is a very recent waterbody as there are virtually no lacustrine endemics neither at the species level nor at the level of intraspecific lineage diversity. Thus, the lake itself cannot be, by any means, termed as an ancient lake. Yet on the other side, the Lake Skadar basin and its hydrological network with a large system of karst spring are definitely ancient, originated more than 2.5 Ma and isolated for most of its history, with a high number of crenal and fluvial endemics, at both the species and the lineage (possibly cryptic or pseudocryptic species) levels, depending on the studied taxa. Further in-depth studies, employing integrative methodology, should be undertaken upon the taxonomy of the local fauna to reveal the actual level of endemism that is probably much higher than observed now in gastropods or crustaceans but also in other notable animal groups such as fishes, leech or aquatic insects that remain only superficially studied, not even mentioning the meiofauna that is not really studied (with an exception of ostracods). Particular attention should be paid to the isolation vs. connectivity patterns of the dozens of springs present in the area. Some of them are likely to be hundreds of thousands years old and in prolonged isolation, enhancing the emergence of divergent and locally endemic lineages or even species, while others – isolated now – could be temporarily connected in the past. Virtually unknown is also the role of underground passages connecting many of these springs. Another thread worth further exploration is the phylogenetic relationship of the local fauna with that of the other karst poljes in the Dinaric areas or the role of Pleistocene eustatic sea regression in faunal exchange between the Skadar and other Periadriatic hydrological systems. Finally, virtually unexplored is the origin of fauna inhabiting the present young lake – is it just a set of widespread lineages inhabiting lacustrine habitats all over Balkans that have high dispersal abilities or where the lake colonised mainly from the small local waterbodies associated with limnocrene springs or small local marshlands. These are only a few examples of research goals and comparative phylogenetic or phylogeographic studies upon the Skadar biota confronted with an independent geological evidence that would help to build up the reliable knowledge upon the history of this fascinating karst system and, in consequence, help to estimate the conservation needs and plan the proper conservation strategy for the area.

References

1. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
2. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82
3. Lasca NP, Radulović V, Ristić RJ, Cherkauer DS (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 17–38
4. Biju-Duval B, Letouzey J, Montadert L, Courrir P, Mugniot JF, Sancho J (1974) Geology of the Mediterranean Sea basin. In: Burk CA et al (eds) The geology of continental margins. Springer, New York
5. Radulović M, Popović Z, Vujisić M, Novaković D (1989) Basic hydrogeological map of SRY 1:100,000, "bar" sheet (in Serbian). Geological Survey of Montenegro, Titograd
6. Radulović MM (2018) Hydrogeology of the Skadar Lake basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
7. Vlahović I, Mandić O, Mrinjek E, Bergant S, Ćosović V, De Leeuw A, Enos P, Hrvatović H, Matičec D, Mikša G, Nemec W, Pavelić D, Pencinger V, Velić I, Vranjković A (2012) Marine to continental depositional systems of outer Dinarides foreland and intra-montane basins (Eocene-Miocene, Croatia and Bosnia and Herzegovina). Mitt Ges Geol Bergbaustud Österr 54:405–470
8. Bianco PG (1990) Potential role of the palaeohistory of the Mediterranean and Paratethys basins on the early dispersal of Euro-Mediterranean freshwater fishes. Ichthyol Explor Freshw 1 (3):167–184
9. Krijgsman W, Hilgen FJ, Raffi I, Sierro FJ, Wilson DS (1999) Chronology, causes and progression of the Messinian salinity crisis. Nature 400:652–655
10. Skoulikidis NT, Economou AN, Gritzalis KC, Zogaris S (2009) Rivers of the Balkans. In: Tockner K, Uehlinger U, Robinson CT (eds) Rivers of Europe. Elsevier/Academic Press, San Diego, pp 421–466
11. Radoman P (1985) Hydrobioidea a superfamily of Prosobranchia (Gastropoda), II. Origin, zoogeography, evolution in the Balkans and Asia Minor, Faculty of Science, Department of Biology, Monographs, vol 1, pp 1–173
12. Buj I, Marčić Z, Caleta M, Sanda R, Geiger MF, Freyhof J et al (2017) Ancient connections among the European rivers and watersheds revealed from the evolutionary history of the genus Telestes (Actinopterygii; Cypriniformes). PLoS One 12(12):e0187366
13. Cvijić J (1911) L'ancien lac égéen. Annales de Géographie 20(111):233–259. https://doi.org/10.3406/geo.1911.7343
14. Popov SV, Rögl F, Rozanov AY, Steininger FF, Shcherba IG, Kovac M (2004) Lithological-paleogeographic maps of Paratethys: 10 maps late Eocene to Pliocene. Cour Forschungsinst Senck 250:1–46
15. Krstić N, Savić L, Jovanović G (2012) The Neogene lakes on the Balkan Land. Ann Géol Pénins Balk 73:37–60

16. Krstić N, Savić L, Jovanović G, Bodor E (2005) Lower Miocene lakes of the Balkan Land. Acta Geol Hung 46(3). https://doi.org/10.1556/AGeol.46.2003.3.4
17. Albrecht C, Wilke T (2008) Ancient Lake Ohrid: biodiversity and evolution. Hydrobiologia 615:103–140. https://doi.org/10.1007/s10750-008-9558-y
18. Wilke T, Schultheiß R, Albrecht C, Bornmann N, Trajanovski S, Kevrekidis T (2010) Native Dreissena freshwater mussels in the Balkans: in and out of ancient lakes. Biogeosci Discuss 7:4425–4461
19. Jovanovska E, Cvetkoska A, Hauffe T, Levkov Z, Wagner B, Sulpizio R, Francke A, Albrecht C, Wilke T (2015) Differential resilience of ancient sister lakes Ohrid and Prespa to environmental disturbances during the late Pleistocene. Biogeosci Discuss 12:16049–16079
20. Wagner B, Wilke T (2011) Evolutionary and geological history of the Balkan lakes Ohrid and Prespa. Biogeosciences 8:995–998. https://doi.org/10.5194/bg-8-995-2011
21. Cvijić J (1899) Glacial and morphological studies of the mountains of Bosnia, Herzegovina and Montenegro. Voice Serb R Acad Sci 57:1–196 (in Serbian)
22. Bešić Z (1983) Geomorphology and geology of the Zeta Valley and Skadar Lake area (in Serbian). In: Ivanović B (ed) Skadar Lake, Book 9 of Scientific meetings. Montenegrin Academy of Sciences and Arts, Titograd, pp 13–23
23. Baldacci A (1929) L'Albania, Roma. Istituto per l'Europa Orientale
24. Miladinović M (1964) Geology and tectonics of the Rumija Mountain area along the Montenegrin coast. Dissertation, University of Belgrade (in Serbian)
25. Boskovic M, Popovic M, Alilovic N (2004). Supplement to Skadar Lake geogenesis, its inflow and outlet components and background on its regulation activities. In: BALWOIS conference proceedings, Ohrid, 25–29 May 2004, pp 1–9
26. Radulović MM (2013) A new view on karst genesis. Carbonates Evaporites 28:383–397. https://doi.org/10.1007/c13146-012-0125-2
27. Radulović MM (2013) Karst landforms submerge evolution? http://geologyresearch.me. Accessed 11 Apr 2013
28. Mihevc A (2010) Geomorphology. In: Mihevc A, Prelovšek M, Hajna NZ (eds) Introduction to the Dinaric karst. Institut za raziskovanje krasa ZRC SAZU, Postojna, pp 30–43
29. Bonacci O (2014) Karst hydrogeology/hydrology of Dinaric chain and isles. Environ Earth Sci. https://doi.org/10.1007/s12665-014-3677-8
30. Mazzini I, Gliozzi E, Koci R et al (2015) Historical evolution and middle to late Holocene environmental changes in Lake Shkodra (Albania): new evidences from micropaleontological analysis. Palaeogeogr Palaeoclimatol Palaeoecol 419:47–59
31. Zanchetta G, VanWelden A, Baneschi I, Drysdale R, Sadori L, Roberts N, Giardini M, Beck C, Pascucci V, Sulpizio R (2012) Multiproxy record for the last 4500 years from Lake Shkodra (Albania/Montenegro). J Quat Sci 27(8):780–789
32. Uncu L (2012) Holocene landscape changes of the Lezha Region: a contribution to the palaeogeographies of coastal Albania and the geoarchaeology of ancient Lissos. Marburger Geographische Gesellschaft, Marburg, Lahn, pp 1–232
33. Knezevic M (2009) Study of the water regime of the Morača River and Skadar Lake. Report committed by WWF MedPO and Green Home under the framework of Sharing Water Project–Skadar Lake component, Podgorica, Sept 2009
34. Merula G (1474) Bellum Scodrense. Gabriele di Pietro, Venezia, pp 1–24
35. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
36. Pešić V, Glöer P (2018) The diversity and conservation status of the molluscs of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
37. Glöer P, Albrecht C, Wilke T (2007) Enigmatic distribution pattern of the Bithyniidae in the Balkan region (Gastropoda: Rissooidea). Mollusca 25:101–110

38. Radoman P (1982) Hydrobioidea a superfamily of Prosobranchia (Gastropoda), I. Systematics, vol 547. Serbian Academy of Sciences and Arts, Beograd (Dep. Sci. 57), pp 1–256, 12 pls
39. Wysocka A, Grabowski M, Sworobowicz L, Mamos T, Burzyński A, Sell J (2014) Origin of the Lake Ohrid gammarid species flock: ancient local phylogenetic lineage diversification. J Biogeogr 41(9):1758–1768
40. Vinarski MV, Schniebs K, Glöer P, Hundsdoerfer AK (2012) Preliminary phylogeography of Lymnaea stagnalis: are there cryptic species of the great pond snail? In: XI international congress on medical and applied malacology, 66 pp
41. Falniowski A, Szarowska M, Glöer P, Pešić V (2012) Molecules vs morphology in the taxonomy of the *Radomaniola/Grossuana* group of Balkan Rissoiidea (Mollusca: Caenogastropoda). J Conchol 41(1):19–36
42. Markova S, Šanda R, Crivelli A, Shumka S, Wilson IF, Vukić J, Berrebi P, Kotlik P (2010) Nuclear and mitochondrial DNA sequence data reveal the evolutionary history of *Barbus* (Cyprinidae) in the ancient lake systems of the Balkans. Mol Phylogenet Evol 55:488–500. https://doi.org/10.1016/j.ympev.2010.01.030
43. Milošević D, Winkler KA, Marić D, Weiss S (2011) Genotypic and phenotypic evaluation of *Rutilus* spp. from Skadar, Ohrid and Prespa Lakes supports revision of endemic as well as taxonomic status of several taxa. J Fish Biol 79(5):1094–1110. https://doi.org/10.1111/j.1095-8649.2011.03090.x
44. Grabowski M, Mamos T, Bącela-Spychalska K, Rewicz T, Wattier RA (2017) Neogene paleogeography provides context for understanding the origin and spatial distribution of cryptic diversity in a widespread Balkan freshwater amphipod. PeerJ 5:e3016. https://doi.org/10.7717/peerj.3016
45. McInerney CE, Maurice L, Robertson AL, Knight LRFD, Arnscheidt J, Venditti C, Dooley JSG, Mathers T, Matthijs S, Eriksson K, Proudlove GS, Hänfling B (2014) The ancient Britons: groundwater fauna survived extreme climate change over tens of millions of years across NW Europe. Mol Ecol 23:1153–1166
46. Habic P (1995) On the development of the classical Dinaric karst in Slovenia. Acta Universitatis Szegediensis: Acta Geographica 34:93–106
47. Frisch W, Kuhlemann J, Dunkl I, Székely B (2001) The Dachstein paleosurface and the Augenstein Formation in the Northern Calcareous Alps – a mosaic stone in the geomorphological evolution of the Eastern Alps. Int J Earth Sci 90:500–518
48. Mocochain L, Audra P, Clauzon G, Bellier O, Bigot J-Y, Parize O, Monteilf P (2009) The effect of river dynamics induced by the Messinian salinity crisis on karst landscape and caves: example of the lower Ardèche river (mid Rhône valley). Geomorphology 106:46–61
49. Sworobowicz L, Grabowski M, Mamos T, Burzyński A, Kilikowska A, Sell J, Wysocka A (2015) Revisiting phylogeography of *Asellus aquaticus* in Europe: insight into cryptic diversity and spatiotemporal diversification. Freshw Biol 60:1824–1840
50. Wysocka A, Sworobowicz L, Mamos T, Grabowski M (2017) Comparative phylogeography of *Gammarus roeselii* Gervais, 1835 and *Asellus aquaticus* Linnaeus, 1758 from the Ohrid, Prespa and Skadar lakes, Balkan Peninsula. In: Lo Brutto S, Schimmenti E, Iaciofano D (eds) Proceedings of the 17th International Colloquium on Amphipoda (17th ICA), September 4th–7th 2017, Trapani (Italy). Biodiversity J 8(2):479–480
51. Grabowski M, Bącela-Spychalska K, Pešić V (2014) Reproductive traits and conservation needs of the endemic gammarid *Laurogammarus scutarensis* (Schäferna, 1922) from the Skadar Lake system, Balkan Peninsula. Limnologica 47:44–51
52. Jabłońska A, Mamos T, Zawal A, Grabowski M (2018) Morphological and molecular evidence for a new shrimp species, *Atyaephyra vladoi* sp. nov. (Decapoda, Atyidae) in the ancient Skadar Lake system, Balkan Peninsula – its evolutionary relationships and demographic history. Zool Anz. https://doi.org/10.1007/698_2018_349
53. Pešić V, Gadawski P, Gligorović B, Glöer P, Grabowski M, Kovács T, Murányi D, Płóciennik M (2018) The diversity of the zoobenthos communities of the Lake Skadar/Shkodra basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham

54. Wittmann KJ, Ariani AP, Daneliya M (2016) The Mysidae (Crustacea: Peracarida: Mysida) in fresh and oligohaline waters of the Mediterranean. Taxonomy, biogeography, and bioinvasion. Zootaxa 4142(1):1–70
55. McKinney FK (2007) The northern Adriatic ecosystem: deep time in a shallow sea. Columbia University Press, New York, 299 pp

Climate Change in the Lake Skadar/Shkodra Region

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Contents

Abstract IPCC Assessment Reports on Climate Change indicate that in the twenty-first century, climate change will be accompanied by an increase in the frequency, intensity, and duration of extreme natural phenomena such as extreme atmospheric precipitation or droughts, extremely high or low air temperatures, etc. In this chapter, we briefly review general characteristics of climate and climate change in the coastal region of Montenegro. Then, using data from ERA-20C, which is the European Centre for Medium-Range Weather Forecasts (ECMWF) first atmospheric

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 63–88, DOI 10.1007/698_2018_350,
© Springer International Publishing AG, part of Springer Nature 2018,
Published online: 7 July 2018

reanalysis of the twentieth century from 1900 till 2010, we are analyzing linear trends and variability of the characteristics of extreme climate events of near-surface air temperature, wind speed, sea-level pressure, snow depth, cloud cover, and atmospheric precipitation for 1950–2010 in the region of Lake Skadar/Shkodra. For the first time, we determined interannual variability of frequency, intensity, and duration of extreme meteorological events in this region, which is a source of valuable information for better understanding the present and future Lake Skadar/Shkodra environment and ecosystem characteristics.

Keywords Albania, Atmospheric precipitation, Cloud cover, Extreme climate events, Lake Skadar/Shkodra, Montenegro, Near-surface air temperature, Regional climate change, Sea-level pressure, Snow depth, Wind speed

1 Introduction

The Fourth (2007) and Fifth (2013, 2014) Climate Change Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) indicate that in the twenty-first century, climate change will be accompanied by an increase in the frequency, intensity, and duration of extreme natural phenomena such as extreme atmospheric precipitation or droughts, extremely high or low air temperatures, etc. [1–4]. All this will lead to floods; droughts; fires; shallowing of rivers, lakes, and water reservoirs; desertification; dust storms; melting of glaciers and permafrost; and algal bloom in the seas, lakes, and freshwater reservoirs. In turn, these phenomena will lead to chemical and biological pollution of water, land, and air. The end result of these events is deterioration in the quality of life of the local population; significant financial losses associated with damage to the housing stock, businesses, roads, agriculture and forestry, and tourism; and, in many cases, human losses.

Under extreme meteorological phenomena are usually understood statistics of "extreme," i.e., sharply standing out against the backdrop of "norm," phenomena in the climate system. As a rule, such phenomena have a special (more often negative) effect on natural systems, which are therefore particularly sensitive to changes in frequency, intensity, and duration of extreme weather events [1–5].

The disadvantage of these studies is the averaging of meteo parameters under study and generalization of conclusions obtained for very large territories and water areas comparable to the size of several countries or seas. In this chapter, we briefly review general characteristics of climate and climate change in the coastal region of Montenegro. Then, using data from ERA-20C reanalysis for 1950–2010, we studied interannual variability of the characteristics of extreme climate events in the area of 1 degree latitude by 1 degree longitude focused on Lake Skadar/Shkodra. Determination of frequency, intensity, and duration of the climatic changes of extreme meteorological events in this region has been done for the first time.

We believe that special attention should be paid, namely, to the study of extreme weather events because they cause the main stress and even damage to economy, infrastructure, agriculture, forestry, tourism, and quality of life of the population in

Montenegro, as well as to the state of the environment and ecosystem of Lake Skadar/Shkodra. We can refer here to yearly forest fires in Montenegro [6], flood waves which became more frequent (e.g., on November 7–8, 2016), severe frosts (e.g., on January 6–12, 2017) [7], strong winds, and storms in the sea. For example, in January 2017 frosts led to formation of a thin ice cover along the shallow northern shoreline of the lake which is a very rare event. Floods have a significant impact on the turbidity and chemical and biological characteristics of Lake Skadar/Shkodra [7].

2 General Climate Characteristics of the Lake Skadar/Shkodra Region

Little is known about regional climate change in the area of Lake Skadar/Shkodra. Below, we gathered the main characteristics of climate in the area of Lake Skadar/Shkodra based on a recent report of the Montenegrin Academy of Sciences and Arts [8]. According to this report, the Lake Skadar water basin is characterized by three different climate types [8]:

1. A mildly warm climate without a dry period over the year in the east and north of the lake basin.
2. A moderately warm climate without a pronounced dry period over the year with dry summers in the northwestern, western, and southwestern part of the lake basin.
3. The Mediterranean-Adriatic climate with a dominant hot and dry summer period with an average air temperature of the warmest month of over 22°C in the littoral region and the Zeta-Bjelopavlici Plain. The lake itself is characterized by this type of climate.

The average air temperature in the Lake Skadar/Shkodra area ranges from 14 to 16°C. The average summer air temperature is 25°C. The highest air temperature in Montenegro was measured in August 2007 at the Zeta-Bjelopavlici Plain and was 44.8°C. Dry and hot summers cause strong evaporation from water bodies while smaller rivers and springs dry up completely. In winter, average air temperature varies from 6 to 9°C. The warmest month is July, and the coldest one is January when the number of days with negative air temperatures may reach 5 days [8].

The average yearly amount of precipitation in the lake area is of 1,800–2,200 L/m^2. In winter (from December to February), the amount of precipitation here is of 850 L/m^2. November is the rainiest month, while July and August are the driest months. The average number of days with precipitation ranges from 110 to 120 days. In winter, snow cover may reach 20–40 cm at the Zeta-Bjelopavlici Plain. The mean annual number of days with snow cover over 10 cm varies from 5 to 10 days and over 30 cm – only 1 day at this plain [8].

The mean annual cloudiness in the area of the lake is 0.45, while mean annual sunshine hours vary between 2,000 and 2,400. Winds are strongly conditioned by local orography. At the Zeta-Bjelopavlici Plain, the most prevailing winds are with the northerly direction of 3–5 and 5–10 m/s and with the southerly direction of 5–10 m/s [8].

The report has only these average characteristics of meteo parameters without information on their interannual variability and cyclicity. Such kind of research was recently done for the period 1950–2010 for the area of the Boka-Kotorska Bay which is located 35 km northwestward of Lake Skadar/Shkodra [9]. Below, we briefly summarized the obtained results.

During these 60 years, the average air temperature in the region of the Boka-Kotorska Bay grew by 1.3°C. The coldest winters were observed in the 1950s and 1960s, and then they became rare with exceptional events in 1981 and 2003. Irregular cycling of relatively cold winters with 5–15 year periods were detected. Warm summers with the air temperature over 22°C were observed about 10 times in 1950–1975 and more than 20 times from 1985 to 2010, i.e., almost yearly. Also, it was found that from one year to another, cold seasons have larger positive and negative air temperature anomalies than anomalies in warm seasons. Air temperature anomalies display interannual variations with an amplitude of the order of 2°C. The corresponding peaks with periods close to 2.9 and 5.6 years were detected in the spectrum of daily temperature anomalies [9].

During the observed 60 years (1950–2010), sea-level pressure increased from about 1,016 to 1,017 hPa. It is interesting that positive anomalies as large as 15 hPa can be observed with periods of about 5–10 years but large negative anomalies can reach only 6–7 hPa, but with smaller periods (2–5 years), i.e., they are more frequent. Similar to air temperature anomalies, sea-level pressure anomalies in cold seasons were several times larger than in warm periods of the year. Thus, positive and negative anomalies in cold seasons could reach 4 hPa, while positive and negative anomalies in warm seasons reached only 1.0–1.5 hPa. As to frequency analysis, we could identify only one peak at a 1-year period and the 15-year period as a characteristic feature for decadal variability [9].

Atmospheric precipitation over the Boka-Kotorska Bay region showed a very little decreasing trend during the 60-year period. Seasonal and interannual variability of precipitation showed peaks which are irregular in time and amplitude. These peaks can be four times larger than the average value of precipitation. From year to year, variability of anomalies showed that they are much larger in cold seasons (both positive and negative anomalies) than in warm seasons. Frequency analysis did not show any significant peaks at periods more than 1 year [9].

Snow cover in the Boka-Kotorska Bay region is very small and rare, but the analysis of its interannual variability has clearly showed a decrease in snow cover from 1950 to 2010. Snowy winters became much more rare, and snow depth during these events became about two times less than in 1950–1970. Anomalies of snow cover have revealed periodicity of about 8–10 years. Frequency analysis did not demonstrate any notable periods of snow cover variability. It means that this process is chaotic like accumulated precipitation in the same region, and it is not related to any global indices like NAO, ENSO, etc. [9].

Mean monthly eastward wind has an order of 1 m/s and is observed, in general, in summer. Mean monthly westward wind is about 50% stronger, and it is observed, in general, in winter and may reach 2.5 m/s. Thus the amplitude of seasonal variability is of the order of 2–3 m/s. The analysis showed a positive trend of about 0.18 m/s during 60 years of observation, and by 2010 the average zonal wind component had reached −0.15 m/s, i.e., almost a balance between westward and eastward wind components. Positive and negative anomalies of a zonal wind component in a cold season were much larger than positive and negative anomalies in a warm season. The 8-year moving average revealed a couple of periodical fluctuations in wind speed anomalies of the order of 12–13 years. Frequency analysis has shown two peaks at periods of 2.1 and 3.8 years [9].

Analysis of meridional wind component has showed little dominance of north-southern transfer of air masses, which during 1950–2010 increased by 0.16 m/s. Analysis of anomalies has showed that in cold seasons anomalies (both positive and negative) are much larger than in warm seasons. The behavior of an accumulated amount of anomalies has showed several breaking points, i.e. years when wind regime significantly changed. This occurred at least in 1965, 1981, and in 1993, which is only partially consistent with the zonal component of wind (1965, 1971, 1983, and 1999). Frequency analysis has shown that there are no statistically significant peaks at periods more than 2 years, except a weak peak period of 2.9 years [9].

Cloud cover in the Boka-Kotorska Bay region demonstrates strong seasonal variability, when in winter it is as large as 75%, and in summer it is often less than 25%. A notable decreasing trend was detected, which means that cloud cover, on average, had decreased by about 4% during 60 years. Analysis of anomalies of cloud cover has shown that from the mid-1950s till the mid-1980s, there was a steady rise of cloud cover over the region with significant interannual variability. Then, from the end of the 1980s till the mid-1990s, we observed a sharp drop of cloud cover with several anomalously clear sky winters (cold season) – 1989, 1990, 1992, and 1993. This is in good agreement with the climatic shift in the North Atlantic Ocean, observed in the end of the 1980s and at the beginning of the 1990s. From the mid-1990s, cloud cover settled at the same level. Frequency analysis revealed spectral peaks at periods of 1, 2.1, 2.4, and 3.6 years [9].

3 Data and Methods

Using daily data from ERA-20C [10], which is The European Centre's for Medium-Range Weather Forecasts (ECMWF) first atmospheric reanalysis of the twentieth century from 1900–2010, we are analyzing linear trends and variability of the characteristics of extreme climate events of near-surface air temperature, wind speed, sea-level pressure, snow depth, cloud cover, and atmospheric precipitation, for 1950–2010 in the region of Lake Skadar/Shkodra (41.5°–42.5°N; 18.5°–19.5°E) (Fig. 1). The area of investigation is much larger than Lake Skadar/Shkodra because

Fig. 1 Map of the research area (41.5°–42.5°N; 18.5°–19.5°E) (https://earth.google.com/)

spatial resolution of the analyzed data is of 1 degree latitude by 1 degree longitude. Also, we tried to focus on the southern coast of Montenegro because the lake is characterized by the Mediterranean-Adriatic climate which is different from the northern part of Montenegro.

In this research, we focused on determination of interannual changes in frequency, intensity, and duration of anomalous and extreme meteorological events in this region, which was done for the first time. Based on daily anomalies, for each year, the number of anomalous and extreme events of the studying parameters which by modulo exceeded one and two standard deviations for 1950–2010, was calculated, as well as interannual changes in the mean amplitude and duration of these extreme events. The method of least squares for positive and negative anomalous and extreme events is used to calculate the linear trends of changes in their number, average amplitude, and duration.

All the anomalies were calculated relative to the average seasonal trend for the period 1950–2010. We considered the events "anomalous" when values of anomalies exceeded one standard deviation and as "extreme" when anomalies exceeded two standard deviations. Both types of events could last a day or more. The same methodology was used for the analysis of extreme air temperature events in the eastern part of the Black Sea [11].

4 Results

4.1 Air Temperature

Changes in the average annual values of amplitude, frequency, and duration of temperature anomalous and extreme events in the region are shown in Figs. 2 and 3. On average, the amplitude of negative-temperature anomalous events exceeds the amplitude of positive-temperature anomalous events by 0.5°C (Fig. 2). Extreme negative phenomena by modulo are even larger than the positive ones: by 3°C in 1950 and by 1.5°C in 2010 (Fig. 3). The amplitude of positive anomalous events has increased over the past 60 years by approximately 0.1°C (Fig. 2), while the amplitude of negative anomalous events remained unchanged (Fig. 2), indicating a general increase in temperature anomalies in the region. The amplitude of extreme positive events also demonstrates growth from about 5 to 7°C, while the amplitude of negative extreme phenomena remains unchanged for the period under consideration at the level of 8°C (Fig. 3). Most likely, this is a consequence of the ongoing global warming. There were years (1953–1954, 1959, 1964, 1967, 1973–1974, 1980–1981, 2005) in which positive extreme phenomena did not occur at all.

As a consequence of global warming, the annual number of negative anomalous events has greatly decreased from an average of 27 at the beginning of the 1950s to 14–16 at the beginning of the 2010s (Fig. 2). The number of positive anomalous events increased from 15–16 in the 1950s to 28–30 in the 2000s. In this decade, there were years (1994, 2000, 2002, and 2008) in which more than 35 positive anomalous events occurred yearly. Also, the number of positive extreme events increased from 2 to 4.5 per year, while the negative ones remained unchanged (Fig. 3).

The duration of anomalous temperature events shows an increase from 2.1 to 2.5 days for positive events and from 2.25 to 2.4 for negative ones. The duration of extreme events remains unchanged at the level of 1.3 days for positive extreme events and 1.9 days for negative ones. In some years, duration of anomalous and extreme positive and negative events is in phase, but in some years, duration of positive events may be long, while for negative, short, and vice versa. This indicates strong interannual variability of anomalous and extreme temperature events in the region (Figs. 2 and 3).

4.2 Zonal Component of Wind Velocity

Figures 4 and 5 show characteristics of anomalous and extreme events of the zonal component of wind velocity at the surface. The red lines correspond to the west-eastern anomalies; the blue lines correspond to the east-western anomalies. It should be taken into account that the average annual value of the zonal wind has an east-western direction with a value close to 0.3 m/s. Therefore, the amplitudes of the west-eastern anomalous and extreme events, although they exceed the amplitude of

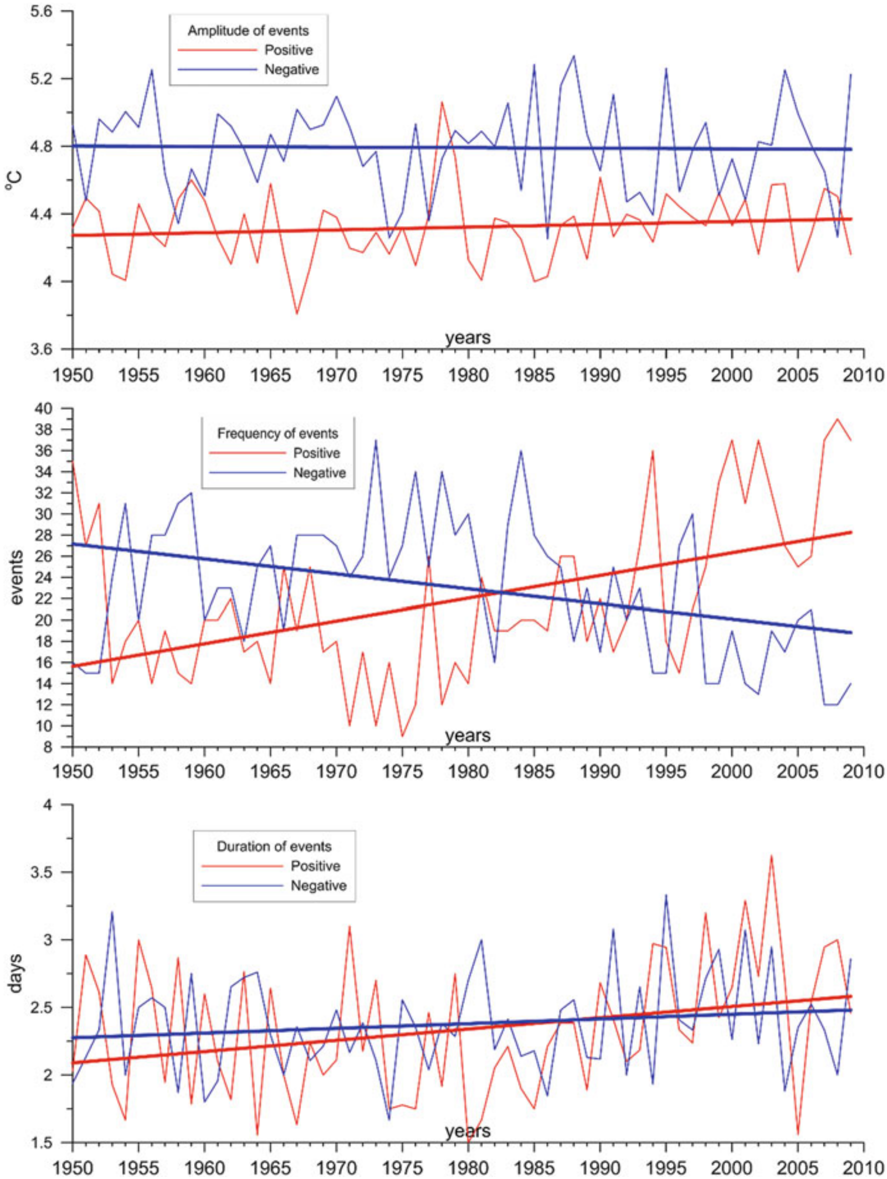

Fig. 2 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of 2 m air temperature with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

the east-western ones by 0.2–0.3 m/s, differ little in absolute terms from them in magnitude. During the period 1950–2010, we observe a rise of the average amplitude (by 0.1 m/s), frequency (from 37 to 40), and duration (from 1.5 to 1.6 days) of

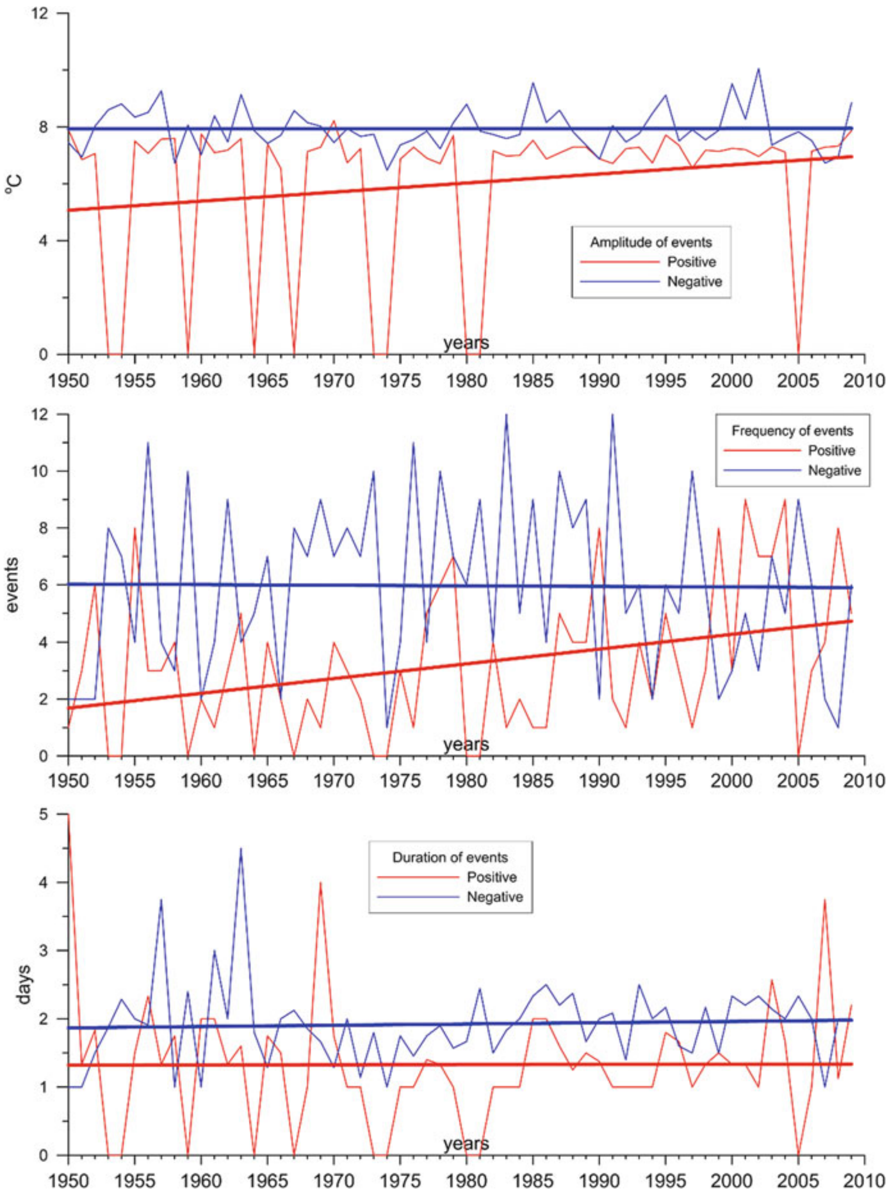

Fig. 3 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of 2 m air temperature with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

the west-eastern anomalous phenomena (Fig. 4). The number of east-western wind speed anomalies decreased from 35 to 30 events per year, which shows general weakening of the east-western air mass transfer in the region. At the same time, we

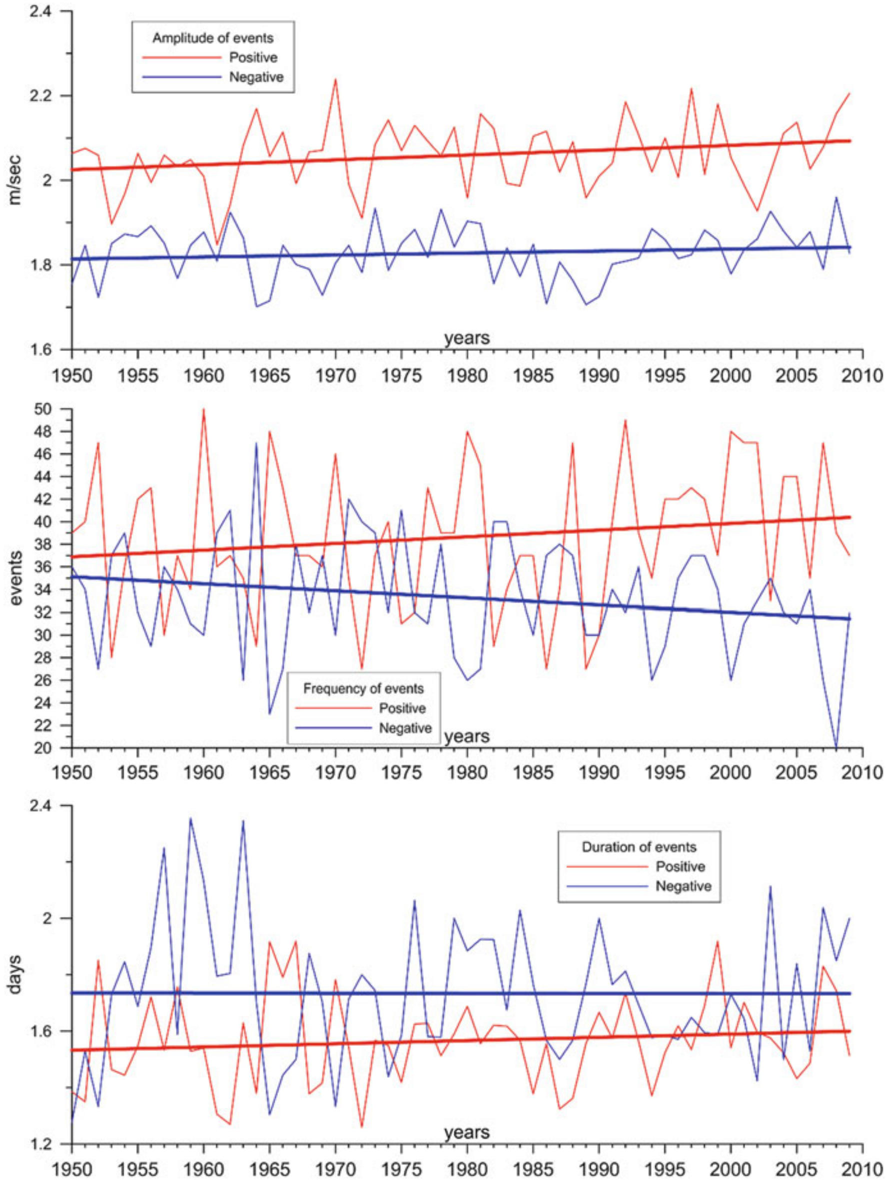

Fig. 4 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of 10 m U wind component with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

observe strong interannual variability of the number of anomalous events (Fig. 4). Thus, the number of anomalous events can vary from year to year by more than two times. All the characteristics of extreme wind speed phenomena show a slight

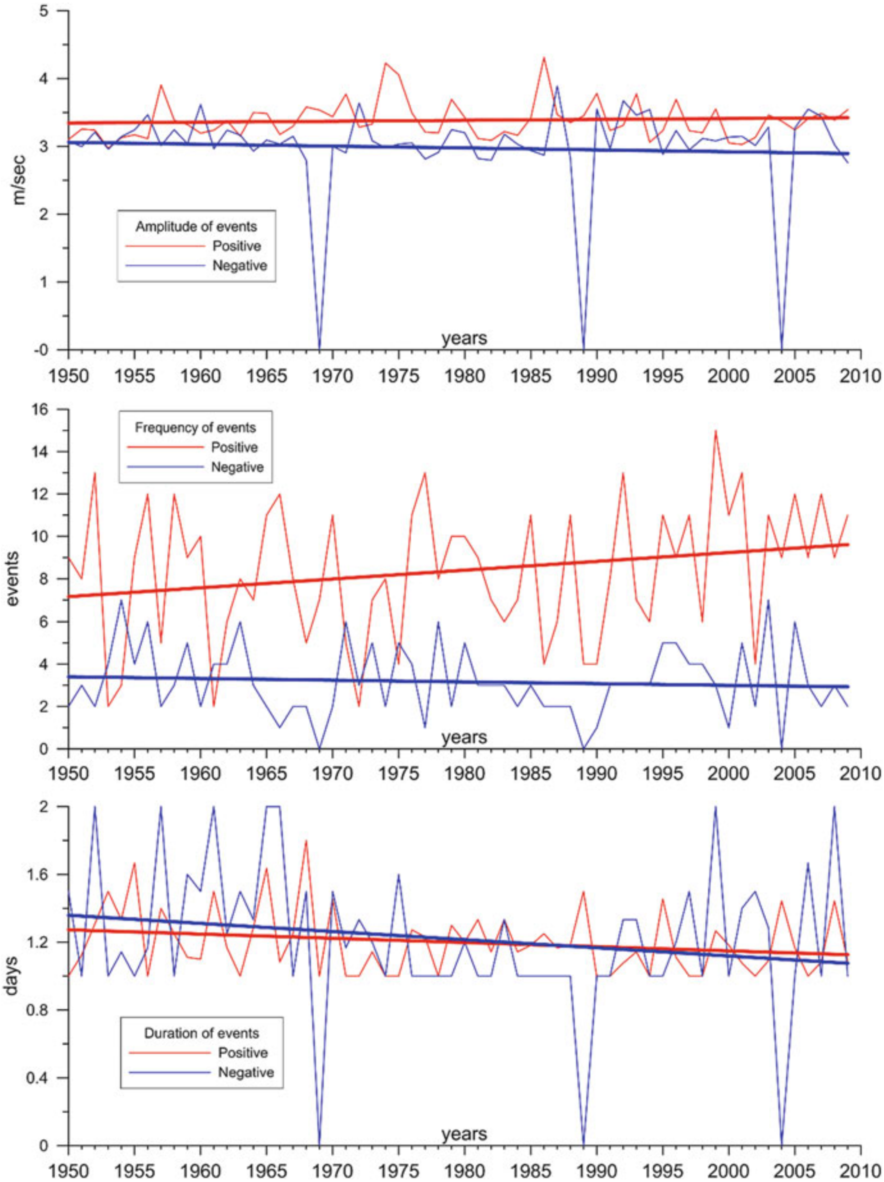

Fig. 5 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of 10 m U wind component with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

decrease (Fig. 5), except for the frequency of the west-eastern events, when the number of these extreme events increased on average from 7 to 11, which confirms the weakening of the east-western air mass transfer.

4.3 Meridional Component of Wind Velocity

The characteristics of anomalous and extreme events of the meridional component of wind velocity at the surface are shown in Figs. 6 and 7. The red line anomalies correspond to the direction from the south to the north and the blue line anomalies, from the north to the south. All the characteristics of the events in the south-northern direction are superior to the north-southern ones, but since the north-southern transfer prevails in the region, this somewhat equates their absolute values. All the characteristics of anomalous events of the meridional wind remain almost unchanged, except for the increase in the number of the north-southern events from about 29 to 33 (Fig. 6). Together with the results for the zonal wind component analysis, this indicates an increase in the annual number of abnormal wind events in the region. Amplitude of anomalous wind events is of the order of 2.5–2.8 m/s, frequency of the events is of 30–35 per year, and duration of anomalous events varies between 1.6 and 2 days (Fig. 6). The characteristics of the extreme phenomena of the meridional wind also remain unchanged except for the reduction of the south-northern events (Fig. 7). Strong interannual variability is observed, for example, in 1960, 1969, 1990, and 1993; no extreme events of the meridional component of wind speed of the north-southern direction occurred. Amplitude of extreme wind events is of the order of 4 m/s, frequency of the events is of 3–10 per year, and duration of extreme events varied between 1 and 1.2 days (Fig. 7).

4.4 Atmospheric Pressure

Changes in the characteristics of anomalous and extreme events of atmospheric pressure at sea level in the region of the Skadar/Shkodra Lake are shown in Figs. 8 and 9. The amplitudes of negative anomalous events exceed the amplitudes of the anomalous events of increased pressure by an average of 1.5 hPa. The amplitudes of the anomalous events of increased pressure increased during 1950–2010 period by approximately 0.5 hPa: from 8.1 to 8.6 hPa (Fig. 8). The amplitudes of the anomalous events of reduced pressure also increased but to a lesser extent. Frequency of positive anomalous events increased from 14 to 18 events per year, while the number of anomalous events of lowered pressure reduced from 23 to 20 events per year. Duration of anomalous events of increased pressure increased on average from 2.4 to 2.6 days, while duration of the anomalous events of low pressure decreased slightly.

The amplitudes of extreme events of reduced pressure exceed that of increased pressure by 2 hPa, both of which demonstrate a slight decrease in the time period

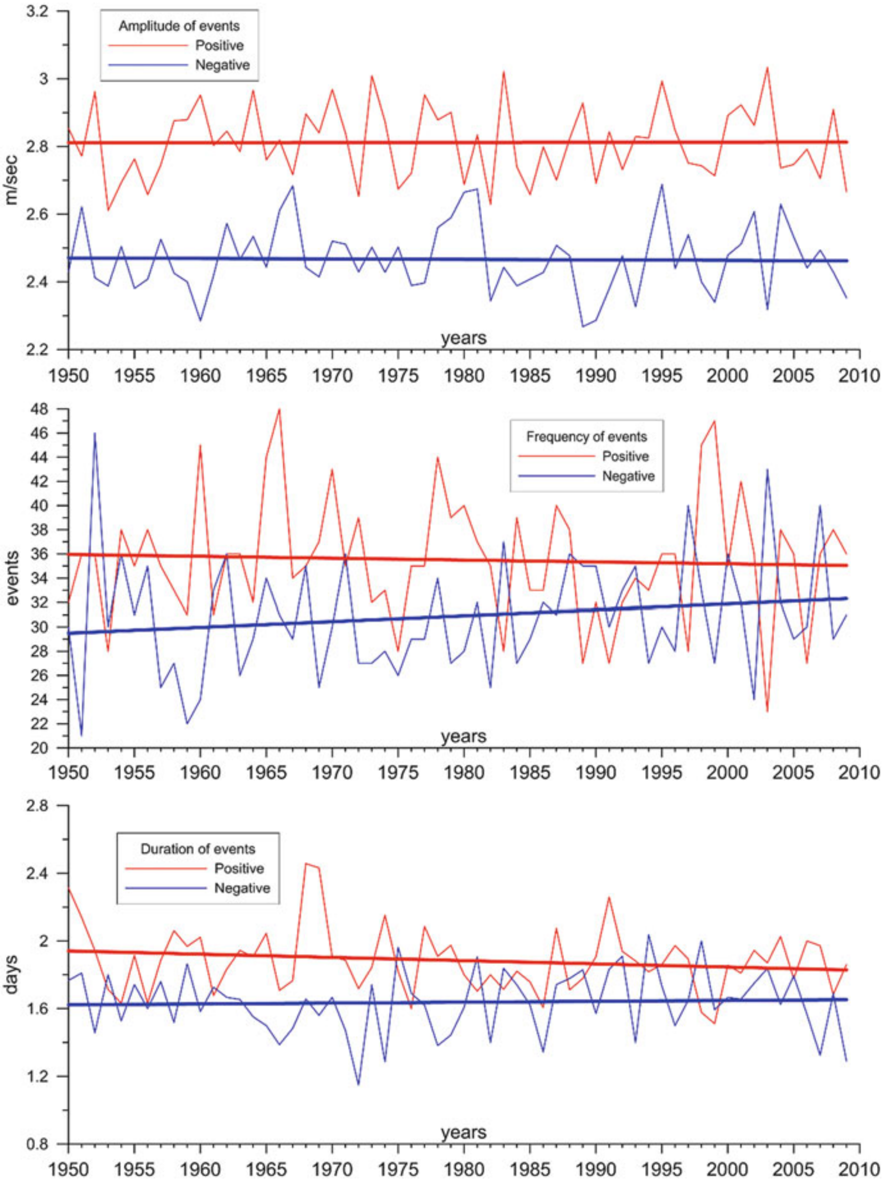

Fig. 6 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of 10 m V wind component with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

under consideration (Fig. 9). The number of negative extreme pressure events in the 1950s, on average, was three times larger than that of positive events. Frequency of extreme events of reduced pressure declined on average from 9 to 8 events per year,

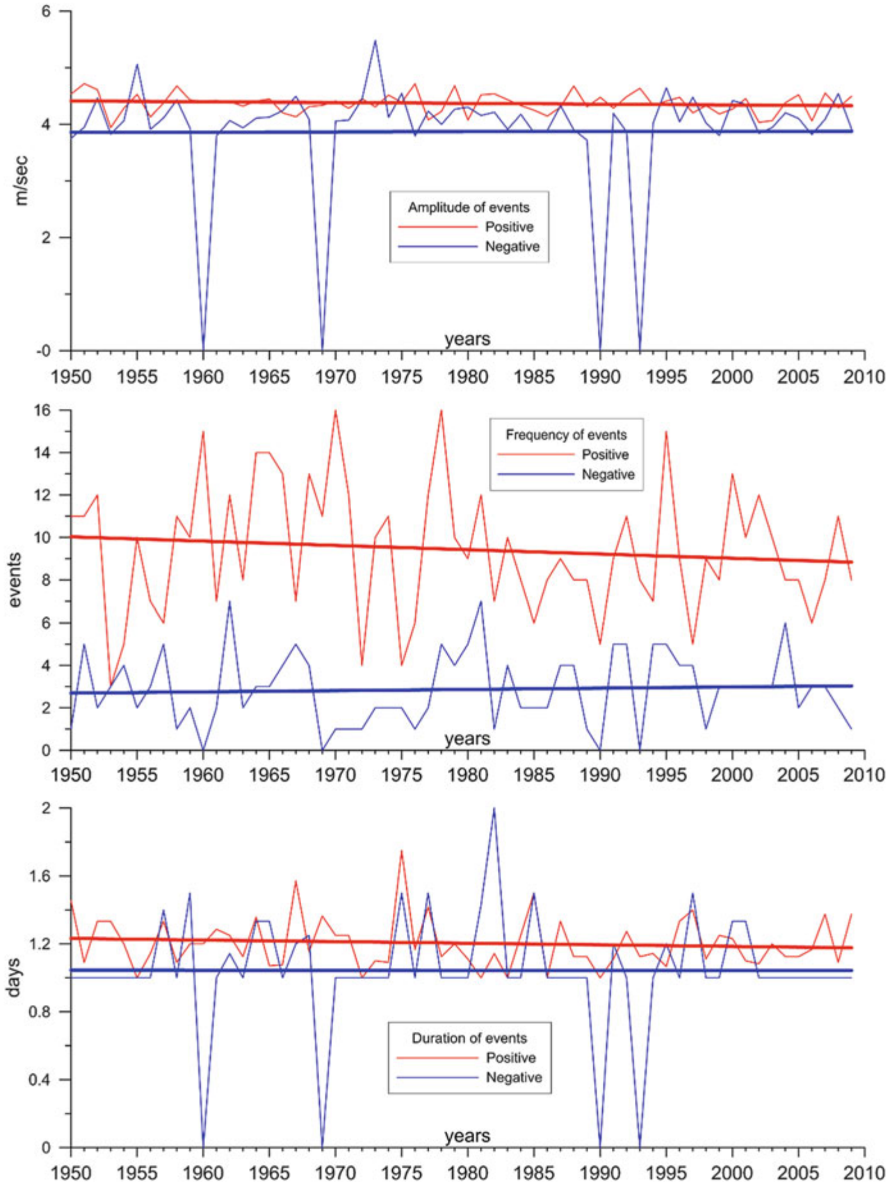

Fig. 7 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of 10 m V wind component with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

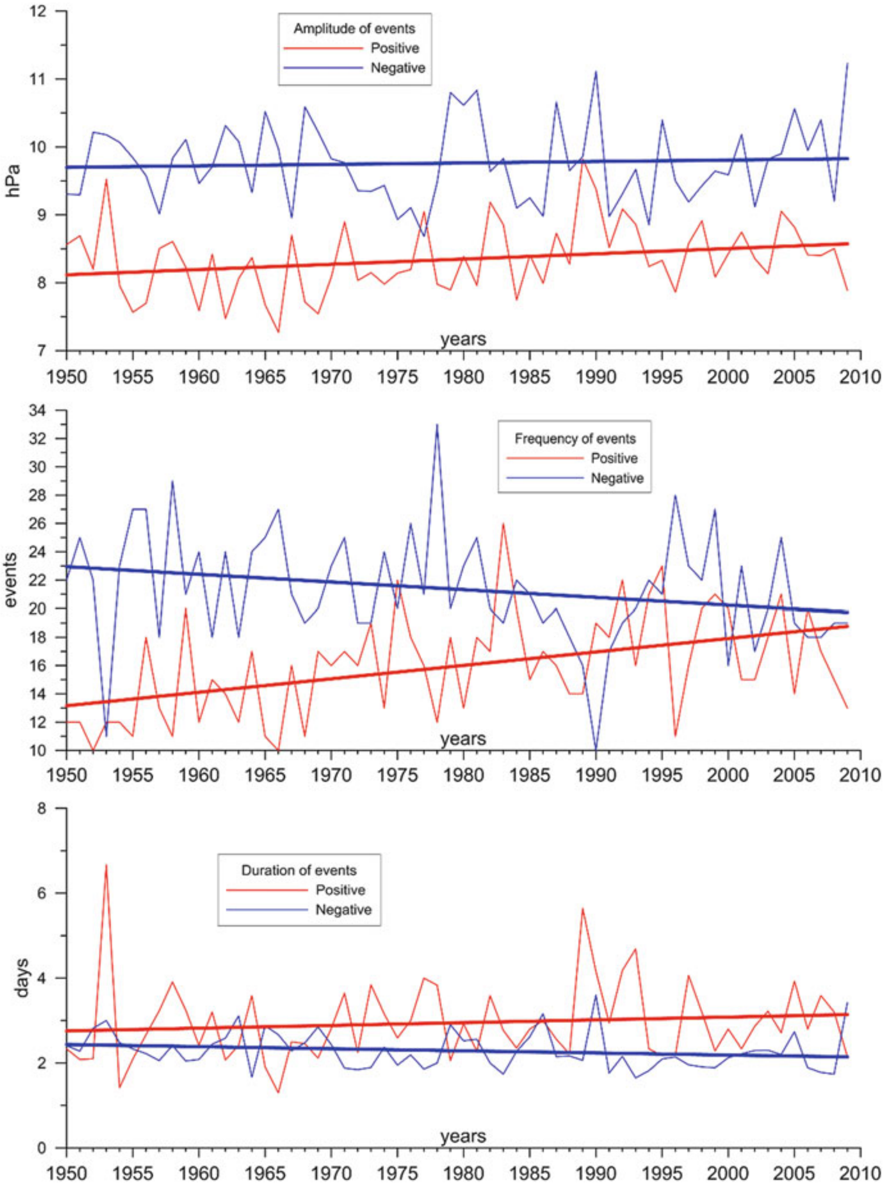

Fig. 8 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of sea-level pressure with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

and frequency of increased pressure increased from 3 to 4. Duration of negative and positive extreme events is approximately the same, and is about 2 days, while there is strong interannual variability. Thus, in 1989, 1992–1994, 1999, and 2007, there

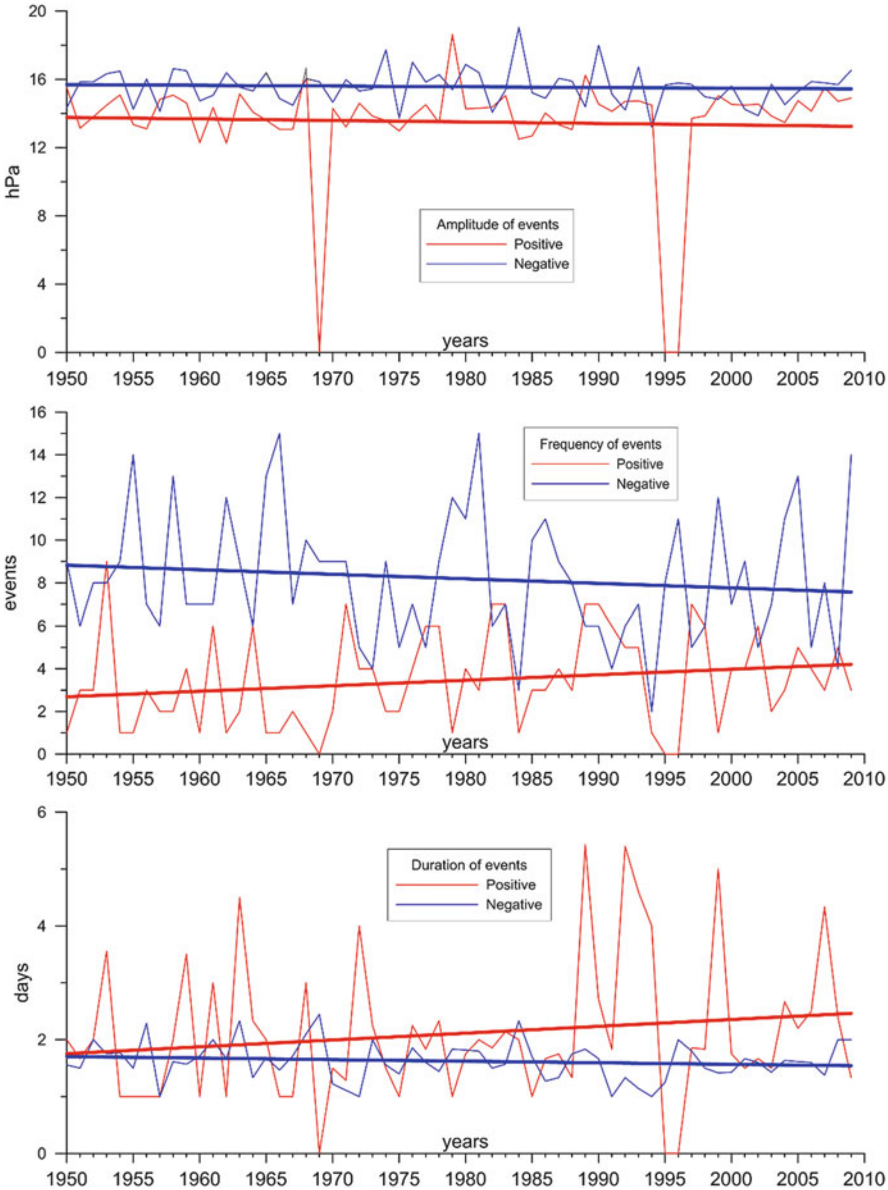

Fig. 9 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of sea-level pressure with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

were anomalously prolonged extreme events of increased pressure related to the so-called blocking anticyclones. Also, in 1969, 1995, and 1996, there were no extreme events of increased pressure (Fig. 9).

4.5 Height of Snow Cover

Figures 10 and 11 show the characteristics of anomalous and extreme events of the height of the snow cover. The amplitude of positive snow cover anomalies decreased

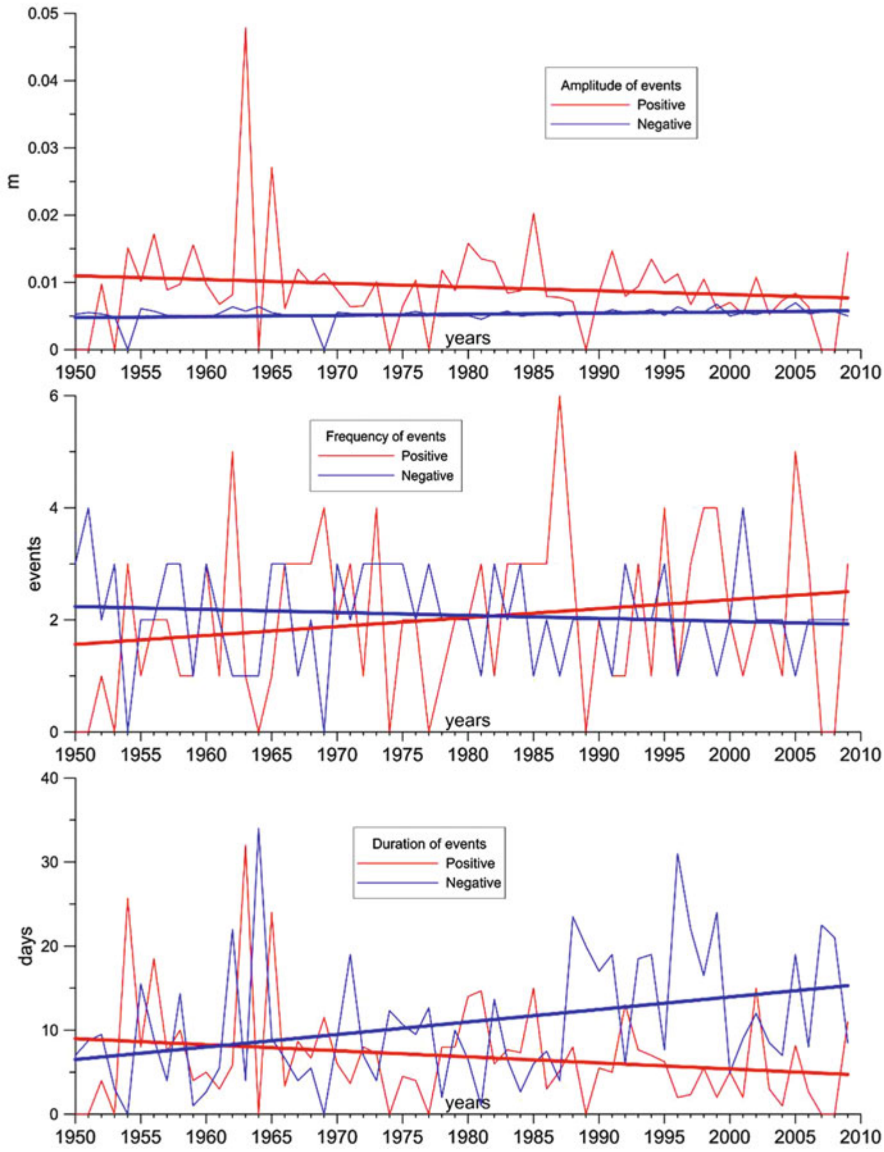

Fig. 10 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of snow depth with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

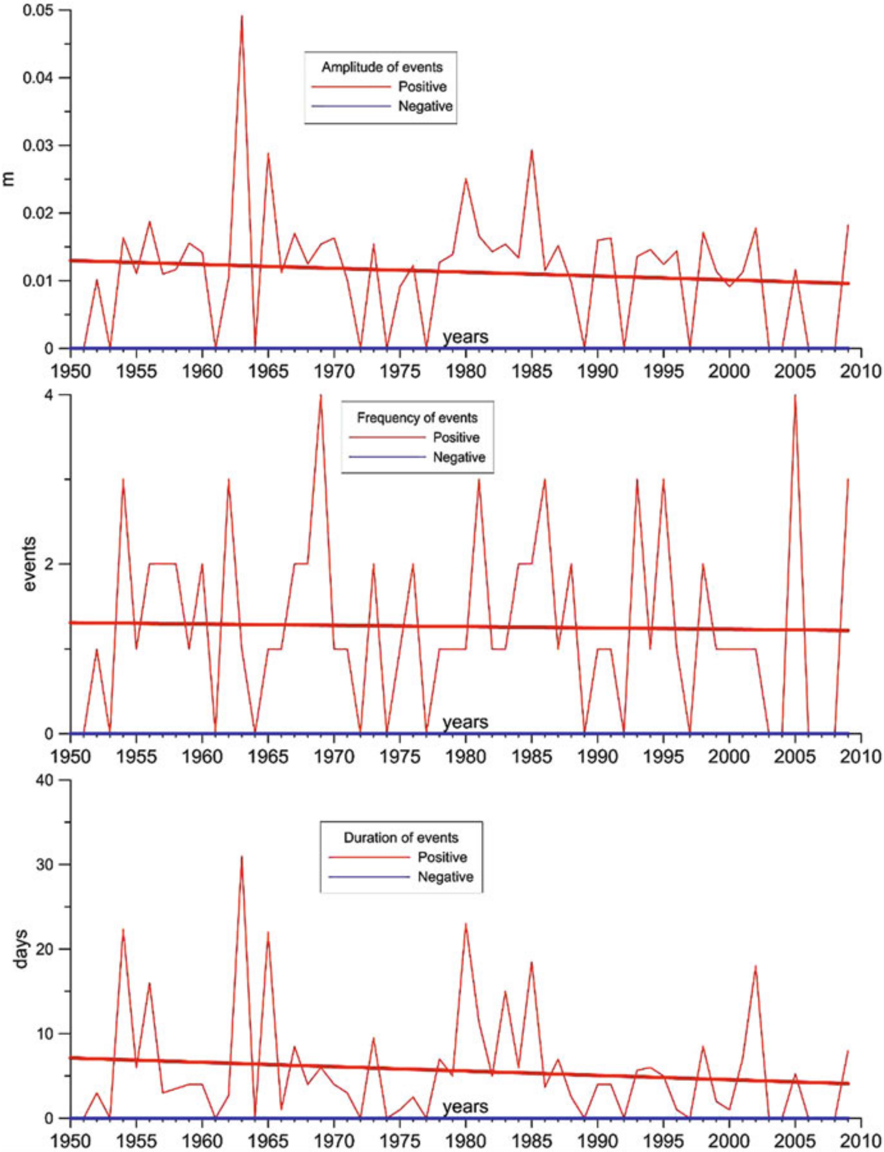

Fig. 11 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of snow depth with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

from 11 to 9 cm, while the amplitude of negative anomalies remained unchanged. The number of positive anomalous events increased from 1.5 to 2.5, while the number of negative anomalies slightly decreased. Duration of positive anomalous events (high snow cover) decreased from 9 to 5 days, while duration of negative anomalous events (low snow cover) increased from 6 to 15 days. In both cases, this is the result of a rise in air temperature in the region (Fig. 10).

We did not detect negative extreme anomalies in the snow depth which are characterized by values which exceed two standard deviations from the average values. This may be regarded as absence of snow. The amplitudes of positive extreme events (extremely high snow cover) show a decrease from 13 to 10 cm. The average number of such extreme events remained unchanged while its interannual variability is high and may reach four events per year. Strong snowfalls, after which snow does not melt for a day or more, become less and less common in the region under consideration. Duration of such extreme events decreased from 7 to 4 days (Fig. 11).

4.6 Cloudiness

Figures 12 and 13 show amplitude, frequency, and duration of anomalous and extreme events with high and low percent cloudiness. Amplitude of positive anomalous events is more or less stable of 0.46, while amplitude of negative events was rising from about 0.50 to 0.52. Frequency of anomalous cloud cover events rose in 1950–2010: positive anomalies occurred from 43 to 46 per year, while negative, from 33 to 38 per year. Frequency of these events shows high interannual variability which often exceeds 50 days per year, i.e., almost weekly. Duration of positive anomalous events is of the order of 1.5 days, while that of the negative ones is 1.8–1.9 days (Fig. 12).

Amplitude of extreme cloudiness events shows an increase for positive anomalies from 0.65 to 0.75 and for negative anomalies from 0.4 to 0.5. The number of positive extreme events decreased from about 3.5 to 2.5 per year, while the number of negative events is 1–1.5 per year. Duration of positive extreme events increased from 0.95 to 1.1 days, while duration of negative events, from 0.6 to 0.7 days (Fig. 13).

4.7 Atmospheric Precipitation

Figures 14 and 15 show characteristics of anomalous and extreme precipitation in the region for the period of 1950–2010. Amplitude of the precipitation anomalies remains unchanged, but the number of positive anomalous events (more rain) slightly decreases from 15 to 14 events per year. Duration of these events is 1.2 days, while duration of negative anomalies is 0.8 days (Fig. 14). The analysis of extreme precipitation events shows a little increase in the amplitude of extreme anomalies: their frequency goes down from 8 to 7 events per year with large interannual variability, and duration of such events is stable and is 1.1 days (Fig. 15).

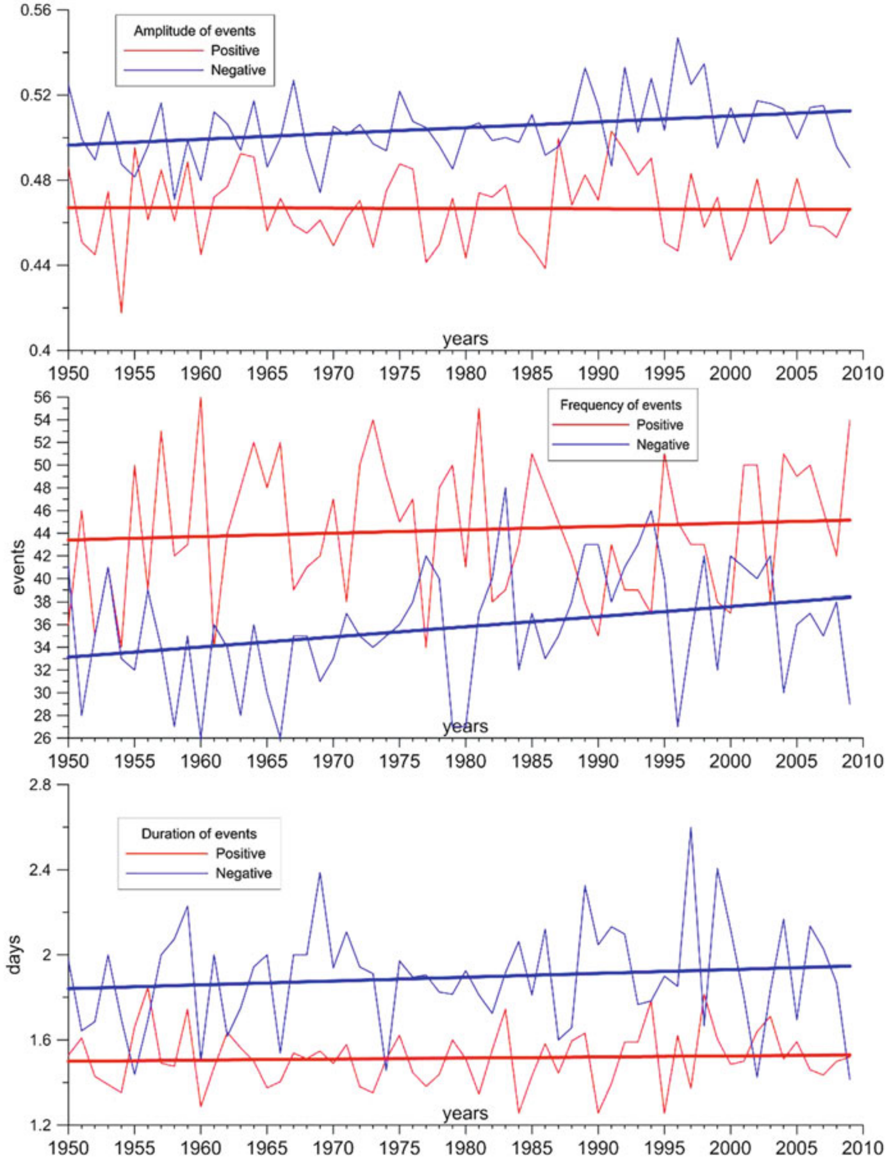

Fig. 12 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of total cloud cover with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

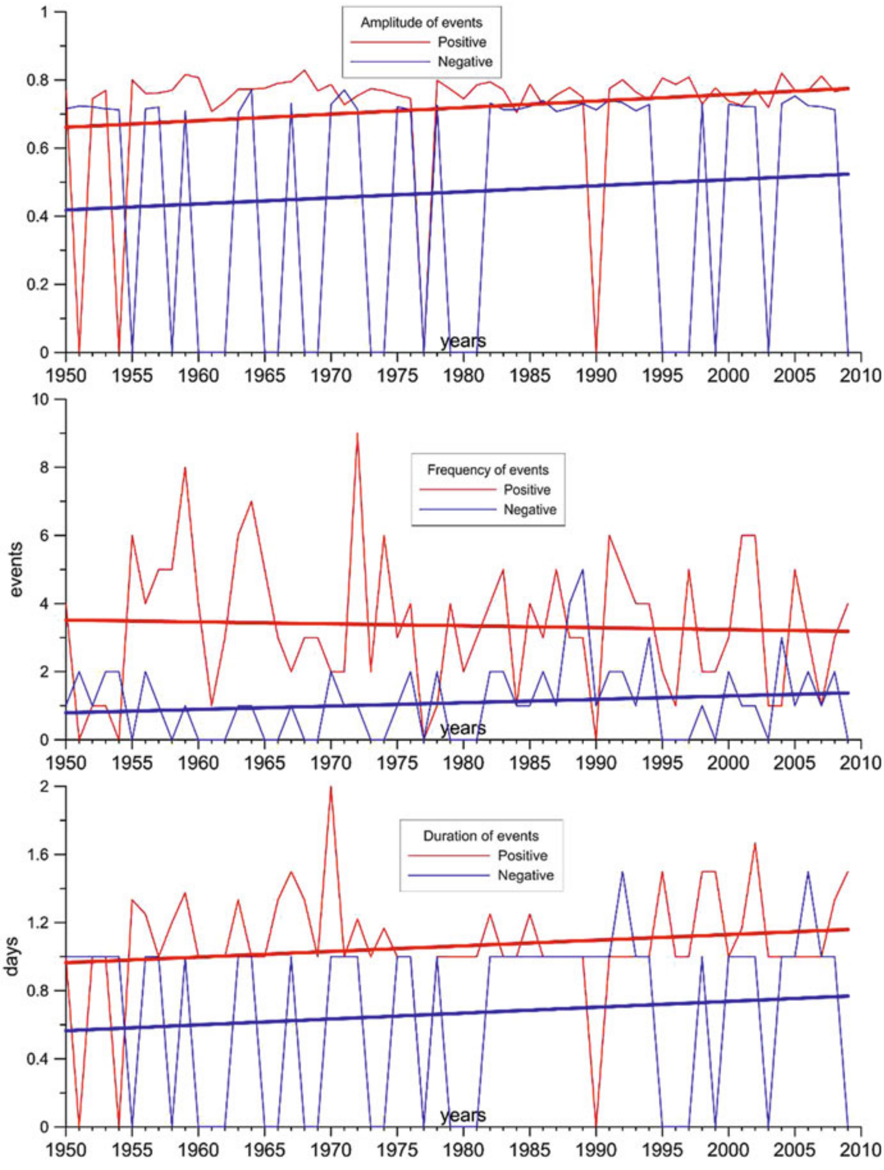

Fig. 13 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of total cloud cover with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

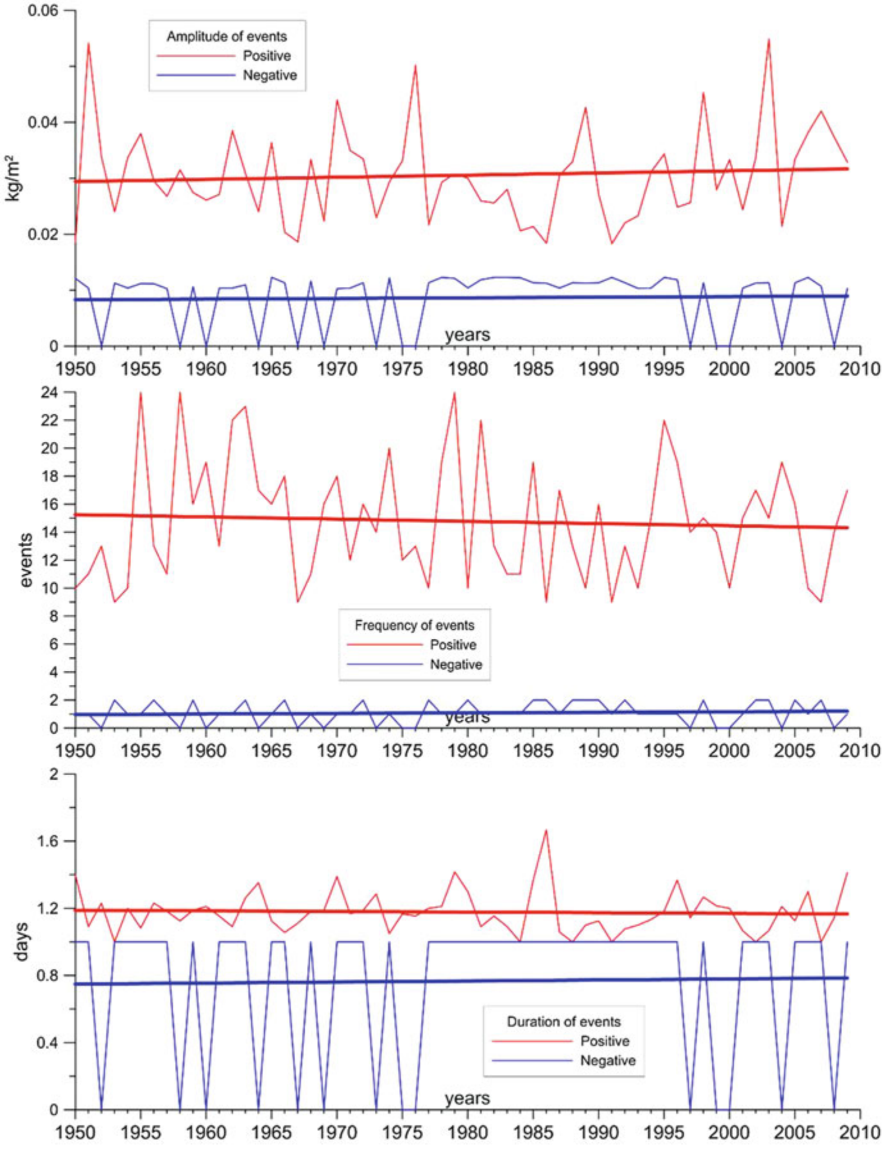

Fig. 14 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of anomalous events of total column rainwater with positive (red lines) and negative (blue lines) anomalies exceeding by modulo one standard deviation, and their linear trends

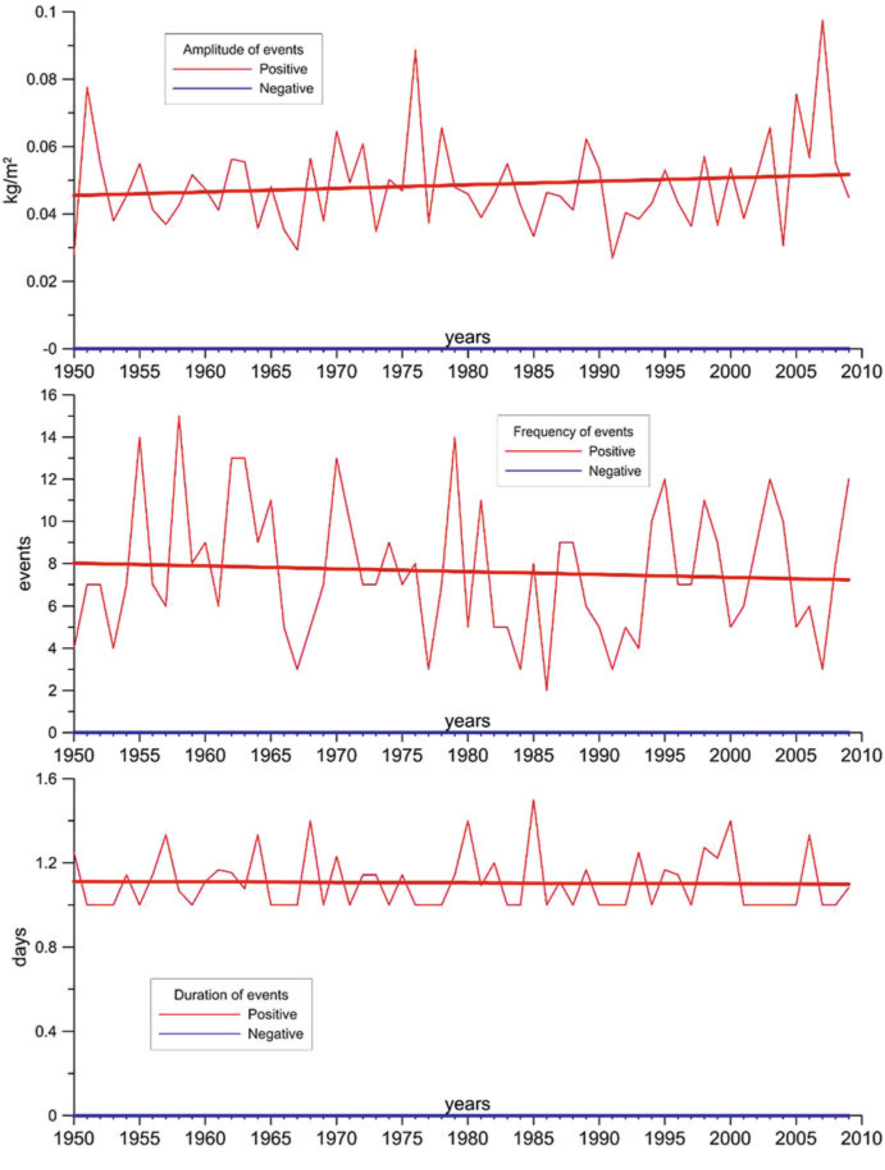

Fig. 15 Annual changes of the average amplitude (top), the number (middle part) and the average duration (lower part) of extreme events of total column rainwater with positive (red lines) and negative (blue lines) anomalies exceeding by modulo two standard deviations, and their linear trends

5 Discussion

IPCC Assessment Reports on Climate Change indicate that in the twenty-first century, climate change will be accompanied by an increase in the frequency, intensity, and duration of extreme natural phenomena such as extreme atmospheric precipitation or droughts, extremely high (heat waves) or low air temperatures, etc. The main goal of this chapter was to analyze anomalous and extreme meteorological events. Using daily data from ERA-20C, which is ECMWF's first atmospheric reanalysis of the twentieth century from 1900–2010, we have analyzed linear trends and interannual variability of the characteristics of anomalous and extreme meteorological events of near-surface air temperature, wind speed, sea-level pressure, snow depth, cloud cover, and atmospheric precipitation for 1950–2010 in the region 41.5°–42.5°N, 18.5°–19.5°E, which is much larger than the area of Lake Skadar/Shkodra.

We considered meteorological events to be "anomalous," when values of anomalies exceeded one standard deviation, and "extreme," when anomalies exceeded two standard deviations. Both types of events could last a day or more. In this research, we focused on determination of interannual changes in frequency, intensity, and duration of anomalous and extreme meteorological events in this region, which was done for the first time.

Here, we would like to focus on the most important results. Thus, for example, amplitude of extreme positive events in air temperature demonstrates growth from about 5 to 7°C, while there were years, 1953–1954, 1959, 1964, 1967, 1973–1974, 1980–1981, 2005, in which extreme phenomena of a positive sign did not occur at all. As a consequence of regional warming, the annual number of negative anomalous events greatly decreased from an average of 27 at the beginning of the 1950s to 14–16 at the beginning of the 2010s. The number of positive anomalous events increased significantly from 15–16 in the 1950s to 28–30 in the 2000s. In years 1994, 2000, 2002, and 2008, more than 35 positive anomalous events occurred yearly. Also, the number of positive extreme events increased from 2 to 4.5 per year, which is also an evident consequence of regional warming.

As a result of regional warming, amplitude of positive snow cover anomalies (high snow cover) decreased from 11 to 9 cm, but the number of these events increased from 1.5 to 2.5. Duration of positive anomalous events reduced from 9 to 5 days, while duration of negative anomalous events (low snow cover) increased from 6 to 15 days. The amplitudes of positive extreme events (extremely high snow cover) show a decrease from 13 to 10 cm. The average number of such extreme events remained unchanged while its interannual variability is high and may reach four events per year. Strong snowfalls, after which snow does not melt for a day or more, become less and less common in the region under consideration. Duration of such extreme events decreased from 7 to 4 days.

As to atmospheric precipitation, we did not find strong changes in the characteristics of the anomalous and extreme events. Amplitude of the precipitation anomalies remained unchanged, but the number of positive anomalous events (more rain) slightly decreases from 15 to 14 events per year. Duration of these events is of 1.2 days, while duration of negative anomalies is of 0.8 days. The analysis of extreme precipitation events shows a little increase in the amplitude of extreme anomalies; their frequency goes down from 8 to 7 events per year with large interannual variability, and duration of such events is stable and is 1.1 days.

Thus, the most interesting results concern interannual changes in amplitude, frequency, and duration of anomalous and extreme air temperature events, which may have an important impact on the environment and ecology of Lake Skadar/ Shkodra.

6 Conclusions

As a result of our research on regional climate change and extreme meteorological events in the coastal region of Montenegro, we can argue that these studies are very important for the economy, infrastructure, agriculture, forestry, water resources, tourism, and quality of life of the population of Montenegro. Since the beginning of the 1960s, numerous multidisciplinary biogeochemical studies of Lake Skadar/ Shkodra have been carried out, which have demonstrated the need to establish an international integrated approach to monitor and protect the ecosystem of Lake Skadar/Shkodra and its basin [12, 13]. All the previous studies of Lake Skadar/ Shkodra did not include a comprehensive research of regional climate change and related extreme meteorological events which can significantly impact and in the nearest future even change the stability of the lake ecosystem. Such kind of studies should be integrated in and coordinated with the ongoing and future in situ biogeochemical monitoring programs. Further regional climate change research should be focused on seasonal peculiarities of regional climate change and related extreme meteorological events, for example, on positive extreme air temperature events in summer months, negative extreme air temperature events in winter months, extreme wind speed and rain events during flowering periods, etc., when the impact of these extreme meteorological events is most sensitive.

Acknowledgments The research was partially supported in the framework of the Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2018-0003). The research was partially done in the framework of collaboration between Prof. Andrey G. Kostianoy and Dr. Marilaure Grégoire from the Interfacultary Center for Marine Research (MARE) and Modelling for Aquatic Systems (MAST), University of Liège, Belgium.

References

1. IPCC Climate Change (2007) The physical science basis. Contribution of WG1 to the IV Assessment Report of the IPCC, Cambridge and New York, 996 pp

2. IPCC Climate Change (2013) The physical science basis. Contribution of WG1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Assessment Report of the IPCC, Cambridge and New York, 1535 pp
3. IPCC Climate Change (2014) Impacts, adaptation and vulnerability. Part B: Regional aspects. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press
4. Managing the risks of extreme events and disasters to advance climate change adaptation (2012) Special report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 594 pp
5. Karl TR, Nicholls N, Ghazi A (1999) CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes workshop summary. Clim Change 42:3–7
6. Kostianoy AG, Soloviev DM, Kostianaia EA, Đurović B, Pestorić B (2017) Satellite remote sensing of the Boka Kotorska Bay. In: Joksimovich A, Djurovic M, Semenov AV, Zonn IS, Kostianoy AG (eds) The Boka Kotorska Bay environment. Springer, Cham, pp 495–520
7. Kostianoy AG, Soloviev DM, Kostianaia EA, Sirota AM (2018) Satellite remote sensing of Lake Skadar/Shkodra. In: Pesic V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
8. Djurovic M (ed) (2014) Development of hydrological and hydraulic study of regulation of Skadar Lake and Bojana Riber water regime. IPA Project, vol 1. Montenegrin Academy of Sciences and Arts, Podgorica
9. Kostianoy AG, Serykh IV, Kostianaia EA, Mitrovic L, Ivanov M (2017) Regional climate change in the Boka Kotorska Bay. In: Joksimovich A, Djurovic M, Semenov AV, Zonn IS, Kostianoy AG (eds) The Boka Kotorska Bay environment. Springer, Cham, pp 473–493
10. Stickler A, Brönnimann S, Valente MA et al (2014) ERA-CLIM: historical surface and upper-air data for future reanalyses. Bull Am Meteorol Soc 95(9):1419–1430
11. Kostianoy AG, Serykh IV, Ekba YA, Kravchenko PN (2017) Climate variability of extreme air temperature events in the Eastern Black Sea. Ecol Montenegrina 14:21–29
12. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
13. Pešić V, Karaman G, Kostianoy A, Vukašinović-Pešić V (2018) Conclusions: recent advances and the future prospects of the Lake Skadar/Shkodra environment. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham

Satellite Remote Sensing of Lake Skadar/Shkodra

Andrey G. Kostianoy, Dmitry M. Soloviev, Evgeniia A. Kostianaia, and Alexander M. Sirota

Contents

Abstract In this chapter, we show capabilities of satellite remote sensing for environmental monitoring of Lake Skadar/Shkodra. A small size of the lake requires usage of high-resolution satellite optical, infrared, and radar data from the ETM+ Landsat-7, OLI and TIRS Landsat-8, MSI Sentinel-2A, Sentinel-1A, Sentinel-1B, and other space platforms with spatial resolution of 1–30 m, which is demonstrated in the chapter. Most of high-resolution satellite data are very expensive; this is why we focused on those data, which are available free of charge. Examples of processed satellite imagery of Lake Skadar/Shkodra in true color, sea surface temperature, water turbidity, chlorophyll-*a* concentration, and lake surface roughness are presented. Establishing of permanent integrated satellite monitoring of the lake is a key task in order to better understand the Lake Skadar/Shkodra environment and ecosystem, as well as transboundary processes characteristic for the lake.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 89–120, DOI 10.1007/698_2018_308,
© Springer International Publishing AG, part of Springer Nature 2018,
Published online: 19 June 2018

Keywords Albania, Chlorophyll-*a* concentration, Environment, Infrared imagery, Lake Skadar/Shkodra, Lake surface temperature, Montenegro, Optical imagery, Satellite monitoring, Satellite remote sensing, Suspended matter, Synthetic aperture radar

1 Introduction

Lake Skadar/Shkodra is the largest lake in the Balkan Peninsula which is shared between Montenegro and Albania as 2/3 and 1/3. Its surface varies from about 350 to 500 km^2 between seasons with the maximum in spring and minimum in late summer. The lake extends for about 44 km in the NW-SE direction at a distance of 15–20 km from the coast of the Adriatic Sea (Fig. 1). Its maximum width is 14 km and maximum depth is 8.3 m. The most important tributaries of Lake Skadar/Shkodra enter the lake from the north: Morača (63% of total river inflow), Crnojevića, Orahovštica, Karatuna, and Plavnica Rivers in Montenegro and Rjolska and Vraka Rivers in Albania. The Buna/Bojana River (which in lower reaches is a border between Montenegro and Albania) has an average outflow of about 300 m^3/s and connects the lake with the Adriatic Sea. Due to seasonal variability in the river

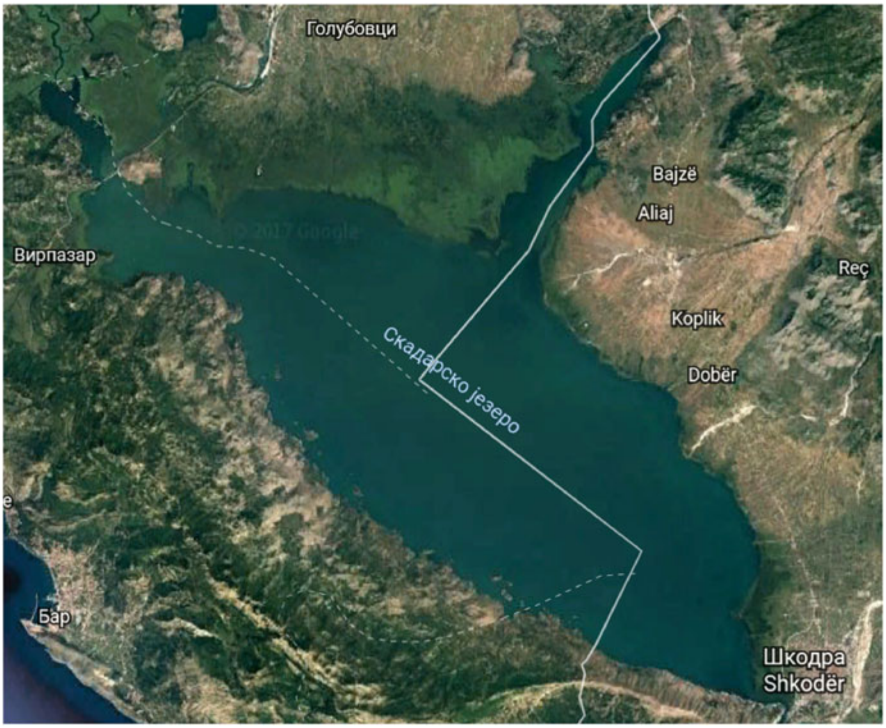

Fig. 1 Satellite view on Lake Skadar/Shkodra (https://earth.google.com/)

runoff to the lake and precipitation/evaporation regime over the lake and its catchment area, the lake level varies from 4.5 to 10.4 m. The Morača River also brings approximately 50,000 tons of suspended matter (including pollutants) to the lake. A characteristic feature of Lake Skadar/Shkodra is the high inflow from a number of temporary and permanent karstic springs, some of which are sublacustrine in cryptodepressions (so-called oko) which can be as deep as 60 m. The best known sublacustrine springs are Raduš and Karuč [1–4].

The exceptional nature and significance of Lake Skadar/Shkodra requires protection of the lake environment and its unique ecosystem. In 1968, the Skadar Lake Park was founded to protect the lake and its shores. Since 1983, in Montenegro Skadar/Shkodra Lake has been proclaimed as a National Park (IUCN management category II) with the surface area of 40,000 ha. Since 1995, the National Park Skadar/Shkodra Lake has been included in the Ramsar Convention List (wetland area of international significance). In 2005, the Albanian Government (Council of Ministers' Decision No. 684 dated 02.11.2005) proclaimed the Albanian part of Lake Skadar/Shkodra a "Managed Natural Reserve" (IUCN Category IV). In 2011, the lake was formally nominated for the UNESCO heritage status. Besides, the lake is one of the most important wintering birds' habitats in Europe and an International Important Bird Area [4].

Nevertheless, the biodiversity and water quality of Lake Skadar/Shkodra are threatened by various forms of economic activities such as tourism and fishery in the lake and agriculture and industry in the lake water basin [4, 5]. According to the Strategic Action Plan for Skadar/Shkodra Lake (April 2007), suggested by the Association for Protection of Aquatic Wildlife of Albania (APAWA) and the Center for Ecotoxicological Research of Montenegro (CETI), the main threats for the environment of Lake Skadar and its basin are [4–6] (1) pollution (industries, municipalities, solid waste, and liquid waste), (2) hunting and fishing, (3) lakeshore development, and (4) water management measures. Additional challenges include (5) increased expansion of tourism, (6) intensification of the agricultural sector, (7) use of the sublacustrine springs for regional water supply in the Montenegrin coastal area, (8) hydropower development at the Drin River in Albania and the Morača River in Montenegro, and (9) flooding problems [4].

Since the beginning of 1960s, numerous multidisciplinary biogeochemical studies of Skadar/Shkodra Lake have been made [7], which have demonstrated the need to establish an international integrated approach to monitor and protect the ecosystem of Lake Skadar/Shkodra and its basin. All previous studies of Lake Skadar/Shkodra did not include satellite monitoring systems which today are widely used for satellite monitoring of the seas, lakes, and rivers [8, 9]. Satellite remote sensing has a number of advantages relative to in situ measurements and, in case of transboundary water bodies, sometimes, becomes the only tool to monitor the whole water body, including those water areas which belong to neighboring countries [10–12]. As concerns Montenegro, we already showed the capabilities of satellite remote sensing techniques for monitoring of another very sensitive water area in Montenegro – the Boka Kotorska Bay [13].

In this chapter, we show capabilities of satellite remote sensing for environmental monitoring of Lake Skadar/Shkodra. A small size of the lake requires usage of high-resolution satellite optical, infrared, and radar data from the ETM+ Landsat-7, OLI and TIRS Landsat-8, MSI Sentinel-2A, Sentinel-1A, Sentinel-1B, and other space platforms with spatial resolution of 1–30 m. Most of high-resolution satellite data are very expensive; this is why we focused on those data, which are available free of charge. Examples of processed satellite imagery of Lake Skadar/Shkodra in true color, sea surface temperature, water turbidity, chlorophyll-*a* concentration, and sea surface roughness acquired in 2017 are presented in the chapter. Establishing of permanent integrated satellite monitoring of the lake in the nearest future is a key task in order to better understand the Lake Skadar/Shkodra environment and ecosystem, as well as transboundary processes which is a characteristic feature of the lake.

2 Data and Methods

We did not carry out any specific satellite monitoring for Lake Skadar/Shkodra, but to demonstrate capabilities of the remote sensing approach for investigation of environmental conditions and phenomena in the lake, we chose and processed the most interesting cloudy free optical and infrared images acquired in different seasons of 2017 by the high-resolution satellite sensors – ETM+ Landsat-7, OLI and TIRS Landsat-8, and MSI Sentinel-2A. These data were used to draw satellite images (maps) in true colors, total suspended matter (g/m^3), and chlorophyll-*a* concentration (mg/m^3). We have to note that absolute values of suspended matter and chlorophyll-*a* concentration were calculated based on standard algorithms elaborated for oceanic conditions. For Lake Skadar/Shkodra, they may result in wrong absolute values which require in situ calibration and validation procedures, but spatial distribution of investigated parameters is correct, which is of high importance. Spatial resolution of the processed true color MSI Sentinel-2A maps was 10 m, while for all the other maps, it was 20 m.

Also, we used synthetic aperture radar images acquired by SAR-C Sentinel-1A and Sentinel-1B (spatial resolution – 20 m) to demonstrate a rare feature on Lake Skadar/Shkodra – ice formation due to very cold weather observed in Montenegro in mid-January 2017.

Raw data from ETM+ Landsat-7, OLI, and TIRS Landsat-8 were downloaded from the US Geological Survey at https://earthexplorer.usgs.gov and https://glovis.usgs.gov, while all the Sentinel data were downloaded from the European Space Agency (ESA) hub https://scihub.copernicus.eu. All these raw data are freely available, but their usage is very difficult for nonspecialists. Thus, the specially developed ESA software SeNtinel Application Platform (SNAP) was used for unpacking and initial processing of raw data and their transformation into different maps. SNAP allows processing both ESA data (Envisat, Sentinel, SMOS, etc.), and other satellite missions like Landsat, NOAA, METOP, Aquarius, Radarsat, and many others. At the final stage of data processing and map drawing, we used our own software, developed during 25 years of our satellite remote sensing practices.

3 Winter 2017

In January 2017, the air temperature in Podgorica (Montenegro), located northward of Lake Skadar/Shkodra, dropped from +10°C on 2 January to −6°C on 7 January. Cold weather with negative day and night temperatures lasted for a week from 6 to 12 January. On 3 and 5 January, it was raining in Podgorica, which is located on the plain, but it resulted in snow cover in the mountains surrounding Lake Skadar/Shkodra from the west and south (Fig. 2). By 15 January, the air temperature had

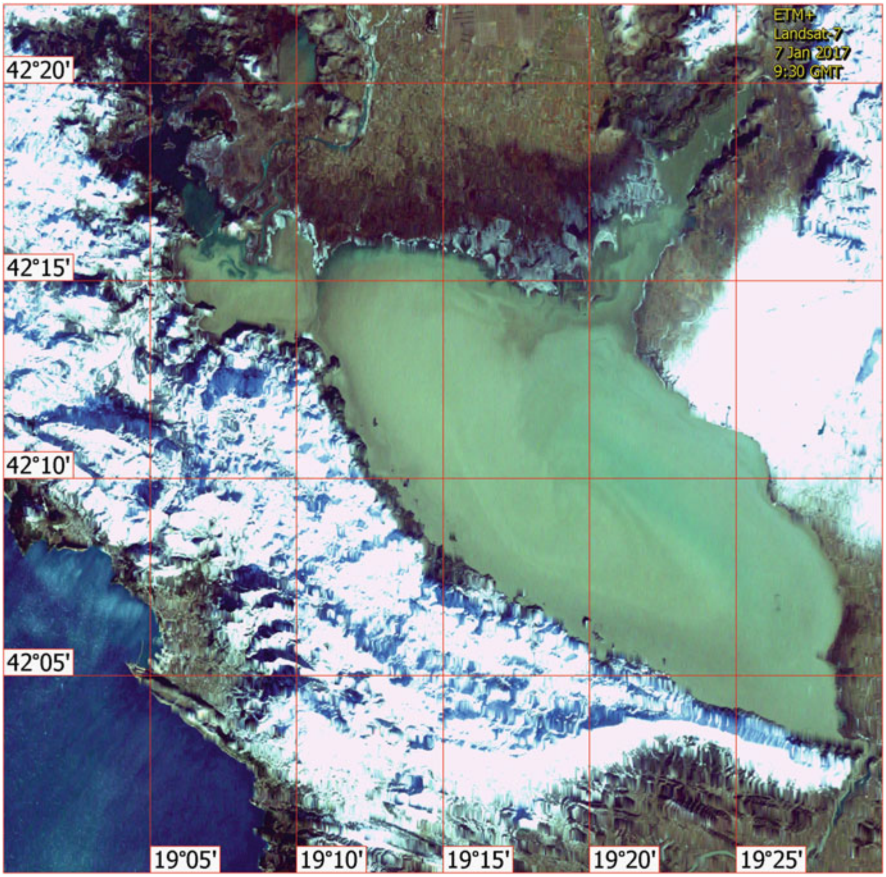

Fig. 2 Satellite view on Lake Skadar/Shkodra in true colors on 7 January 2017 (ETM+ Landsat-7). White colors show snow cover

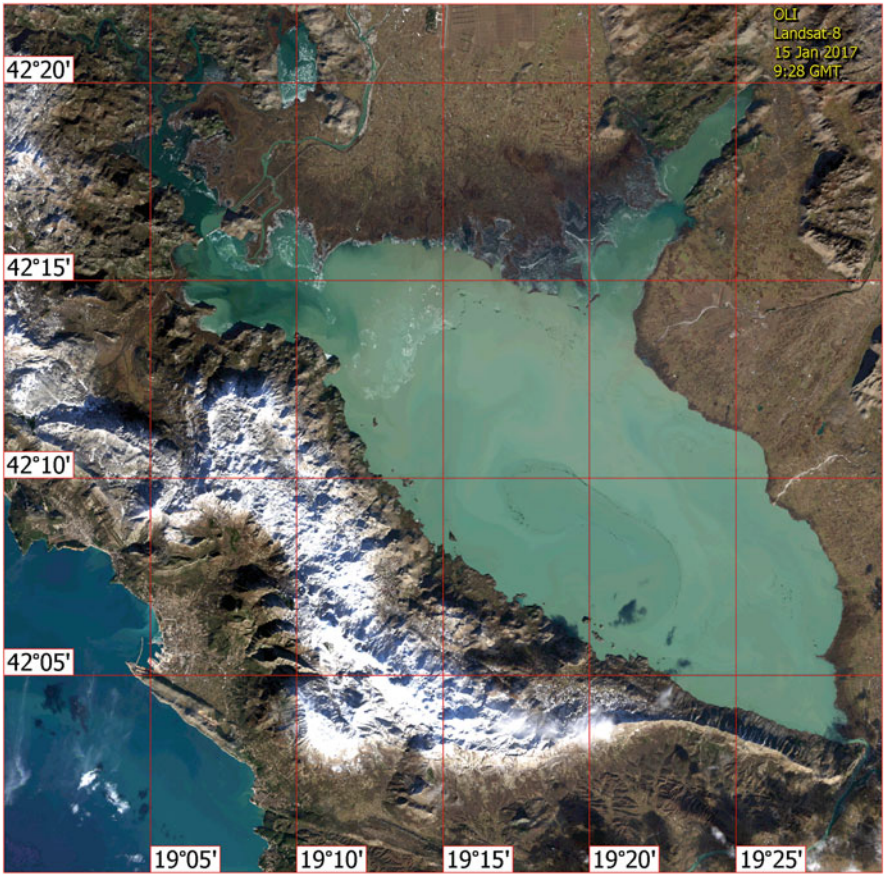

Fig. 3 Satellite view on Lake Skadar/Shkodra in true colors on 15 January 2017 (OLI Landsat-8). White colors show snow cover

increased up to +10°C and snow cover melted significantly, which is evident from Fig. 3. White color lines along the northern coastline of the lake show ice cover which has established along the shores with very shallow waters (Figs. 2 and 3). Figure 3 also shows that in the northwestern part of the lake, there are some white traces which indicate floating ice.

Both figures demonstrate very turbid waters in the lake with concentration of total suspended matter (TSM) of more than 50 g/m^3 in the whole area of the lake. Apparently, this is the result of rain on 3 and 5 January in the region of Lake Skadar/Shkodra and its water basin and the northern wind of 6 m/s that blew on 6–7 January over the lake. On 13 January, another rain contributed to high turbidity of lake waters observed on 15 January (Fig. 3). Weather in Shkoder (Albania), located at the southeastern corner of the lake, was similar to that observed in Podgorica: it was a bit warmer, but negative air temperatures and rainy weather were observed on the same days. This means that the weather over the lake was almost uniform. The single difference was observed in the wind speed and direction, for example, on 7 January, in Shkoder wind of 7 m/s blew from the east to the west.

Probably, this combination of winds blowing from the north in the northwestern part of the lake and from the east in the southeastern corner resulted in a cyclonic (counterclockwise) circulation of lake waters which became visible by a very good tracer – turbid waters with high concentration of suspended matter. This cyclonic circulation has a form of a lake-size gyre with a center in the middle of the lake. Little is known about currents in Lake Skadar/Shkodra [14], but due to its shallowness (mean depth – 5 m), the wind direction should play a key role in the formation of the circulation patterns in the lake.

On 11 February 2017, we see the opposite circulation – an anticyclonic gyre (clockwise rotation) which is well seen in the true colors image, total suspended matter, and chlorophyll-*a* concentration maps (Figs. 4, 5, and 6). It looks like turbid

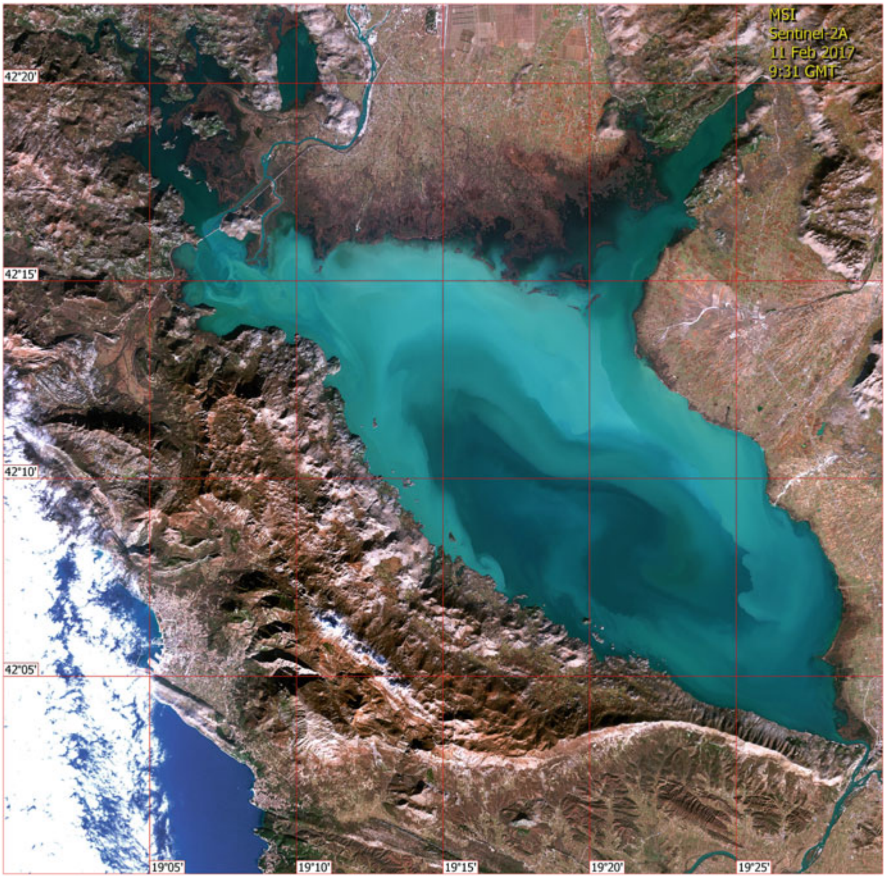

Fig. 4 Satellite view on Lake Skadar/Shkodra in true colors on 11 February 2017 (MSI Sentinel-2A). White colors show snow cover on the top of the mountains. White fields over the Adriatic Sea is cloudiness

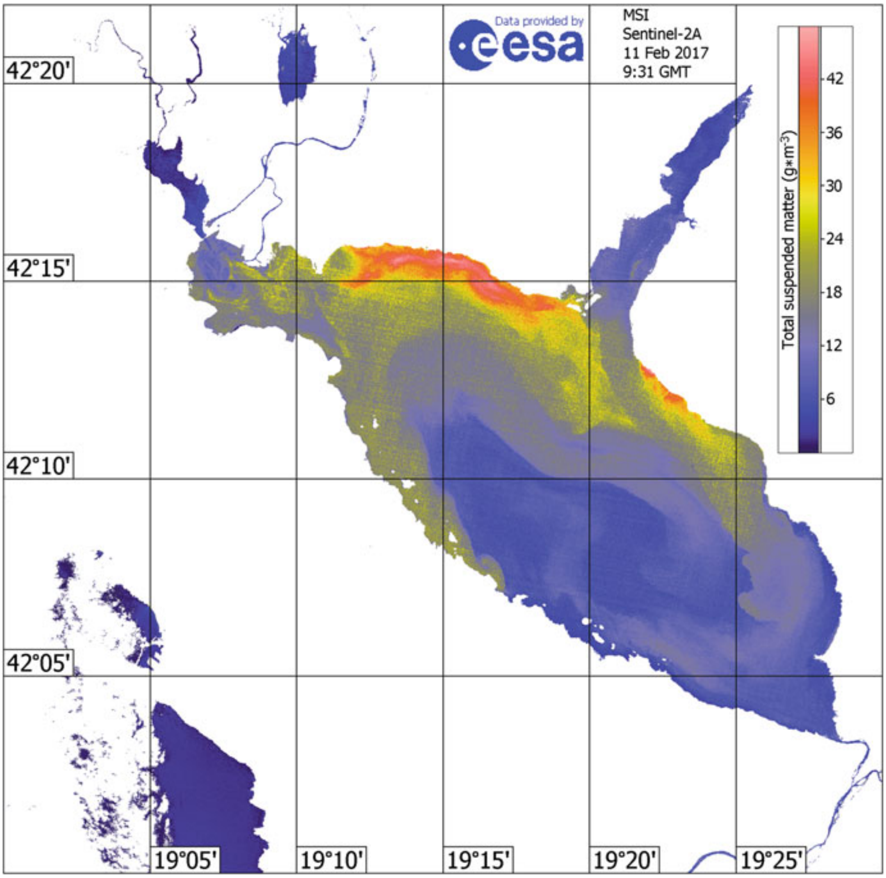

Fig. 5 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 11 February 2017 (MSI Sentinel-2A)

waters originate in the middle of the southern coast of the lake (where there are no sources of turbid waters like river inflow), then move along the coast northward, turn eastward where they reach maximum concentration of suspended matter of about 30–45 g/m^3, flow along the eastern coast, and turn back northwestward in the southeastern corner. Central and southern parts of the lake are quite clear as concentration of suspended matter is less than 10 g/m^3 (Fig. 5). A similar spatial pattern is displayed in the chlorophyll-*a* concentration map (Fig. 6).

We tried to understand the reason of anticyclonic circulation in the lake, in this case through the analysis of wind conditions in Podgorica and Shkoder. Meteo stations showed that the last rain in Shkoder was in the evening of 6 February and in Podgorica, in the evening of 7 February, so it is not likely that turbid waters were generated by rain and related river runoff. On 9–11 February, in Podgorica, the wind of 2–3 m/s blew from the south and southwest to the north and northeast. In Shkoder,

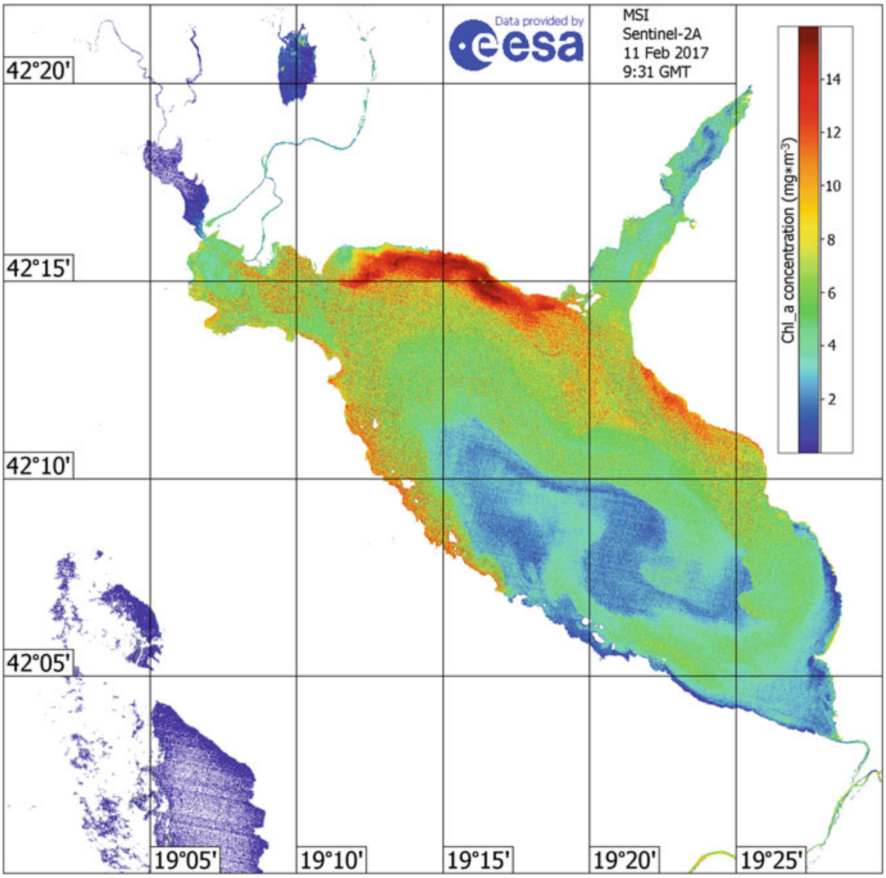

Fig. 6 Chlorophyll-*a* concentration (mg/m^3) in Lake Skadar/Shkodra on 11 February 2017 (MSI Sentinel-2A)

on 9 February, the wind blew from the northwest (3 m/s); on 10 February, from the east (3 m/s); and on 11 February, from the west (3 m/s). We would like to note here that the satellite image under discussion was acquired early in the morning (09:31 GMT) of 11 February, so wind conditions in the previous days are more important for generation of water circulation. It is still unclear why such weak wind generates turbidity in the lake via resuspension of bottom sediments.

Further analysis of satellite images and wind conditions has showed that by 16 February the circulation in lake was the same – clockwise (Fig. 7), which can be explained by the same wind forcing over the lake: in Podgorica the wind (2–3 m/s) blew from the southern directions, and in Shkoder the wind (2–3 m/s) blew mostly from the western directions. Water circulation was traced by characteristic spatial distribution of suspended matter, which, in general, was similar in shape and concentrations to that of 11 February (Fig. 5), but turbidity became more

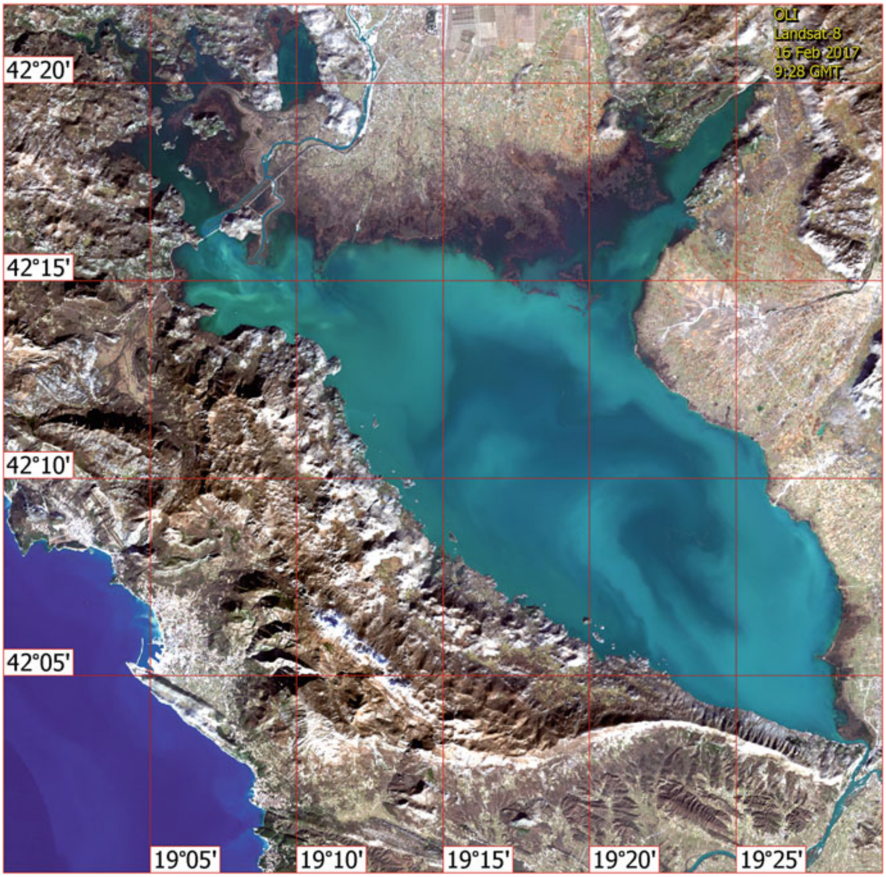

Fig. 7 Satellite view on Lake Skadar/Shkodra in true colors on 16 February 2017 (OLI Landsat-8). White colors show snow cover on the top of the mountains

uniform, contrasts in TSM had significantly decreased, and even the central part of the lake became less clear (Fig. 8). Apparently, this is the result of permanent wind and water circulation that during 5 days slowly mixed water in the lake. Also, Fig. 7 demonstrates a set of fine structures like filaments, jets, meanders, and eddies of 1–5 km in size or width.

Figure 9 shows the lake surface temperature which, on the one hand, corresponds to the circulation and turbidity patterns and, on the other hand, is consistent with evident physical processes when surface turbid waters in shallow areas warm up faster than clear waters located in deeper areas. Thus, we observe warmer waters (9–10°C) in the shallowest areas and bays, relatively cold waters (7–8°C) almost everywhere in the lake area, and the coldest waters (6–7°C) in the central part of the lake (Fig. 9). We have to note that in the same satellite image, the sea surface temperature in the coastal zone of the Adriatic Sea is much warmer (12–13°C).

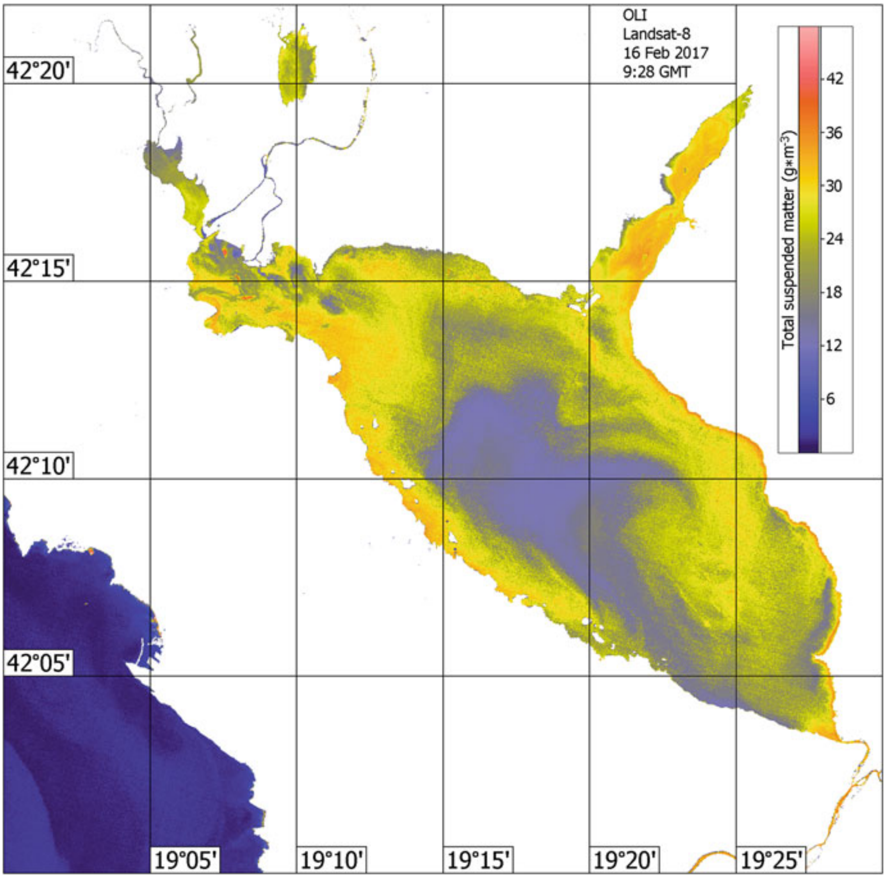

Fig. 8 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 16 February 2017 (OLI Landsat-8)

Warming of lake waters resulted from sunny weather with the air temperature that varied from 13 to 15°C in Podgorica and from 11 to 14°C in Shkoder during a week before satellite image acquisition on 16 February.

4 Spring 2017

On 14 April 2017, we see again a lake-size cyclonic gyre with counterclockwise water circulation due to the fine bands of turbid waters which turn in a spiral from the coastal zones to the center of the lake (Fig. 10). Waters of the lake are quite clear (TSM < 5 g/m^3), except of the bands of turbid waters with TSM values reaching 10–15 g/m^3 (Fig. 11). High TSM values are also observed in the northwesternmost

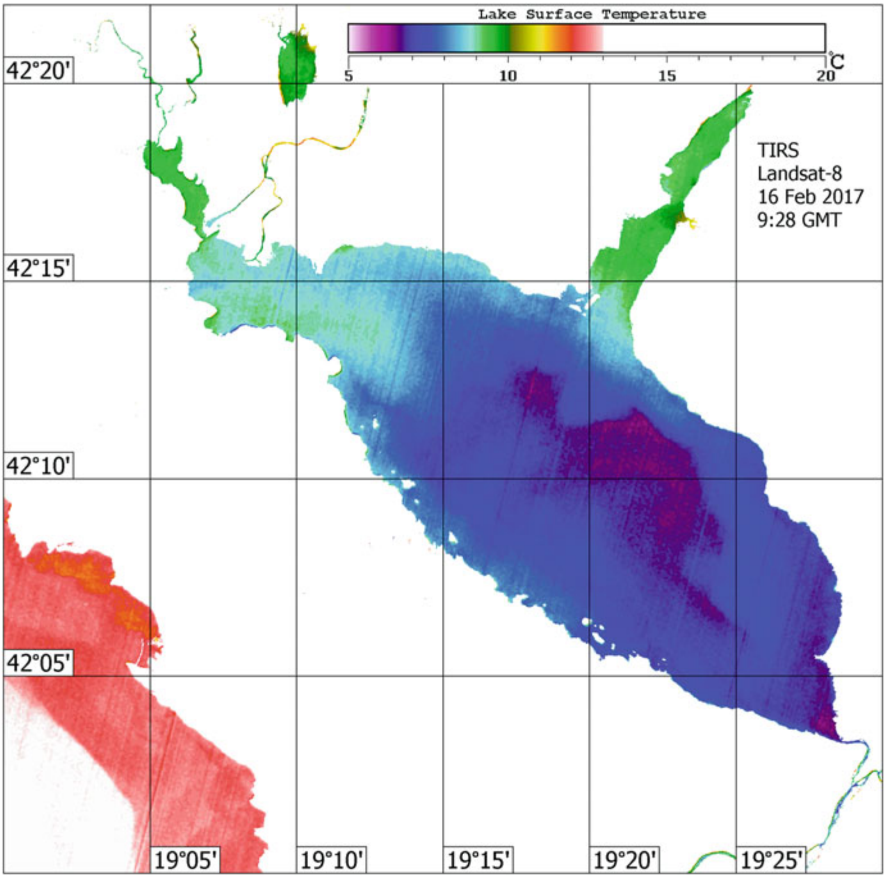

Fig. 9 Water surface temperature (°C) in Lake Skadar/Shkodra on 16 February 2017 (TIRS Landsat-8)

shallow extremity of the lake and along the northern shores. Maximum chlorophyll-*a* concentrations (2–3 mg/m^3) were found in the same bands in the middle of the lake and up to 5–8 mg/m^3 – along the northern shores (Fig. 12). The lake surface temperature displayed a general gyre (but without notable bands) with the highest temperatures (17–18°C) along narrow coastal zones, while the surface temperature in the main part of the lake varied between 15.5 and 16.5°C (Fig. 13).

Analysis of weather conditions in Podgorica and Shkoder showed that during the days before satellite image acquisition, the wind of 3–4 m/s blew from the south in Podgorica and the wind of 5–6 m/s blew from the southwest in Shkoder. With this wind, we could expect an anticyclonic gyre like the one on 11 and 16 February (see Figs. 4 and 7), but it was clearly cyclonic. Such discrepancy means that the wind registered at Podgorica and Shkoder is not characteristic for the lake, and mechanisms of generation of cyclonic or anticyclonic circulation in the lake require further

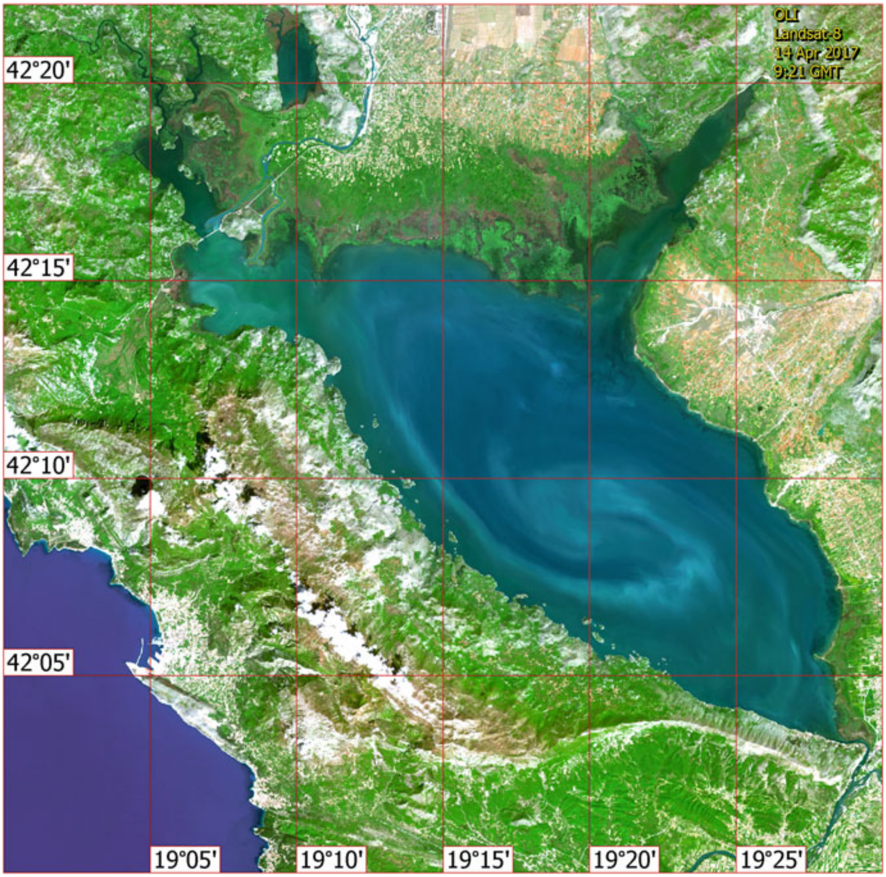

Fig. 10 Satellite view on Lake Skadar/Shkodra in true colors on 14 April 2017 (OLI Landsat-8)

detailed research [14]. For both sites during the week before satellite image acquisition, the weather was sunny and air temperatures varied between 21 and 25°C in Podgorica and 18–22°C in Shkoder. The lake warmed up quickly, and its temperature became a bit higher than in the coastal zone of the Adriatic Sea (Fig. 13).

Eight days later, on 22 April 2017, we observe the same cyclonic gyre in the lake (Fig. 14). The wind in Podgorica blew from the north on 19–21 April and a day before satellite image acquisition it was 6 m/s. In Shkoder, on 19–20 April, the wind (4–5 m/s) blew from the west, and on 21 April, it was 2 m/s, from the south. So, for both cyclonic gyres observed on 14 and 22 April, the wind in Podgorica was southern and northern on these 2 days, correspondingly; and in Shkoder, the wind direction was almost the same on both days. Thus, for the abovementioned two cases of anticyclonic circulation in February and two cases of cyclonic circulation in April, it is not possible to establish typical wind patterns (based on Podgorica and Shkoder

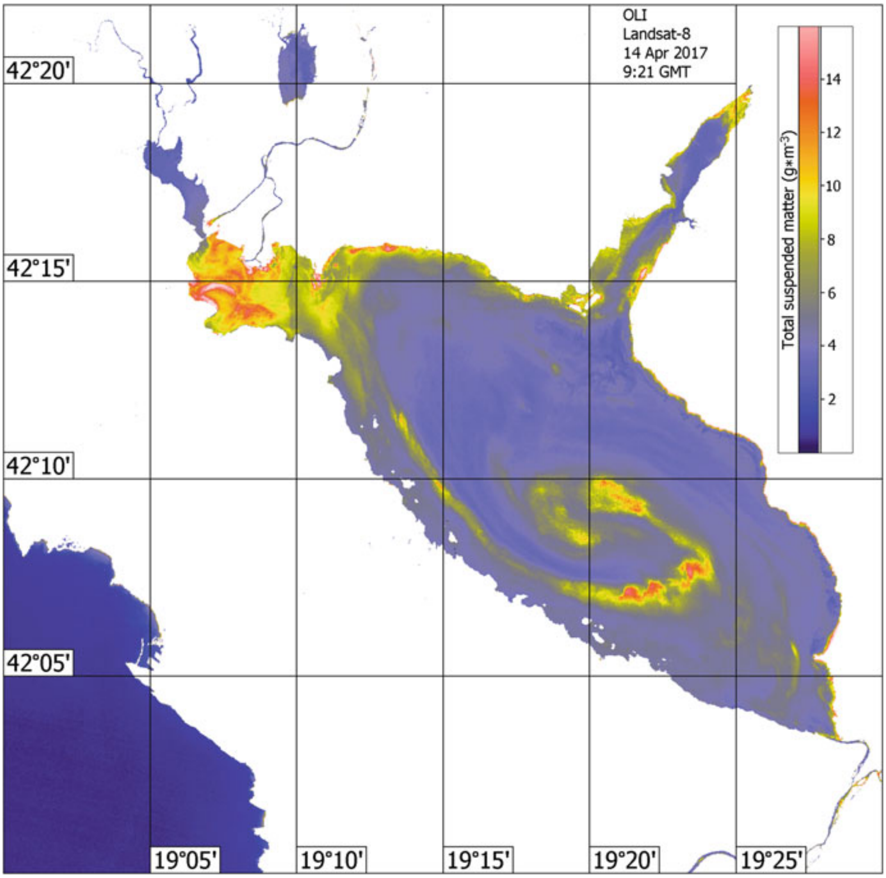

Fig. 11 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 14 April 2017 (OLI Landsat-8)

weather stations) which are responsible for cyclonic or anticyclonic circulation in Lake Skadar/Shkodra.

Spatial distribution of TSM displayed a characteristic feature of cyclonic circulation with spiral bands of higher concentrations of TSM (15–20 g/m^3) in the central part of the lake, but the highest TSM concentrations (>25 g/m^3) were observed in the southeasternmost coastal part of the lake (Fig. 15). This can be explained by the rain that occurred in Shkoder from the evening of 18 April till the evening of 19 April, i.e. 2–3 days before the image acquisition.

Maximum chlorophyll-*a* concentrations (about 10 mg/m^3) were found in the same bands in the middle of the lake and more than 15 mg/m^3 – along the southeastern shores (Fig. 16).

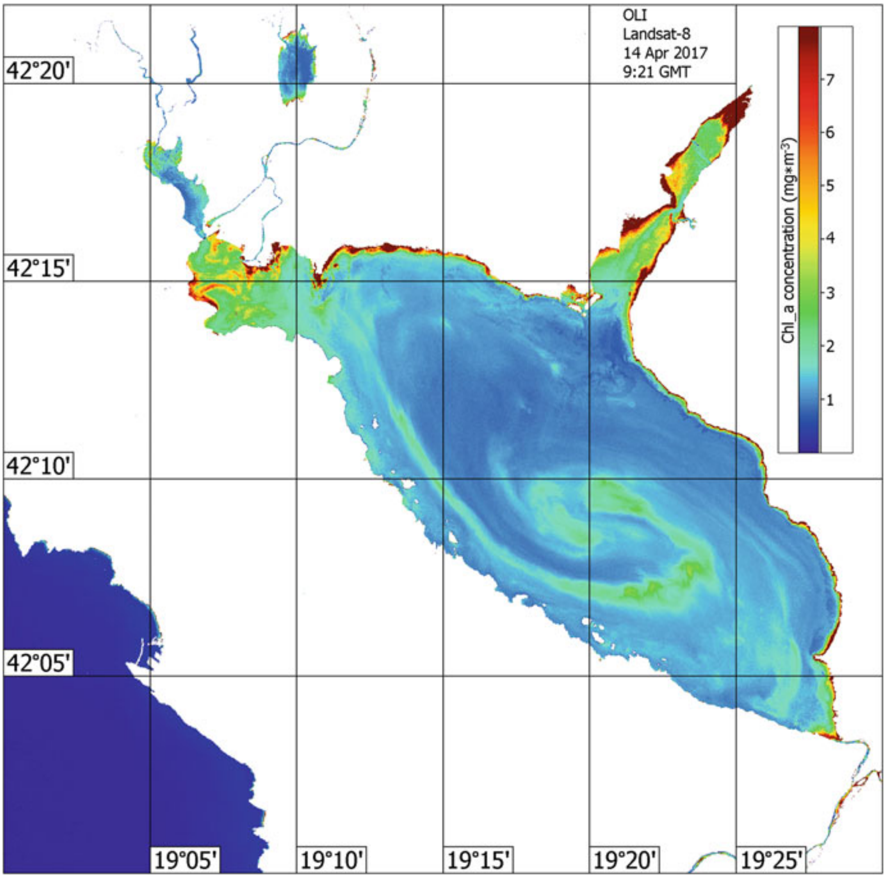

Fig. 12 Chlorophyll-*a* concentration (mg/m^3) in Lake Skadar/Shkodra on 14 April 2017 (OLI Landsat-8)

5 Summer 2017

On 4 August 2017, we observe cyclonic circulation in the southeastern part of the lake which became evident thanks to characteristic spatial distribution of turbid waters (Fig. 17). The whole area of the lake is quite clear with TSM < 4 g/m^3. Waters involved in cyclonic circulation have TSM of 6–8 g/m^3. The most turbid waters (TSM > 12 g/m^3) are located in the northwestern and northeastern parts of the lake (Fig. 18). Chlorophyll-*a* spatial distribution shows a similar pattern with concentrations of $<$2 mg/m^3 in the central part of the lake and $>$6 mg/m^3 in the northwestern and northeastern parts of the lake (Fig. 19). The cyclonic gyre is visible in both characteristics.

Analysis of weather conditions showed that in Podgorica on 2–3 August, the wind of 2–3 m/s blew from the south and in Shkoder on 2 August the wind of 2 m/s

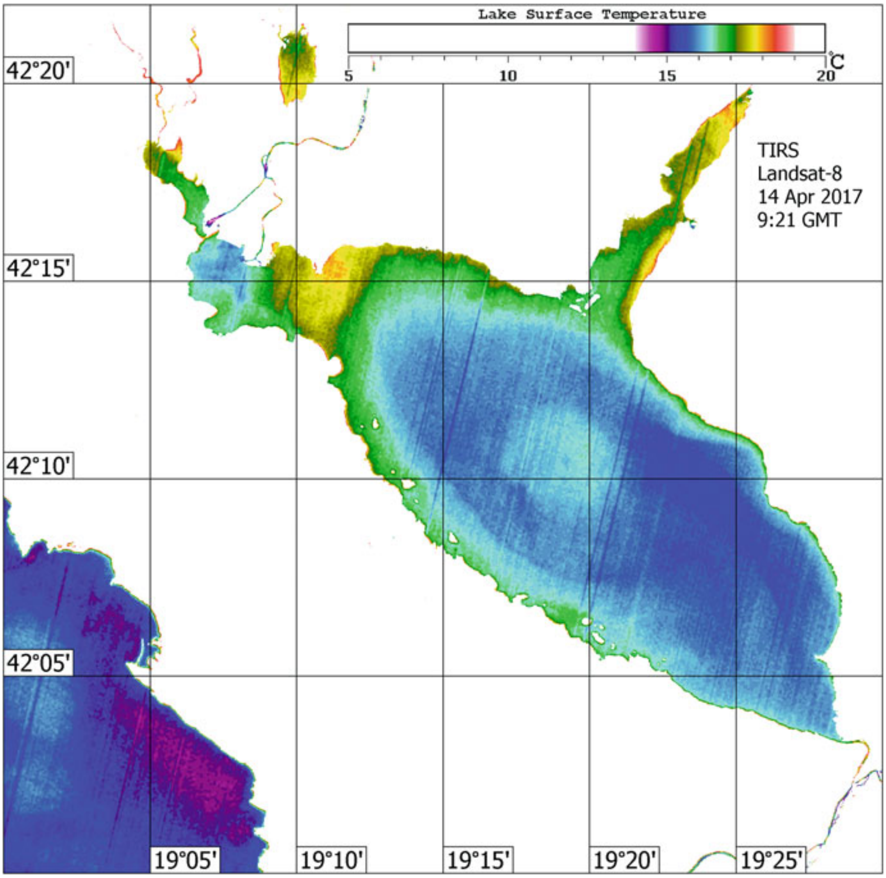

Fig. 13 Water surface temperature (°C) in Lake Skadar/Shkodra on 14 April 2017 (TIRS Landsat-8)

blew from the southwest and on 3 August, it was calm. So these wind conditions were almost the same as observed before 14 April which led also to formation of a cyclonic gyre in the lake (Fig. 10). Increased concentrations of TSM and chlorophyll-*a* in the northwestern and northeastern parts of the lake cannot be explained by rain or strong wind-wave mixing because both phenomena were not observed in the previous week. As concerns the air temperature, during 5 days before satellite image acquisition, it was 37–40°C in Podgorica and 36–39°C in Shkoder. These hot and sunny conditions over the lake led to strong warming of the lake surface waters: about 27°C in the central part of the lake and 28–29°C in its northeastern extremity (Fig. 20).

Fig. 14 Satellite view on Lake Skadar/Shkodra in true colors on 22 April 2017 (MSI Sentinel-2A)

6 Autumn 2017

On 28 November 2017 due to the presence of turbid waters, we again observe cyclonic circulation in the southeastern part of the lake (Fig. 21). TSM in the whole area of the lake is characterized by concentrations of 10–15 g/m^3. The highest TSM values are observed in the spiral bands forming a cyclonic gyre and along some of the coastal zones (Fig. 22). Chlorophyll-*a* spatial distribution shows a similar pattern with concentrations of 6–8 mg/m^3 in the central part of the lake and >12 mg/m^3 along the eastern shore of the lake northwestward of Shkoder (Fig. 23).

Analysis of weather conditions showed that in Podgorica on 27 November, the wind of 8–9 m/s blew from the north and in Shkoder on 27 November, the wind of 0–5 m/s blew from various directions. So these wind conditions were close to those observed before 22 April which led also to formation of a cyclonic gyre in the lake

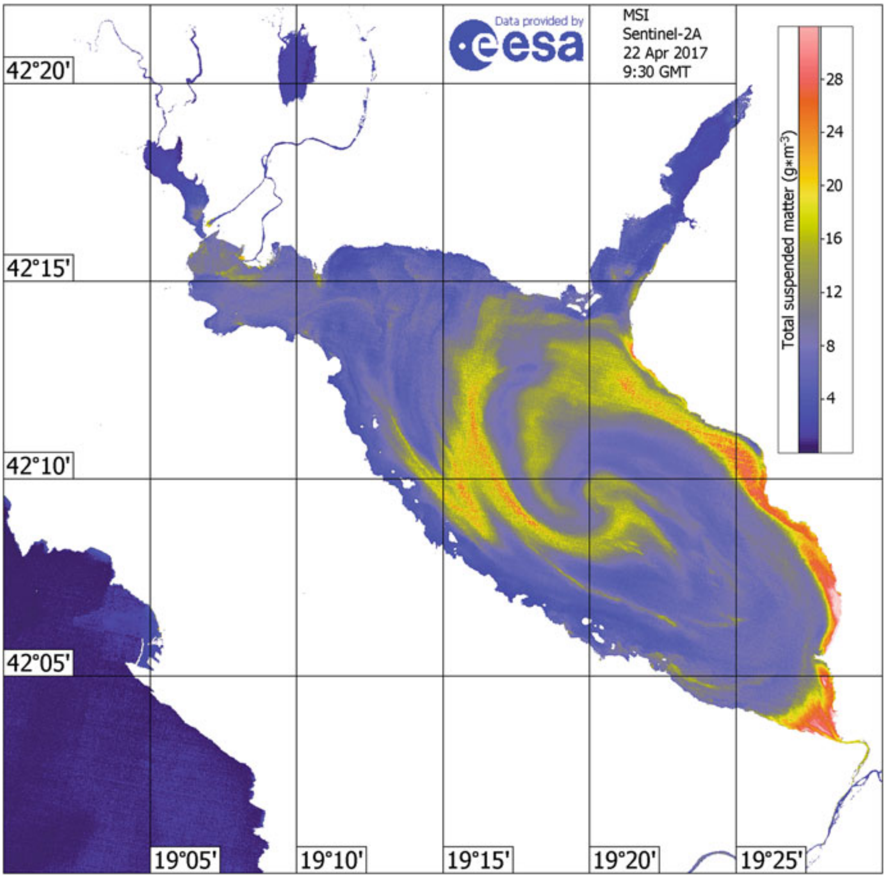

Fig. 15 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 22 April 2017 (MSI Sentinel-2A)

(Fig. 14). Increased concentrations of TSM in the lake could be explained by light rain registered in Podgorica and Shkoder on 26–27 November 2017.

7 Synthetic Aperture Radar Imagery

Synthetic aperture radar (SAR) imagery is used to detect ice cover, oil pollution, and ships on the sea surface, flooded areas in the coastal zones of seas, lakes and rivers, etc. [8, 9]. The main advantage of SAR is the ability to provide satellite data almost in all weather (cloudy) conditions regardless of the presence of light (day/night).

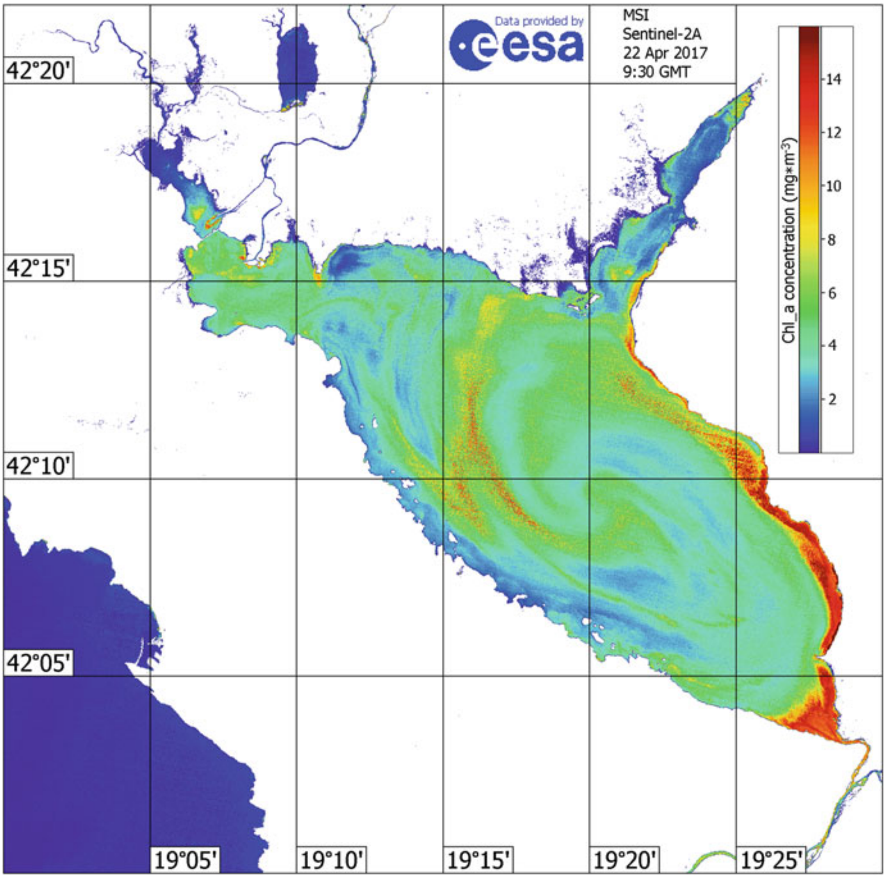

Fig. 16 Chlorophyll-*a* concentration (mg/m^3) in Lake Skadar/Shkodra on 22 April 2017 (MSI Sentinel-2A)

SAR imagery of the sea or lake surface is more difficult to interpret because it reflects roughness of the water surface at the level of gravity-capillary waves with the wavelength less than a few centimeters. Dumping of gravity-capillary waves by different natural (atmospheric, oceanic, and biogenic) phenomena or anthropogenic (oil pollution, waste, sewage) factors results in the variations of the backscatter signal received by SAR on a satellite. Long-standing experience in SAR imagery analysis, as well as supplementary meteorological, oceanographic (limnological), biological, and other information, is required for correct interpretation of SAR imagery. We do believe that SAR imagery of Lake Skadar/Shkodra will be useful in the monitoring of flooded areas, as well as of rare cases of oil pollution or ice cover.

We would like to remind here that in January 2017, cold weather in Podgorica (down to −6°C on 7 January) with negative day and night temperatures lasted for a

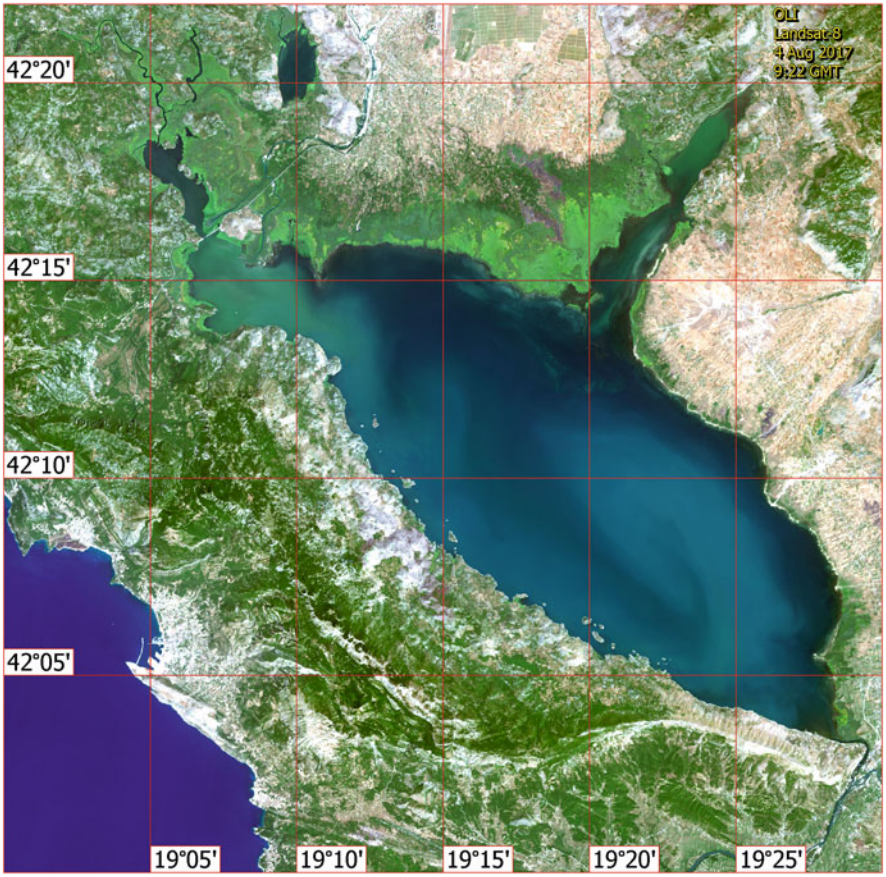

Fig. 17 Satellite view on Lake Skadar/Shkodra in true colors on 4 August 2017 (OLI Landsat-8)

week from 6 to 12 January. This led to formation of a thin ice cover along the shallow northern shoreline which was visible on true color images acquired on 7 and 15 January (Figs. 2 and 3). Analysis of available SAR imagery has confirmed our observations made in optical imagery.

On 4 January (Fig. 24), we observe a black color almost everywhere on the lake which means that there was no wind at the time of image acquisition (16:31 GMT). The meteo station in Podgorica showed the northern wind of <1 m/s and the air temperature of +4–7°C. Calm weather is one of the limiting factors for detection of any phenomena at the sea or lake surface. On 9 January (16:39 GMT), we see ice cover which appeared in the northwestern and northeastern shallow parts of the lake (Fig. 25). On 15 January (15:40 GMT), ice cover became more evident in the SAR image which was displayed as grey fields in the coastal zone of the northern part of the lake and in the open lake (Fig. 26). On 13–15 January, the air temperature in Podgorica varied between −3 and +9°C, but ice cover was still there due to the low

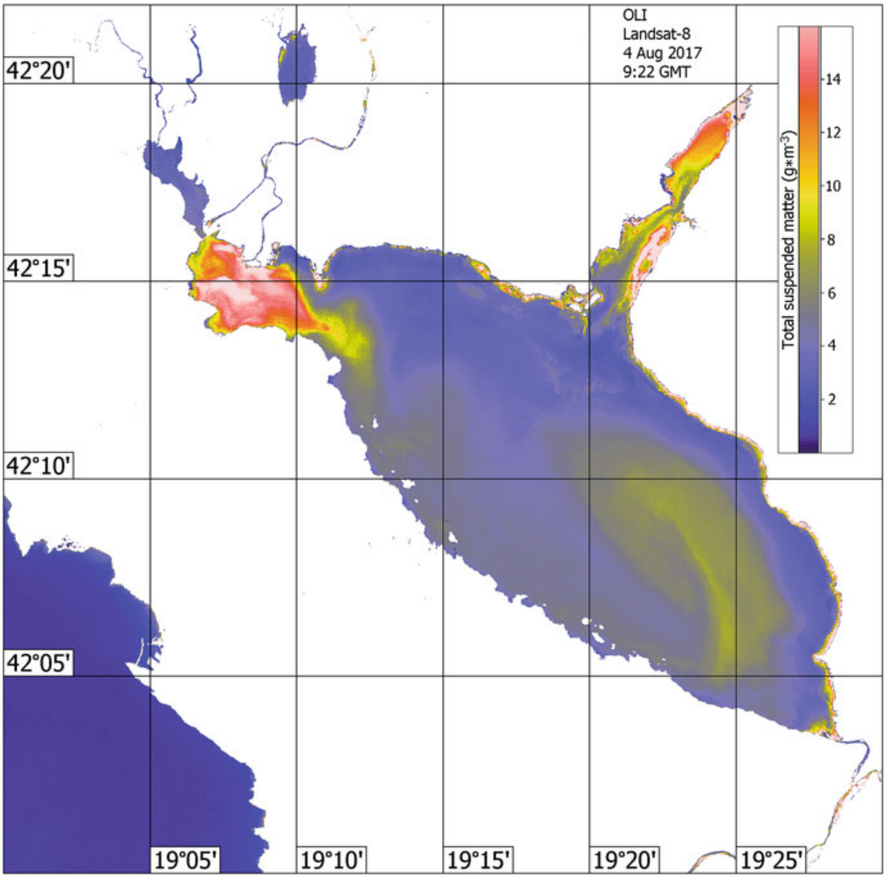

Fig. 18 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 4 August 2017 (OLI Landsat-8)

water temperature. By 21 January, ice cover melted everywhere on the lake which was justified by the SAR image obtained on this day (Fig. 27). In this image, we again see almost a uniform black color all over the lake surface which is explained by a very low wind force. The meteo station in Podgorica recorded the northern wind of 1.4 m/s.

Finally, we would like to mention a SAR image acquired on 22 April 2017 (Fig. 28) to show that the wind pattern over the lake is not uniform, because the backscatter signal has at least six large areas with a different level of the signal (different brightness and structure). According to the data from the Podgorica and Shkoder meteo stations, in Podgorica the wind of 3 m/s blew from SSE and in Shkoder, it was 4 m/s from the west. Apparently, these data do not correspond to the actual wind characteristics over the lake itself. This means that not in all cases we can rely on data from meteo stations in Podgorica and Shkoder when analyzing different hydrophysical processes in the lake.

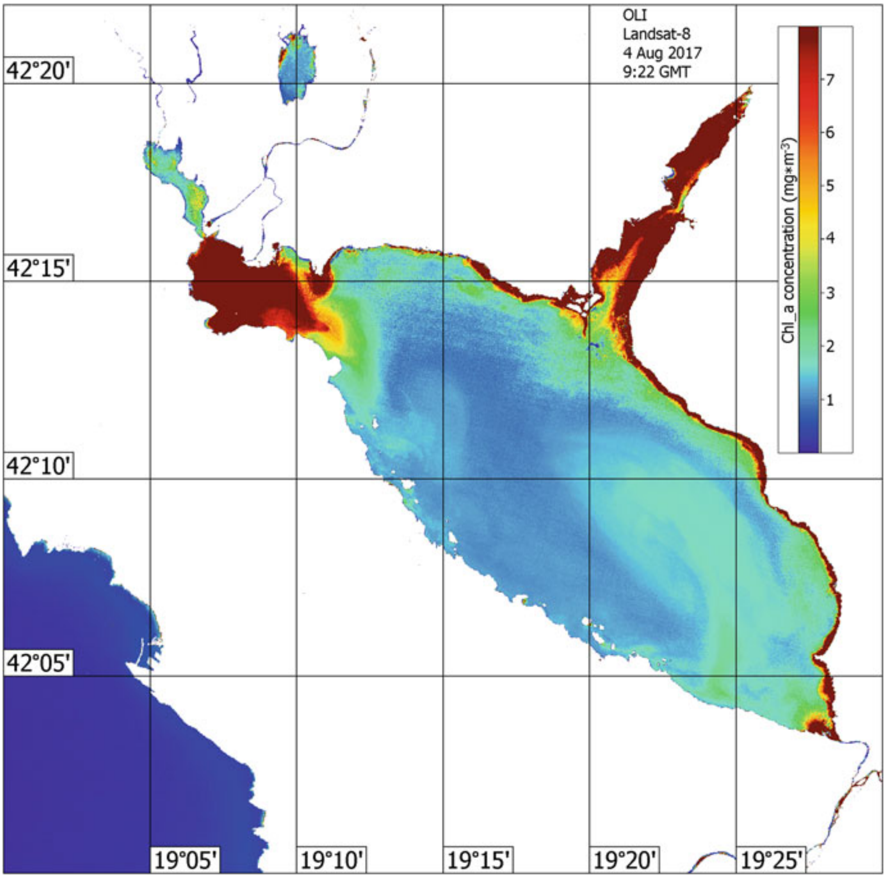

Fig. 19 Chlorophyll-*a* concentration (mg/m^3) in Lake Skadar/Shkodra on 4 August 2017 (OLI Landsat-8)

8 Conclusions

In this chapter, we have demonstrated capabilities of satellite remote sensing for establishing permanent monitoring of the lake surface temperature; concentration of total suspended matter and chlorophyll-*a*, turbid waters, and ice cover (rare events); and water circulation patterns, as well as for control of flooded areas and possible cases of oil pollution. Modern sensors allow to control the abovementioned characteristics of Lake Skadar/Shkodra with high spatial (10–100 m) and temporal (1–10 days) resolution. We discovered cyclonic and anticyclonic lake-size gyres which seem to be a characteristic feature for the lake circulation though we could not yet establish favorable wind patterns responsible for cyclonic or anticyclonic water

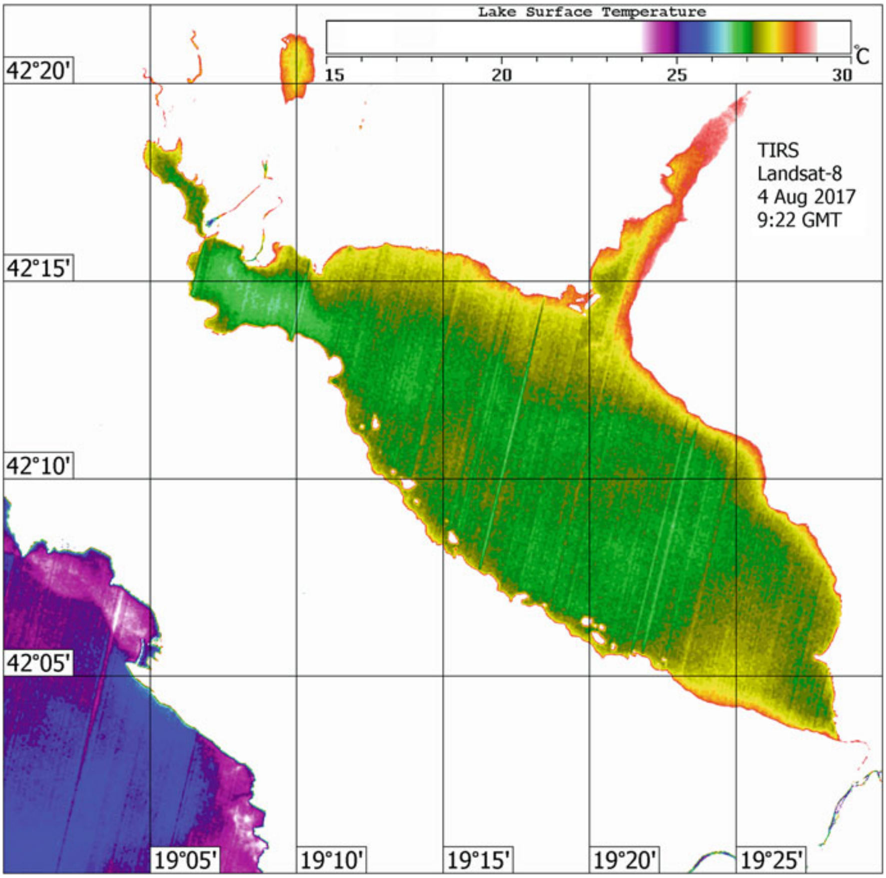

Fig. 20 Water surface temperature (°C) in Lake Skadar/Shkodra on 4 August 2017 (TIRS Landsat-8)

circulation. The statistics for year 2017 shows that the presence of cyclonic gyres dominates.

Yearly flooding of the northwestern shores of Lake Skadar/Shkodra which occurs in November–April due to rain over the watershed area leads to a significant increase of the lake area from about 350 to 500 km^2. These events have a significant impact on erosion of the lake shores, redistribution of pollutants and sediments, nutrients exchange, habitat for lake organisms, and feeding/breeding grounds for waterfowl and fish [2]. The use of remote sensing technology can be especially helpful in estimation of the extent of the floodplains, flooded zones, suspended matter spatial distribution, and concentration. This is especially important in relation to existing plans to construct new hydropower dams on the Morača River in Montenegro and a hydropower plant on the Drin River near Bushati in Albania [5].

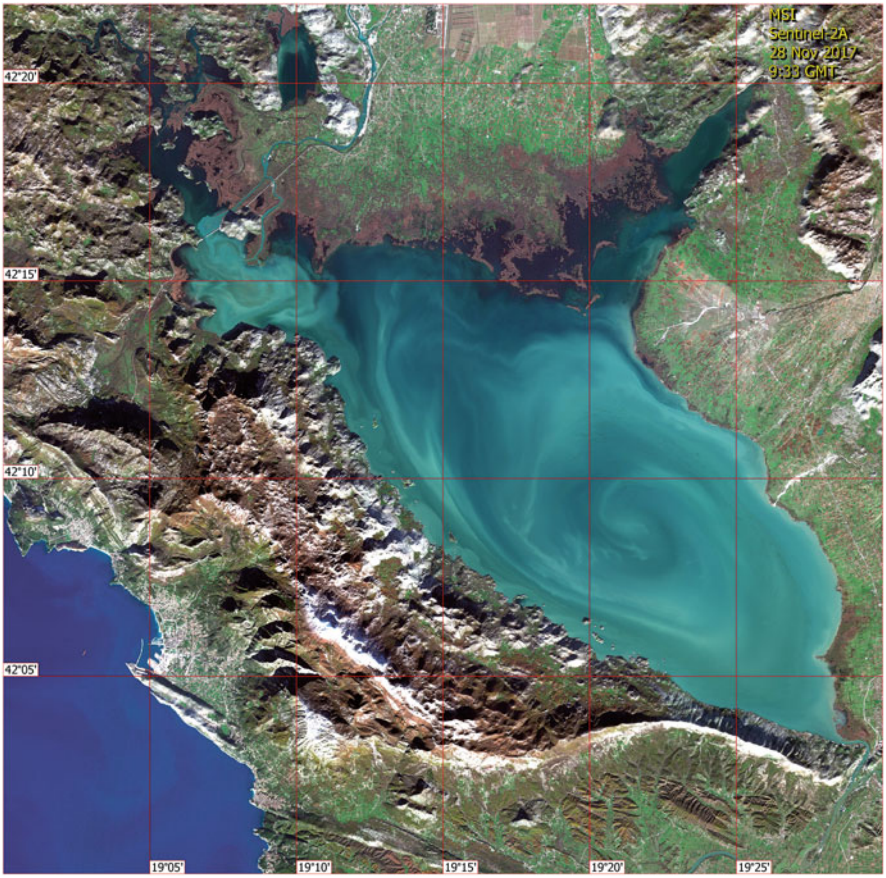

Fig. 21 Satellite view on Lake Skadar/Shkodra in true colors on 28 November 2017 (MSI Sentinel-2A)

The Morača River brings more than 60% of the total river runoff to the lake and the main part of pollutants and nutrients gathered on the watershed area. Thus, it has a great influence on water transparency, temperature, electrical conductivity, pH, dissolved oxygen, nutrient concentration, and microbial, planktonic, and zoobenthos diversity and their composition in Lake Skadar/Shkodra [2, 5, 15]. It was found that the highest concentration of heavy metals in the water, sediments and macrophytes, as well as the highest concentration of polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) are detected near the mouth of the Morača River [3, 7]. Examples of satellite imagery of Lake Skadar/Shkodra that we acquired in all seasons of 2017 showed that cyclonic or anticyclonic gyres play a very important role in the redistribution of physical, chemical, and biological characteristics of lake waters on the whole surface of the lake. It was found that these gyres have a size of

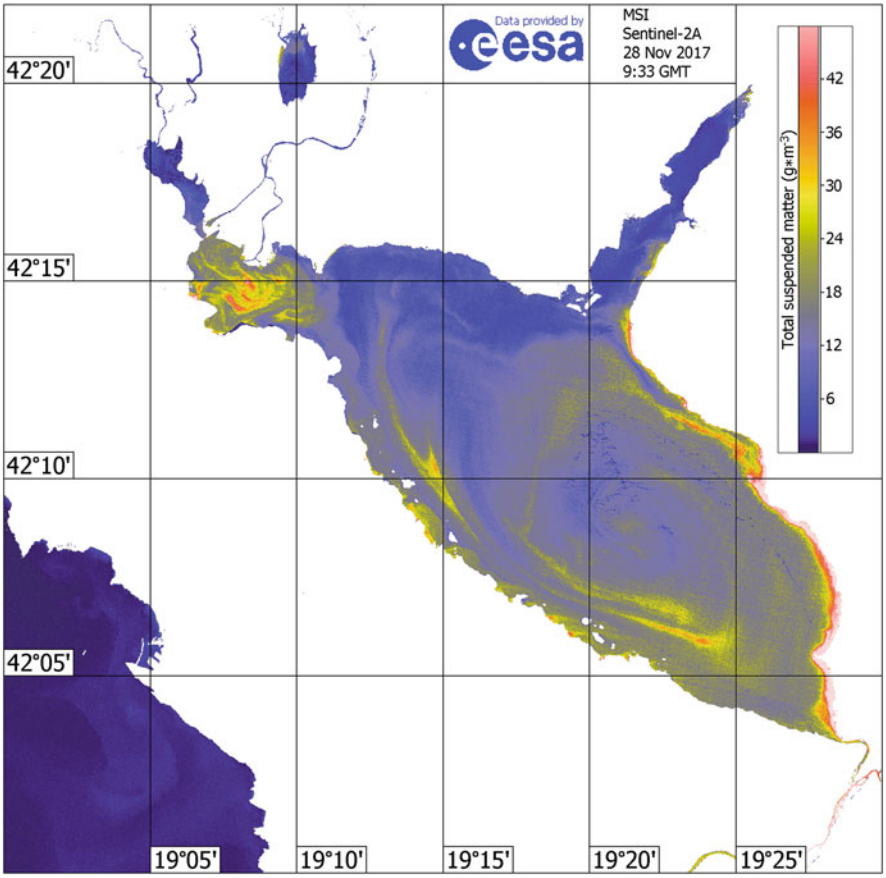

Fig. 22 Total suspended matter (g/m^3) in Lake Skadar/Shkodra on 28 November 2017 (MSI Sentinel-2A)

the lake; thus, they are responsible for the transboundary (between Montenegro and Albania) transfer of water and pollution which was not taken into account before.

Based on the mean annual chlorophyll-*a* concentration, Lake Skadar/Shkodra can be classified as mesotrophic, but during summer, when the greatest phytoplankton abundance and biomass occurs, the trophic level of the lake increases to the eutrophic and even to hypertrophic level [16, 17]. These changes in the trophic level lead to changes in the community structure of the phytoplankton, zooplankton, and zoobenthos. Satellite remote sensing allows providing regular maps of chlorophyll-*a* concentration in cloudy free conditions. After in situ calibration, chlorophyll-*a* concentration will be consistent with values measured in situ. Thus, satellite monitoring will play a significant role in characterization of spatial patterns of eutrophication, as well as in investigation of seasonal and interannual variability of lake eutrophication and its consequences (overgrowing of shores, etc.).

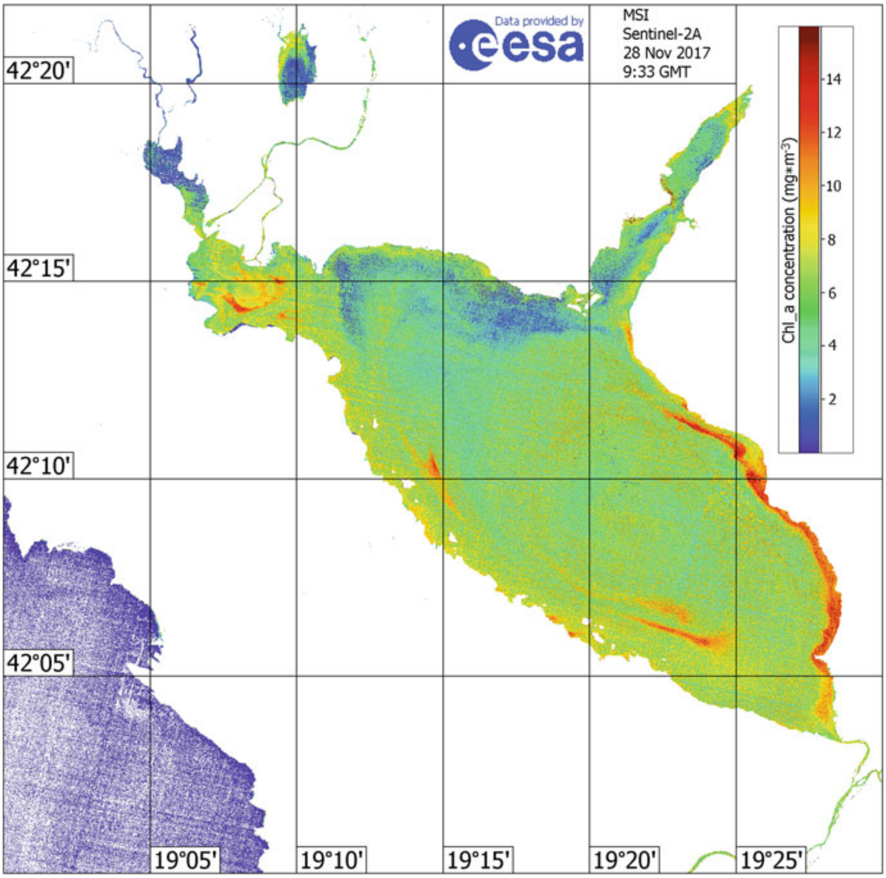

Fig. 23 Chlorophyll-*a* concentration (mg/m^3) in Lake Skadar/Shkodra on 28 November 2017 (MSI Sentinel-2A)

A large number of sublacustrine springs in Lake Skadar/Shkodra play a significant role in the overall biodiversity of the lake. Moreover, recent studies have shown that they have their own endemic species which require special protection measures for sublacustrine springs [18, 19]. Some of the sublacustrine springs in the lake can be detected from space due to the water temperature contrast (springs waters are usually colder) at the lake surface [20]. This experience in the application of high-spatial-resolution remote sensing technique for monitoring of sublacustrine springs in Lake Skadar/Shkodra can be continued on a regular basis to get seasonal and interannual characteristics of their behavior.

The discovered gyres seem to be a previously unknown characteristic feature of Lake Skadar/Shkodra. It is likely that this new finding will require modification of water quality assessment methods and guidelines for lake monitoring programs, closer coordination of monitoring programs between Montenegro and Albania, as

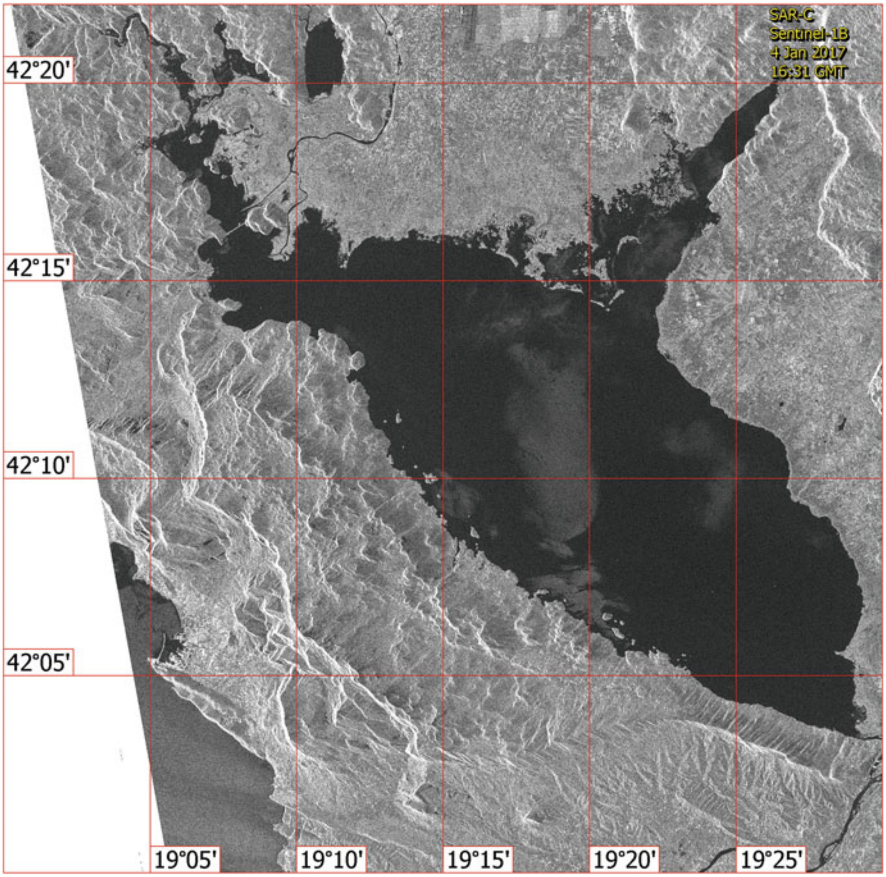

Fig. 24 SAR image of Lake Skadar/Shkodra on 4 January 2017 (16:31 GMT, SAR-C Sentinel-1B)

well as participation of the international scientific community in lake monitoring programs. Satellite remote sensing can also help in identification of reference sites for in situ monitoring which is a rather complicated task due to seasonal and interannual variability in the anthropogenic pressure on the lake, inhomogeneous spatial distribution of pollution, natural variations in the ecosystem, weather, and climate.

The abovementioned examples of satellite imagery and applications made evident that a special permanent satellite monitoring program of Lake Skadar/ Shkodra is required in the nearest future. It should be integrated in and coordinated with the ongoing and future in situ biogeochemical monitoring programs.

Acknowledgments The research was partially supported in the framework of the Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2018-0003).

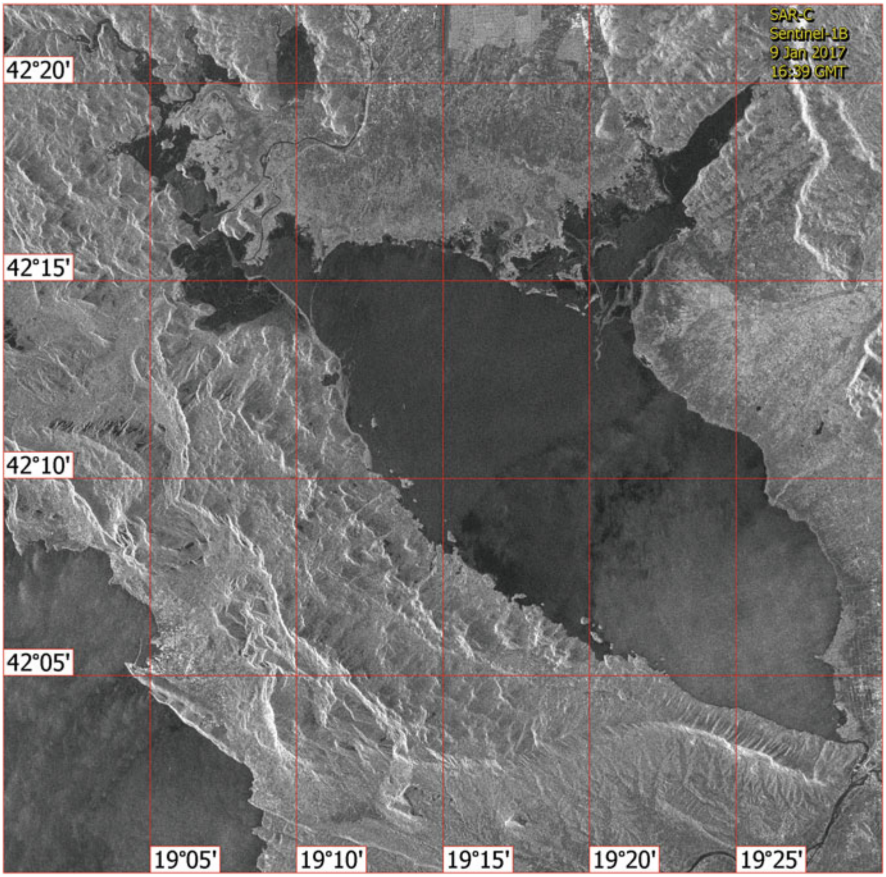

Fig. 25 SAR image of Lake Skadar/Shkodra on 9 January 2017 (16:39 GMT, SAR-C Sentinel-1B)

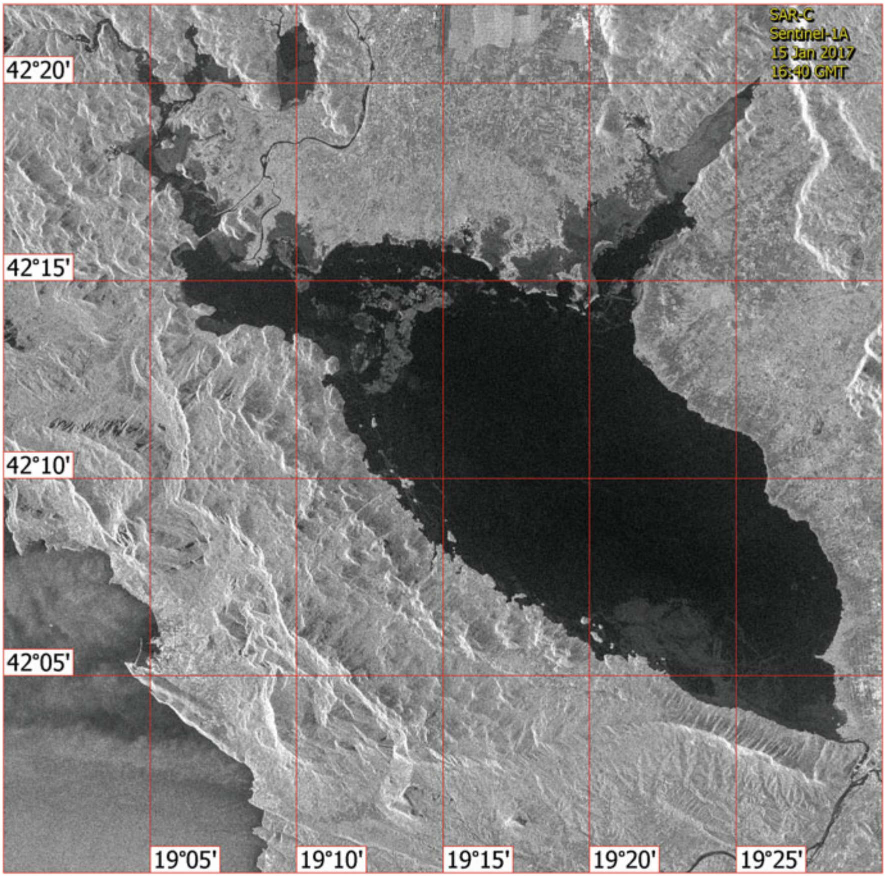

Fig. 26 SAR image of Lake Skadar/Shkodra on 15 January 2017 (16:40 GMT, SAR-C Sentinel-1B)

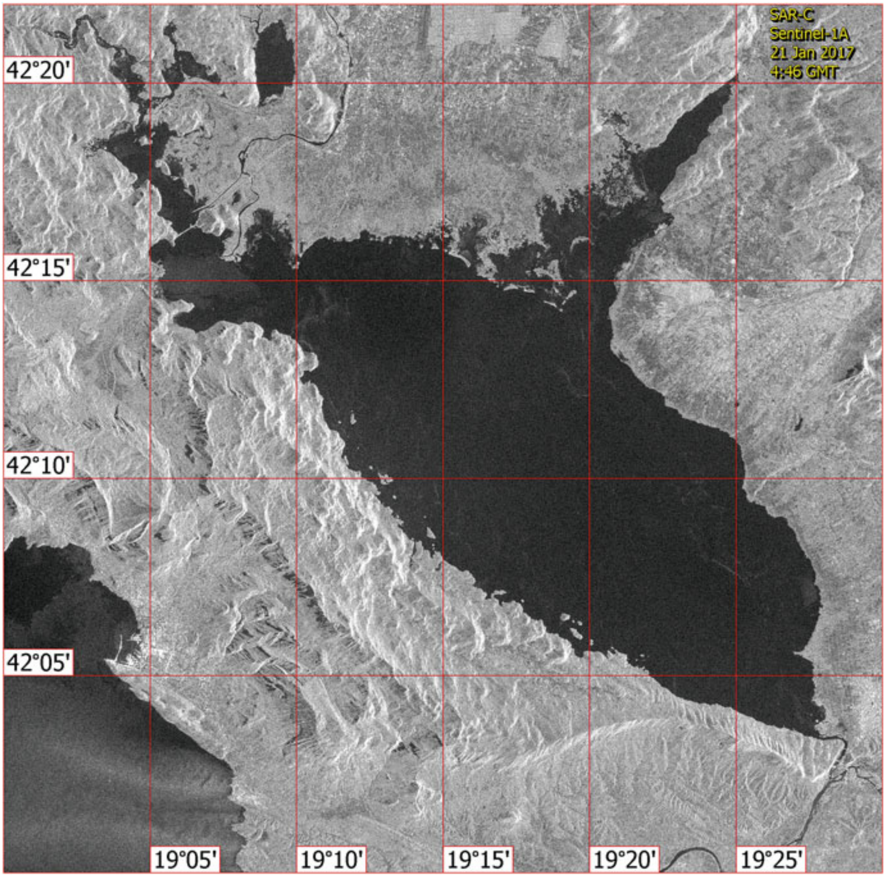

Fig. 27 SAR image of Lake Skadar/Shkodra on 21 January 2017 (04:46 GMT, SAR-C Sentinel-1A)

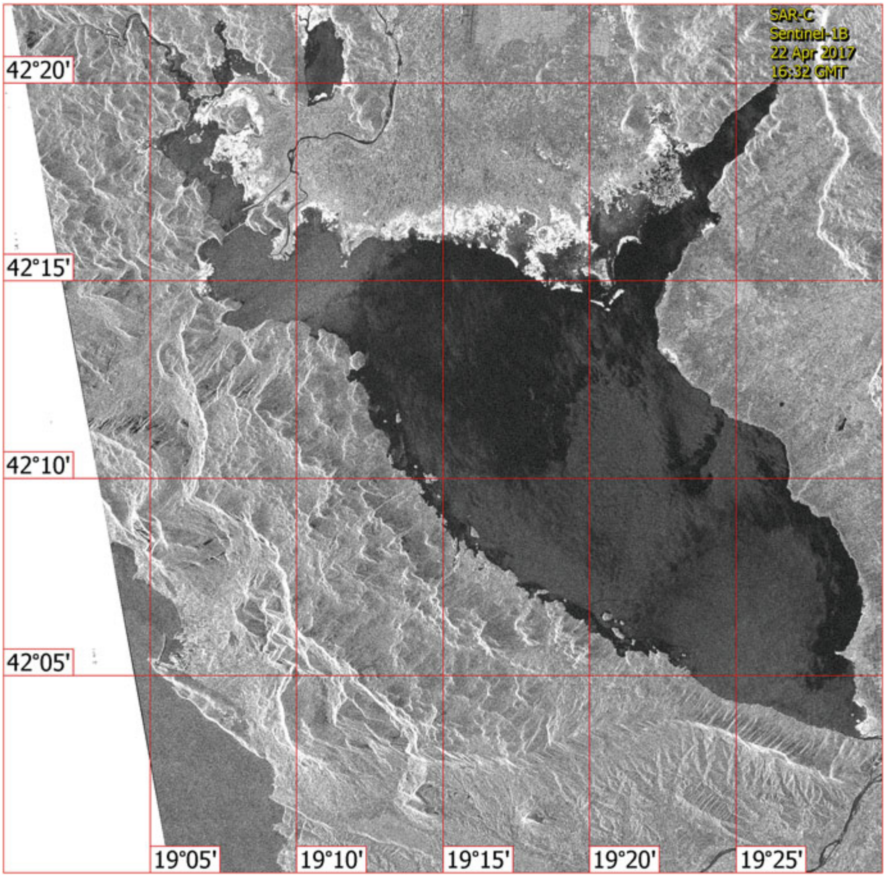

Fig. 28 SAR image of Lake Skadar/Shkodra on 22 April 2017 (16:32 GMT, SAR-C Sentinel-1B)

References

1. Lasca NP, Radulović V, Ristić RJ, Cherkauer DS (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 17–38
2. Beeton AM (1981) Physical conditions of Lake Skadar and its basin. General introduction. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 15–17
3. Royal Haskoning, Keukelaar F, De Goffau A, Pradhan T et al. (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515, Podgorica, p 111
4. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham

5. Pešić V, Karaman G, Kostianoy A, Vukašinović-Pešić V (2018) Conclusions: recent advances and the future prospects of the Lake Skadar/Skhodra environment. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
6. APAWA & CETI (2007) The Strategic Action Plan (SAP) for Skadar/Shkodra Lake. Albania & Montenegro. GEF, World Bank, LSIEMP, Shkodra-Tirana-Podgorica, p 72
7. Vukašinović-Pešić V, Blagojević N (2018) Metal pollution: evidences from plants, aquatic invertebrates and fishes from the Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
8. Lavrova OY, Kostianoy AG, Lebedev SA, Mityagina MI, Ginzburg AI, Sheremet NA (2011) Complex satellite monitoring of the Russian seas. IKI RAN, Moscow, p 470. (in Russian)
9. Lavrova OY, Mityagina MI, Kostianoy AG (2016) Satellite methods of detection and monitoring of marine zones of ecological risks. Space Research Institute, Moscow, p 336. (in Russian)
10. Kostianoy AG, Lebedev SA, Kazmina MV, Tsepelev VY, Varlashina VM, Neschadimova TG (2012) Satellite monitoring of transboundary waters of Russia and Estonia. Signal, Moscow, p 16
11. Grishin NN, Kostianoy AG (2013) The use of satellite monitoring of suspended matter transport for the assessment of transboundary environmental impact of construction the Russian section of the offshore gas pipeline Nord stream. Curr Probl Remote Sens Earth Space 10(1):303–319. (in Russian)
12. Kostianoy AG, Lebedev SA, Semenov AV (2015) On the need for satellite monitoring of transboundary waters of Russia. Probl Post Soviet Space 2(4):18–33. (in Russian)
13. Kostianoy AG, Soloviev DM, Kostianaia EA, Đurović B, Pestorić B (2017) Satellite remote sensing of the Boka Kotorska Bay. In: Joksimovich A, Djurovic M, Semenov AV, Zonn IS, Kostianoy AG (eds) The Boka Kotorska Bay environment. Springer, Cham, pp 495–520
14. Lee KK (1981) Application of mathematical modelling in studying of Lake Skadar circulation patterns. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 56–65
15. Petrović G (1981) Chemical investigations of water and sediment of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 68–96
16. Rakočević J (2018) The phytoplankton and trophic state of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Cham
17. Peveling R, Brämick U, Densky H, Parr B, Pietrock M (eds) (2017) Initial characterisation of Lakes Prespa, Ohrid and Shkodra/Skadar (Implementing the EU Water Framework Directive in South-Eastern Europe). Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH
18. Jacobi GZ (1981) Zoobenthos from sublacustrine springs in Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, pp 251–263
19. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
20. Radulović M, Sekulić G (2015) Determining locations of sublacustrine springs by remote sensing: the Skadar Lake case example Montenegro. Constr Unique Build Struct 2(29):73–86

The Water and Sediment Chemistry of Lake Skadar

Vlatko Kastratović

Contents

Abstract Lacustrine systems are complex water systems in terms of the transport and interaction with chemical substances. This work aims to contribute as the basis for (1) further testing for the purposes of adopting a final method of the systematic monitoring of the state of the environment of Lake Skadar and (2) defining pollution prediction modeling based on comparative analyses of the content of the chemical parameters in the abiotic and biotic parts of the lake ecosystem. Freshwater systems can not only be contaminated at different levels but are also exposed to fairly long-term pollution caused by chemicals deposited in sediments. The existing data clearly indicate that the planned monitoring of the chemical composition of sediment samples taken from sites under anthropogenic influence, together with the analysis of other indicators of the aquatic environment, enables us to quickly and comprehensively recognize the current situation of what are still largely preserved and extremely important ecosystems such as Lake Skadar.

Keywords Lake ecosystems, Lake Skadar, Natural water, Pollution, Sediment

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 121–140, DOI 10.1007/698_2018_251,
© Springer International Publishing AG 2018,
Published online: 27 April 2018

1 Introduction

Lake ecosystems are dynamic natural systems that change depending on a combination of environmental factors. The resulting quality arises as a result of many factors: starting from the means of the genesis of the lake, through its geographical position and the corresponding climate and hydrological characteristics, the morphometry of the lake, and the characteristics of the catchment area, to the physical, chemical, and biological factors in the water system itself [1]. The lake's response to external and internal changes is often long-term and long lasting.

However, recent anthropogenic impacts have a decisive influence on the changes in the dynamics of any lake ecosystem, so rapid ecosystem changes are increasingly becoming a trend. Lake Skadar is a highly vulnerable ecosystem affected by various types of anthropogenic pressures. Anthropogenic factors and activities including tourist activity and the destructive effects on soil from neighboring farms influence Lake Skadar. Intensive fishing, inefficient sewage systems and water utility problems, stationary industrial facilities, and increased land and water usage are also characteristic issues [2].

The specificity of the chemical composition of lake water is closely connected with the characteristics of their hydrological regime. Compared to rivers, lakes are characterized by slow water replacement, i.e., water remains in them longer. This occasionally, under appropriate climatic conditions, contributes to increased water evaporation from lake and their greater mineralization [3]. Mineralization of lakes primarily depends on mineralization of inflowing rivers. In addition it depends on the ratio of the amount of water into the lake, the amount of water that evaporates from it, and the amount of flow away from the lake. An important influence on the hydrochemical regime of the lake is demonstrated by biological processes that are particularly intense in shallow lakes [4–6].

When taking the whole basin in overview, Lake Skadar surface water is derived from direct precipitation on the lake surface, a number of occasional and constant water courses, among which the greatest quantity is represented by the Morača River, and a number of sublacustrine springs ("okos") [7]. The lake discharges only by its outflow, i.e., with the River Bojana, and evaporation from its surface. Based on the water balance of Lake Skadar, it can be calculated that water in the lake changed three to four times a year [7].

The chemical composition of lake water is often not uniform in depth, which depends on seasonal variations and external temperature factors. Deep layers contain a greater amount of dissolved substances and increased concentrations of cation and anion. This situation continues until the input of solar energy diminishes (usually in autumn) and there is sufficient mixing of the water (by wind) to mix the upper and lower layers together. Many investigations showed a uniform distribution of chemical parameters from the surface to the bottom owing to the shallowness of Skadar Lake and frequent mixing events [8].

Aquatic ecosystems are also receivers of numerous substances that are in various chemical and physical forms in the air as a consequence of increasingly intense air pollution [3]. Natural waters, especially freshwater systems, are not only contaminated at different times but also condemned to fairly long-term pollution caused by substances deposited in the sediments since the time of early human activities [9].

The achieved level of precision and accuracy of instrumental analytical methods today, and the training and experience of the analysts, keeps errors in the determination of the content of chemical parameters to a minimum [10]. The greatest source of inaccuracies might be the sampling of the materials themselves; hence, it is especially important to ensure that the sampled material is truly representative. The preparation of the samples for analysis must be consistent with the accepted standards in order that the results are comparable with those from other geographic areas.

Research on the water and sediment chemistry of Lake Skadar began in the 1960s [4] with the goal of understanding the chemical nature of the lake and the major natural conditions that affect water quality. In addition, it was also important to determine the concentrations of the chemical substances that were present in order to understand their dynamics in the lake's ecosystem.

These water and sediment analyses of the lake showed a difference between the physical and chemical conditions in the pelagic area and the littoral one, especially where aquatic macrophytes grow. These differences are the result of the influence of allochthonous matter, the chemical changes to surface water-sediments, and the biological production of the lake [4].

Lake Skadar consists of many different smaller ecosystems. In accordance with the classification system under the Habitats Directive on Lake Skadar, ten different major types of wetland habitats have been identified [11]. Primarily for this reason, there is sometimes a discrepancy between the results of individual monitoring in relation to conclusions regarding the pollution trends of Lake Skadar. Most of the available monitoring results do not have identical sampling locations. The collected data on the chemical composition of the water and the sediment of Lake Skadar depend on the selection of the location and sampling point and on the year, season, time of day, climatic conditions, depth of the water column or sediment, and many other factors. Nevertheless, even though these limitations apply, from the collected data, some general trends in the quality of the water and sediment of Lake Skadar have been identified over recent decades.

2 The Chemical Composition of the Water and Sediment of Lake Skadar

2.1 The Water

The quality of water in lakes is a very complex and varied category for several reasons. The lake's response to external and internal changes is long-term, meaning a year represents the minimum time required to test the water quality in lakes.

Knowing the quality of the water in lakes is necessary in order to define the ecological status of the given ecosystem, but it is also important from the standpoint of the use of the water (for fish farming, swimming, irrigation, and so on). Finally, there is the question of legislation regarding water quality in lakes. In Montenegro, according to the valid regulations, the quality of water in accumulations is defined by the Decree on the Classification and Categorization of Waters, "Official Gazette of Montenegro" No. 2/07 [12]. According to this regulation, the waters of Lake Skadar are classified in classes A2, C, and K2 (II category) which means that drinking water from this source can be used after proper conditioning (coagulation, filtration, and disinfection), that they are waters that can be used for the cultivation of less valuable fish species (cyprinids), and that they show a satisfactory bathing quality.

Tables 1 and 2 gives the collected available parameters of the chemical quality of the water of Lake Skadar over several recent decades.

The water *temperature* of Lake Skadar varies throughout the year and depends on the sampling period. Usually the water temperature is 2–4°C lower than the air temperature. According to the available data from 2016 [15], the surface water temperature ranged from 7.2°C in December (Kamenik) to 27.2°C in August (Podhum). The difference in water temperature between the surface and the bottom of the water column is approximately 1.5°C.

Transparency decreases over the year up to the summer, when it is minimal. It then increases until the end of the year. In the winter, the density of phytoplankton is low, and the volume of traffic is significantly lower, which affects the increased transparency. The opposite effect is provided by the increased inflow of water and sediment from the tributaries of the lake during the autumn and winter. In recent years, the greatest transparency was 5–5.5 m in the middle of the lake [15]. At other locations it is 1–4 m depending on the time of year. Most often, the transparency is least at the tourist sites of the lake: Virpazar, Plavnica, and Vranjina.

The color gives an indication of the relative amount of dissolved organic matter in the water. The color of the Skadar Lake water varies from 5 to 10 Pt-Co (platinum-cobalt standard or Pt-Co units). At some locations, like Virpazar and Vranjina, the color values between 0 and 20 Pt-Co are considered clear [13].

The *turbidity* in the measurements during 2013–2014 was below the detection limit (<0.20 NTU) at the six tested sites except for one measured from Kamenik in October (at the bottom of the lake) when it was 2.68 NTU [8]. Even so, this result is also in the A1 class of water quality.

According to the content of *suspended matter*, the waters of Lake Skadar belong to the A1 class, and have not changed since the beginning of the measurement of this parameter in the 1970s. It is interesting that the content of suspended matter has, in fact, been least over the last decade. The relatively low content of suspended matter and low turbidity are to be expected since it is a flatland lake that does not receive inflow from mountain torrents that transmit sand, gravel, and large pebbles.

Based on the results presented in Table 1, it can be concluded that the lake's waters are mildly to moderately alkaline. Local differences in *pH* values are conditioned by the input quantities of groundwater and phytoplankton productivity. A slightly higher pH value is recorded in June, the time of the highest organic

Table 1 Minimum and maximum values and mean values ± standard deviation of individual parameters in the water of Lake Skadar

Parameters	Year, references, number of locations in parentheses						
	1972–1973 [5] (13)	1974–1976 [6] (19)	1990–1995 [13] (7)	1998–2001 [13] (7)	2008 [14] (5)	2013–2014 [8] (6)	2008 and 2010–2016 [15] (9)
Color Pt mg/L		5–9 5.44 ± 0.96	5 5 ± 0	2–20 9 ± 6	<5		
Turbidity NTU			0.6–2.0 1.5 ± 0.4	0.7–10.4 3.8 ± 3.7	<0.2	0–2.68 0.15 ± 0.37	
Turbidity as Si mg/dm^3	0.16–0.58	2.34–18.7 6.75 ± 4.79	2.34–7.01 4.67 ± 1.36	1.40–21.0 7.48 ± 7.48			1.00–3.38[a] 1.83 ± 0.72
Suspend. mat. mg/dm^3		1–11 3.2 ± 3.0	1.0–2.6 1.5 ± 0.5	0.5–3.6 1.5 ± 1.2		0.05–45.6 2.28 ± 6.88	0–4 0.61 ± 0.93
pH	7.2–8.5	7.10–8.15 7.89 ± 0.29	8.07–8.24 8.17 ± 0.07	7.84–8.42 8.20 ± 0.21	7.65–8.22 7.99 ± 0.24	7.64–8.47 8.07 ± 0.20	8.0–8.6 8.24 ± 0.13
Conductivity µS/cm 20°C		190–322 256 ± 39.5	200–235 212 ± 13.5	154–242 184 ± 32	209–320 276 ± 46	195–273 233 ± 22	148–321 229 ± 36
Dissolved O_2 mg/dm^3	5–12	9.20–11.3 10.5 ± 0.60	9.5–12.2 10.4 ± 1.0	8.8–11.5 9.8 ± 0.9	5.2–10.0 8.6 ± 2.1	7.90–13.1 10.6 ± 1.3	5.2–11 8.8 ± 1.0
BOD-O_2 mg/dm^3		1.1–4.5 2.4 ± 0.9	1.02–3.84 1.95 ± 1.05	1.00–2.58 1.68 ± 0.68		0.70–4.49 2.10 ± 0.83	0.7–5.4 2.37 ± 0.96
COD_{KMnO4} mg/dm^3		0.5–4.2 2.1 ± 1.2					0.9–4.1 2.5 ± 0.6
Diss. org. $mat._{KMnO4}$ mg/dm^3	12–45	2.2–16.9 6.43 ± 3.56			3.96–4.96 4.54 ± 0.37		
Ca^{2+} mg/dm^3	31–42	27.2–52.8 42.4 ± 6.4	28.8–38.4 32.7 ± 3.18	48.5–54.4 51.2 ± 1.88			24.6–62.9 41.3 ± 8.32
Mg^{2+} mg/dm^3	5–17	1.4–21.6 12.4 ± 4.5	10.6–18.3 14.0 ± 2.66	5.58–12.5 6.99 ± 2.45			5.10–15.3 7.16 ± 1.67

(continued)

Table 1 (continued)

Parameters	Year, references, number of locations in parentheses						
	1972–1973 [5] (13)	1974–1976 [6] (19)	1990–1995 [13] (7)	1998–2001 [13] (7)	2008 [14] (5)	2013–2014 [8] (6)	2008 and 2010–2016 [15] (9)
Hardness dH°		6.28–10.5 8.54 ± 1.15	7.39–8.74 7.84 ± 0.45	8.1–10.5 8.8 ± 0.8			5.2–10 7.2 ± 1.2
Na^+ mg/dm^3		0.7–4.5 2.03 ± 1.04	2.10–3.60 2.64 ± 0.49	1.8–3.0 2.4 ± 0.4	4.1–5.3 4.8 ± 0.5		1.8–12.8 3.25 ± 1.57
K^+ mg/dm^3		0.14–1.46 0.44 ± 0.32	0.50–0.80 0.60 ± 0.13	0.15–0.61 0.40 ± 0.15			0–1.7 0.6 ± 0.3
Fe^{2+} mg/dm^3		0–0.08 0.013 ± 0.021	0.002–0.045 0.028 ± 0.013	0.08–0.15 0.11 ± 0.02	0.02–0.05 0.04 ± 0.01		0–0.42 0.06 ± 0.05
HCO_3^- mg/dm^3	87–254 157 ± 33	104–250 166 ± 34	183–207 191 ± 9	171–183 181 ± 7			129–226 174 ± 25
Cl^- mg/dm^3	1.5–3.6	6.0–9.8 7.8 ± 1.1	5.0–8.5 6.6 ± 1.3	7.4–10.8 8.5 ± 1.1	4.0–6.5 4.9 ± 1.0	1.6–5.8 3.3 ± 0.8	2.4–12 5.2 ± 2.1
SO_4^{2-} mg/dm^3	4–30	3.2–23.0 12.5 ± 3.9	5.8–10.2 7.9 ± 1.9	7.78–13.9 11.5 ± 2.1		0.9–7.5 4.8 ± 1.1	1.0–20.3 6.1 ± 2.8
F^- Mg/dm^3		0.06–0.25 0.11 ± 0.04	0.015–0.025 0.017 ± 0.004	0.06–0.20 0.11 ± 0.05	0.04–0.12 0.07 ± 0.03	0.04–1.94 0.50 ± 0.75	
NO_3^- mg/dm^3	0–1.20 0.26 ± 0.25	1.00–9.00 2.74 ± 2.46	0.45 0.45 ± 0	0.002–7.61 1.40 ± 2.75	1.0–2.0 1.4 ± 0.4	0.004–3.37 0.96 ± 0.91	0–2.93 0.84 ± 0.72
NO_2^- μgN/dm^3	12–30	0–26 4 ± 8	0	0–20 10 ± 10	2–6 3 ± 2	3–30 10 ± 6	0–30 5 ± 5
NH_4^+ μg/dm^3	0–310 30 ± 40	0	0	19–72 44 ± 17	<50	10–260 60 ± 50	10–190 80 ± 40
PO_4^{3-} μg/dm^3	0–122 15 ± 18		0–80 30 ± 40	20–85 49 ± 24		<DL-132 37 ± 24	0–440 62 ± 58

Total P as µgP/dm^3	4–350 64 ± 94					3–56 20 ± 9	
TOC mg/dm^3			0.05–2.32 0.68 ± 0.78	0.05–2.53 0.87 ± 0.73		1.05–2.64 1.66 ± 0.45	2.45–4.24[a] 2.98 ± 0.45
Phenols µg/dm^3		0–3 0.56 ± 0.92	0–1 0.24 ± 0.38	0–17 3.6 ± 4.3			0–7 2 ± 2
Detergents µg/dm^3			0–23 6.6 ± 8.7	0–75 36 ± 33			0–69 23 ± 16
Mineral oils µg/dm^3			0–635 372 ± 214	0–263 64 ± 99			
Oils and grease mg/dm^3			0.6–8.2 2.7 ± 2.5	0.07–8.9 2.0 ± 2.6			
PAHs mg/dm^3			0.000	0.000			
PCB_S and cong. µg/dm^3			0–9 2 ± 2	0			
Trihalomethanes mg/dm^3			2.05–9.65 7.03 ± 3.00	0–12.7 3.29 ± 4.55			

[a]Only 2015 and 2016

Table 2 The minimum and maximum metal concentrations in the water (μg/dm^3) and the mean concentration ± standard deviation

Metals	Year, references, number of locations in parentheses					
	1974–1977 [6] (19)	1990–1995 [13] (7)	1998–2001 [13] (7)	2005 [13] 6(8)	2008 [14] (5)	2011 [10] (6)
Cu	2–20	0–2 0.09 ± 0.5	2–10 6 ± 3	<10	2–4 3 ± 1	1–14 7 ± 4
B		3–30 12 ± 10	3–30 12 ± 10	<50		
Zn	1–88	1–3 2 ± 1	0–10 6 ± 4	<50	4–10 6 ± 2	2–8 5 ± 2
Co	0.1–0.5				<3	<1
Cr	0–1	0.5–9 5 ± 2	2–8 4 ± 2	<50	<2	<2
Mn	1–55	1–10 5 ± 4	8–21 12 ± 4	<10	4–60 23 ± 23	5–14 10 ± 3
Ni	0–1	1–6 3 ± 2	2–7 5 ± 2	<10 (<50)	10–13 12 ± 1	<1
Cd		0–1 0.7 ± 0.4	0–2 1 ± 1	<1	<1	<1
Pb	1–10	7–12 9 ± 2	1–11 4 ± 3	<1	<5	<5
As	0	<10	<10			
Hg	0	<1	<50	<1 (<2)		
V						2–7 4 ± 2
Sr						19–52 35 ± 10

production, and in October, at the end of the vegetative period of the plants [2, 8]. There are slightly lower pH values during the winter months. A slight change in the pH value with the depth of water is also noticed, but some regularity was not noticeable [8]. According to the Decree on the Classification of Water, the waters of Lake Skadar belong to the A and A1 classes according to the parameter provided there.

Electroconductivity is directly related to the content of soluble matter in the water. The content of basic ions in freshwater forms 90–95% of the total salt content [3]. Lake Skadar water is weakly mineralized, and its electrolytic conductivity rarely exceeds 300 μScm^{-1} (Table 1), which according to this criterion is classified in the A class of waters. Greater conductivity, i.e., greater content of mineral salts, is found in the littoral zone relative to the pelagic zone. In the littoral zone, greater water conduction is seen in the areas of intensive tourism when compared to rarely visited places or underwater sources. Soluble mineral substances are mainly present in the water due to remobilization from the sediment. Conductivity tests show that there is generally no difference in relation to the sampling depth, which shows us the relatively good mixing of the lake water and its uniform mineralogical composition [10].

In natural waters, the ions Ca^{2+} and Mg^{2+} are constantly present, which cause general water hardness. Their basic amount in the water is due to the dissolution of minerals that are present in the sediment of Lake Skadar (limestone, dolomite, gypsum, and polyalumosilicate). The water hardness and the content of Ca^{2+} did not change significantly over several decades of tests, while the content of Mg^{2+} significantly decreased from 1995. Based on the hardness, the water of Lake Skadar belongs to the category of soft waters.

The ions Na^+ and K^+ are found in almost all natural waters. The content of potassium in natural waters is usually not large, since it is taken from the water by plant and animal organisms as a biologically active element [13]. The content of the ions N^+ and K^+ in the water of Lake Skadar has remained almost unchanged over a long period of investigation.

Divalent iron (Fe^{2+}) comes into the lake from groundwater by the dissolving of minerals containing iron under the action of acids (carbonic, humic, and others). In surface waters, the concentration of trivalent iron compounds is irrelevant, because under the pH conditions in the lake (pH 6–8), there is complete salt hydrolysis [3]. In the Lake Skadar waters, there are a small amount of Fe^{2+} ions, and by mean values of the content, it belongs to the A and A1 class of water.

Hydrogencarbonate ions (HCO_3^-) often predominate in freshwater relative to other anions. Their presence in the lake waters relates to the dissolution of carbonate minerals under the action of carbon(IV)-oxide [3]. For the Lake Skadar water, the content of the hydrogencarbonate ions is characterized by their general alkalinity. Thanks to a long testing period, it can be concluded that the content did not change significantly, even over the last 20 years, although a slight decrease can be noticed.

The concentration of *chloride* (Cl^-) in the waters of Lake Skadar is relatively low (Table 1). Over decades of investigation, the content of chlorides did not change significantly in the lake, and some regularity cannot be noticed. The chlorides in natural waters appear from the dissolution of chloride-containing minerals. Chlorides are permanent components of the water of municipal waste and some industrial wastewater. Increased concentrations of chloride in the water may be an indirect indicator of water pollution from wastewater [3].

The content of *sulfates* (SO_4^{2-}) in the waters of Lake Skadar is relatively low (Table 1). The maximum value over the last 10 years has not exceeded 20.3 mg/dm^3, while the mean value is 6.1 mg/dm^3. Compared to earlier research [5, 6, 13], the content of sulfates is even decreasing. The small content of sulfate is conditioned only by geological factors [5, 6]. There is no consequence for the content of sulfates due to rinsing from agricultural areas and from wastewater or atmospheric precipitation due to air pollution by industrial emissions.

The concentration of *fluoride* (F^-) in the water depends on the geological characteristics of the region through which the water flows and where it is located [16]. Human activity can affect the level of fluoride in the environment. In particular, the proximity of factories for the production of aluminum can increase the amount of fluoride in the lake by several multiples, due to the use of cryolite (Na_3AlF_6) in its production. The mean value of all the results of fluoride in the water of Lake Skadar taken so far is a low value and places the water in class A using this parameter.

However, research results from six locations in October 2013 [8] exceeded the limit value for the A3 class of water. It is interesting that the same research [8] in the same locations in February 2014 shows a negligible amount of F^-.

The content of *oxygen* in water is one of the most important parameters for assessing the long-term quality of lake water. The content of O_2 is the result of processes that are introduced (from the atmosphere and from biogenic production) and its removal in the natural decomposition of organic substances in water by microorganisms and the respiration of animals and plants [17]. The amount of dissolved oxygen in the water of the lake changes depending on both daily and seasonal fluctuations. In the summer period, the dissolved oxygen content declines to a concentration of 5–8 mg/dm^3 due to the higher temperatures and the increased respiration rates of aquatic organisms. In the winter, the dissolved oxygen content increases to 11–13 mg/dm^3. The lowest values were recorded from the middle of the lake [5, 6, 8, 13–15]. With the depth of the water column, the content of the oxygen slightly changes without any obvious regularity.

The mean values of *biological oxygen consumption* (*BOD_5*) of the previous monitoring of the waters of Lake Skadar are relatively low for the surface water, which indicates a low level of loading of organic matter [6, 8, 13, 15]. Lower values of BOD_5 are recorded at places far from the shore and in the middle of the lake (classes A and A1). The highest values of BOD_5 are observed in the tourist parts of the lake (classes A2 and A3). With the sampling depth, the value of BOD_5 decreases. The highest values of BOD_5 occur in the autumn months, while for the rest of the year, there is no clear trend of change.

The relatively low values of *chemical oxygen demand* (*COD*) and *oxidability* are the result of the still acceptable amount of organic matter in the waters of Lake Skadar. The lowest values are recorded in the pelagic zone (middle of the lake) [8]. The concentration of organic matter expressed through COD and oxidability in other parts of the lake are relatively uniform and acceptable for surface waters. In relation to the time of year, greater values are recorded in the summer and the autumn. Research is carried out in the period 2010–2016. Analyses done by the Institute of Hydrometeorology and Seismology of Montenegro [15] did not show an increase in COD values relative to the period 1974–1976.

Inorganic nitrogen compounds (NH_4^+, NO_2^-, NO_3^-) in the waters of Lake Skadar can be formed due to decomposing organic compounds containing nitrogen or due to atmospheric rainfall that washes fertilizers from the soil (ammonium, nitrogen, and nitrates). The content and the significant representation of different nitrogen compounds depend on the conditions of arrival of the nitrogenous compounds in the water or water regime. At a time of increased water supply, an increase in the concentration of organic nitrogen compounds has been observed due to the release of organic residues from the surface of the soil [13]. In the summer, soluble nitrogen compounds are used by water organisms, so their content in the water is then the least and is often below the limit of instrument detection.

Larger amounts of *nitrate* (NO_3^-) are recorded in the winter and the spring when the land impact was high [8]. In all previous studies (Table 1), the content of nitrates shows no correspondence with the location, season, or depth of sampling below

10 mg/dm^3 NO_3^- which, according to this parameter, classifies the waters of Skadar Lake into class A.

Nitrites (NO_2^-) are intermediates in the oxidation of ammoniacal nitrogen into nitrate nitrogen. In the waters of Lake Skadar, spatial, temporal, and depth variations in the content of nitrite can be observed. They are the result of rinsing from the surrounding agricultural holdings and of microbiological activities. The minimum values are observed in remote areas of the shore and in the middle of the lake in the summer. The greatest values are recorded in the autumn in near-shore areas, especially close to those areas visited by tourists [8].

The values of *ammoniacal nitrogen* during July are extremely high at all sites, which is directly related to the high temperatures, the lowest water level in the lake, and the significant microbial activity. In addition, the inflow of ammoniacal nitrogen from diffuse sources of pollution (leachate wastewater, the discharge of fertilizers from surrounding fields, and so on) is not negligible [13]. The trend in the change in NH_4^+ concentration is uneven from year to year. Otherwise, most of the previous analyses of this parameter classify the waters of Lake Skadar in class A2 [5, 6, 8, 12–15]. Sites near the shore have almost double the content (about 1 mg/dm^3 NH_4^+ ions) compared to places far from the shore. Ammonium ion content generally increases in the summer in the surface layers of water. The lowest values occur in the autumn [5, 6, 8, 13–15]. If municipal and wastewaters, as sources of ammonia, are discharged outside of the lake, they are largely decomposed before they reach the lake waters.

Eutrophication is one of the main problems of the pollution of the lake with significant economic and ecological consequences [18]. The main causes of eutrophication are the infliction of suspended deposits and the introduction of nutrients, particularly phosphorus, which lead to the disturbance of the equilibrium of the oxygen regime. The concentration of *phosphate* (PO_4^{3-}) in the waters of the lake originates externally, from outer entry, and internally from sediment remobilization [18]. Phosphates can be introduced into the lake by leaching fertilizers from farms and grasslands and from inoperative sewage systems.

The average value of phosphate (PO_4^{3-}) in the period 2010–2016 was more than four times higher than its concentration in the 1980s [5] and more than double its value for the period 1990–1995 [13]. However, the measurements from 2013 to 2014 [8] show slightly less than half the values of the HMZCG measurements for the period 2010–2016 [15].

The same measurements from the period 2013–2014 show more than three times less *total phosphorus* (*TP*) values compared to the 1980s (Table 1). The OECD [19] defined a value of 30 μg/dm^3 TP as the eutrophication limit. Considering the latest available data for TP [8], this limit was only exceeded in one measure out of eight from Kamenik (49 μg/dm^3) and one at Plavnica (56 μg/dm^3). At other measuring points, the content of total phosphorus was in the range 1–30 μg/dm^3. As with most freshwater lakes, and also in Lake Skadar, the amount of phosphorus is less than that of nitrogen, so phosphorus is a limiting nutrient for plant growth (phytoplankton) [2].

The *total organic carbon content (TOC)* is a measure of the contamination with organic matter and the degree of biodegradation of organic matter present in water. The organic matrix of natural waters consists of natural organic compounds and possible elements from anthropogenic pollutants. They are not contaminants in the classical sense, but they consume a large amount of oxidants and bind to hydrophobic pollutants and heavy metals, increasing their solubility, buffering low-alkaline waters, and affecting biological activity.

During 2013–2014, TOC was beyond class A2 only at Plavnica. This parameter was beyond class A2 at Kamenik, Starcevo, and the middle of the lake only in the autumn and at Virpazar in the spring [8]. During 2015–2016, TOC was beyond class A3 at all sampling locations. The greatest values of TOC occur in the shallow part of the lake due to the occurrence of plankton and warmer water (in the summer). The lowest values were recorded at Virpazar and the largest in the area of Ckla and Kamenik.

The highest content of *phenols* was recorded in the period 1998–2001 (Table 1). Over the last few years, the phenol content has been slightly increased. In the period 2010–2012, according to the average annual value of the phenol, the waters of Skadar Lake were classified in class A1. In the period from 2013 to 2016, the water according to the content of phenols was in class A2. In terms of locations, somewhat greater average values were recorded in the areas of Virpazar and Kamenik (2.0 μg/dm^3) and the least in the area of Ckla (with a mean value of 0.9 μg/dm^3).

According to the content of *detergents*, the waters of Lake Skadar have, over the past few years, gone beyond the limits of class A2. The greatest detergent content was recorded at locations under the influence of incoming rivers – the Morača, the Crnojevića, and the Virpazarska (at the locations of Vranjina, Virpazar, and Kamenik) [15]. The least content of detergents in the water of the lake was in the area of Podhum, Ckla, and Starcevo, which are in class A2 in terms of quality according to this parameter [15].

Mineral oils enter natural waters through wastewater. They slowly decompose in water and can accumulate in aquatic organisms for which they are toxic. The measurements performed in 1990–1995 show an almost worrying content of mineral oils (Table 1). However, between 1998 and 2001, the content decreased almost six times [13]. One of the reasons is probably the repair of the aluminum factory that was carried out in that period. The measurements carried out during 2005 did not show the presence of mineral oils in the waters of Lake Skadar except in one place despite testing at six test locations [13].

The appearance of *polychlorinated biphenyls* (*PCBs*) and/or *polyaromatic hydrocarbons* (*PAHs*) is a suitable indicator of the possible industrial contamination of surface waters [20]. In the period 1995–2000, their presence in the waters of Lake Skadar was not recorded. The available data for 2005 [13] show that PCBs and PAHs were less than 0.1 μg/dm^3 and 0.01 μg/dm^3, respectively. The maximum permissible limit in accordance with Regulation 2/07 [12] on the Quality of Water for class A1 is 0.2 μg/dm^3.

The contents of cyanide (CN^-), hydrogen sulfide (H_2S), and pesticides and herbicides were examined in the period 1990–1995 and again between 1998 and 2001 [13]. During these periods, the presence of these substances in the waters of Lake Skadar was not detected.

2.1.1 Heavy Metals in the Waters of Lake Skadar

The values of concentration of heavy metals in Lake Skadar waters based on the available literature are given in Table 2.

In the Lake Skadar waters, there are low concentrations of heavy metals (Table 2). The levels in the sediments and organisms are significantly greater, due to their increase in natural processes. Even in relatively intact areas, the metal content can vary between different water systems, as a consequence of the variation in sediment characteristics and the concentration of organic matter [10].

Although the presented results are hardly comparable due to the different times, locations, and sampling sites, it is noticeable that over the decades there has been no significant increase in the content of heavy metals and some even show a slight decrease in concentration.

The release of pollutants into the aquatic environment leads to the distribution of certain metals over wider areas. For this reason, the average level of a metal can temporarily be increased in lakes. Temporarily increasing concentrations of metals in water is generally harmful to plants and animals. The risk of temporary biological disorders can best be assessed by analyzing the concentration of metal in water. The risk of damage is greater if it is a long-term exposure, even at lower concentrations. Harmful effects in plants due to instant exposure to metals are observed if concentrations are three to ten times greater than concentrations that are usually toxic over a longer period of time [10].

Based on the results of the metal content in the water, it can be concluded that the tributaries of the lakes, or polluters located on their banks, have a slight influence on the quality of the waters of Lake Skadar [10].

The water of Lake Skadar, based on the content of metals, corresponds to the requirements of water quality class A1 of the Regulation on Classification and Categorization of Waters ("Official Gazette of Montenegro" No. 2/07) [12], while the value of Mn content corresponds to class A2. The identified metal concentrations in the water do not represent a risk or represent only a very low risk to the plants in the Lake Skadar ecosystem. The concentration of heavy metals is lower than the limits established by the EU Directive (75/440/EEC) [21] on the Required Quality of Surface Water Intended for Human Consumption.

2.2 *The Sediments*

As awareness grows of the significance of the sediments for the Lake Skadar ecosystem, more research is being done on its quantitative composition, the determination of its chemical components, and its interaction with the water and the biota [10].

Analysis of sediment quality is important for several reasons: the quality of the sediments shows the current state of the aquatic system and can be used to detect the presence of contaminants that are not soluble after their release into the surface waters [22, 23]; in evaluating the pollution of water environments, it provides a precise picture of pollution over a long period of time [24], so that the time trends of pollution can be analyzed on the basis of the profile depth [25]; and it is useful to estimate the level of the contamination of aquatic ecosystems not only because of its ability to accumulate chemicals but also because of the possibility of releasing pollutants into the water as a secondary source of pollution [26, 27].

Some physical and chemical characteristics of the sediment of Lake Skadar are given in Table 3 during the four different seasons in 2011 from six locations around the lake.

The measured physical and chemical characteristics of the sediments did not change depending on the examined season, while for some characteristics of the sediment, there are statistically significant spatial variations [10]. The acidity, both active and potential, and redox potential are in a narrow interval for individual locations. Generally speaking, the pH of the sediment is the result of very complex reactions and the state of the system. It was found that an increase in pH significantly affects the cations Na^+, K^+, Ca^{2+}, and Mg^{2+} [3]. Sediments from the Crni Žar location show neutral reactions and sediments from other locations exhibit alkaline reactions. The exchangeable acidic hydrogen ions (H^+) are formed that are more loosely bound in the adsorptive complex of the sediment, and from there they are pushed into the solution using a salt such as KCl [3]. Potential (exchangeable) acidity has almost the same values in the sediment from Raduš, Plavnica, and River Crnojevića. Somewhat greater values were recorded from the left and right mouths of the Morača River, and the lowest value came from the location of Crni Žar [10]. In the sediments of Lake Skadar, there are oxic-anoxic conditions with a range of potentials which favor the reduction of metal oxide and the release of metal ions into the water, as well as their remobilization, i.e., re-bonding, to form sediment. The conductivity of the sediment is the least from the left mouth of the Morača River, which is a consequence of the greater precipitation of carbonates at that location [10]. The mobilization and transport of certain cations in the sediment depend on the Eh-pH conditions, i.e., from the solubility or insolubility of the solid phase that occurs from certain cations. The greatest conductivity was recorded at the location of Plavnica [10], due to water runoff from the agricultural areas of Zeta, which dissolves salts.

Table 3 Some physical and chemical characteristics of the sediments of Lake Skadar [10]

pH (in the water)	Exchangeable pH	EMS mV (in the water)	EMS mV (in 1KCl)	Conductivity μS/cm	Organic matter (%)	Carbonates (%)
6.72–8.12 7.55 ± 0.34	5.92–7.38 6.93 ± 0.32	−55.8–24.1 −27.2 ± 18.4	−18.8–54.2 3.28 ± 16.1	251–898 597 ± 169	2.02–24.8 11.0 ± 7.1	3.83–41.5 29.8 ± 12.3

Minimum and maximum values and mean value ± standard deviation

The content of organic matter was significantly greater in the sediments of Crni Žar due to conspicuous primary production, while the lowest content of organic matter was recorded in the sediments from the left and right estuaries of the River Morača.

Although in the sediments there is often only a small amount of organic matter, it plays a very important role in the quality and properties of the sediment in the lake [3]. The sedimentary organic substance comes from living organic substances and their metabolic products. From the release of organic molecules into the environment until their incorporation into the sediment, numerous physical, chemical, and biological processes take place that affect the structure, quantity, and spatial distribution of organic matter in sediments [28].

According to research by Vemić et al. [29], the content of organic matter ranged between 4.7 and 21.5%, similar to the data in Table 3. They also found the lowest value in the sediment from the mouth of the River Morača and considerably greater values in areas with well-developed vegetation. Additionally, Vujačić [14] found similar values for the organic matter in the sediment of the lake, from 4.49 to 15.35% (with a mean value of 10.23%).

The recorded quantities of total organic matter in the period 1972–1973 were from 6.8 to 9.2% in the pelagic zone, while near the mouth of the River Crnojevića, the values ranged from 16.1 to 41.2% [5]. Therefore, in relation to previous research [5, 14, 28] on the sediment of Lake Skadar, the content of organic substance is in the same range or lower. Although the presented results are hardly comparable due to the different times, locations, and sampling sites, it is noticeable that over the decades there has been no significant increase in the content of organic matter and some sites have even shown a slight decrease in concentration.

For the period 1972–1973, Petrović [5] reports that the content of total inorganic matter in the pelagic sediments amounts to 90.8–93.2%, while in the vicinity of the mouth of the Crnojevića River, the amount ranges from 58.8 to 90.2%. The carbonate content is very similar to that of the Ca^{2+} ion, an average of about 6.6% for CO_3^{2-} (ranging 4.1–13.7%) in the littoral (Rudina, Poseljani, Grab) and, at other tested sites, an average of 19.5% CO_3^{2-} (ranging 18.4–20.6%).

Surface waters, above the sediment covered by vegetation, considerably dissolve carbonates, compared to places which are deficient in vegetation. Mostly due to this reason, for the most part, the lowest carbonate content was recorded in the sediments of Crni Žar (a mean value of 4.46%) [10], while the mean values for other locations ranged from 29.4 to 39.3% carbonates. An increase in the deposition of carbonate in the lake sediments occurs due to the erosion of the surrounding rock and the arrival of underground water saturated with CO_2 [3].

X-ray diffraction analysis has determined the mineralogical composition of the investigated sediments. They consist of α-quartz, SiO_2, calcite, $CaCO_3$, kaoline 1T, $Al_2Si_2O_5(OH)_4$, corundum, α-Al_2O_3, dolomite, $CaMg(CO_3)_2$, wustite (FeO) 8F, and manganosite (MnO) 8F [10].

Data on the quality of the sediments in Lake Skadar and regarding the PAH and PCB content are limited. There are only fragmentary data on PAH and PCB content in several locations of the lake for the period 1990–2005 [13]. Limited data represent a problem for a more detailed analysis. It can be concluded that both the PCB and the PAH in the sediments are greater at the inlet points of the River Morača than at other locations around the lake: 0.3–0.5 μg/kg PAH and 0.8–100.7 μg/kg PCB for the period 1993–1996 [13]. This indicates that pollutants come from the River Morača. However, the quantities of these pollutants were reduced in 2005: 0.09 μg/kg PAH and less than 0.01 μg/kg PCB [13]. This reduction in PAH and PCB can be viewed as caused by the onflow of the lake. Another plausible reason is the transfer of the pyralene barrel from the aluminum plant to a separate bunker, thus removing the main source of groundwater contamination by these substances [13].

2.2.1 Heavy Metals in the Sediments

The values of the concentration of heavy metals in the sediments of Lake Skadar based on the available literature are given in Table 4.

Because of the lack of relevant national regulations for sediment, the results are compared with Dutch standards and allowed limits [32].

According to Keukelaar et al. [13], mercury at all eight examined locations exceeds the maximum approved values (MAV) according to Dutch limits. At the same time (2005), the concentration of arsenic was far below the MAV.

According to GIZ [8], the content of mercury was 0.2–0.4 times and arsenic 0.02–0.1 times the maximum approved values (MAV) provided by the Dutch limits. Mercury and arsenic were least present at Virpazar. The maximum value of mercury was recorded in the sediment from Kamenik, being about twice that found in other places. In the Podhum area, the greatest amount of arsenic was found, with values about six to seven times greater than at the other examined sites [8]. The value contents of mercury and arsenic were similar at other locations. The authors [8] report that the content of other metals was found in the greatest quantity in the sediments of Podhum and Kamenik. At the former site, this may be a consequence of groundwater influence, but at Kamenik, the influence of the River Crnojevića and the right branch of the River Morača, perhaps with leachate from the Cetinje dump, are more likely to be the sources [8].

The content of the ten studied metals (in parentheses in ppm) in the sediments of Lake Skadar followed this decreasing order: Mn (229) $>$ Ni (77.5) ~ Zn (76.1) $>$ Cr (68.4) $>$ Sr (56.2) $>$ Cu (33.7) $>$ V (28.3) ~ Pb (28.1) $>$ Co (8.98) $>$ Cd (0.40) [31]. The largest shares (in parentheses in %), based on the total amount, were Cd (72.2%), Sr (68.7%), and Mn (67.6%), found in the sediment associated with hydrated and Fe, Mn oxides (the reducible fraction); Co (71.1%), Pb (66.9%), Cu (64.0%), and Ni (54.1%), in the oxidizable (organic) fraction, and the greatest shares of Cr (50.6%), V (46.8%), and Zn (35.4%) were incorporated in the crystal lattice of the minerals (the residual fraction) [31]. The greatest quantities in the exchangeable, easily soluble fraction, are, based on the total content, Sr (17.5%) and Cd (10.4%) and the lowest Cr (0.35%) and Zn (0.31%). The most mobilized and mobilization (potentially mobile) metals, with the lowest content in the residual fraction, are Sr

Table 4 Minimum and maximum concentrations of metals in the sediments (mg/kg) and mean concentration ± standard deviation

Metals	Year, references, and number of locations in parentheses							
	1974–1977 [6] (19)	1993–1996 [13] (7)	2005 [13] (8)	2005 [30] (10)	2005 [2] (5)	2008 [14] (5)	2010 [29] (10)	2011 [31] (6)
Cd		0.92–1.66 1.21 ± 0.24	<0.625	0–15.3 1.46	0.10–1.01 0.29 ± 0.40	0.20–1.58 0.70 ± 0.52	0–0.8 0.4 ± 0.2	0.27–0.66 0.40 ± 0.13
Cu	14–44	0.40–19.4 3.81 ± 6.94	3.7–12.2 9.1 ± 3.7	2.70–37.6 19.5	10.4–27.7 21.7 ± 7.41	21.6–44.9 29.3 ± 9.02	11.1–33.0 21.1 ± 6.2	23.9–54.4 33.7 ± 8.92
Co	8–29		2.0–6.2 4.8 ± 1.9			8.00–24.3 15.0 ± 5.96		5.12–13.2 8.98 ± 2.74
Cr	85–380	4.6–8.6 6.8 ± 1.4	15.0–45.0 27.2 ± 11.5		43.8–86.0 61.5 ± 15.9	27.0–149 92.8 ± 44.4	23.6–91.4 52.9 ± 22.0	35.6–127 68.4 ± 28.3
Mn	244–1,007	120–450 320 ± 118				368–1,765 994 ± 589	199–733 392 ± 147	95.4–424 229 ± 104
Ni	25–168	2.0–7.0 4.8 ± 1.6	20.0–65.0 42.5 ± 24.6		63.5–136 106 ± 29.3	71–209 155 ± 52	28.1–116 69.2 ± 30.4	29.3–137 77.5 ± 39.8
Pb	6–35	12.4–30.0 15.9 ± 6.3	<5.0	0–44.4 12.0	40.2–49.4 45.6 ± 3.84	13.6–35.1 22.9 ± 7.74	0.1–15.9 11.7 ± 4.7	16.6–46.2 28.1 ± 9.88
Zn		1.0–14.6 3.3 ± 5.0	10.2–40.0 19.1 ± 9.1	17.4–4,010 414	48.6–87.2 64.0 ± 14.6	43.0–131 80.6 ± 33.9	1.4–53.3 33.8 ± 14.6	47.6–135 76.2 ± 23.5
V								18.1–49.5 28.3 ± 9.89
Sr	64–170							16.8–113 56.2 ± 29.8
As			2.5–7.0 3.6 ± 2.2					
Hg			0.29–1.77 0.76 ± 0.52					
Al (%)		0.44–8.02 3.13 ± 2.71	0.35–0.52 0.42 ± 0.08			3.78–8.12 4.94 ± 17.9	0.008–1.52 1.03 ± 0.44	
Fe (g/kg)		0.012–5.74 1.07 ± 2.10		19.02		24.2–70.5 52.0 ± 18.9	9.8–20.8 14.1 ± 3.2	

(3.85%), Cd (6.29%), and Co (6.41%), while the most immobilized metals are Cr, V, and Zn [31].

The values of the geo-accumulation index in the sediments for Cu, Co, Cr, Mn, Zn, V, and Sr show that the sediment is not contaminated with these metals. The geo-accumulation index of Cd (for samples from Raduš and Plavnica), Ni (for samples from Plavnica and the left mouth of the Morača), and Pb (for sample from Raduš, Plavnica, and the right mouth of the Morača) shows that the sediment was unpolluted to moderately polluted, while Cd (in samples from Crni Žar) and Pb (in samples from Crni Žar and Rijeka Crnojevića) showed moderate contamination.

The values of the pollution load index (PLI) indicate only the presence of a basic level of contamination of the sediments of Lake Skadar by the ten investigated metals [31]. The results of PLI from the sampling points decrease in the following order: the left mouth of the Morača > the right mouth of the Morača > Plavnica > Rijeka Crnojevića > Crni Žar> Raduš.

Based on the values of the enrichment factor (EF), it can be concluded that the Sr, V, Mn, and Co in the sediments of Lake Skadar come only from lithogenic sources, without any anthropogenic origin. Zinc, nickel, and chromium are under low anthropogenic load, while the cadmium and lead represent a moderate to severe load in the sediments of Lake Skadar [31].

3 Conclusions

Comparisons of recent [8, 14, 15] with older data (covering about 40 years) [5, 6] showed no significant differences in the studied parameters of the water and sediment chemistry of Lake Skadar. This can be explained by the factors such as the large flowability of the lake, the large amount of rainfall, the permeability of the soil, and so on. The relative well-preserved state of the lake ecosystem also is correlated with the significantly reduced extent of industrial production around the lake in the last decades. As a general conclusion, it can be said that the lake ecosystem is still in a good condition. For this reason, precautions can and should be taken to preserve the current state of the lake and to support the sustainable use of this ecosystem.

The concentrations of most chemical parameters in the water and sediments are generally low showing small seasonal and local variations. Lake waters, according to national standards, are classified in the A2, C, and K2 classes (II category). Higher concentrations and deviation from the above categories in recent years are most often shown by the following parameters: temperature, oxygen saturation, ammonia, nitrites, TOC, and detergents. These deviations occur at locations under the influence of inflowing rivers. The potential risks of the content of heavy metals in the water and sediments of Lake Skadar vary in the range from "no risk" to "low risk" to the environment [31].

The existing data clearly indicate that the planned monitoring of the chemical composition of sediment samples taken from those sites under anthropogenic influence, together with the analysis of other indicators of the aquatic environment, enables us to quickly and comprehensively recognize the situation of lakes that are still largely preserved and thus represent extremely important ecosystems, such as Lake Skadar.

References

1. Bartram J, Balance R (2001) Water quality monitoring – a practical guide to the design and implementation of freshwater quality studies and monitoring programmes. Spon Press, London. Published on behalf of UNEP and WHO, Chapter 2
2. Šundić D, Radujković B (2012) Skadar Lake water pollution, "Integrated ecosystem management of Lake Skadar–EMA-plan". NGO Green Home, Podgorica
3. Đarmati Š, Veselinović D, Gržetić I, Marković D (2008) Environment and its protection. Faculty of Applied Ecology, Futura, Belgrade
4. Knežević M (2009) Study of the water regime of the Morača River and Skadar Lake. WWF MedPO and Green Home, Podgorica, p 104
5. Petrović G (1981) Chemical investigations of water and sediments of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research, Titograd, Montenegro, Yugoslavia, pp 68–96
6. Filipović SP (1981) Effects of pollution on Lake Skadar and its most important tributaries. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research, Titograd, Montenegro, Yugoslavia, pp 97–108
7. Radulović V (1997) Contribution to the knowledge of water inflow of Lake Skadar. In: Natural values and protection of Lake Skadar, Podgorica. Montenegrin Acad Sci Arts 44:109–125
8. Đurašković P (2014) Report of physical-chemical and microbiological investigations of Skadar Lake water and sediment quality (Montenegrin side). In: Initial characterisation of lakes Prespa, Ohrid and Shkodra/Skadar (implementing the EU Water Framework Directive in South-Eastern Europe), Volume of Annexes. Deutsche Gesellschaft fur Internationale Zusammenarbeit GmBH (GIZ) and Institute of Hydrometeorology and Seismology (IHMS), Bonn and Podgorica, pp 51–70
9. Burton GA (2002) Sediment quality criteria in use around the world. Limnology 3(2):65–76
10. Kastratović V (2013) Aquatic macrophytes of Skadar Lake as bioaccumulators of heavy metals – role in monitoring water system and the possibility of remediation. Dissertation, Faculty of Natural Sciences and Mathematics, University of Montenegro, Podgorica
11. Green Home (2013) Environmental management action plan, assessment of the threatening factors on biodiversity of the lake, especially aquatic and forest vegetation and draft actions that guarantees their protection – until 2016. Montenegro – Albania, Shkoder, Podgorica. http://www.greenhome.co.me/fajlovi/greenhome/attach_fajlovi/eng/mainpages/2014/01/pdf/Assessment_of_the_threatening_factors_on_biodiversity_of_the_Skadar_Lake.pdf. Accessed 12 Dec 2017
12. Official Gazette of Montenegro (2007) Decree on categorization and classification of surface and ground waters in Montenegro No 2/07
13. Keukelaar F, De Goffau A, Pradhan T et al (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515. Royal Haskoning, Podgorica, p 166
14. Vujačić A (2010) Distribution of metals in water, sediment and cyprinid fish species of Skadar Lake. Master thesis, Faculty of Sciences, University of Novi Sad
15. Institute of Hydrometeorology and Seismology of Montenegro (2017) Annual report 2008 and annual report 2010-2016. http://www.meteo.co.me/misc.php?text=57&sektor=3. Accessed 12 Dec 2017
16. El-Said GF, Draz SEO (2010) Physicochemical and geochemical characteristics of raw marine sediment used in fluoride removal. J Environ Sci Health A 45:1601–1615

17. Kukučkin ĐM, Kukučkin MN (2013) Physico-chemical composition of world natural waters. Faculty of Technology and Metallurgy in Belgrade, University of Belgrade, Belgrade
18. Marković M (2015) A model of the ecological status enhancement of the closed system of water body lake reservoirs. Dissertation, University of Novi Sad, Faculty of Technical Sciences, Novi Sad
19. OECD (1982) Eutrophication of waters. Monitoring, assessment and control. Organization for Economic Co-operation and Development, Paris
20. Sanders G, Hamilton-Taylor J, Jones KC (1996) PCB and PAH dynamics in a small rural lake. Environ Sci Technol 30(10):2958–2966
21. Council Directive 75/440/EEC of 16 June 1979 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States (25 July 1975) Off J Law 194:26
22. Štrbac S (2014) The content and mobility of heavy metals and organic compounds in the ecosystem of the Tisza River. Dissertation, University of Belgrade, Multidisciplinary Studies, Belgrade
23. Chapman PM, Wang F, Janssen C, Persoone G, Allen HE (1998) Ecotoxicology of metals in aquatic sediments: binding and release, bioavailability, risk assessment, and remediation. Can J Fish Aquat Sci 55:2221–2243
24. Villares R, Puente X, Carballeira A (2003) Heavy metals in sandy sediments of the Rías Baixas (Nw Spain) Rubén Villares. Environ Monit Assess 83:129–144
25. Prohić M, Juračić M (1989) Heavy metal sin sediment – problems concerning determination of the anthropogenic influence, study in the Krka River Estuary, Eastern Adriatic Coast, Yugoslavia. Environ Geol Water Sci 13:145–151
26. Forstner U, Heise S (2006) Assessing and managing contaminated sediments: requirements data quality – from molecular to river basin scale. Croat Chem Acta 79:5–14
27. Mariani CF, Pompeo MLM (2008) Potentially bioavailable metals in sediment from a tropical polymictic environment – Rio Grande Reservoir, Brazil. J Soil Sediment 8:284–288
28. Vitorović D, Jovančićević B (2005) Basics of organic geochemistry – for students of the Faculty of Chemistry, University of Belgrade. Faculty of Chemistry, University of Belgrade, Belgrade
29. Vemić M, Rousseau D, Laing GD, Lens PNL (2014) Distribution and fate of metals in the Montenegrin part of Lake Skadar. Int J Sediment Res 29:357–367
30. Duborija A, Strugar V, Duborija N (2006) The research of presence and behaviour of heavy metals in water environment of Skadar lake (Serbia & Montenegro). In: Advances in waste management, 4th WSEAS international conference on waste management, water pollution, air pollution, indoor climate (WWAI'10), Kantaoui, Sousse, 3–6 May 2010, pp 134–138
31. Kastratović V, Jaćimović Ž, Bigović M, Đurović D, Krivokapić S (2016) Environmental status and geochemical assessment sediments of Lake Skadar, Montenegro. Environ Monit Assess 188:449
32. MvV (2000) Circular on target values and intervention values for soil remediation. Dutch target and intervention values, 2000 (the New Dutch List). Annexes. Ministerie van Volkshulsvesting, Ruimtelijke Ordeningen Milieubeheer. http://www.esdat.net/Environmental%20Standards/Dutch/annexS_I2000Dutch%20Environmental%20Standards.pdf. Accessed 8 Apr 2016

Metal Pollution: Evidences from Plants, Aquatic Invertebrates and Fish from Lake Skadar

Vesna Vukašinović-Pešić and Nada Blagojević

Contents

Abstract Over recent decades, Lake Skadar and its basin have experienced varying states of pollution by heavy metals which originate mainly from the industrial waste and sewage waters in the Montenegrin and Albanian part of the lake, respectively. This paper aims to give an overview of our knowledge of heavy metals in macrophytes, aquatic invertebrates (molluscs) and fish from Lake Skadar and their potential as biomonitoring agents for environmental monitoring. Up to now, heavy metals have been investigated in five macrophytes, one mollusc (*Viviparus mamillatus*) and seven fish species from Lake Skadar. The obtained results showed that several macrophytes, snails and fish species can be successfully used to assess heavy metal pollution of Lake Skadar. Moreover, it has been shown that the heavy metal concentrations tend to be non-uniformly distributed among the different organs of macrophytes, snails and fishes from Lake Skadar indicating that different tissues can be used as biomonitoring agents of heavy metal contamination. In order to draw conclusions on the current degree of heavy metal pollution of the Lake Skadar ecosystem, an integrated approach which combines the analysis of heavy metals in the water, sediment and aquatic organisms is urgently required.

Keywords Bioindicator, Contamination, Fish, Heavy metals, Lake Skadar, Macrophytes, Snails, Water

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 141–152, DOI 10.1007/698_2017_232,

© Springer International Publishing AG 2018, Published online: 22 April 2018

1 Introduction

Lake Skadar is the largest lake in the Balkans and represents the hot spot of biodiversity for many biotic groups [1]. Despite the fact that Lake Skadar is protected as a national park in Montenegro, the protection of the lake's ecosystem is still an acute problem, considering that there are several cities (including Podgorica and Shkodra) and many smaller settlements that threaten the lake's ecosystem by their industrial, communal and agricultural activities. Therefore, Lake Skadar has become a recipient for various pollutants that mainly originate from industrial wastes in the Montenegrin part and the sewage of the city of Shkodra in the Albanian part of the lake [2]. The physico-chemical characteristics of the Lake Skadar waters are the result of the inflow of main tributaries, exchange between the sediment and the water, extensive flooding and anthropogenic pollution [3]. Among the pollutants that enter Lake Skadar, heavy metals are particularly important because of their toxicity and their ability to accumulate in aquatic organisms [4]. In order to draw conclusions on the current degree of the contamination of Lake Skadar ecosystem by heavy metals, an integrated approach which combines the analysis of heavy metals in the water, sediment and aquatic organisms is extremely necessary (Fig. 1).

In this paper, we give an overview of the studies of heavy metals in macrophytes, aquatic invertebrates (molluscs) and fish from Lake Skadar.

2 Heavy Metals in Macrophytes

Macrophytes have a significant role in the functioning of the lake ecosystem as an important food source for aquatic herbivores and detritivores. They affect nutrient cycling through the transference of chemical elements from the sediment to the water, having a large impact on the overall chemistry of the lake [3]. The ability of aquatic plants to accumulate heavy metals has often been used for assessing water quality and monitoring the metal contamination of aquatic ecosystems [5].

The data related to the content of heavy metal in macrophytes of Lake Skadar are relatively recent. The first data on the concentration of heavy metals in macrophytes in Lake Skadar were given by Keukelaar et al. [6] but unfortunately without specifying the species, making it unclear which of the macrophytes living in the lake were investigated. More recently, heavy metals in the macrophytes of Lake Skadar were the subject of the PhD dissertations of Vlatko Kastratović in 2013 [7] and Dragana Petrović in 2017 [8], which resulted in a number of papers published thereafter [9–15]. On the Albanian side of Lake Skadar, the content of heavy metals in macrophytes was the subject of a study conducted by Bektesi and Myrtay in 2014 [16]. The list of macrophytes from Lake Skadar in which heavy metals were studied is given in Table 1.

The concentrations of heavy metals significantly vary between the different macrophyte species and among the different organs of the same species.

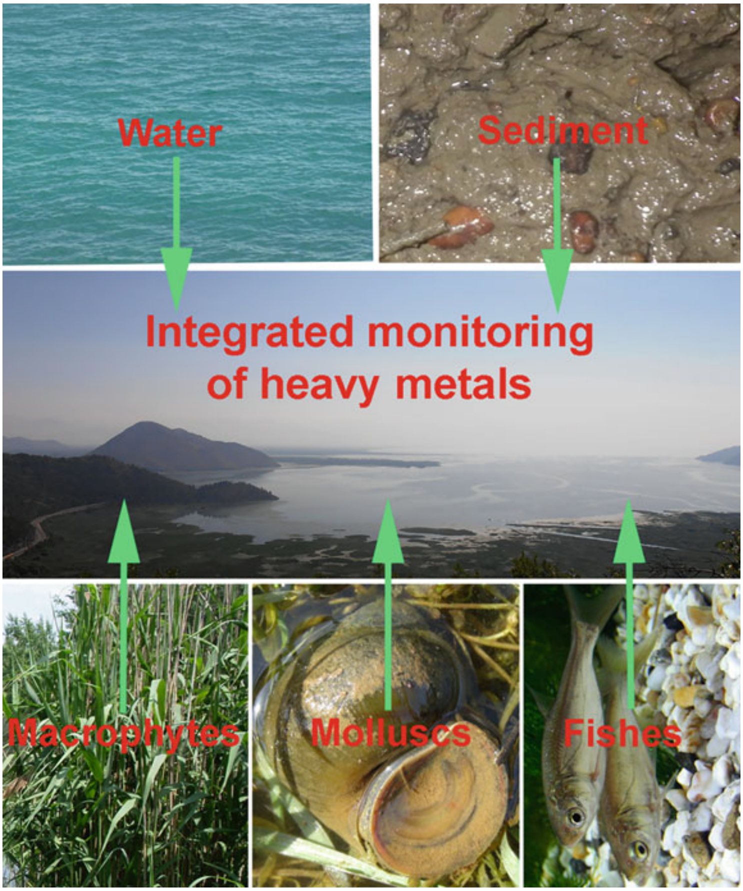

Fig. 1 Integrated monitoring of heavy metals in Lake Skadar

Concentrations of heavy metals in macrophytes are often higher than in the water and sediment, making them potential bioindicators of metal pollution in the aquatic environment [10, 11]. The heavy metal concentration in *Phragmites communis* from Lake Skadar can be ten to several thousand times higher than in the water [9]. Moreover, the concentration of Cd, Cu, Mn, Zn and Sr in *P. communis* was greater than in the sediment [9]. In *Ceratophyllum demersum* and *Lemna minor*, the concentration of heavy metals lies between the concentration in the sediment and water and has the order: sediment > leaf > stem > water for *C. demersum* [10] and sediment > root > leaf > water for *L. minor* [11]. In *Trapa natans*, the concentration of heavy metals follows a similar pattern: sediment > root > stem > leaf > water with the exception of Pb, for which concentration at most of the studied localities were higher in the leaves than in the stems [8].

Many studies have shown that concentrations of heavy metals significantly vary between different organs of the same plant [17]. Kastratović et al. [9] found

Table 1 The list of macrophytes from Lake Skadar in which heavy metals have been studied

Species	Growth form	Studied tissues	Heavy metal	References
Phragmites australis (common reed)	Emergent	Root	Cd, Cu, Co, Cr, Mn, Ni, Pb, Zn, V, Sr	[9, 12]
		Leaf		
		Stem		
Ceratophyllum demersum (hornwort)	Submerged	Leaf	Cd, Cu, Co, Cr, Mn, Ni, Pb, Zn, V, Sr	[10, 12, 16]
		Stem		
Lemna minor (common duckweed)	Free floating	Root	Cd, Cu, Co, Cr, Mn, Ni, Pb, Zn, V, Sr	[11, 12]
		Leaf		
Trapa natans (water chestnut)	Submerged	Root	Cd, Co, Cr, Cu, Fe, Mn, Pb, Zn	[8, 14, 15]
		Leaf		
		Stem		
Vallisneria spiralis (tape grass)	Submerged	Leaf	Pb, Zn, Cu, Ni	[16]

significant differences in the concentration of heavy metals in the roots, stems and leaves of *Phragmites australis* from Lake Skadar. They found the highest concentrations of Zn, Cd, V and Co in the roots, while the highest concentrations of Sr were detected in the leaves [9]. A similar pattern was observed for *Trapa natans* from Lake Skadar with the highest concentration of all the studied metals detected in the roots [8]. Therefore, both *Phragmites australis* and *Trapa natans* could be considered as a root bioaccumulation species with high monitoring potential for national and transboundary programmes for the environmental assessment of water pollution. In submerged macrophytes such as *Ceratophyllum demersum*, the concentrations of all the investigated metals with the exception of Pb and Sr were found to be highest in the leaf [10]. On the other hand, in the floating *Lemna minor*, the average seasonal concentrations of heavy metals, with the exception of Pb in summer, were higher in the roots than in the leaves [11].

Metal uptake by macrophytes and the concentration of heavy metals in different plant tissues depends on the vegetation period and consequently on the sampling time. In *Phragmites australis*, concentrations of Ni, Pb, Mn and Cr during the vegetation period followed the trend, root > stem > leaf, but after the completion of the vegetative season, the concentration of heavy metal in leaves increased above that found in the stems [9]. For *Ceratophyllum demersum*, the highest contents of Cd, Co, Cr, Pb, V and Sr were found at the beginning of the vegetation season, that of Ni and Zn during the season and of Cu and Mn at the end of the season [10].

The distribution of heavy metals between different parts of the macrophytes depends on their mobility [17]. In the study on heavy metal distribution in the emersed *P. australis* from Lake Skadar, all the investigated metals showed the greatest mobility from the stem to the leaves, particularly in the post-growing season [9]. The most mobile metals from the root to the above-ground plant parts were Sr and Cu, while Cr, V and Co showed the least mobility [10]. In *Trapa natans*, the highest mobility was detected for Zn, Cd and Cu and the least for Pb, Fe Cr and

Mn [8]. Among the studied metals, only Cu shows the highest translocation from roots to stems, while other metals show the highest translocation from stems to leaves [8]. In the submerged *Ceratophyllum demersum*, the highest ratio of leaf/stem concentration was recorded for Mn, whereas the lowest ratio was found for Pb [10]. On the other hand, in a free-floating *L. minor*, the highest mobility was observed for Sr and Pb, while the least mobility was detected for Mn, V and Cu [11].

It is well known that plants accumulate certain metals regardless of their concentrations in the water and sediment, being something that depends on the concentration of the available metals in soils, solubility sequences and plant species [4]. The bioaccumulation capacities of *C. demersum* and *L. minor* from Lake Skadar for Mn were several times higher than those for the other metals [10, 11]. A higher concentration of Zn was found in the roots of *Lemna minor* compared to the sediment [11].

The accumulation of heavy metals in plants also depends on the concentration of these elements in their environment: it is known that water plants "prefer" some elements like Mn, Ni, Cu, Mo, V, Sr, Ba, Fe and Al [18]. Furthermore, the difference between the extent of the metals' bioaccumulation capacity among the different plant organs depends on the vegetation period but also on the age of the plants and the presence of pollution sources [19]. Kastratović et al. [9] showed that the bioaccumulation of metals by the roots (BCF_{root}) of *Phragmites communis* from Lake Skadar increased until the end of the vegetation season and then decreased, with the exception of Cd and Pb which slightly increased even after the end of the vegetation period. The accumulation of metals by the roots from the sediment followed the order: Mn > Zn > Cd > Cu > Co > Pb > V > Sr > Cr > Ni [9]. On the other hand, the bioaccumulation of metals by stems (BCF_{stem}) increased from April to August, and decreased in October, whereas accumulation by the leaves (BCF_{leaf}) constantly increased during and after the vegetation period [9]. In *Trapa natans*, the accumulation of metals by the roots from the sediment had the order: Mn > Cd > Zn > Cu > Co > Cr > Fe > Pb [8]. Correlation analysis revealed a significant relationship between the concentrations of Cd in the sediment and the roots of *Trapa natans* [8]. In the free-floating *Lemna minor*, the highest concentrations of heavy metals in the roots and in the leaves were detected at the end of the vegetative season in October [9]. The bioaccumulation ability for the selected metals for *Lemna minor* followed the order: Mn > Zn > Ni > Co > Pb > Cu > Cr > V > Sr > Cd [11].

Some studies have shown that the concentration of heavy metals in various organs of the macrophytes from Lake Skadar varies spatially and might possibly reflect pollution sources. Kastratović et al. [10] studied heavy metal content in the stem and leaves of *Ceratophyllum demersum* from six localities along the Lake Skadar shoreline. They found significantly higher concentrations of Mn, Ni and Zn at Raduš, Plavnica and the mouth of the right arm of the River Morača, of Cd at Rijeka Crnojevića and of Cu and Pb from the mouth of the left and right arms of the River Morača, respectively [10]. Similarly in *Trapa natans*, the highest concentrations of the heavy metals were observed at the lake tributaries and the mouth of the River Morača [8]. The free-floating *Lemna minor* had the highest concentration of the heavy metals at the mouth of River Morača [11]. Generally, we can speculate that the highest concentration of heavy metals at the mouth of the Morača River is mainly due to the industrial waste originating from the Aluminium Plant in Podgorica [2]. It can be concluded that it is of importance to assess the levels of heavy metals in macrophytes as they can reflect current levels of environmental contamination.

3 Heavy Metals in Molluscs

Molluscs (snails and mussels) are often used in monitoring and water quality assessment as bioindicators of heavy metal pollution in freshwater ecosystems [20, 21]. Heavy metals in the molluscs of Lake Skadar have been the subject of only one study. Vukašinović-Pešić et al. [22] analysed the heavy metal content in the different tissues of *Viviparus mamillatus* from Lake Skadar and two rivers, the Matica and the Zeta, which form part of its drainage system. *V. mamillatus* is a relatively common and viviparous species that inhabits lakes and slowly flowing rivers in the Lake Skadar basin [1]. Moreover this is the largest (shell up to 60 mm in height) gastropod species in Lake Skadar making it suitable for use in monitoring programmes related to heavy metal pollution [21]. Vukašinović-Pešić et al. [22] in their study of heavy metals in *V. mamillatus* showed significant differences in the concentrations of all the studied metals (with exception of Pb) between the different tissues of this snail. This study demonstrated that the different tissues of *V. mamillatus* can be used as biomonitoring agents for assessing heavy metals in the aquatic environment: the head with tentacles can be used for Cd, Zn and Fe, the mantle for Cd and Zn and the foot for Fe [22]. The study conducted by Vukašinović-Pešić et al. [22] indicated that metal accumulation might affect the growth performance of *V. mamillatus* as the correlation analysis revealed significant negative correlations between Pb, Cd, Cu and Zn in the different tissues and allometric parameters. The comparative analysis of the heavy metal content in snails and fish from Lake Skadar showed that the concentrations of all the metals (with the exception of Cd in liver of *Cyprinus carpio*) are higher in *Viviparus mamillatus*. It is very likely that this is because *V. mamillatus* is a benthic suspension feeder usually found in a muddy substrate [23].

4 Heavy Metals in Fishes

Fish are an important component in most aquatic ecosystems, and due to their complex habitat requirements, fish fauna represents reliable bioindicators of water pollution. They are widely used to evaluate the contamination of aquatic habitats by heavy metals [24, 25]. Many studies have shown that fish, due to their ecological characteristics (length of life, diet and distribution) and economic significance, can be a suitable parameter in the monitoring of aquatic systems [24–26].

Heavy metals in the fish of Lake Skadar have formed the subject of only a few studies. The first data were given by Filipovic et al. [27, 28] who studied the concentrations of heavy metals in three fish species (the common carp, the bleak and the rudd) from Lake Skadar. After a long pause, the content of heavy metal in the fish of Lake Skadar was studied by Keukelaar et al. [6] as a result of a scientific collaboration conducted within the framework of the project "Lake Shkoder Transboundary Diagnostics Analysis Project, Albania & Montenegro, 2006". They studied the content of heavy metals in five fish species from Lake Skadar: *Cyprinus carpio* (the common carp), *Carassius gibelio* (the Prussian carp), *Perca fluviatilis* (the perch), *Rutilus prespensis* (the yellow roach) and *Anguilla anguilla* (the European eel). Later on, Aleksandar Vujačić [29] in his master's thesis provided valuable data on the content of heavy metals in various organs (liver, gills and adipose tissue) of two fish species (*Cyprinus carpio* and *Alburnus alburnus*) from Lake Skadar. Recently Rakočević et al. [26] studied the concentrations of 11 trace elements in the muscles of six fish species from Lake Skadar: *Scardinius knezevici*, *Alburnus scoranza*, *Cyprinus carpio*, *Rutilus prespensis*, *Anguilla anguilla* and *Perca fluviatilis* (Table 2).

All the above-mentioned studies have shown that the concentrations of heavy metals in fish from Lake Skadar are below the maximum permitted levels allowed for human use according to both national [31] and international FAO/WHO [32] standards for food consumption. Having said that, the standards for heavy metals vary from country to country. In Montenegro, the norms for the allowed amount of heavy metals in fish are defined only for three elements: Hg, Pb and Cd [31]. Therefore, it can be concluded that all the studied fish species can be used for consumption without a health risk. Based on the available data [6, 26–29], it can be concluded that the contents of heavy metals in the studied fish species from Lake Skadar decrease in the following order: Zn > Fe > Al > Mn > Cu > Hg > Cr > Co > Ni > As > Pb > Cd. The concentration of the essential elements Fe and Zn was the highest, while the

Table 2 The list of fish species from Lake Skadar in which heavy metals have been studied

Species	Feeding habits	Heavy metal	References
Cyprinus carpio (common carp)	Omnivorous	Pb, Cd, As, Cr, Ni, Fe, Al, Mn, Zn, Cu, Co, Hg	[6, 26–30]
Carassius gibelio (Prussian carp)	Omnivorous	Pb, Cd, As, Cr, Ni, Fe, Al, Mn	[6]
Perca fluviatilis (perch)	Predator	Pb, Cd, As, Cr, Ni, Fe, Al, Mn, Zn, Cu, Co, Hg	[6, 26]
Rutilus prespensis (yellow roach)	Benthophagous	Pb, Cd, As, Cr, Ni, Fe, Al, Mn, Zn, Cu, Co, Hg	[6, 26]
Anguilla anguilla (European eel)	Predator	Pb, Cd, As, Cr, Ni, Fe, Al, Mn, Zn, Cu, Co, Hg	[6, 26]
Alburnus scoranza (bleak)	Planktivorous	Pb, Cd, As, Cr, Ni, Fe, Al, Mn, Zn, Cu, Co, Hg	[26–29]
Scardinius knezevici (rudd)	Herbivorous	Pb, Cd, As, Cr, Ni, Fe, Mn, Zn, Cu, Co, Hg	[26–28]

concentration of toxic elements (Ni, As, Pb, Cd) in all the mentioned studies was either very low or below the detection limit of the instrument. The highest concentration of Cd, Cr and Co was found in bleak and of Pb and Ni in carp, while the greatest concentration of As and Hg was detected in the European eel [26]. In terms of the other elements, the highest concentration of Fe, Mn and Al was detected in the roach and of Zn in the carp, while the concentration of Cu was at a comparable level in all the fish species examined [26].

Rakočević et al. [26] found significant differences in the accumulations of Zn, Mn, Fe and As in the muscles of six fish species from Lake Skadar mentioning that total metal accumulation was the highest in the roach and least in the perch. The European eel accumulates arsenic comparably more than other species examined from Lake Skadar [26]. It is well known that fish accumulate elements in different organs such as the liver, kidney, gills and muscles [33, 34]. Vujačić [29] who studied the accumulation of heavy metals in the different organs of two fish species (*Cyprinus carpio* and *Alburnus scoranza*) from Lake Skadar found that the accumulation of Pb, Cd, Cu, Zn and Fe was highest in the liver, of Mn, Ni, Al and Co in the gill and of Cr in the adipose tissue. In the fish, the adsorption of the metal from water is predominantly taken through the gills and the gastrointestinal tract [34] and accumulated in the inner organs. Therefore, different fish tissues can be used as indicators of the heavy metal contamination of an aquatic environment [35]. The concentrations of heavy metals in the inner organs of fish are generally higher than in fish muscle [36] which is most frequently used for routine analysis. Concentrations of Zn in the liver of the common carp are 11 times, concentrations of Fe are 15 times, and concentrations of Cd are more than 52 times greater than in adipose tissue of *C. carpio* [29].

The distribution of heavy metals in the different fish tissues depends on their affinity to the specific organs. For example, it is well known that Hg predominantly accumulates in fish muscle [37], while Pb easily accumulates in the bones, gills, kidneys, liver and scales [38]. The muscles, gills, livers and adipose tissue examined for metal accumulation in the common carp and the bleak from Lake Skadar showed differences due to their ability to accumulate heavy metals (Table 3). The higher

Table 3 The comparison of the metal accumulation levels in the different tissues of the bleak (*Alburnus scoranza*) and the common carp (*Cyprinus carpio*)

	Bleak	Common carp
Pb	Liver > adipose tissue > gills > muscle	Liver > adipose tissue > muscle > gills
Cd	Liver > muscle > adipose tissue > gills	Liver > gills > muscle > adipose tissue
Cu	Liver > gills > muscle > adipose tissue	Liver > adipose tissue > gills > muscle
Zn	Muscle > liver > gills > adipose tissue	Liver > gills > adipose tissue > muscle
Mn	Gills > muscle > adipose tissue > liver	Gills > liver > adipose tissue > muscle
Fe	Liver > gills > muscle > adipose tissue	Liver > gills > adipose tissue > muscle
Ni	Gills > adipose tissue > liver > muscle	Gills > adipose tissue > liver > muscle
Cr	Adipose tissue > gills > liver > muscle	Adipose tissue > gills > liver > muscle
Al	Gills > liver > adipose tissue	Gills > liver > adipose tissue
Co	Gills > adipose tissue > liver > muscle	Gills > adipose tissue > liver > muscle

concentrations of Pb, Cd, Cu, Zn and Fe in the liver of the common carp from Lake Skadar are in agreement with Vinodhini and Narayanan [33] who showed that the liver accumulates relatively higher amounts of heavy metals. The higher accumulation of Cu and Zn in the liver is associated with the exchange – depositing function of the liver. On the other hand, as can be seen from Table 3, in the common carp and the bleak from Lake Skadar, Ni, Al, Mn and Co accumulate in the gills. The gills are in direct contact with the water, and thus they can accurately reflect the metal pollution [39].

The distribution of heavy metals in the different fish tissues depends on a number of factors such as the age and length of the fish, food availability as well as their mobility and their position in the food chain [40, 41]. In Lake Skadar, the highest concentration of Hg was found in the predatory eel and perch [26]. This is in agreement with the literature [42] which showed that predatory fish belonging to the higher trophic levels contained more Hg than planktonophagous and benthophagous species. Vujačić [29] found that the accumulation of almost all elements with the exception of Cr in adipose tissue, Cu in the liver and Ni in the gills was generally higher in the common carp than in the bleak. It is very likely this is because the carp is a benthic feeder and has contact with the sediments more often, where the metal concentrations were higher than in the water [43], while the bleak is a planktivorous fish which searches for food mainly in the surface water layers. Rakočević et al. [26] found a significant positive correlation between accumulation and the age and size of the six fish examined from Lake Skadar for Cu, Ni and As and the negative correlation for Mn and Zn. The accumulation of the other elements (Fe, Cr, Hg, Pb and Cd) in the fish examined was relatively independent with regard to their size and age [26]. The impact of the age of the fish on the distribution of heavy metals is associated with the higher metabolic rate in young specimens: concentrations of Zn and Mn were higher in younger than in older fish from Lake Skadar [26].

Rakočević et al. [26] showed that the metal pollution index (MPI) in the six fish species from Lake Skadar ranges from 0.165 to 0.338, concluding that Lake Skadar should be treated as an unpolluted system. Based on the available but scarce data in the literature, it can be confirmed that the concentrations of the selected heavy metals have changed slightly since the early 1980s [26].

References

1. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
2. APAWA and CETI (2007) The strategic action plan (SAP) for Skadar/Shkodra Lake, Albania & Montenegro. GEF, World Bank, LSIEMP, Shkodra, Tirana, Podgorica, 72 p
3. Beeton AM (1981) Relationships of aquatic macrophytes to the chemistry of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović/Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 109–113

4. Gupta AK, Sinha S (2007) Phytoremediation capacity of the plants growing on tannery sludge dumping site. Bioresour Technol 98:1788–1794
5. Jastrzębska M, Cwynar P, Polechoński R, Skwara T (2010) The content of heavy metals (Cu, Ni, Cd, Pb, Zn) in common reed (*Phragmites australis*) and floating pondweed (Potamogeton natans). Pol J Environ Stud 19:243–246
6. Keukelaar F, De Goffau A, Pradhan T et al (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515, Podgorica. Royal Haskoning, Nijmegen, 111 pp
7. Kastratovic V (2013) Akvaticne makrofite Skadarskog jezera kao bioakumulatori teskih metala-uloga u monitoring vodenih sistema i mogucnost remedijacije. Dissertation, University of Montenegro
8. Petrovic D (2017) Ekofizioloske, biohemijske i anatomske odlike vrste *Trapa natans* L. na podrucju Skadarskog jezera. Dissertation, University of Montenegro
9. Kastratović V, Krivokapić S, Đurović D, Blagojević N (2013) Seasonal changes in metal accumulation and distribution in the organs of *Phragmites australis* (common reed) from Lake Skadar, Montenegro. J Serb Chem Soc 78:1241–1258
10. Kastratović V, Krivokapić S, Bigović M, Đurović D, Blagojević N (2014) Bioaccumulation and translocation of heavy metals by *Ceratophyllum demersum* from the Skadar Lake, Montenegro. J Serb Chem Soc 79:1445–1460
11. Kastratović V, Jaćimović Ž, Đurović D, Bigović M, Krivokapić S (2015) *Lemna minor* L. as bioindicator of heavy metal pollution in Skadar Lake (Montenegro). Kragujevac J Sci 37:123–134
12. Kastratović V, Jaćimović Ž, Bigović M, Đurović D, Krivokapić S (2016) The distribution and accumulation of chromium in the water, sediment and macrophytes of Skadar Lake. Kragujevac J Sci 38:125–134
13. Kastratović V, Jaćimović Ž, Bigović M, Kosović M, Đurović D, Krivokapić S (2017) Seasonal patterns of Cu in a system of sediment-water-macrophytes. Fresenius Environ Bull 26:1247–1253
14. Petrović D, Krivokapić S, Jančić D (2013) Contents of heavy metals (Zn, Mn, Cu) in different parts of *Trapa natans* L. from Skadar Lake, Montenegro. Nat Montenegrina 12:925–935
15. Petrović D, Jančić D, Furdek M, Mikac N, Krivokapić S (2016) Aquatic plant *Trapa natans* L. as bioindicator of trace metal contamination in a freshwater lake (Skadar Lake, Montenegro). Acta Bot Croat 75:236–243
16. Bekteshi A, Myrtaj E (2014) Heavy metals in the Shkodra Lake ecosystem. J Environ Prot Ecol 15:834–841
17. Branković S, Pavlović-Muratspahić D, Topuzović M, Glisić R, Banković D, Stanković M (2011) Environmental study of some metals on several aquatic macrophytes. Afr J Biotechnol 10:11956–11965
18. Greger M (1999) Metal availability and bioconcentration in plants. In: Prasad MNV, Hagemeyer J (eds) Heavy metal stress in plants – from molecules to ecosystems. Springer, Heidelberg, pp 1–27
19. Vardayan LG, Ingole BS (2006) Studies on heavy metal accumulation in aquatic macrophysics from Sevan (Armenia) and Carabolim (India) lake system. Environ Int 32:208–218
20. Elder JF, Colins JJ (1991) Freshwater molluscs as indicators of bioavailability and toxicity of metals in surface water systems. Arch Environ Contam Toxicol 122:37–79
21. Blagojević N, Vukašinović-Pešić V, Grudić V, Pešić V (2014) Endemic freshwater snails as an environmental indicator of metal pollution of the Zeta River, Montenegro. J Environ Prot Ecol 15:210–216
22. Vukašinović-Pešić V, Blagojević N, Vukanović S, Savić A, Pešić V (2017) Heavy metal concentrations in different tissues of the snail *Viviparus mamillatus* (Küster, 1852) from lacustrine and riverine environments in Montenegro. Turk J Fish Aquat Sci 17:557–563
23. Jakubik B (2009) Food and feeding of *Viviparus viviparus* (L.) (Gastropoda) in dam reservoir and river habitats. Pol J Ecol 57:321–330

24. Birungi Z, Masola B, Zaranyika MF, Naigaga I, Marshall B (2007) Active biomonitoring of trace heavy metals using fish (*Oreochromis niloticus*) as bioindicator species. The case of Nakivubo wetland along Lake Victoria. Phys Chem Earth 32:1350–1358
25. Mansour S, Sidky M (2002) Ecotoxicological studies. 3. Heavy metals contaminating water and fish from Fayoum Governorate, Egypt. Food Chem 78:15–22
26. Rakočević J, Šuković D, Marić D (2018) Distribution and relationships of eleven trace elements in muscle of six fish species from Skadar Lake (Montenegro). Turk J Fish Aquat Sci 18:647–657
27. Filipovic S, Vukovic T, Knezevic B (1980) Microelements iron and copper in the muscles of some cyprinoid fish species of Skadar Lake. God Biol Inst Sarajevu 33:51–57
28. Filipovic S, Vukovic T, Knezevic B (1981) Microelements cadmium and chromium in the muscles of some cyprinoid fish species of Skadar Lake. Ichthyologia 13:21–28
29. Vujačić A (2010) Distribucija metala u vodi, sedimentu i ciprinidnim vrstama riba Skadarskog jezera. Master thesis, Faculty of Sciences, University of Novi Sad
30. Filipović S (1997) Aluminium in water and the muscles of some cyprinoid fish. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera. CANU, Naučni skupovi, Knjiga 44, pp 355–362
31. Official Gazette of Montenegro (2009) Regulation of permitted levels of trace metals, mycotoxins and other substances in food, No 81/2009
32. FAO/WHO (1989) Evaluation of certain food additives and the contaminants mercury, lead and cadmium. WHO technical report series, No 505
33. Vinodhini R, Narayanan M (2008) Bioaccumulation of heavy metals in organs of fresh water fish *Cyprinus carpio* (Common carp). Int J Environ Sci Technol 5:179–182
34. Squadrone S, Prearo M, Brizio P, Gavinelli S, Pellegrino M, Scanzio T, Guarise S, Benedetto A, Abete M (2013) Heavy metals distribution in muscle, liver, kidney and gill of European catfish (Silurus glanis) from Italian rivers. Chemosphere 90:358–365
35. Alam M, Allinson G, Stagnitti F, Tanaka A, Westbrooke M (2002) Arsenic contamination in Bangladesh groundwater: a major environmental and social disaster. Int J Environ Health Res 12:235–253
36. Staniskiene B, Matusevicius P, Budreckiene R, Skibniewska K (2006) Distribution of heavy metals in tissues of freshwater fish in Lithuania. Pol J Environ Stud 15:585–591
37. Wiener J, Krabbenhoft D, Heinz G, Scheuhammer A (2003) Ecotoxicology of mercury. In: Hoffman DJ, Rattner BA, Burton Jr GA, Cairns J (eds) Handbook of ecotoxicology. CRC Press, Boca Raton, pp 409–464
38. Dallas HF, Day JA (1993) The effect of water quality variables on riverine ecosystems: a review. Water Research Commission Report No. 351–360
39. Teienh C, Kroglund F, Salbu B, Rosseland B (2006) Gill reactivity of aluminium species following liming. Sci Total Environ 358:206–220
40. Al-Yousuf M, El-Shahawi M, Al-Ghais S (2000) Trace metals in liver, skin and muscle of Lethrinus lentjanfish species in relation to body length and sex. Sci Total Environ 256:87–94
41. Papagiannis I, Kagalou I, Leonardosc J, Petridisd D, Kalfakakoua V (2004) Copper and zinc in four freshwater fish species from Lake Pamvotis (Greece). Environ Int 30:357–362
42. Łuczynska J, Brucka-Jastrzebska E (2006) Determination of heavy metals in the muscles of some fish species from lakes in North-Eastern Poland. Pol J Food Nutr Sci 15:141–146
43. Yancheva V, Stoyanova S, Velcheva I, Georgieva E (2016) Histological response of fish gills to metal pollution: Common carp, *Cyprinus carpio* L., and Common Rudd, *Scardinius erythrophthalmus* L., from Topolnitsa Reservoir, Bulgaria. Acta Zool Bulg 68:103–109

The Phytoplankton and Trophic State of Lake Skadar/Shkodra

Jelena Rakočević

Contents

Abstract According to the high number of registered microalgae (1,069 taxa), Lake Skadar represents one of the biodiversity hot spots of Europe. The lake is unstratified, due to its shallowness and vertical mixing caused by the wind-driven hydrodynamics. The main limiting factor for phytoplankton growth in Lake Skadar is the amount of phosphorus. The phytoplankton dynamics and distribution are generally governed by meteorological and hydrological factors that induce distinct temporal and spatial heterogeneity. The central, pelagic zone of the lake is characterized by the dominance of euplanktonic species, mostly centric diatoms, during the whole annual cycle. The western and northwestern, more isolated, and shallower parts of the lake have a greater abundance of greens and blue-greens (that overdominate diatoms during the summer) and a higher percentage of resuspended benthic-epiphytic forms. The average chlorophyll *a* concentration indicates mesotrophic conditions in Lake Skadar, but during midsummer, when the highest phytoplankton abundance and biomass occurs, the trophic level of the lake increases to eutrophy. Comparison to former phytoplankton data shows distinct differences in terms of the qualitative and quantitative composition of the phytoplankton community of Lake Skadar, which indicate lake eutrophication.

Keywords Eutrophication, Lake Skadar, Phytoplankton, Seasonal dynamics, Trophic state

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 153–168, DOI 10.1007/698_2017_233,

© Springer International Publishing AG 2018, Published online: 29 April 2018

1 Introduction

The earliest data about the phytoplankton of Lake Skadar can be found in articles dating from the beginning of the twentieth century. Forti [1] presented the first taxa list including 38 phytoplankton species, while Brehm and Zederbauer [2] and Gessner [3] provided some additional taxonomic data on the phytoplankton community. Although these early studies were sporadic and quite limited in scope, they gave the first floristic information about the phytoplankton community.

Nedeljković [4] presented the first data about the ecology and biogeography of the different communities in Lake Skadar (on the Montenegrin side), including a more detailed description of the phytoplankton. In the following years, the floristic list of phytoplankton was supplemented to include 352 species by Milovanović [5–9]. Quantitative analyses of phytoplankton were done occasionally, focusing exclusively on phytoplankton abundance and rarely covering more than one season. Jerković [10] studied the ultrastructure of Lake Skadar diatoms under an electronic microscope and described a new species, *Cyclotella skadariensis* Jerkovic.

However, the greatest contribution to the algal research of Lake Skadar was made by Smiljka Petković [11–19] who mostly paid attention to the identification of algal taxa and the description of the seasonal dynamic of the phytoplankton community. In the period 1972–1977, a comprehensive investigation of Lake Skadar was conducted within the framework of the project "Limnological Investigations of Lake Skadar" as a result of scientific collaboration between the Biological Institute (Montenegro) and the Smithsonian Institution (USA). This work led to the compilation of a checklist including 685 algal species from the following classes: Bacillariophyceae, Cyanophyceae, Chlorophyceae, Euglenophyceae, Chrysophyceae, Dinophyceae, and Xanthophyceae [20]. In addition, more detailed data about the abundance, horizontal distribution, and seasonal dynamic of phytoplankton were presented.

After a pause of almost three decades in phytoplankton research, Rakočević [21, 22] studied the composition, seasonal succession, and spatial heterogeneity of phytoplankton as well as the ecological factors that influence the phytoplankton structure and dynamic in Lake Skadar. For the first time, the trophic state of Lake Skadar was estimated on the basis of the phytoplankton composition and biomass (chlorophyll *a*). These studies showed significant changes in the taxonomical composition as well as increases in the total phytoplankton abundance in comparison to former investigations.

The first comprehensive investigations of algal periphyton in Lake Skadar, specifically of epiphytic diatoms, were carried out by Rakočević [23–25] who studied the structure and seasonal succession of the epiphytic diatoms on nine different aquatic macrophytes. This work resulted in a taxa list that included 125 species of epiphytic diatoms, of which 60 were recorded in Lake Skadar for the first time.

On the Albanian side of the lake, phytoplankton was the subject of various studies conducted by Rakaj [26–30] who researched the species composition, distribution, and seasonal changes of phytoplankton. As a result of these studies, another

255 species of algae, identified only on the Albanian side of the lake, were included in the taxa list of Lake Skadar.

As a result of the collaboration between Montenegrin and Albanian scientists in 2002 (via the project "The promotion of the networks and the scientific exchanges between the South-Eastern European countries, Lake Skadar, Montenegro"), a biodiversity database of Lake Skadar was created. A checklist of algal species was completed for the first time, including in total 1,069 species of microalgae registered in Lake Skadar in the period 1900–2000 on both the Montenegrin side and the Albanian side of the lake [31]. Such a high number of taxa univocally confirm that Lake Skadar is a biodiversity hot spot for Europe.

In the following text, the phytoplankton of Lake Skadar is described on the basis of both previous and recent investigations of this community, according to the available literature data.

2 Phytoplankton Composition

According to Petković [20], the phytoplankton community of the Montenegrin part of Lake Skadar consists of 685 species from 7 classes: Chlorophyceae, Bacillariophyceae, Euglenophyceae, Cyanophyceae, Dinophyceae, Chrysophyceae, and Xanthophyceae. A detailed floristic list of recorded species is given in Petkovic [20]. Chlorophyceae had the highest number of taxa – 369 (54%), of which Desmidiales were represented by 199 species (29%) and Chlorococcales by 170 (24.8%). Bacillariophyceae were in second place in terms of species number, with 134 species (20%). Other contributors to species composition to a lesser extent included Euglenophyceae (78 species, 12%), Cyanophyceae (59 species, 9%), Chrysophyceae (14 species, 2%), Dinophyceae (13 species, 2%), and Xanthophyceae (9 species, 1%).

The phytoplankton community of Lake Skadar consists of two ecological formations: typical pelagic populations (euplanktonic forms) and tychoplanktonic populations (benthic/epiphytic forms). The pelagic forms are mostly represented by the genera *Pantocsekiella*, *Fragilaria*, and *Synedra* (diatoms), *Scenedesmus* and *Pediastrum* (chlorococcalean greens), *Ceratium* and *Peridinium* (dinoflagellates), *Merismopedia* and *Microcystis* (blue-greens), and *Dinobryon* (chrysophytes). The second element of the phytoplankton community is benthic/epiphytic forms that are mostly represented by pennate diatoms, of which the largest number of species is recorded within the genera *Cymbella*, *Navicula*, *Gomphonema*, and *Nitzschia*. In the case of shallow lakes, the surface/volume ratio is considerably higher in comparison to large and deep lakes. The littoral zone of Lake Skadar, especially the wide shallow flood region of the north and northwest shore of the lake, is characterized by well-developed aquatic macrophyte communities. Therefore, the ratio of benthic habitats in Lake Skadar is high, which results in a significantly higher proportion of detached taxa of benthic and epiphytic origin (meroplankton) in comparison to typical pelagic species.

In 2002, due to a collaboration between Montenegrin and Albanian algologists, algal lists for both sides of the lake were compiled, and the final floristic list of algae was expanded to 1,069 species for Lake Skadar as a whole [32]. According to this joint list, greens are still predominant in terms of the taxa number but with a lower proportion (44%). This is a consequence of the increased number of diatom taxa that were subsequently added to the list, and thus their share increased to 33% (Fig. 1).

The most recent investigation of phytoplankton on the Montenegrin side of the lake [22], carried out in 2004 (after a pause of almost 30 years), showed the qualitative dominance of diatoms and a distinctly lower proportion of greens in the phytoplankton community (Fig. 2) in comparison to the previous data of Petkovic [20], primarily due to the significantly lower number of registered desmids (2% in comparison to the previous 29%). Since desmids are considered to be indicative of an oligotrophic environment, the significant decrease in taxa number of these algae may be a sign of eutrophication. It should be emphasized that the most recent investigation covered only 1-year cycle and a lower portion of the lake (only the Montenegrin side), while the former floristic list, with high number of desmids, was formed as a result of all the previous studies in the lake. However, such a big discrepancy regarding number of desmids unequivocally indicates that the qualitative composition of phytoplankton has been changed in the last 30 years.

Generally, in all the investigations of phytoplankton, greater species richness characterized the littoral parts of Lake Skadar, due to the lower water depth and the

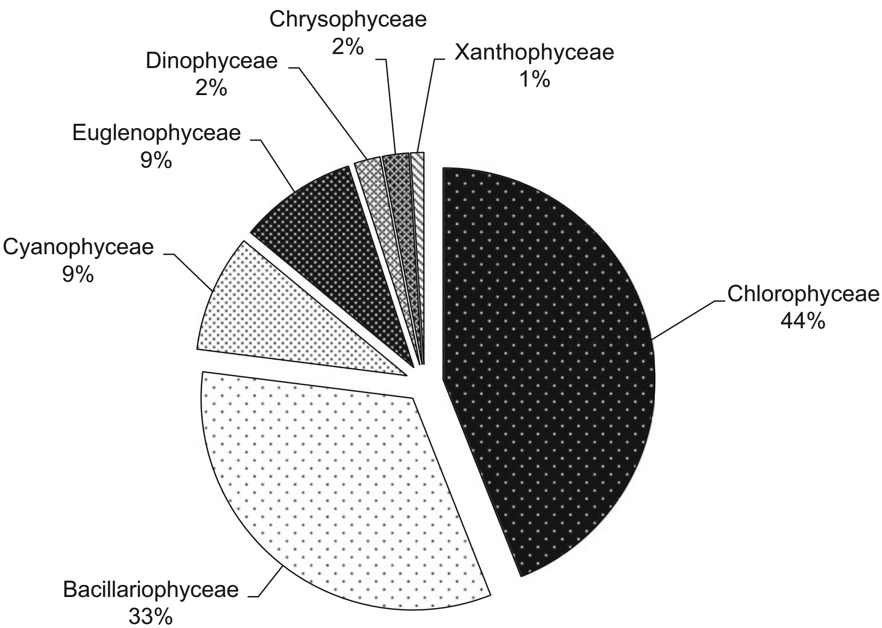

Fig. 1 Proportion of different algal classes in the phytoplankton community of Lake Skadar according to the joint list from the Montenegrin and Albanian side of the lake

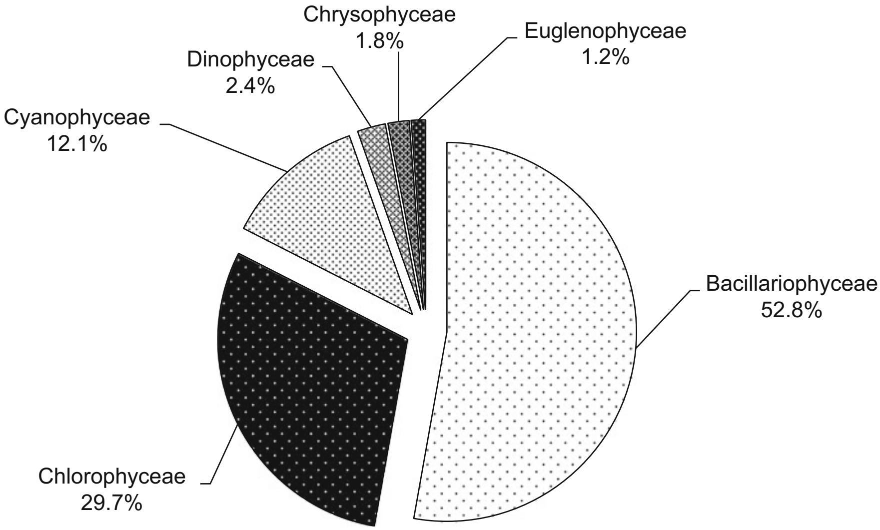

Fig. 2 The proportion of different algal classes in the phytoplankton community on the Montenegrin side of Lake Skadar according to the most recent data

proximity of macrophytic vegetation (benthic and epiphytic forms, mainly pennate diatoms, resuspended from the lakebed and macrophytes). By contrast, significantly lower species richness characterized the lake pelagial where euplanktonic forms qualitatively dominate in the phytoplankton community (mainly centric diatoms and chlorococcaceans). The lowest number of species is registered in the sublacustrine springs.

The other pattern characteristic for Lake Skadar is the increase in both species richness and the diversity index with increasing temperature and light intensity. Therefore, the maximum species number in the lake occurs in the summer period. Accordingly, the values of diversity indices also rise with water temperature [21], being the lowest in the winter (1.42) and the highest in the summer (3.2). The last point might be explained by the polymictic nature of Lake Skadar and consequently the absence of a steady-state in the phytoplankton community during the summer. Therefore, the main disturbance factor that prevents competitive exclusion and promotes high phytoplankton diversity in Lake Skadar over the summer is wind-driven water mixing.

3 Seasonal Dynamics and Distribution

According to Petković [20], the total phytoplankton abundance in Lake Skadar in 1977 averaged from several thousands of cells/L (winter) to 6×10^5 cells/L (summer). Peaks of phytoplankton abundance did not appear at the same time in different parts of the lake. The causeway at Vranjina divides the lake into two waterbodies. Velje Blato is the main portion of the lake spreading southeast from the causeway. The peaks of phytoplankton abundance in this part of the lake differed between the littoral (with a peak in summer, 2–4 $\times$ 10^5 cells/L) and the pelagial (with a peak in spring, 8 $\times$ 10^5 cells/L). Vučko Blato represents the part of the lake northwest of the causeway, and it is more isolated and strongly affected by rivers (the Crnojevića and the right branch of the Morača). This part of the lake was characterized by the highest phytoplankton abundance during the whole annual cycle, with a peak in summer in both the pelagial (1.5 $\times$ 10^6 cells/L) and the littoral (1 $\times$ 10^6 cells/L). Centric diatoms (mainly *Pantocsekiella ocellata* and *Discostella glomerata*) quantitatively dominated the phytoplankton community during the whole year in all parts of the lake.

According to the most recent investigation by Rakočević [22], conducted in 2004, the total phytoplankton abundance in Lake Skadar Lake ranges from several hundred cells/L (in winter) to 5 $\times$ 10^6 cells/L (in summer). Considering average monthly abundances, there are two peaks: a first (lower) peak in March (8.7 $\times$ 10^5 cells/L), due to high density of diatoms, and a second (higher) peak in June (2.4 $\times$ 10^6 cells/L) as a consequence of the high density of greens and locally blue-greens or dinoflagellates. In all parts of the lake, a greater phytoplankton density is observed in comparison to the previous data. The observed pattern in the horizontal distribution of phytoplankton is a decrease in abundance from the northwest toward the southeast part of the lake and a several orders of magnitude lower phytoplankton abundance in the Albanian part of the lake. The phytoplankton was uniformly distributed throughout the water column, since there were no significant differences in phytoplankton abundance at the different investigated depths (being 0 m, 1 m, 2 m, and 3 m).

Phytoplankton abundance was correlated to water temperature, transparency, conductivity, oxygen concentration, pH, and total nitrogen and phosphorus [22], and regression analysis showed that 62% of phytoplankton abundance variation could be explained by the investigated parameters ($R^2 = 0.62$; $p < 0.0005$). However, among the analyzed parameters, only water temperature and total nitrogen were found to be of statistical significance. The peak of total phytoplankton abundance in Lake Skadar occurs in the summer and is associated with the highest water temperature and the greatest nutrient concentration in water, both being related to the alternation of a dry and a rainy season. Lake Skadar has pronounced water-level fluctuations: a low level during the summer and a significantly higher level during the winter and early spring when the flatlands on the northern and northeastern shores are flooded. The lowest nutrient amount in the water is present in the period of high water level due to the dilution effect. By contrast, lower amount of falls and water discharges from inflowing rivers (especially the River Morača) during the summer, associated with the high water temperature that increases the decomposition rate and the intensity of the internal loading of nutrients, results in the greatest concentration of nutrients in the water during the summer period. Furthermore, the frequent winds and low depth do not permit the formation of permanent thermal stratification. More or less constant mixing events promote the resuspension of the sediments and raise nutrients from the bottom even during the summer. All these factors disable steady-state formation (the “clear-water” equilibrium phase) in the phytoplankton community during the summer period.

The seasonal succession of phytoplankton in Lake Skadar shows distinct spatial heterogeneity, as often happens in shallow lakes, especially those with a large surface area. In the past [20], diatoms made up the highest proportion (i.e., quantitative domination) in the phytoplankton community during the whole annual cycle in all parts of the lake. Nowadays, a similar situation is present only in the eastern, more open zone of Velje Blato (especially in the pelagial and steep southeastern littoral; see Fig. 3) where diatoms have their peak of abundance in the summer (July, 2.1×10^6 cell/L). In other parts of the lake (Vučko Blato and northwestern part of Velje Blato; see Fig. 4), diatoms dominate the phytoplankton community only during the winter and early spring, with a peak in March (1.3×10^6 cell/L), but during rest of the year, the proportion of diatoms in the phytoplankton community is reduced to 20–40%.

During the spring, the most abundant diatoms in the phytoplankton community are pennate species regarded as benthic forms: *Fragilaria capucina*, *Ulnaria ulna*, *Ulnaria acus*, and *Ulnaria delicatissima*. The summer period is characterized by the quantitative domination of centric diatoms (regarded as typical euplanktonic forms), mostly *Pantocsekiella ocellata* – the typical perennial species of Lake Skadar. Small centric diatoms are well adapted to turbulent and turbid systems. The small algae have a larger absorptive surface than larger algae and a lower settling rate. A high summer abundance of *P. ocellata* can also be related to selective grazing by zooplankton, which is mostly based on size, and therefore predation by some grazers is probably lessened. However, the abundance of centric diatoms decreases during

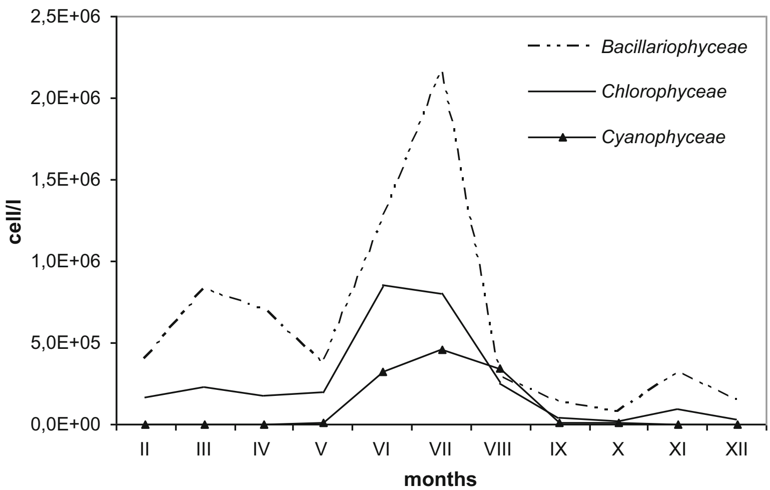

Fig. 3 Seasonal dynamic of the main phytoplankton groups in the eastern and southeastern part of Velje Blato

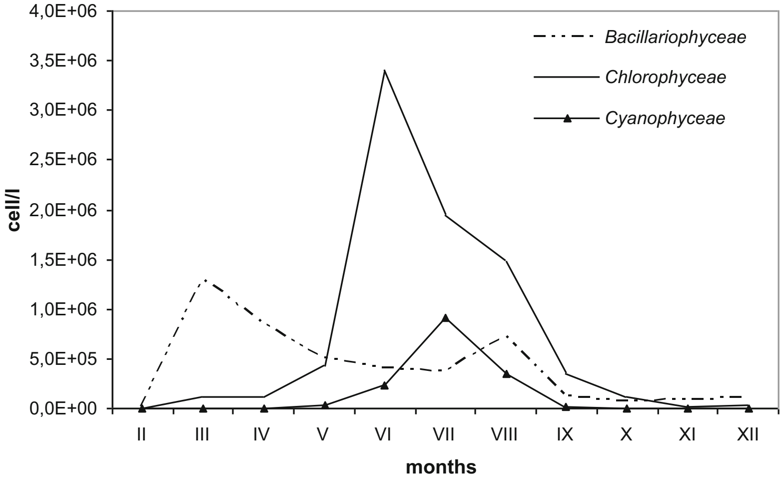

Fig. 4 Seasonal dynamics of the main phytoplankton groups in Vučko Blato and the western and northwestern part of Velje Blato

the autumn and especially the winter, while *P. ocellata* remains the dominant species in the phytoplankton community until the spring.

Chlorophyceae develop mainly from late spring until autumn and attain their peak in abundance in the summer (4.3–35 $\times$ 10^5 ind/L). The highest abundance of greens characterizes Vučko Blato and the western part of Velje Blato. In these parts of the lake, greens quantitatively dominate the phytoplankton community during the whole summer period (Fig. 4). The most abundant greens in this period are *Pandorina morum*, *Planctonema lauterbornii*, and Chlorococcales from the following genera: *Crucigeniella*, *Coelastrum*, *Oocystis*, *Sphaerocystis*, *Scenedesmus*, and *Pediastrum*. Being almost entirely deprived of self-motility, Chlorococcales are completely dependent on water turbulence to keep them suspended in the water column and therefore exhibit their greatest abundance in turbulent waters. They are the dominant greens around mouths of Morača and Plavnica and the sublacustrine spring at Karuč as well as in the eastern pelagic part of Velje Blato. *Pandorina morum* and *Planctonema lauterbornii* dominate the phytoplankton community during the summer peak in the western part of Velje Blato and especially in Vučko Blato, where these species reach their highest abundance. Filamentous green alga *Planctonema lauterbornii* is usually characteristic of highly eutrophic lakes and was not detected as abundant in the phytoplankton community in the past. In previous studies [20], the most abundant greens in the summer were Chlorococcales in all parts of the lake, but their proportion in the total phytoplankton abundance was lower in comparison to diatoms during the whole annual cycle in all parts of the lake.

Cyanophyceae develop mainly in the summer with a peak abundance in July or August (1–6 $\times$ 10^5 ind/L) in all parts of the lake. Water temperatures above 20°C and a decrease in water transparency contribute to the increase in blue-green density in the summer. The greatest abundance of blue-greens characterizes Vučko Blato and the western part of Velje Blato, while the lowest abundance is observed in the lake parts around river mouths and the sublacustrine spring at Karuč. The dominant species in the blue-green community of Vučko Blato and the western part of Velje Blato is the filamentous alga *Anabaena variabilis*. A slight bloom of this species (1.2×10^6 cells/L) was recorded in July 2004 in the western part of Velje Blato. *Anabaena variabilis* is capable of storing phosphorus and fixing atmospheric nitrogen which is a competitive advantage in conditions of low nutrient concentration in water. However, this species was not recorded with significant abundance in the past. Besides *Anabaena variabilis*, the blue-greens, present with significant abundance in the lake, are colonial species, *Merismopedia punctata*, *Merismopedia glauca*, and *Microcystis incerta*, that dominate the community of blue-greens in other parts of the lake (the eastern part of Velje Blato and the river mouths). Colonial *Merismopedia* species were the most abundant blue-greens in the summer in all parts of Lake Skadar in the past.

Dinophyceae showed a low occurrence, with significant abundance ($2–30 \times 10^4$ cell/L) only during the warm period of the year (June to October). They are mostly represented by *Peridiniopsis beroliense* and *Peridiniopsis cuningtonii*. Only around the sublacustrine spring at Karuč do these algae have a distinctly higher abundance (June: 1.5×10^6 cell/L) and even dominate in the phytoplankton community. Karuč is quite an isolated part of the lake with the lowest temperature and concentration of nutrients. The ability of dinoflagellates to migrate vertically and take up nutrients in the deeper layers of the lake, their mixotrophic abilities, as well as the high grazing resistance may be the features that enable their dominance in this part of the lake. In the past, dinoflagellates were mostly represented by *Ceratium hirundinella*. This species was present in the phytoplankton community with a proportion of 10–69%, mostly in May and September. However, at present, this species occurs only sporadically and with insignificant abundance.

Chrysophyceae also exhibit a low occurrence being mostly represented by *Dinobryon divergens* and *Dinobryon sociale*. The abundance of these algae is greatest in July in the part of the lake around the sublacustrine spring at Karuč (2.2×10^5 cell/L). Similarly to dinoflagellates, *Dinobryon* species are mixotrophic, which gives them more opportunities under nutrient limitation. Therefore, the low water temperature and extremely low nutrient concentration near the sublacustrine spring at Karuč are probably the reasons for the greater abundance of *Dinobryon* species in this part of the lake.

In a general sense, the horizontal heterogeneity of the phytoplankton is characteristic of shallow lakes with a high surface to volume ratio. In Lake Skadar, there is distinct spatial heterogeneity of some limiting factors for phytoplankton growth (light availability, water temperature, and local concentration of nutrients), but the horizontal heterogeneity of the phytoplankton is mainly a consequence of wind-driven water movement and river discharge. Since these factors also vary seasonally, it can be said that both the spatial and temporal distribution of the main groups of phytoplankton in Lake Skadar are mostly connected to hydrological and meteorological factors.

4 The Trophic and Saprobic State

Chlorophyll a concentration in the water is an indirect measure of the phytoplankton biomass. This parameter is one of the most commonly used biological parameters for the estimation of the trophic state of lakes. According to Rakočević and Hollert [21], the concentration of chlorophyll a in Lake Skadar ranges from 0.12 to 39.78 μg/L during the annual cycle. The annual average of chlorophyll a concentration is 5.9 μg/L, which indicates the mesotrophic state of the lake according to OECD criteria [32]. The average winter and summer concentration amounts to 3.19 μg/L and 10.1 μg/L, respectively, with a peak in August (18.49 μg/L) in all parts of the lake. These values indicate a mesotrophic state in winter and a eutrophic state in summer. The vertical distribution of chlorophyll agreed with that of the phytoplankton abundance indicating the uniform distribution of phytoplankton through the water column.

However, when considering different parts of the lake, there is notable spatial heterogeneity in chlorophyll *a* concentration that is particularly pronounced during the summer. The lowest concentrations characterize the pelagial, open, eastern, and southeastern parts of the lake, but going toward the west, the concentration rises, being greatest in Vučko Blato (during the peak in August, the amount of chlorophyll *a* in this part of the lake reaches 39.78 μg/L). The increase in chlorophyll *a* concentration in a direction southeast to northwest is in agreement with the rise in phytoplankton abundance, but also connected with the shift from diatoms to greens and blue-greens, since the latter two algal groups are known to have larger dimensions and a higher amount of chlorophyll in their cells in comparison to diatoms.

The relationship between the levels of the physicochemical parameters and the chlorophyll *a* concentration in Lake Skadar was determined by multiple regression [21]. The coefficient of determination was relatively high ($R^2 = 0.71$), and the established relationship was highly significant ($p = 0.0001$). The resultant prediction equation was:

$$\log(\mathrm{Chl}\ a) = -3.7 - 1.6\log(\mathrm{SD}) + 4.1\log(\mathrm{DO}) - 0.5\log(\mathrm{TP}) + 0.3\log(\mathrm{TN})$$

where, Chl a = concentration of chlorophyll a (μg/L), SD = Secchi depth (m), DO = dissolved oxygen (mg/L), TP = total phosphorus (mg/L), and TN = total nitrogen (mg/L).

However, although there is often a strong correlation between total phosphorus and algal chlorophyll *a*, the equation using only total phosphorus as the independent variable was not significantly effective for predicting the chlorophyll *a* concentration in Lake Skadar ($r = 0.2$, $p = 0.2$): $\log(\mathrm{Chl}\ a) = 1.08 + 0.2\log(\mathrm{TP})$. This is supported by the fact that the chlorophyll *a* concentration observed during the winter indicated the mesotrophic status of the lake, although the total phosphorus concentrations in the water were below the limit of detection (indicating an oligotrophic status). The dominant algae in the phytoplankton community of Lake Skadar during the winter are centric diatoms that are very efficient in their phosphorus utilization and have the capability of storing phosphorus. That might explain the greater winter chlorophyll *a* concentration than might be expected according to (the extremely limited) amount of available phosphorus in the water.

Beside chlorophyll *a*, the OECD criteria [32] for the trophic categorization of lakes are water transparency (the Secchi depth) and the total phosphorus concentration (TP) in the water. Using all three parameters, trophic state indices (TSI) [33] were calculated for Lake Skadar. When all three variables are used, it is possible to get different index values, as was observed in Lake Skadar (Table 1).

The trophic state index based on water transparency has higher values in comparison to the other two indices, during the whole annual cycle. This indicates that the phytoplankton is not the main factor which influences the light attenuation in Lake Skadar. That is an expected finding considering the large amount of sediment that rivers bring to the lake, as well as the frequent wind-promoted mixing and resuspension of the sediments from the lakebed due to its low depth. In any case, the average monthly values of the trophic indices based on transparency and chlorophyll are close together, but both are above the values of the phosphorus trophic index during the whole annual cycle. In other words, the average annual values of the trophic indices based on chlorophyll concentration and transparency (43 and 48, respectively) indicate the same trophic status of the lake – mesotrophy. However, the highest values of both indices, recorded in August, indicate eutrophic conditions. On the other hand, the average annual trophic index based on total phosphorus (35.6) indicates an oligotrophic state in the lake, while the highest value of this index, recorded in July (47.4), indicates mesotrophic conditions. Therefore, the phosphorus trophic index lowers the trophic state of Lake Skadar by one class in comparison to the other two indices.

According to Carlson [34], the differences in the index values and the relationship between the three used TSI variables may be used for the identification of factors that limit algal biomass in lakes. If the trophic indices based on chlorophyll and transparency are above the trophic index based on total phosphorus (a situation observed in Lake Skadar), that suggests that phytoplankton growth in the lake is primarily limited by phosphorus. Generally, lakes are phosphorus-limited when the total

Table 1 Trophic state indices derived from chlorophyll *a* (TSI Chl), water transparency (TSI SD), and total phosphorus (TSI TP) in Lake Skadar

	TSI (Chl)	TSI (SD)	TSI (TP)
February	32.4	49.4	27.1
March	34.6	45.9	28.4
April	40.2	46.3	33.8
May	43.8	48	34.9
June	46.6	52	43.4
July	48.5	54	47.4
August	57.6	58	45.5
September	44.3	51	34.9
October	44.0	46	30.2
November	38.4	44	27.4
December	36.2	43	27.4

nitrogen to total phosphorus ratio (TN/TP) is above 15 [32]. The TN/TP ratio in Lake Skadar is 25 [21], which confirms the finding derived from the trophic state indices that phosphorus is a main limiting nutrient in Lake Skadar. In former investigations of Lake Skadar, the TN/TP ratio was significantly lower (<10). This shift in the TN/TP ratio might be responsible for the observed changes in phytoplankton composition (e.g., the replacement of diatoms with greens and blue-greens during the summer) in comparison to the former situation in the lake (featuring the quantitative domination of diatoms during the whole year).

However, the values of all three trophic indices in the lake have the same seasonal trend: a rise from March until August and then a decline. Therefore, the trophic state of Lake Skadar is unequivocally highest in the summer (specifically in August).

Phytoplankton may also be used to assess the degree to which the decomposition of organic material occurs in the lake (the saprobity level). According to bioindicator species, saprobity indices [35] were calculated for Lake Skadar and their values are between 1.5 and 2.40 [21]. The range of these values classifies Lake Skadar as beta-mesosaprobic, meaning moderately polluted with organic compounds. Although all parts of the lake are within the same range of saprobity, somewhat lower values in the saprobic index characterize the sublacustrine springs and the pelagial, open, eastern part of Velje Blato, while the highest values of the saprobic index are observed in Vučko Blato.

5 Summary

There have been 1,069 taxa of microalgae registered so far during investigations of Lake Skadar, with Chlorophyceae and Bacillariophyceae being best represented. The phytoplankton of Lake Skadar consists of typical pelagic populations and tychoplanktonic populations. The latter dominate in the phytoplankton community in terms of taxa number due to lake shallowness and the high proportion of benthic/epiphytic habitats. Therefore, greater species richness characterizes the phytoplankton in the littoral parts of Lake Skadar in comparison to the open, pelagic portion, and such spatial heterogeneity is typical for lakes with a high surface to volume ratio. Species richness also changes depending on the season, being highest in the summer in all parts of the lake.

Phytoplankton is uniformly distributed through the water column. The wind-driven turbulence and mixing associated with low depth do not permit the formation of thermal stratification and consequently steady-state formation in the phytoplankton community of Lake Skadar. These phenomena, together with its short residence time and significant changes to the water level due to the alternation of a dry and rainy season, are important species selection factors which induce heterogeneous spatial and temporal patterns. Therefore, meteorological and hydrological factors are the main force that governs the phytoplankton dynamics and distribution in Lake Skadar.

Lake Skadar is a typical example of the fact that the seasonal succession of phytoplankton in shallow polymictic lakes shows significant deviations from the PEG model of phytoplankton succession characteristic for lakes in the temperate zone. The peaks of phytoplankton abundance and biomass (chlorophyll *a*) are associated with the highest nutrient concentrations and water temperature and occur in the summer in all parts of Lake Skadar. However, significant horizontal heterogeneity in terms of the algal biomass and dominant algal groups is observed over the summer period. The central, pelagic part of the lake exhibits similarity to the previous phytoplankton data: diatoms are still the most abundant members of the phytoplankton community during the whole year, with a maximum abundance in the summer. This part of the lake is characterized by lower phytoplankton abundance and biomass. On the other hand, in the northern littoral and western parts of the lake, especially in Vučko Blato, diatoms, which previously dominated in terms of abundance during a whole annual cycle, now dominate the phytoplankton community only during cold, rainy period of November to April (with a peak in March). However, during the warm period of the year, they are replaced by greens and/or blue-greens which are responsible for the summer peak of phytoplankton abundance. Additionally, greater phytoplankton abundance and biomass are observed in these parts of the lake. A shift in species composition is one of the most consistent effects of eutrophication on phytoplankton. The shift from diatoms to greens and blue-greens in Lake Skadar may be connected with the increase in the TN/TP ratio over the last 30 years. The other observed change in the phytoplankton community is a significant increase in total abundance in comparison to the previous data, what also might be a sign of eutrophication.

According to the mean annual chlorophyll *a* concentration, Lake Skadar can be classified as mesotrophic, but during the summer, the average amount of chlorophyll *a* indicates eutrophic conditions. Chlorophyll *a*, Secchi depth, and total phosphorus were used for the calculation of trophic state indices for Lake Skadar, and their values were highest in the summer. This indicates that the deterioration of water quality in Lake Skadar takes place in the warm period of the year. There is also an evident increase in the trophic state from the southeast toward northwest of the lake.

All the changes observed in the phytoplankton community in comparison to former times indicate that the trophic level of Lake Skadar has increased over the last 30 years and that the lake has deteriorated to some extent, which is especially pronounced in its shallow, northwestern part – Vučko Blato. The quite limited communication with the main water mass associated with extensive macrophytic growth has obviously accelerated the aging process in this part of the lake. In order to protect Lake Skadar, it is necessary to keep nutrient enrichment under control, especially regarding the influx of untreated sewage water and the use of fertilizers in the environs of the lake.

References

1. Forti A (1902) Primi appunti per uno studio sul Phytoplancton del Lago di Scutari d'Albania (presentato da G. B. de Toni). Atti del Reale Istituto Veneto di Scienze, Lettere ed Arti 61:704–708
2. Brehm V, Zederbauer E (1905) Das September plankton des Skutari sees. Verh der Zool-Bot Gess 55:47–55
3. Gessner F (1934) Limnologischer Untersuchungen am, Skadar (Skutari). Glasn Bot Zavoda i Bašte Univ Beograd 3(1–2):56–62
4. Nedeljković R (1959) Skadarsko jezero: Studija organske produkcije u jednom karsnom jezeru. Posebno izdanje Biološkog instituta 4:1–156
5. Milovanović D (1959) Organska produkcija Skadarskog jezera – produkcija fitoplanktona. Zbornik radova Biološkog instituta 3:1–16
6. Milovanović D (1967) Rezultati jednogodišnjih ispitivanja primarne produkcije Skadarskog jezera. Arch Biol Sci 19(3–4):165–181
7. Milovanović D (1967) Populaciona struktura i karakter algi makrofitske zone Skadarskog jezera. Arch Biol Sci 19:1–12
8. Milovanović D (1968) Alge perifitona u asocijaciji *Potameto perfoliati –Ranunculetum fluitans* W. Koch. Skadarskog jezera. Polj Šum 14(3):15–20
9. Milovanović D, Živković A (1965) Plankton Skadarskog jezera (1957-1958). Zbornik radova Biološkog Instituta 8(4):1–36
10. Jerković L (1974) New diatom species of Skadar lake (Yugoslavia) – *Cyclotella skadariensis*. First Balkan Congress of Electron Microscopy, Sarajevo, pp 57–58
11. Petković S (1970) Ishrana skobalja (*Chondrostoma kneri* H., 1843) Skadarskog jezera. Polj Šum 14(4):12–20
12. Petković S (1971) Prilog poznavanju fitoplanktona Skadarskog jezera sa posebnim osvrtom na dinamiku brojnosti i ritam razvica *Ceratium hirundinella* (O.F. Müll) Schrank. Polj Šum 17(1):19–40
13. Petković S (1975) Prilog poznavanju taksonomije i distribucije Bacillariophyceae, u slatkim vodama Crne Gore. Polj Šum 21(2):33–56
14. Petković S (1975) Prilog poznavanju taksonomije i distribucije Euglenophyceae (Euglenaceae: genus *Phacus*) u slatkim vodama Crne Gore. Polj Šum 21(4):81–90
15. Petković S (1976) Prilog poznavanju taksonomije i distribucije Chlorophyta: Chlorococcales (*Scenedesmus* i *Pediastrum*) u slatkim vodama Crne Gore. Polj Šum 22(1):57–72
16. Petković S (1976) Prilog poznavanju taksonomije i distribucije Euglenophyceae (Euglenaceae: genus *Trachelomonas*) u slatkim vodama Crne Gore. Polj Šum 22(2):81–85
17. Petković S (1977) Nove vrste u flori alga Skadarskog jezera. Glas Republ Zavoda zašt prirode - Prirodnjackog muzeja 10:75–80
18. Petković S (1978) Osnovne karakteristike sastava i distribucije fitoplanktona jednog sublakustricnog izvora u Skadarskom jezeru. Polj Šum 25(2):29–46
19. Petković S (1979) Neke karakteristike florističkog sastava letnjeg fitoplanktona sublakustričnog izvora ("oka") Ploča u Skadarskom jezeru. CANU, Glasnik odjeljenja prirodnih nauka 5:18–23
20. Petković S (1981) Phytoplankton of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research, Titograd, pp 163–189
21. Rakočević J, Hollert H (2005) Phytoplankton community and chlorophyll *a* as trophic state indices of Lake Skadar. Environ Sci Pollut R 12(3):146–152
22. Rakočević J (2012) Spatial and temporal distribution of phytoplankton in Skadar Lake. Arch Biol Sci 64(2):585–595
23. Rakočević J (2001) Epiphytic diatoms of Lake Skadar. Polj Šum 47(3–4):127–138
24. Rakočević J (2002) Structure and seasonal dynamic of Epiphtic diatom communities in Crnojevića River. Natura Montenegrina 1:41–58

25. Rakočević J (2002) Structure and seasonal dynamic of epiphytic diatom communities of Plavnica. Natura Montenegrina 1:59–76
26. Rakaj M (1999) Ecuria stinore e fitoplanktonit te Liqenit te Shkodres per periudhen pranvere vere. Bio Eko 2:3–7
27. Rakaj M (2000) Te dhena mbi krizofitet dhe ksanthofitet (Chrysophyceae dhe Xanthophyceae) e Liqenit te Shkodres. Bio Eko 3:9–11
28. Rakaj M, Kashta L (1999) Te dhena mbi algat e gjelbra (Chlorophyta) te Liqenit te Shkodres. Studime Biologjike, Tirane 1:107–118
29. Rakaj M, Hindak F, Hindakova A (2000) Phytoplankton species diversity of the Albanian part of Lake Shkodra in 1998-1999. Biologia, Bratislava 55(4):329–342
30. Rakaj M, Miho A, Kashta L (2001) Data on diatoms from Shkodra lake. Studime Biologjike 5–6:237–241
31. Rakocević J, Marash R (2002) Biodiversity database of the Shkodra/Skadar Lake, section: algae. Technical report of the project: "The promotion of the networks and exchanges in the countries of South - Eastern Europe", Regional Environmental Center (REC), 52 pp
32. Organization for Economic Cooperation and Development (1982) Eutrophication of waters. Monitoring, assessment and control. OECD, Paris, 154 pp
33. Carlson RE (1977) A trophic state index for lakes. Limnol Oceanogr 22:363–369
34. Carlson RE (1983) Discussion on 'Using differences among Carlson's trophic state index values in regional water quality assessment', by Richard A. Osgood. Water Resour Bull 19:307–309
35. Pantle R, Buck H (1955) Die Biologische Überwachung der Gewässer und die Darstellung der Ergebnisse. Gas-Wasserfach 96:609–620

Charophytes (Charales) of Lake Skadar/Shkodra: Ecology and Distribution

Jelena Blaženčić, Lefter Kashta, Aleksandra Vesić, Vera Biberdžić, and Branka Stevanović

Contents

Abstract Charophytes or stoneworts (Charales, Characeae) are submerged green macroscopic algae of great importance for the environmental and economic sustainability of the aquatic ecosystem of Lake Skadar/Shkodra. In the course of many years of research of these algae in the Montenegrin and the Albanian part of Lake Skadar/Shkodra, 30 taxa of charophytes have been registered in the rank of species, forms and varieties. These taxa belong to the four genera of the Characeae family existing in the lake – namely, *Chara*, *Nitella*, *Tolypella* and *Nitellopsis*. The largest number of taxa belongs to the genus *Chara*, namely, 12 species, 3 forms and 2 varieties, 10 species belong to the genus *Nitella*, 2 species belong to the genus

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 169–202, DOI 10.1007/698_2018_265,
© Springer International Publishing AG 2018,
Published online: 27 April 2018

Tolypella and, finally, only 1 species belongs to the genus *Nitellopsis*. The ecological and phytocenological characteristics of each taxon, as well as the hydrological and geomorphological characteristics of their finding sites, are presented in order to emphasize the fact that Lake Skadar/Shkodra is one of the most significant charophyte diversity centres in the Balkan Peninsula. All the data presented in this study are based on our own field investigations, as well as herbarium and literature surveys.

Keywords Charales, Charophyte flora, Distribution, Ecology, Lake Skadar/Shkodra

1 Introduction

The submerged macroscopic algae charophytes or stoneworts (Charales, Characeae) are one of the dominant components of the Lake Skadar/Shkodra aquatic vegetation. Their role in this aquatic ecosystem is multifunctional, in view of the fact that they affect both abiotic and biotic general characteristics of the lake. Due to primary production and the ability to use bicarbonates as a source of carbon dioxide, they affect the general characteristics of the lake water and the quantity of the lake biomass. Moreover, they provide habitats for other lake organisms, either by overgrowing the lake bottom as the deepest submerged vegetation or by spreading in shallow, littoral waterbodies, formed after periods of floods; charophytes colonize these waterbodies fast. They colonize the northern, north-eastern and eastern shore of the lake (Fig. 1), whose shoreline is shared by Montenegro (110.5 km) and Albania (57.5 km). The lake shore settled by charophytes is characterized by a wide flood zone, whose boundaries shift in accordance with the fluctuating level of water in the course of the year. In the wet winter and spring seasons, it is a vast floodplain, reduced to a significantly smaller surface during the droughty period in the summer. The silty and sandy limestone sediment of this part of the lake and the relatively calm waters, without big and frequent turbulences, with favourable chemical composition and neutral to slightly alkaline reaction (pH), largely meet the ecological requirements of charophytes. On the other hand, the southern and south-eastern rocky shoreline, in both the Montenegrin and the Albanian part, is very steep and basically scarcely occupied by aquatic plants in general, regardless of whether they are algae or vascular aquatic plants (Fig. 2). As far as this part of the lake is concerned, it is only in the bays that rich macrophytic vegetation has developed, where charophytes are rarely to be found, like, for example, at the site called Murići.

Lake Skadar/Shkodra, as the biggest lake in the Balkan Peninsula, is situated on the border between Montenegro and Albania, about two-thirds of the lake belonging to Montenegro and one-third to Albania. The surface of the lake amounts to 400 km^2, increasing by almost one-third of the total surface at the time of floods. The basic geomorphological, hydrological, pedological and physical-chemical characteristics of the lake make it a unique hydro-ecological system [1–3]. The geological foundation of Lake Skadar/Shkodra is composed of limestone and dolomites, with 37% of

Fig. 1 Emergent and floating vegetation in shallow coastal zone of the northern part of the lake (Photo by J. Blaženčić)

calcium carbonate [4, 5]. Based on that, as well as on the ratio of dissolved electrolytes, the lake belongs to the calcium bicarbonate type. The silt of the lake mostly contains over 75% of clay, while in some particular zones, as well as at the river confluences and in the bays, it is sand that is dominant [4].

For charophytes, and, generally, for the development and production of aquatic vegetation, the most important characteristics of Lake Skadar/Shkodra are as follows:

1. The lake is a cryptodepression, whose water level fluctuates in the course of the year from approximately 5 to 10 m, since it is filled with waters from the surrounding mountains during the winter and spring seasons, particularly from the Morača (and Zeta) Rivers, the Crnojevića River, and other smaller influxes and springs, as well as from numerous temporary and permanent karst springs, including sublacustrine springs, so-called oka ("eyes"), as much as up to 60 m deep [2, 6]. From the lake the water flows out through the Bojana/Buna River directly into the Adriatic Sea.
2. The lake is relatively shallow (its average depth being 5–8 m), surrounded by coastal sub-Mediterranean vegetation in the region of perhumid variant of south Adriatic Mediterranean climate of type V, according to [7]. This type of climate is characterized by abundant precipitation in the winter, spring and autumn months, by winters colder than those in the Adriatic coastal region, as well as by dry and hot summers, with daily temperatures often rising above 35°C.

Fig. 2 Steep rocky shoreline of the southern part of the lake and little bays with macrophytic vegetation (Photo by V. Stevanović)

3. Favourable climate conditions contribute to the great productivity of the lake, and its relative shallowness and polymictic thermal stratification enable the fast turnover or circulation of the produced biomass, which is why this basically eutrophic lake has the properties of an oligotrophic one [4].
4. A system of favourable ecological properties makes this lake the most significant charophyte diversity centre in the Balkan Peninsula. It is generally known that this lake is a hot spot of freshwater biodiversity in the Balkan Peninsula, which is of great importance for preserving both the lake (aquatic) flora and vegetation [5, 8, 9] and its fauna, particularly the endemic species of animals and plants.

With a view to preserving its living world, in 1983 Lake Skadar/Shkodra was designated a national park (IUCN category II – habitat/species management area) in Montenegro, while the part belonging to Albania was categorized as a Managed Nature Reserve (IUCN category IV) in 2005. In addition, the lake is considered to be one of Europe's largest reserves of wading birds and a resting place of migratory birds, which is why it was designated an Important Bird Area (IBA) in 1989. Since 1996, this lake has been included in the Ramsar List of Wetlands of International Importance.

Today, Lake Skadar/Shkodra is burdened by anthropogenic pollution, not only as an extremely attractive tourist destination and a place of recreational activities but also as a usable water supply resource, as well as a resource of other lake materials, which has led to secondary eutrophication, i.e. relatively moderate water pollution with organic compounds. Numerous lake organisms, including charophytes, are very sensitive to environmental changes, such as eutrophication, which is why certain changes can be expected in the future, both as regards their composition and the threat to the living world of this lake.

The first registered charophyte taxa in Lake Skadar/Shkodra are *Chara vulgaris* L. f. *montenegrina* Vilh. 1912 (sub *C. foetida* A. Br. f. *montenegrina* Vilh. 1912) and *Chara globularis* Thuill. f. *lacustris* Mig. 1897 (sub *C. fragilis* Desv. f. *lacustris* Mig.). They were found on the Plavnica site (11) and were described by Vilhelm in 1912 on the basis of the material collected by Rohlena on his botanical trips in Montenegro [10]. Most probably, this material originates from 1900, when it was recorded, according to Pulević's reconstruction that Rohlena had stayed in the region of Lake Skadar/Shkodra [11].

As far as the Montenegrin part of Lake Skadar/Shkodra is concerned, up until 1980s charophytes were sporadically mentioned in research papers on aquatic and wetland flora and vegetation [12]. Intensive and systematic research into charophytes in this part of the lake commenced in 1980s and has continued to date [13–25].

Data on charophytes in the Albanian part of Lake Shkodra/Skadar are of recent date and can mainly be found in research papers on the flora of freshwater algae of Albania [26–30] or the flora and ecology of aquatic macrophytes [31–34].

From the first data on charophytes in this lake to date, in the span of 105 years (1912–2017), out of the six known genera, representatives of four genera have been recorded, belonging to the order Charales, family Characeae: *Chara*, *Nitella*, *Tolypella* and *Nitellopsis*. All in all, 30 charophyte taxa were registered, in the rank of species, forms and varieties, with 13 identical species found both in the Montenegrin and the Albanian part of the lake. Charophytes belonging to these four genera are the permanent members of the macrophytic communities of the lake, particularly in its coastal area. In these communities, charophytes are most frequently companion species; it is only rarely that some of them are dominant or that they are edificatory species. In view of the fact that the entire lake is relatively shallow, particularly in the coastal area, charophytes are usually diffusely spread on the silty and sandy bottom, rarely creating smallish patches from their tender thalli.

Macrophytic vegetation of the lake is characterized by the zones of emergent, floating and submerged plants. In the zone of emergent plants, the dominant species are the following *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L.) Palla, *Typha angustifolia* L., *Butomus umbellatus* L., *Pycreus longus* (L.) Hay., *Sium latifolium* L., *Sparganium ramosum* Huds. The most represented floating macrophytes in the lake are *Nymphaea alba* L., *Nuphar luteum* (L.) Sm., *Polygonum amphibium* L., *Potamogeton natans* L., *Lemna minor* L. and others. It is important to mention that among the floating plants, there is also an endemo-relict plant *Trapa longicarpa* M. Jank. ssp. s*cutariensis* M. Jank., the subspecies of the genus *Trapa* (the water chestnut), which is restricted to Lake Skadar/Shkodra.

The most significant among the submerged species of the macrophytic vegetation of the lake are *Potamogeton perfoliatus* L., *P. lucens* L., *P. pectinatus* L., *P. crispus* L., *Myriophyllum spicatum* L., *Najas marina* L., *Ceratophyllum demersum* L., *Vallisneria spiralis* L.. and others. Charophytes overgrow the bottom of the lake, existing among vascular, i.e. higher aquatic, emergent, floating and submerged plants. The most represented charophytes are *Chara globularis* Thuill. 1799, *Chara virgata* Kütz. 1834, *Chara vulgaris* L. 1753, *Nitellopsis obtusa* (Desv. in Loisel.) J. Groves 1919, *Nitella opaca* (Bruzelius) C. Agardh 1824, *Nitella hyalina* (DC.) C. Agardh 1824, *Nitella mucronata* (A. Braun) Miq. in H.C. Hall 1840 emend. Wallman 1853, *Nitella syncarpa* (Thuill.) Chevall. 1827 and others [5, 14, 35, 36].

The micropaleontological investigations of fossil charophytes found in the Holocene sediment cores in the Albanian part of Lake Skadar/Shkodra yielded very interesting results. The findings show that the formation of this lake originates from a vast flat marshland that evolved into a lake some 2000 years ago [37]. Fossil charophytes were studied in the Holocene sediments from two sediment cores (SK 13 and SK 19) in the Albanian part of the lake [37, 38]. They were attested by the presence of extremely abundant gyrogonites (calcified oospores) whose morphology was previously illustrated based on living material [39]. According to these explorations, the charophyte vegetation appeared around 4,500 cal years BP. During the Middle Holocene, from 4,500 to 2000 cal years BP, the charophyte record was continuous in the southern, Albanian part of the Skadar/Shkodra basin, where a swamp area with locally shallow lakes developed. Charophytes disappeared from the eastern shore (core SK 19) of the lake during Roman times (2000 cal years BP). This change was related to amplified water turbidity related to deforestation, enhanced settlement and more intensive land use. In the western Albanian part of the lake (core SK 13), the Characeae disappeared a little later, around 1,274 cal years BP [37]. Four morphological types of charophyte gyrogonites were identified: *Lychnothamnus barbatus* (Meyen) Leonhardi 1863, *Nitellopsis obtusa*, *Chara aspera* Willd. 1809 and *Nitella hyalina*. Another one, and still undetermined gyrogonite, might belong to one of the endemic *Chara* species of the Balkans, i.e. *Chara ohridana* (Lj. Kostić) W. Krause 1997 or *Chara kokeilii* A. Braun 1847 [38]. *Lychnothamnus barbatus* and *Chara aspera* provided by far the most frequent gyrogonites, whereas *Nitellopsis obtusa* was rare. *Nitella hyalina* was represented by very rare, large oospores, characterized by a spongy outer wall. Surprisingly, *L. barbatus* has not been hitherto recorded living in Lake Skadar/Shkodra, although it is known from other lakes in the Balkans. The very typical gyrogonite morphology (illustrated by [39, 40]) leaves no doubt that the species has had a long record of occurrence in the area of Lake Skadar/Shkodra (through the period of the Middle Holocene). It may have disappeared probably because of human environmental disturbance or, possibly, it still grows in some parts of the lake that have not been explored.

2 Study Sites and Charophyte Sampling

Lake Skadar/Shkodra, as a shallow freshwater hydrographic system, with high annual amplitudes of water level fluctuation, is characterized by a prominent littoral zone or shore in the narrow sense of the word, a coastal zone and shallow coastal waters. The sites where charophytes were registered are situated in the northern, north-eastern and eastern parts of the lake; in the coastal zone; at the confluences of the rivers or springs and the lake; in the springs, wetlands and watercourses; as well as in the flood zone at the time of maximum water level. Charophytes were collected from the lake between 1979 and 2017, at 19 sites in the Montenegrin and 11 sites in the Albanian part of the lake (Fig. 3). At all the studied sites, charophytes grew in mixed macrophytic communities, together with other, especially vascular plants.

Field studies in the coastal zone were implemented by direct sampling of lake material from the shore, i.e. from the shallows. In deeper waters the transect method was applied. Plant samples were taken by specially constructed boathooks, i.e. grapnels attached to a rope on which metrage was marked (Fig. 4). Charophytes and other aquatic plants were collected along transects for each metre of depth, from the surface to the lower boundary of vegetation. The samples were fixed in 4% formaldehyde in plastic dishes and/or herbalized. Water transparency was measured in situ with a Secchi disk, and water reaction was determined by PEN pH metre with a scale from 0 to 14.

Voucher specimens (herbarium and/or wet collections) of charophytes were deposited in the Herbarium of the University of Belgrade (BEOU), the National Herbarium, the Faculty of Natural Sciences at the University of Tirana (TIR) and the Natural History Museum of Montenegro (NHMM).

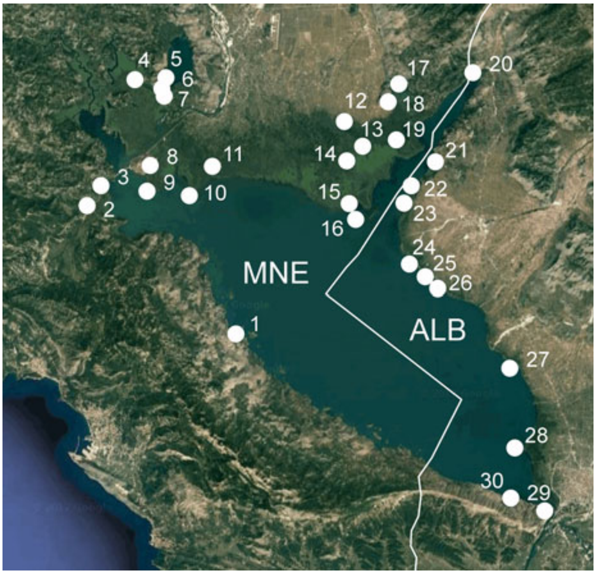

Fig. 3 Map of the lake with numbered sampling localities: Murići (1), Virpazar–Crmnička rijeka (2), Dabovići (3), Karatuna (4), Gornje Blato (5), Biševina (6), Šegrtica (7), Morača (8), Morača–ušće (9), Manastirska tapija–Pijesci (10), Plavnica (11), Zbelj–izvori (12), Zbeljska rijeka (13), Kujov brijeg (14), Crni Žar (15), Koraćica (16), Vitoja–izvori (17), Podhum–izvori (18), Pančeva oka (19), Gjiri Hotit (20), Shegan (21), Kosan (22), Kamice (23), Jubice (24), Sterbeq (25), Kalldrun (26), Grile (27), Bishti Qenise (28), Buna Bridge (29), Shiroka (30)

Fig. 4 Sampling tool, grapnel, with taken plant sample (Photo by J. Blaženčić)

Charophytes were determined by a stereo optical microscope. The specimens covered by a carbonate coating were previously treated by 5% hydrogen chloride (HCl), in order to remove the layers of calcium carbonate (CaCO3).

The species were identified with the following identification keys [41–49]. Furthermore, the identification of macrophytes, the aquatic plants with which charophytes grew, was implemented according to [50–53].

In the presentation of individual species, literature was cited for each piece of information, whereas for unpublished data, the authors cited the legator, the sampling time and the abbreviated name of the collection in which the specific charophyte was stored. In addition, each site at which a specific taxon was found is marked by a number in brackets, by which the site, i.e. the sampling point, is marked on the map of the lake. The map of the lake with numbered sampling localities is given in Fig. 3. The localities were georeferenced using Google Earth software, while the map was created using the R software [54, 55].

3 Ecology and Distribution of Charophytes

Based on our own field research, as well as gathered literature and herbarium data, Table 1 was compiled. It shows a list of charophyte species in Skadar/Shkodra Lake with their representation in Montenegrin and Albanian part of the lake.

Table 1 List of charophyte species in Skadar/Shkodra Lake with their representation in Montenegrin and Albanian part of the lake

No	Species	Montenegro	Albania
1	*Chara aspera*	+	
2	*Chara braunii*	+	
3	*Chara connivens*	+	+
4	*Chara contraria* (incl. f. *capillacea*)	+	+
5	*Chara fragifera*		+
6	*Chara globularis* (incl. f. *lacustris*)	+	+
7	*Chara kokeilii*	+	+
8	*Chara ohridana*	+	
9	*Chara rudis*	+	
10	*Chara tenuispina*	+	
11	*Chara virgata*	+	
12	*Chara vulgaris* (incl. var. *longibracteata*, var. *gymnophylla* and f. *montenegrina*)	+	+
Subtotal		11	6
1	*Nitellopsis obtusa*	+	+
Subtotal		1	1
1	*Nitella brachyteles*	+	
2	*Nitella capillaris*	+	
3	*Nitella confervacea*	+	+
4	*Nitella flexilis*	+	
5	*Nitella gracilis*	+	
6	*Nitella hyalina*	+	+
7	*Nitella mucronata*	+	+
8	*Nitella opaca*	+	+
9	*Nitella syncarpa*	+	+
10	*Nitella tenuissima*	+	+
Subtotal		10	6
1	*Tolypella glomerata*	+	+
2	*Tolypella prolifera*	+	
Subtotal		2	1
Total		24	14

In both the Montenegrin and the Albanian part of the lake, on the (northern to eastern) gently sloping shores, within the coastal aquatic and wetland vegetation, charophytes overgrow the bottom of the lake in a mosaiclike pattern, creating low patches, more or less scattered between submerged, floating and/or emergent macrophytes.

The overall number of registered charophytes in the entire studied area (the Montenegrin and Albanian parts of the lake) is 30 taxa, out of which 25 taxa are in the rank of species, 3 in the rank of variety and 3 in the rank of form. Out of that number, 12 species, 2 varieties and 3 forms belong to the genus *Chara*, 10 species belong to the genus *Nitella*, 2 species belong to the genus *Tolypella* and 1 species belongs to the genus *Nitellopsis*. In the Montenegrin part of the lake, there are 24 species, 1 variety (*Chara vulgaris* L. var. *gymnophylla* (A. Braun) Hy 1914) and 3 forms (*Chara contraria* f. *capillacea* Mig. 1897, *C. globularis* f. *lacustris* and *C. vulgaris* f. *montenegrina*), while in the Albanian part, there are 14 species and 1 variety (*Chara vulgaris* L. var. *longibracteata* (Kütz.) J. Grov. Bull.-Web. 1924). It is interesting to mention that 13 identical species were found both in the Montenegrin and the Albanian part of the lake, namely, 6 of the genus *Nitella*, 5 of the genus *Chara*, 1 species of the genus *Tolypella* and 1 of the genus *Nitellopsis*. However, some differences in the composition of charophytes from the Montenegrin and the Albanian part of the lake were identified, so that the species *Chara fragifera* Durieu 1859 has hitherto been found only in the Albanian part of the lake, while it was only in the Montenegrin part that six species of the genus *Chara* were identified (*C. aspera*, *Chara braunii* C. C. Gmel. 1826, *C. ohridana*, *Chara rudis* A. Braun in Leonh. 1882, *Chara tenuispina* A. Braun 1835, *C. virgata*), with one variety and three forms, as well as four species of the genus *Nitella* (*Nitella capillaris* (Krock.) J. Groves et Bull.-Webst. 1920, *Nitella flexilis* (L.) C. Agardh 1824, *Nitella brachyteles* A. Braun 1864 and *Nitella gracilis* (Sm.) C. Agardh 1824 and one species of the genus *Tolypella* (*Tolypella prolifera* (Ziz ex A. Braun) Leonh. 1863).

Family: *Characeae*
Subfamily: Chareae Leonh., 1863
Genus: *Chara* Vaillant, 1719

So far the largest number of charophyte taxa of the genus *Chara* has been identified in Lake Skadar/Shkodra, namely, 12 species, 2 varieties and 3 forms. In the Montenegrin part of the lake, 11 species of the genus *Chara*, 3 forms and 1 variety were identified, while in the Albanian part, 6 species and 1 variety of this genus were found. The species of the genus *Chara* (as well as the representatives of the genera *Nitella*, *Tolypella* and *Nitellopsis*) colonize the coastal zone of the lake, where the water is mainly calm and transparent, growing on a silty and sandy sediment. In the coastal area, especially in the bays, the species of the genus *Chara* grow protected against the turbulent water (undulating water) by other aquatic plants. The populations of the species *Chara* were also identified in the slow-running springs, in the watercourses and at the confluences of the rivers, karst springs and peatbogs, as well as the water depressions retaining water after it withdraws from flooded areas during the dry season of the year. The largest number of species was registered at a depth of 0.5–2.5 m, rarely deeper than that – as was the case with the species *Chara vulgaris* var. *gymnophylla* – recorded at a depth of 3.0 m in the Karatuna River (4) (Fig. 5).

The species of the genus *Chara* are the most frequent community members in the mixed macrophytic communities *Scirpo-Phragmitetum* W. Koch. 26, *Nymphaeetum albo-luteae* Nowinski 1928, *Eleochari-Hippuridetum* Passag. 55, *Potametum perfoliati* Lakušić 1976, *Potametum pectinati* Carasten 1955 and *Potameto-Najadetum* H_ić et Mic. 60. However, the species of this genus also form charophyte communities *Charetum fragilis* Corillion 1957 and *Chareto-Nitellopsidetum obtusae* J. & Ž. Blaž. 1983 [5, 14].

Fig. 5 The locality Karatuna in Montenegro where *Chara vulgaris* var. *gymnophylla* was found at 3 m depth (Photo by J. Blaženčić)

The most frequently identified species in the lake is *C. globuralis*, found at ten sites in the Montenegrin part of the lake and at seven sites in the Albanian part. The species *Chara virgata* was also registered at ten sites, but only in the Montenegrin part of the lake. The species *C. vulgaris* was identified at seven sites in the Montenegrin part and five sites in the Albanian part of the lake. The remaining nine species of the genus *Chara* were most frequently found only at one or at three sites at most. Among the rarely found species of the genus *Chara*, there are also those registered back in 1980, such as *C. braunii*, *C. rudis* and *C. tenuispina*. These species were found 37 years ago at the Plavnica site (11) and have never been registered again anywhere in the lake.

The most significant data on the presence of the species of this genus in Lake Skadar/Shkodra have been gathered on the basis of some recent studies. After a long time, in 2017 a new finding site of the species *Chara connivens* Salzm. ex A. Braun 1835 in this lake was registered at the site Manastirska tapija – Pijesci (10). Moreover, in 2005, at the site Karatuna (4) and Manastirska tapija – Pijesci (10), the species *Chara ohridana*, until then unregistered in Lake Skadar/Shkodra, was recorded as well. Furthermore, in the Albanian part of the lake, new finding sites were registered: for the species *Chara connivens*, the Kamice site (23), found in 1998; for the species *Chara contraria* A. Braun ex Kütz. 1845, the Shegan site (21), found in 2003, and Gjiri Hotit (20), found in 2016; and for *C. kokeilii* registered at the Jubice site (24) in 2013. Especially striking is the presence of the species *Chara fragifera* at the site Kalldrun (26), where it was found in 1996, as well as at the site Shegan (21), where it was collected in 2003. The Kalldrum and Shegan sites are the only two known sites of *C. fragifera*, not only in Lake Skadar but generally in the aquatic habitats of Montenegro and Albania.

Furthermore, the presence of a significant number of the species of the genus *Chara* in the Montenegrin part of the lake, as compared to the Albanian part, is most likely the result of years of exploration in this part of the lake, including a large number of sites along the lake.

***Chara aspera* Willd. 1809**

Chara aspera was found only at the Plavnica site (11) at this lake, although it is generally widespread in various aquatic habitats in Montenegro [25]. It grows along the shore and watercourses, in the shallows between the submerged parts of reed (*Phragmites australis*) and rushes (*Schoenoplectus lacustris*), on silty, clay or sandy deposit [14]. *C. aspera* forms populations with the species *Nitella gracilis*, *N. syncarpa*, *N. opaca*, *Nitellopsis obtusa*, *Tolypella glomerata* (Desv.) Leonh. 1863, *Chara kokeilii* and the vascular plants of the community *Potametum perfoliati* [5].

Localities:

Montenegro: Plavnica (11): [14, 18, 25, 56].

***Chara braunii* C. C. Gmel. 1826**

Chara braunii was identified only at one place in Lake Skadar/Shkodra, in the slow-running shallow water of the rivulet Plavnica, nearby its confluence with the lake. The sediment on which it grows is silty or sandy. At this site its populations are protected by emergent plants, dominated by the species *Phragmites australis* and *Schoenoplectus lacustris*.

Although in most cases charophytes are the indicators of good water quality, there are some species of these algae which can endure a higher degree of organic pollution (e.g. *Chara vulgaris*). Such species also include *Chara braunii*, whose presence in habitats indicates that the water is enriched by organic substances. Typical habitats for this species are fishponds, ricefields and flood zones of lakes and rivers – precisely the biotopes characterized by a higher quantity of organic substances in their waters [46, 57]. Therefore, its presence in Lake Skadar/Shkodra, although of local nature and within a small population, indicates that the waters of the site Plavnica are characterized by intense eutrophication. *Chara braunii* grows with the species *Nitellopsis obtusa*, *Chara vulgaris*, *C. rudis* and *Potamogeton pectinatus*.

Localities:

Montenegro: Plavnica (11): [25]

***Chara connivens* Salzm. ex A. Braun 1835**

Chara connivens exists at several places in Lake Skadar in Montenegro (10, 11), as well as in Albania (23), in the usual conditions characteristic of this lake (water of neutral reaction, silty or sandy substrate in the coastal shallows). At the finding site in Albania, only male plants were registered, while in Montenegro both male and female plants were found. *Chara connivens* most often grows in mixed populations with the species *Chara vulgaris*, *Nitella confervacea* (Bréb.) A. Braun ex Leonh. 1863, *Najas marina*, *Najas minor* All., *Vallisneria spiralis*, *Potamogeton perfoliatus*, *P. lucens*, *P. pectinatus*, *P. acutifolius* Link, *P. pusillus* L., *P. crispus* and *Myriophyllum spicatum.*

Localities:

Montenegro: Plavnica (11): [14, 15, 25]; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 28. 06. 2012, 08. 07. 2017, Leg. V. Biberdžić, 08. 07. 2017.* NHMM

Albania: Kamice (23): Leg. *L. Kashta, 10. 06. 1998.* TIR

Chara contraria A. Braun ex Kütz. 1845

Chara contraria was registered in the calm, slow-running waters at the confluence of the rivers Morača (9) and Crmnica near Virpazar (2) in the Montenegrin part of the lake, as well as in the shallows (0.5 m) at the sites Shegan (21) and Gjiri Hotit (20) in the Albanian part of the lake. It grows on detritus, silty or silty-sandy substrate, in community with the species *Nitella hyalina*, *N. opaca*, *N. flexilis*, *N. mucronata*, *Nitellopsis obtusa*, *Chara globularis*, *C. ohridana*, *Najas minor*, *N. marina*, *Vallisneria spiralis*, *Potamogeton pusillus*, *P. pectinatus*, *Zannichellia palustris* L. and *Eleocharis acicularis* (L.) Roem. & Schult.

Localities:

Montenegro: Morača–ušće (9): [25]; Leg. *V. Biberdžić, 12. 09. 1998*. NHMM, Plavnica (11): [25]; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001.* NHMM; Karatuna (4): Leg. *V. Biberdžić, 16. 05. 2002, 11. 09. 2005, 23. 09. 2007.* NHMM; Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 04. 08. 2001*. NHMM

Albania: Shegan (21): Leg. *L. Kashta, 04. 05. 2003*. TIR; Gjiri Hotit (20): Leg. *L. Kashta 25. 09. 2016*. TIR

Chara contraria f. capillacea Mig. 1897

Just like the previous species, *Chara contraria f. capillacea* was recorded in the slow-running shallows at the confluences of the rivers Crmnica and Morača with the lake (2, 8) on a sandy (the Morača) and silty substrate (the Crmnica). It grows in a population with the species *Nitella opaca*, *N. flexilis*, *N. mucronata*, *Nitella tenuissima* (Desv.) Kütz. 1843, *Chara virgata*, *C. globularis*, *Eleocharis acicularis*, *Zannichellia palustris* and *Riccia fluitans* L. f. *terrestris* C. Jens.

Localities:

Montenegro: Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 20. 05. 2001.* NHMM, Leg. *V. Biberdžić, 29. 07. 2001.* NHMM; Morača (8): Leg. *V. Biberdžić, 14. 06. 2006.* NHMM

Chara fragifera Durieu 1859

Chara fragifera was found only at two sites in the Albanian part of the lake. At the Kalldrun site (26), it grows in the coastal, sandy shallows, while at the Shegan site (21), it was found near a karst spring. At this locality, only male plants were observed [28].

Localities:

Albania: Kalldrun (26): [28]; Shegan (21): Leg. *L. Kashta, 04. 05. 2003*. TIR

***Chara globularis* Thuill. 1799**

The species *Chara globularis* was registered at a large number of sites in the coastal area of the Montenegrin and the Albanian part of the lake, in different habitats (along the rivers, in the springs, watercourses, pools, peatbogs, karst springs). At all the sites where it was found, it grew on various substrates – detritus, silt, sand or sand mixed with silt – at the depth between 0.2 and 2.5 m. Apart from being detected in different habitats, *C. globularis* participates in the formation of a large number of aquatic communities, such as *Scirpeto-Phragmitetum*, *Sparganio-Glicerietum* Br.-Bl.25, *Potametum pectinati*, *Charetum fragilis*, *Chareto-Nitellopsidetum obtusae* and *Potametum perfoliati* [14]. In these communities, it most often grows together with the charophytes *Chara vulgaris*, *C. rudis*, *C. kokeilii*, *C. contraria*, *C. virgata*, *C. ohridana*, *Nitellopsis obtusa*, *Nitella syncarpa*, *N. opaca*, *N. gracilis*, *N. capillaris* and *Tolypella prolifera* and with numerous higher aquatic plants, such as *Riccia fluitans f. terrestris*, *Sagittaria sagittifolia* L., *Alisma plantago-aquatica* L., *Nymphaea alba*, *Nuphar luteum*, *Vallisneria spiralis*, *Potamogeton perfoliatus*, *P. lucens*, *P. pectinatus P. pusillus*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Najas marina*, *N. minor* and others.

Localities:

Montenegro: Plavnica (11): [10, 14, 15, 18, 22, 25, 46, 56, 58–61]; Leg. *V. Biberdžić, 12. 09. 1998; 22. 07. 2001, 22. 07. 2001*, *18. 08. 2001, 17. 06. 2017*. NHMM; Crni Žar (15): Leg. *V. Biberdžić, 18. 10. 2001*. NHMM; Koraćica (16): [25]; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001*. NHMM; Virpazar–Crmnička rijeka (2): [25]; Leg. *O. Vizi, 26. 06. 2001;* Leg. *V. Biberdžić, 29. 07. 2001, 04. 08. 2001,* NHMM; Murići (1): Leg. *V. Biberdžić, 08. 08. 2001*. NHMM; Gornje Blato (5): Leg. *V. Biberdžić, 16. 05. 2002, 23. 09. 2007*. NHMM; Karatuna (4): Leg. *V. Biberdžić, 16. 05. 2002, 11. 09. 2005, 24. 08. 2005, 16. 10. 2005, 23. 09. 2007*. NHMM; Kujov brijeg (14): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Podhum–izvori (18): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM

Albania: Buna Bridge (29): [27]; Jubice (24): [27]; Shegan (21): [27]; Leg. *L. Kashta, 07. 07. 1999*. TIR; Leg. *L. Kashta, 25. 09. 2001*. TIR; Leg. *L. Kashta, 08. 2013*. TIR; Shiroka (30): Leg. *V. Zeneli, 28. 07. 2015*. TIR; Grile (27): Leg. *L. Kashta, 06. 1996*. TIR; Kamice (23): Leg. *V. Zeneli, 28. 07. 2015*. TIR; Bishti Qenise (28): Leg. *L. Kashta, 24. 09. 2016*. TIR

***Chara globularis* Thuill. f. *lacustris* Mig. 1897 (sub *Chara fragilis* Desv. f. lacustris Mig.)**

This taxon was recorded by Vilhelm in 1912 [10], on the basis of the material brought to him by the Czech botanist J. Rohlena from his botanical trips in Montenegro. According to [11], Rohlena was in the area of Virpazar in 1901, which is why this year can be considered the year when the first charophytes were sampled in the region of Lake Skadar/Shkodra in Montenegro.

Localities:

Montenegro: Plavnica (11): [10].

Chara kokeilii A. Braun 1847

The species *Chara kokeilii* was found only at two places in Lake Skadar/Shkodra – at the confluence of the river Plavnica (11) in Montenegro and at the Jubice site (24) in Albania (Fig. 6).

It grows in the coastal parts of the lake, protected against winds and water undulations by the emergent and submerged macrophytic vegetation of the community *Potametum perfoliati*. The samples were collected at the depth of 1.0 and 2.0 m, from a silty substrate. This charophyte most often grows together with other charophytes, such as *Chara globularis*, *C. vulgaris*, *C. tenuispina*, *Nitella syncarpa*, *N gracilis*, *N. capillaris*, *N. confervacea*, *Tolypella prolifera* and *T. glomerata*, as well as with different aquatic plants, such as *Potamogeton perfoliatus*, *P. lucens*, *P. pectinatus*, *P. acutifolius*, *P. pusillus*, *P. crispus*, *Myriophyllum spicatum*, *Najas marina* and *N. minor.*

Localities:

Montenegro: Plavnica (11): [14, 21, 22, 25, 46, 62]
Albania: Jubice (24): Leg. *V. Zeneli, 24. 06. 2013*. TIR

Chara ohridana (Lj. Kostić) W. Krause 1997

Lake Skadar/Shkodra is a new finding site of the Balkan endemic species *Chara ohridana*. The samples of *C. ohridana* were collected at the sites Manastirska tapija – Pjesci (10) and Karatuna (4) in the Montenegrin part of the lake. Its mosaiclike patches, growing on a sandy substrate, were noted at the depth of 2.0–3.0 m, at places with no water undulations. Apart from a large number of shells of freshwater mussels *Dreissena polymorpha* attached to the thallus *C. ohridana*, the following frequent submerged species of charophytes grew together with

Fig. 6 The habitus of *Chara kokeilii* (Photo by M. Petrović-Đurić)

C. ohridana, *Nitella hyalina*, *Nitellopsis obtusa*, *Chara globularis* and *C. contraria*, as well as the vascular macrophytes *Najas minor*, *N. marina*, *Vallisneria spiralis*, *Potamogeton pusillus*, *P. pectinatus* and others.

Localities:

Montenegro: Manastirska tapija–Pjesci (10): [25]; Karatuna (4): Leg. *V. Biberdžić, 11. 09. 2005.* NHMM

Chara rudis A. Braun in Leonh. 1882

The perennial robust *Chara rudis* was recorded in the slow-running waters of the confluence of the Plavnica River and the lake, at the depth of 0.2–2.5 m, on a silty substrate or detritus. This species is a member of the plant community *Charetum fragilis*, where it grows together with the plants *Chara vulgaris*, *Sagittaria sagittifolia*, *Ranunculus aquatilis* L., *Alisma plantago-aquatica*, *Potamogeton pectinatus*, *P. acutifolius*, *P. pusillus* and *Myriophyllum spicatum*.

Localities:

Montenegro: Plavnica (11): [14, 15, 18, 25, 56]

Chara tenuispina A. Braun 1835

Chara tenuispina colonizes shallow waters, up to 1.0 m deep, growing on a silty or silty-sandy substrate. In the community *Potametum perfoliati*, it grows together with the species *Chara globularis*, *C. vulgaris*, *C. kokeilii*, *Nitellopsis obtusa*, *Nitella gracilis*, *N. capillaris*, *N. syncarpa*, *N. confervacea*, *Tolypella prolifera*, *T. glomerata*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton crispus*, *P. perfoliatus*, *P. lucens*, *Najas marina* and *N. minor* [13, 14].

Localities:

Montenegro: Plavnica (11): [14, 15, 25]

Chara virgata Kütz. 1834

Chara virgata inhabits the coastal area of the lake, as well as the shallows of the slow-running rivulets in the flood zone of the lake, as well as the shallow springs and peatbogs. It grows on detritus, silt or a silty-sandy substrate, at the depth of up to 2 m. This species often found grouped with other charophytes, such as *Nitellopsis obtusa*, *Chara vulgaris*, *C. globularis*, *Nitella syncarpa*, *N. capillaris*, *N. hyalina*, *N. gracilis*, *N. opaca* and *Tolypella prolifera*, and different aquatic plants like *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Potamogeton perfoliatus*, *P. pectinatus*, *Zannichellia palustris*, *Najas marina*, *Najas minor* and *Utricularia vulgaris* L.

Localities:

Montenegro: Plavnica (11): [25]; Leg. *V. Biberdžić, 12. 09. 1998, 22. 07. 2001, 18. 08. 2001, 14. 06. 2006, 17. 06. 2017*. NHMM; Crni Žar (15): Leg. *V. Biberdžić, 18. 10. 2001*. NHMM; Manastirska tapija–Pjesci (10): Leg. *V. Biberdžić, 28. 06. 2012*. NHMM; Virpazar–Crmnička rijeka (2): Leg. *O. Vizi, 26. 06. 2001*. NHMM; Leg. *V. Biberdžić, 29. 07. 2001*, *15. 08. 2001*. NHMM; Gornje Blato (5): [25]; Leg. *V. Biberdžić, 16. 05. 2002, 23. 09. 2007.* NHMM; Karatuna (4): [25]; Leg. *V. Biberdžić, 16. 05. 2002; 16. 10. 2005*. NHMM; Kujov brijeg (14):

Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Zbelj–izvori (12): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Podhum–izvori (18): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Vitoja–izvori (17): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM

***Chara vulgaris* L. 1753**
Chara vulgaris is registered at six sites in the Montenegrin part of the lake (2, 10, 11, 12, 17 18) and five sites in the Albanian part of the lake (21, 23, 26, 27, 29). It most frequently colonizes the coastal sides of the lake at the depth of 0.2–2.5 m, at places protected by vascular macrophytes against crashing waves. Besides, it was also found in the slow-running waters of watercourses, at the confluence of the rivers and the lake, in the streams and springs and on detritus, silt or clay substrates. It is a member of the mixed plant communities *Scirpeto-Phragmitetum*, *Nymphaeetum albo-luteae*, *Potametum pectinati*, *Charetum fragilis*, *Chareto-Nitellopsidetum obtusae* and *Potametum perfoliati*. In these communities it most often grows together with the species *Nitellopsis obtusa*, *Chara globularis*, *C. virgata*, *C. rudis*, *C. tenuispina*, *Nitella syncarpa*, *N. gracilis*, *N. capillaris*, *N. opaca*, *N. confervacea*, *Tolypella prolifera* and *T. glomerata*, as well as the vascular plants *Schoenoplectus lacustris*, *Typha angustifolia*, *Sagittaria sagittifolia*, *Phragmites australis*, *Sparganium ramosum*, *Nymphaea alba*, *Nuphar luteum*, *Potamogeton pectinatus* and others.

Localities:

Montenegro: Plavnica (11): [14, 15, 18, 21, 25, 56]; Leg. *V. Biberdžić, 05. 09. 1997, 12. 09. 1998*, *30. 05. 2001, 22. 07. 2001*, *18. 08. 2001*. NHMM; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001*. NHMM; Virpazar–Crmnička rijeka (2): Leg. *O. Vizi, 26. 06. 2001,* NHMM; Zbelj–izvori (12): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Podhum–izvori (18): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Vitoja–izvori (17): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM

Albania: Buna Bridge (29): [27]; Kalldrun (26), Grile (27): [28]; Kamice (23): Leg. *L. Kashta, 10. 06. 1998*. TIR; Shegan (21): Leg. *L. Kashta, 12. 06. 1996*. TIR; Leg. *V. Zeneli, 29. 07. 2015*. TIR.

***Chara vulgaris* L. var. *longibracteata* (Kütz.) J. Grov. Bull.-Web. 1924**
Chara vulgaris var. *longibractea* was registered only in the Albanian part of the lake, at the sites Buna Bridge (29) and Grile (27), in habitats of the same ecological properties as those inhabited by *C. vulgaris* var. v*ulgaris*. Its talus contains numerous specimens of the mussel *Dreissena blanci*.

Localities:

Albania: Buna Bridge (29): [28]; Grile (27): [27, 28]; Leg. *V. Zeneli, 28. 06. 2015*. TIR.

***Chara vulgaris* L. f. *montenegrina* Vilh. 1912 (sub *Chara foetida* A. Br. f. *montenegrina* Vilh. 1912)**
This form of the species *Chara vulgaris* f. *montenegrina* was registered by Vilhelm in the periodically flooded part of the lake, at the Plavnica site (11), back in 1912. More than eight decades later, in 1998, its existence was confirmed at the same site;

at the confluence of the Plavnica River and the lake; in the slow-running, almost stagnant, water; and on a silty substrate. Furthermore, in 1998, several other species such as *Chara globularis*, *C. virgata* and *Potamogeton pusillus* were found at Plavnica together with *C. vulgaris* f. *montenegrina.*

Localities:

Montenegro: Plavnica (11): [10]; Leg. *V. Pustahija, 12. 09. 1998*. NHMM

***Chara vulgaris* L. var. *gymnophylla* (A. Braun) Hy 1914**

Chara vulgaris var. *gymnophylla* was noticed in the flood zone of Lake Skadar/Shkodra, at the Šegrtica site (7), in the clear waters of the Karatuna River, at the depth of 2.0–3.0 m and on a silty-sandy bottom, densely overgrown with submerged aquatic plants. *C. vulgaris* var. *gymnophylla* grew with the species *Nitellopsis obtusa*, *Ceratophyllum demersum*, *Najas marina*, *Myriophyllum spicatum* and *Zannichellia palustris* and with some rare specimens of the species *Potamogeton lucens.*

Localities:

Montenegro: Šegrtica (7): Leg. *V. Biberdžić, 11. 09. 2005*. NHMM

Family:	*Characeae*
Subfamily:	*Chareae* Leonh. 1863
Genus:	*Nitellopsis* Hy. 1889

***Nitellopsis obtusa* (Desv. in Loisel.) J. Groves 1919**

The monotypic genus *Nitellopsis* has been represented in Lake Skadar/Shkodra with the freshwater species *N. obtusa*, which can sometimes also be found in brackish waters. In Montenegro it was only registered in this lake (Fig. 7). In Albania, it has been recorded aslo from Ohrid and Prespa lakes [31, 63]. It colonizes the coastal parts of the lake, most frequently growing at places protected by floating or emergent vegetation against winds and crashing waves. The same species was also recorded in the slow-running waters of the watercourses, at the river confluences and in the flood zone of the lake. It grows on a silty substrate, at the depth of 0.5–3.0 m, in the lake water of neutral or weak alkaline reaction. The maximum depth at which the populations of *N. obtusa* can develop depends on its competitive "struggle" for light with the floating and emergent plants surrounding it (*Nymphaea alba*, *Trapa longicarpa* ssp. *scutariensis*, *Phragmites australis*), as well as on its rivalry with the submerged vascular plants (*Ceratophyllum demersum*, *Myriophyllum spicatum*) in the battle for space.

An interesting community was noticed at the Plavnica site (11) – *Chareto-Nitellopsidetum obtusae* J. & Ž. Blaž. 1983, where *Nitellopsis obtusa* and *Chara vulgaris* are edificatory species [14]. *N. obtusa* most often grows with charophytes such as *Chara globularis*, *C. vulgaris*, *C. rudis*, *C. contraria*, *C. ohridana*, *Nitella capillaris* and *N. hyalina*, as well as the vascular floating and submerged plants *Sagittaria sagittifolia*, *Nymphaea alba*, *Nuphar luteum*, *Trapa longicarpa* ssp. *scutariensis*, *Najas marina*, *N. minor*, *Ranunculus aquatilis*, *Vallisneria spiralis*, *Potamogeton perfoliatus*, *P. lucens*, *P. pectinatus*, *P. pusillus*, *P. crispus*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Zannichellia palustris* and others [13–15, 21, 31].

Fig. 7 The sample of *Nitellopsis obtusa* (Photo by J. Blaženčić)

Localities:

Montenegro: Plavnica (11): [14, 21, 25]; Dabovići (3): [15, 25]; Leg. *V. Biberdžić, 04. 08. 2001.* NHMM; Koraćica (16): [25]; Karatuna (4): [25]; Leg. *V. Biberdžić, 16. 05. 2002*, *16. 10. 2005, 24. 08. 2005, 11. 09. 2005, 23. 09. 2007, 16. 10. 2005.* NHMM; Gornje Blato (5): [25]; Leg. *V. Biberdžić, 23. 09. 2007*. NHMM; Biševina (6): Leg. *V. Biberdžić, 23. 09. 2007.* NHMM; Šegrtica (7): Leg. *V. Biberdžić, 11. 09. 2005.* NHMM; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001, 28. 06. 2012, 02. 08. 2012*. NHMM; Crni Žar (15): Leg. *V. Biberdžić, 18. 10. 2001.* NHMM; Pančeva oka (19): Leg. *V. Biberdžić, 02. 08. 2012, 31. 07. 2017*. NHMM; Skadar/Shkodra Lake: [46]
Albania: Bishti Qenise (28): [32]; Leg. *L. Kashta, 24. 09. 2016.* TIR; Sterbeq (25): [31]

Family: Characeae
Subfamily: *Nitelleae* Leonh. 1863
Genus: *Nitella* Ag. 1824

During several decades of research, ten species of the genus *Nitella* were registered. Individual or several species of this genus are most frequently and predominantly present in the almost stagnant waters at the confluences of the rivers, streams, karst springs and watercourses – always in the coastal part of the lake. They were found in relatively shallow waters, at the depth of 0.1–2.0 m. However, in the Montenegrin part of the lake, the species *Nitella opaca* was registered at the depth of 2.5–3.0 m, at the locality Dabovići (3), while in the Albanian part of the lake, *N. syncarpa* was found at the depth of 4.5 m, at the locality Bishti Qenise (28). The species of the genus *Nitella* grow on a silty or sandy-silty substrate. They are frequently members of the mixed communities *Potametum pectinati* Carasten 1955 and *Potametum perfoliati* Lakušić 1976. In these communities, they overgrow the bottom of the lake in mosaiclike patterns, at places where the vegetation is thinned out and where light reaches the lake bed bottom, unhindered by floating vascular plants. In these communities, the species of the genus *Nitella* grow with other charophytes, most often with the species *Chara globularis*, *C. kokeilii*, *Nitella capilaris*, *Tolypella glomerata* and *T. prolifera*. Noteworthy, the species *Nitella hyalina* and *N. opaca* were the most frequently recorded. Namely, the species *N. hyalina* was registered at seven sites in the Montenegrin and two in the Albanian part of the lake, while the species *N. opaca* was registered at seven sites in the Montenegrin and four in the Albanian part of the lake. In addition, it is important to note that these two species are invariably present in all the findings ever since 1980 until today. In contrast, the other *Nitella* species, such as *N. brachyteles*, *N. capillaris*, *N. flexilis* and *N. tenuissima*, were recorded only at one or two sites. Moreover, some of them have not been registered for a relatively long period. For example, the species *N. brachyteles* and *N. tenuissima* were recorded for the last time 16 years ago (2001), *N. flexilis* was recorded 12 years ago (2005) and *N. capillaris* 10 years ago (2007). In this respect, the mentioned species could almost be regarded as endangered, but in order to reach such a definitive conclusion, detailed studies would have to be undertaken, both at their earlier sites and at the entire lake shore colonized by charophytes.

So far more species of *Nitella* have been found in the Montenegrin (10) than in the Albanian (six) part of the lake. This can be explained by the longer shoreline studied, a larger number of explored localities, greater diversity of habitats and a longer period of research in the Montenegrin than in the Albanian side of the lake. Nevertheless, a significant number of species of the genus *Nitella*, sensitive to increased organic water pollution, and a considerable number of sites (22) where they were found testify to the still relatively favourable hydrological, i.e. general ecological conditions in Lake Skadar/Shkodra.

The species of the genus *Nitella* were registered at 22 of 30 studied sites in the lake, namely, 13 sites in the Montenegrin and 9 sites in the Albanian part of the lake, along the entire northern and eastern shore of the lake. The largest number of species was recorded at the Plavnica site (nine), although the findings date back from the period before the construction of the tourist complex. Due to the construction, and later to the massive use of the tourist facilities in the summer period, the habitat has been disrupted, together with the richest community of charophytes in this lake.

Nitella brachyteles A. Braun 1864

Nitella brachyteles was found in the Montenegrin part of the lake, at the confluence of the Crmnica River near Virpazar, at the depth of 1.5 m, in the areas with more favourable light regime, in macrophytic vegetation, between the white (*Nymphaae alba*) and the yellow water lily (*Nuphar luteum*).

Localities:

Montenegro: Virpazar, Crmnička rijeka (2): [25]

***Nitella capillaris* (Krock.) J. Groves et Bull.-Webst. 1920**

Nitella capillaris was registered in the Montenegrin part of the lake in the coastal part of the Plavnica River, at its confluence with the lake, at the depth of 0.7–2.0 m. It thrives there as the member of the community *Potametum perfoliati.* At this site, *N. capillaris* forms underwater meadows together with other charophytes, giving specific appearance to the vegetation of the lake bottom, usually in association with the species of the genus *Tolypella*.

Localities:

Montenegro: Plavnica (11): [13–15, 18, 21, 25, 56]; Leg. *V. Biberdžić, 14. 06. 2006*. NHMM

***Nitella confervacea* (Bréb.) A. Braun ex Leonh. 1863**

Nitella confervacea was reported from several sites on the lake shore, as well as at the confluences of the rivers Plavnica and Crmnica (in the Montenegrin part), as well as in the streams Bishti Qenise and Shiroka (in the Albanian part), at the depth of 0.2–1.5 m. It grows in mixed plant communities together with the numerous species of all the four genera of charophytes characteristic of the lake, as well as with various macrophytes, dominated by *Potamogeton perfoliatus* [14, 28].

Localities:

Montenegro: Plavnica (11): [14, 18, 22, 25, 56]; Murići (1): Leg. *V. Biberdžić, 08. 08. 2001*. NHMM; Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 15. 08. 2001*. NHMM; Gornje Blato (5): Leg. *V. Biberdžić, 23. 09. 2007.* NHMM; Leg. *M. Jovićević 18. 09. 2016.* NHMM; Karatuna (4): Leg. *V. Biberdžić, 23. 09. 2007.* NHMM; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 29. 08. 2012, 08. 07. 2017*. NHMM; Leg. *V. Biberdžić, 18. 10. 2001*. NHMM

Albania: Shiroka (30): [27, 28]; Bishti Qenise (28): [27]

***Nitella flexilis* (L.) C. Agardh 1824**

Nitella flexilis grows in the coastal area of the Montenegrin part of the lake and in the area of the lake tributaries, both in very shallow waters (0.3 m), at places without either emergent or floating vascular plants (the banks of the Crmnica River near Virpazar), and in deeper waters (2.5 m), where it thrives in mixed communities together with other charophytes, such as *Chara globularis*, *C. vulgaris*, *C contraria*, *C. virgata*, *Nitella opaca*, *N. gracilis*, *N. mucronata* and *N. hyalina*, and vascular plants, such as *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Najas minor*, *Potamogeton lucens*, *P. pusillus* and *Vallisneria spiralis.*

Localities:

Montenegro: Plavnica (11): [18, 25]; Virpazar–Crmnička rijeka (2): [25]; *Leg. V. Biberdžić, 20. 05. 2001.* NHMM; Karatuna (4): Leg. *V. Biberdžić, 16. 10. 2005.* NHMM

Nitella gracilis (Sm.) C. Agardh 1824

Nitella gracilis colonizes the coastal zone of the Montenegrin part of the lake, especially at places where waterbodies retain water in the periods of low water levels. It was observed that it formed cushion-like patches on the silty bottom, at the confluence of the Plavnica River, within the plant communities *Scirpeto-Phragmitetum* W. Koch 1926 and *Potametum perfoliati* Lakušić 1976, at the depth of 2.0 m, together with other charophyte species [14].

Localities:

Montenegro: Plavnica (11): [14, 18, 21, 22, 25, 56]; Crni Žar (15): Leg. *V. Biberdžić, 18. 10. 2001.* NHMM; Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 15. 08. 2001.* NHMM; Gornje Blato (5): Leg. *V. Biberdžić, 16. 05. 2002, 23. 09. 2007.* NHMM

Nitella hyalina (DC.) C. Agardh 1824

Nitella hyalina was observed both in the Montenegrin and the Albanian part of the lake. In the Montenegrin part, it occurred in different habitats at a large number of sites, in the coastal part of the lake (11, 2, 15, 16), at the river banks or confluences (2, 8) or in the wetlands (5), while in the Albanian part of the lake, it was found in shallow waters between emergent (*Schoenoplectus lacustris*, *Phragmites australis*) and floating plants (*Trapa longicarpa* ssp. *scutariensis*) (Fig. 8). This species forms small, fragile and tender patches, but even underwater meadows

Fig. 8 The locality Koshan in Albania where *Nitella hyalina* was found (Photo by L. Kashta)

Fig. 9 Part of the talus of *Nitella hyalina* (Photo by V. Biberdžić)

(Fig. 9), in shallow waters, up to 0.3 m deep. In the mixed populations of the community *Scirpo-Phragmitetum*, it grows with other charophytes (*Nitellopsis obtusa*, *Nitella opaca*, *N. gracilis*, *N. confervacea*, *Chara globularis*, *C. virgata*, *C. contraria*, *C. ohridana*), as well as with vascular plants (*Schoenoplectus lacustris*, *Najas minor*, *N. marina*, *Hippuris vulgaris* L., *Vallisneria spiralis*, *Potamogeton pusillus*, *P. pectinatus*, *P. crispus*, *Myriophyllum spicatum*, *Ceratophyllum demersum*).

Localities:

Montenegro: Plavnica (11): [22, 46, 56]; Virpazar–Crmnička rijeka (2): [25]; Gornje Blato (5): [25]; Leg. *V. Biberdžić, 16. 05. 2002,* Leg. *V. Biberdžić, 23. 09. 2007.* NHMM; Koraćica (16): [25]; Manastirska tapija–Pijesci (10): [25]; reka Karatuna (4): [25]; Leg. *V. Biberdžić, 11. 09. 2005, 16. 10. 2005, 23. 09. 2007*, NHMM; Crni Žar (15): Leg. *V. Biberdžić, 18. 10. 2001*. NHMM

Albania: Kosan (22): Leg. *L. Kashta, 10. 08. 2010.* TIR; Leg. *L. Kashta, 04. 08. 2016*, TIR; Bishti Qenise (28): Leg. *L. Kashta, 24. 09. 2016.* TIR

***Nitella mucronata* (A. Braun) Miq. in H.C. Hall 1840 emend. Wallman 1853**

Nitella mucronata was present in the Montenegrin part of the lake at the confluences of the Crmnica River, the Plavnica River as well as in Zbeljska Rijeka. Furthermore, it frequently colonizes the coastal area of the Albanian part. This species grows at the depth of up to 2 m, on a silty, clay and sandy sediment, in the water of neutral and weak alkaline reaction. *N. mucronata* lives in mixed populations with other charophytes (*Nitella opaca*, *N. syncarpa*, *Tolypella prolifera*, *Chara globularis*, *C. virgata*, *C. vulgaris*) and with higher aquatic plants (*Ceratophyllum demersum*, *Potamogeton pusillus*, *Spirodela polyrhiza* (L.) Schleiden, *Ricciocarpos natans* (L.) Corda, *Riccia fluitans f. terrestris*, *Utricularia vulgaris*, *Potamogeton lucens*, *P. perfoliatus*, *Najas marina*).

Localities:

Montenegro: Plavnica (11): [14, 18, 23, 25]; Leg. *V. Biberdžić, 17. 06. 2017*. NHMM; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001*. NHMM; Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 20. 05. 2001, 04. 08. 2001, 15. 08. 2001*. NHMM; Zbeljska rijeka (13): Leg. *V. Biberdžić, 23. 05. 2002*. NHMM; Kujov brijeg (14): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM

Albania: Grile (27): Leg. *V. Zeneli, 24. 06. 2013*. TIR

***Nitella opaca* (Bruzelius) C. Agardh 1824**

Nitella opaca was recorded in the coastal area of the Montenegrin and the Albanian part of the lake, at the depth of 0.2–2 m. In addition, it was also found in the habitats at the river confluences with the lake, in the rivulets of the lake flood zone and in the watercourses and karst springs. It grows on silt or sand. At most sites, both male and female plants were present [26, 27]. *N. opaca* is a member of the communities *Potametum pectinati* Carnsten 1955 and *Charetum fragilis* Corillion 1957, registered at the Plavnica site (11) [14]. In the habitats where it can be found, it forms underwater meadows [14, 21, 46] with other species of charophytes (*Nitellopsis obtusa*, *Chara globularis*, *C. contraria*. *C. vulgaris*, *Nitella syncarpa*, *N. mucronata*, *Tolypella prolifera*) in the places with more light among vascular plants (*Trapa longicarpa* ssp. *scutariensis*, *Najas marina*, *N. minor*, *Nymphaea alba*, *Nuphar luteum*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton pectinatus*, *P. pusillus*, *Zannichellia palustris*).

Localities:

Montenegro: Plavnica (11): [14, 18, 25, 56, 61]; *Leg. V. Biberdžić, 30. 05. 2001, 22. 07. 2001, 18. 08. 2001*. NHMM; Dabovići (3): [21, 25]; Virpazar–Crmnička rijeka (2): Leg. *V. Pustahija, 20. 05. 2001*. BEOU; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001*. NHMM; Karatuna (4): Leg. *V. Biberdžić, 16. 05. 2002,* NHMM; Podhum–izvori (18): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM; Vitoja–izvori (17): Leg. *V. Biberdžić, 12. 07. 2012*. NHMM

Albania: Shiroka (30): [26]; Shegan (21): [27]; Gjiri Hotit (20): Leg. *L. Kashta, 25. 09. 2016*. TIR; Bishti Qenise (28): Leg. *L. Kashta, 25. 09. 2016*. TIR

***Nitella syncarpa* (Thuill.) Chevall. 1827**

Nitella syncarpa occurred in different habitats in the coastal area of the lake, in the watercourses, springs and streams and in the zone of flood meadows. It grows in stagnant or slow-running clear waters and on detritus, silt or silt mixed with sand. This species colonizes shallow waters of up to 0.5 m [28], although it can be more frequently found at greater depths of 1.5–4.5 m [14, 27, 32]. Together with other charophytes (*Chara globularis*, *C. kokeilii*, *C. vulgaris*, *C. vulgaris* var. *longibracteata*, *C. virgata*, *Nitella gracilis*, *N. capillaris*, *N. confervacea*, *Tolypella prolifera*, *T. glomerata*, *Nitellopsis obtusa*) and vascular plants (*Nuphar lutea* (L.) Sm., *Najas marina*, *Potamogeton perfoliatus*, *Vallisneria spiralis*), *N. syncarpa* is a member of the communities *Scirpeto-Phragmitetum* W. Koch 1926 and *Potametum perfoliati* Lakušić 1976. In the zone of flood meadows, at the confluence of the Plavnica River, it was found growing together with the species *Spirodela polyrhiza*, *Ricciocarpos natans*, *Riccia fluitans* f. *terrestris*, *Utricularia vulgaris* and *Vallisneria spiralis* [23].

Localities:

Montenegro: Plavnica (11): [21, 22, 25, 46]; Leg. *V. Biberdžić, 30. 05. 2001, 18. 08. 2001, 05. 06. 2005, 14. 06. 2006.* NHMM; [23]; Manastirska tapija–Pijesci (10): Leg. *V. Biberdžić, 18. 08. 2001.* NHMM; Vitoja–izvori (17): Leg. *V. Biberdžić, 27. 07. 2006.* NHMM

Albania: Grile (27): [27, 28]; Jubice (24): [27, 32]; Shiroka (30): [32]; Bishti Qenise (28): [32]

***Nitella tenuissima* (Desv.) Kütz. 1843**

Nitella tenuissima was recorded in the coastal area of the Montenegrin and the Albanian part of the lake. It was also registered at the confluence of the Crmnica River near Virpazar. It usually grows at the depth of 0.2–1.0 m, in the water of neutral to weak alkaline reaction, on a silty-sandy substrate. This species forms mixed populations with the charophytes *Chara virgata*, *C. globularis*, *C. contraria* f. *capillacea* and *Nitella opaca* and with higher aquatic plants, such as *Eleocharis acicularis*, *Zannichellia palustris*, *Riccia fluitans* f. *terrestris*, *Potamogeton pusillus*, *P. crispus* and *P. lucens* [18, 61].

Localities:

Montenegro: Plavnica (11): [18, 22, 25, 61]; Virpazar–Crmnička rijeka (2): Leg. *V. Biberdžić, 29. 07. 2001, 15. 08. 2001.* NHMM

Albania: Sterbeq (25): [26]; Shegan (21): [27]

Family:	*Characeae*
Subfamily:	*Nitelleae* Leonh., 1863
Genus:	*Tolypella* A. Br. em. von Leonh., 1876

Only two species of the genus *Tolypella* have been found in Lake Skadar/Shkodra, namely, *T. glomerata* and *T. prolifera*. Both species were recorded in the Montenegrin part of the lake at the confluence of the Plavnica River site (11). However, in the Albanian part of the lake, it was only *T. glomerata* that was registered at the Shegan site (21). Like the majority of other species of charophytes, both species of the genus *Tolypella* grow in the coastal area in shallow waters (0.2–1.0 m), on a silty or sandy substrate. Their presence at the Plavnica site (11) is striking; there they define the main appearance of the charophyte vegetation of the lake bottom, together with the species of the genus *Nitella*. Both species of the genus *Tolypella* are members of the mixed plant community *Potametum perfoliati*, where they grow with other representatives of charophytes, namely, *Chara globularis*, *C. vulgaris*, *C. tenuispina*, *C. kokeilii*, *Nitella gracilis*, *N. capilaris*, *N. syncarpa* and *N. confervacea*, overgrowing the bottom in mosaiclike patterns at places where macrophytic vegetation is thinned out [14, 33].

It should be mentioned that *Tolypella glomerata* and *T. prolifera* were first recorded at the Plavnica site in 1980. When the construction of the "Plavnica" tourist complex began in 1998, this charophyte habitat was destroyed, and many species which had been earlier recorded at Plavnica site were never found again. Nevertheless, the species *T. prolifera* was found again at this site in 2001, which is a good sign that this habitat is recovering and that the gradual restoration of the floristically richest charophyte community of the lake can be expected. In the Albanian part of the lake, at the Shegan site (21), the presence of *T. glomerata* was recorded in 2003 [33]. Future research should confirm this finding site and most likely discover new ones.

Interestingly, the site Plavnica (11) at Lake Skadar/Shkodra is the only place where the species of this genus can be found in Montenegro. However, in Albania, *Tolypella glomerata* is not limited to Lake Skadar/Shkodra but is also recorded on two other localities: Velipoja [28] and Tepelena (Leg. *L. Kashta 16. 04. 2010* TIR). Bearing in mind that the species' presence at the lake has so far been recorded only at two sites, Plavnica (11) and Shegan (21), and knowing that Plavnica (Montenegro) has been significantly degraded by anthropogenic activities, as well as that both species colonize a small area, it is clear that their survival in this lake is threatened. The uncertain survival of these species adversely affects the maintenance of the overall charophyte diversity of Lake Skadar/Shkodra.

4 Importance of Charophytes for Lake Skadar/Shkodra Biota

From the first discovery of charophytes in Lake Skadar/Shkodra to the intensive research of these algae in the course of the twentieth and the beginning of the twenty-first century, the total of 25 species were recorded, accounting for 40% of the charophyte flora of Europe (62 species) and 53% of the charophyte flora of the Balkans (47 species), i.e. around 60% of this algae flora of Western and Central Balkans (42 species) [19]. This percentage rises to as much as 81% if the number of charophytes in Lake Skadar/Shkodra (25) is compared to the number of charophytes of Montenegro (31 species) or 93%, if it is compared to the total number of charophytes of Albania (27).

Lake Skadar/Shkodra contains charophytes belonging to the genera *Chara*, *Nitellopsis*, *Nitella* and *Tolypella*. All the registered taxa mainly colonize shallow, calm, almost stagnant waters and can most frequently be found at the depth of 1.5–2.0 m and rarely at greater depths. They can much more often be found in shallow waters (up to 0.5 m), especially in the aquatic habitats formed in the flooded areas along the lake shore and its rivers – tributaries. The genus *Chara* is represented by 17 taxa (12 species, 3 forms and 2 varieties), *Nitella* by 10 species, *Tolypella* by 2 species and *Nitellopsis* by only 1 species. At almost all 19 sites in the Montenegrin part of the lake and 11 sites in the Albanian part, the following species were present:

Chara globularis, *C. virgata*, *C. contraria*, *C. vulgaris*, *Nitella opaca* and *N. syncarpa*. However, the species *Chara aspera*, *C. braunii*, *C. kokeilii*, *C. ohridana*, *C. rudis*, *C. fragifera*, *Nitella opaca*, *N. capillaris*, *Tolypella glomerata* and *T. prolifera* were also found, although extremely rarely. Of exceptional significance is the new discovery of the endemic species *Chara ohridana* in this lake, as yet another site among the rare habitats of this Balkan charophyte [64]. Furthermore, the species *Nitella hyalina* was also recorded in Lake Skadar/Shkodra, as a charophyte rarely found in the Balkan Peninsula. So far it has been registered only at several sites in Croatia [65, 66], Macedonia (in the river Drim, in the village Struga, Leg. *J. Blaženčić, 15. 09. 2009*) and Greece [67]. However, the species *N. hyalina* was registered at seven sites in the Montenegrin part of the lake and at two sites in the Albanian part. Apart from that, *Chara fragifera*, so far known to grow only in the flood zones around the Danube in Romania [68], was found in the Albanian part of the lake. Such discoveries made Lake Skadar/Shkodra an important charophyte diversity centre in the Balkans.

The charophytes of Lake Skadar/Shkodra are mainly members of several mixed aquatic plants communities. Among them the communities *Nymphaeetum albo-luteae*, *Potametum pectinati*, *Charetum fragilis* and *Chareto-Nitellopsidetum obtusae* [14] are characterized by the largest number and most diverse composition of charophytes.

Charophyte fasciae are almost always of mixed composition, and only very rarely are one or two species dominant, as is the case with *Chara globularis* in the community *Charetum fragilis* or *Chara vulgaris* and *Nitellopsis obtusa* in the community *Chareto-Nitellopsidetum obtusae*. The populations of these species are usually more or less diffusely spread across the lake bottom in mosaiclike patterns; these patches are denser at places with more light, between spaced out floating macrophytes, or at unoccupied places at the lakebed, between the underwater stems and rhizomes of vascular plants.

The ratio between the genera *Chara* and *Nitella*, as two most numerous genera of the family Characeae, can be important for the characterization and general hydrological properties of the aquatic habitats of charophytes. Thus, according to the literature available [64, 65, 69], in some lakes in the Balkan Peninsula, the ratio between the species of the genus *Chara* and the species of the genus *Nitella* is 2:1 (Baćinska lakes in Croatia), or 4:1 (Lake Ohrid in Macedonia), or even 7:1 (Plitvice Lakes in Croatia), which is why these lakes can be characterized as "*Chara*-type" lakes. In contrast, in Lake Skadar/Shkodra, the number of the species of the genus *Chara* (12) and the number of the species of the genus *Nitella* (10) are almost equal, i.e. 1:1. It is certain that future studies, conducted even more thoroughly and including a larger number of sites, will define more conclusively the representation of these two genera in this lake. Based on the data collected so far (indicating a slight prevalence of the taxa belonging to the genus *Chara*), we can only speculate about certain trends concerning the composition of charophytes in the lake, which could somewhat affect or even change Krause's assumption that Lake Skadar/Shkodra is a "*Nitella*-type" lake [22].

The species recorded in this lake most often include those which are geographically widespread, such as *Chara vulgaris*, *C. globularis* and *C. contraria*. However, the presence of charophytes which are rarely found around the world, and only at a small number of sites, such as the species *Chara kokeilii*, is of utmost importance for the general status of Lake Skadar/Shkodra. This species was registered in some places in Europe (Denmark, Austria and Hungary) [22, 44, 70, 71]. In the Balkan Peninsula, the mentioned species was registered at several sites in Macedonia (Lake Ohrid, [64]), Greece (the lake on the island of Evia, [72]), Bulgaria (the Black Sea coast, [73]) as well as in the Montenegrin and the Albanian part of Lake Skadar/Shkodra (*Leg. V. Zeneli, 24. 06. 2013.* TIR). At all these sites, this charophyte is barely surviving, forming small populations, and threatened by extensive tourism and/or pronounced eutrophication of water. According to the IUCN Red List Categories and Criteria, it is classified as a critically endangered (CR) species, at high risk of global extinction [19, 73].

Furthermore, the species *Tolypella glomerata*, *T. prolifera* and *Chara fragifera* were rarely observed in the aquatic ecosystems of the Balkans [19]. These species most often colonize small, shallow and ephemeral waterbodies (ponds, wetlands, recesses in a foundation), and more rarely lakes. They start and end their growth and development within a short time span in the spring, before their habitats dry out. In Lake Skadar/Shkodra they were found in shallow coastal waters and in aquatic habitats in the flood zones.

The presence of certain species in Lake Skadar/Shkodra, such as the Balkan endemic species *Chara ohridana*, points to the diversity of charophyte flora of this lake and to the importance of maintaining its overall floristic (and faunistic) composition and diversity. The endemite *C. ohridana* was registered in Macedonia in Lake Ohrid and Lake Prespa, in the Crni Drim River and in the puddles around Lake Dojran [16, 46, 63, 74], in Greece (Leg. *A. Hospers, 29. 05. 2001*. Herbarium et Leiden in the Netherlands), and in Albania, i.e. in the Albanian part of Lake Prespa (Leg. *A. & M. Hospers 29. 05. 2001*. Herbarium et Leiden in the Netherlands [31, 64] and Ohrid Lake [63]). In Lake Ohrid, in Macedonia, this species colonizes both the coastal zone and the deeper parts of the lake (over 9 m), where it often forms monospecies communities [64]. In contrast to this, in Lake Skadar/Shkodra, at a new finding site of this species in the Balkans, *C. ohridana* grows individually or in small patches in the mixed community *Scirpo-Phragmitetum* at the depth of up to 3 m. It should be mentioned that this species is at risk of extinction at all sites where it has been found until now, except for those at Lake Ohrid. This is mainly due to the fact that its populations are fragmented and restricted to a small number of localities which are under considerable anthropogenic influence (eutrophication, extensive tourist development, recreational activities). Such precarious life conditions have already decided the fate of *C. ohridana* in the lake Dojran in Macedonia. The uncontrolled use of lake water for agricultural purposes, the consequent lowering of water level and the drying out of the ponds where this species grew led to disappearance of *C. ohridana* from its sites around the lake Dojran [75].

In general, the number of charophytes species, size and diversity of their populations and/or settlements as well as their proportional representation in an aquatic ecosystem expressed in percents clearly indicate the overall characteristics of an aquatic habitat, the state of its preservation and the threat to it [76]. Alltogether, they are considered to be the indicators of clean waters. However, Lake Skadar/Shkodra contains both the charophytes which are the bioindicators of clean and unpolluted waters and those which are tolerant of an increased presence of nutrients. Thus, for instance, the species *Chara virgata* and *C. rudis* grow exuberantly in waters with low levels of nutrients [77, 78], while the species *Chara globularis*, *C. vulgaris*, *C. braunii* and *Nitella mucronata* are very tolerant of an increased presence of dissolved organic matters. The abundance of charophytes of different ecological requirements and possibilities leads to the conclusion that hydrological conditions in the lake are still relatively favourable despite the fact that this lake has been under strong anthropogenic pressure in the last several decades. Unfavourable anthropogenic activity is conducive to changing the composition and distribution of certain species of both vascular aquatic plants and charophytes. The most striking change has so far been noted at the confluence of the Plavnica River, where abundant charophyte populations and once lush macrophytic vegetation vanished (Figs. 10 and 11). In contrast, other species became invasive in ecologically changed conditions, such as *Trapa longicarpa* ssp. *scutariensis* and *Elodea canadensis*, which massively conquered and overgrew certain parts of the Albanian section of the lake [31]. Such changes affect the development and presence of a number of other organisms and are among extremely dangerous factors particularly endangering submerged plants and the overall charophyte flora of Lake Skadar/Shkodra.

Fig. 10 The locality Plavnica in 1980 (Photo by J. Blaženčić)

Fig. 11 “Plavnica” tourist complex in 2007 (Photo by J. Blaženčić)

5 Concluding Remarks

The analysis of the floristic data accumulated in the course of several decades of research of charophytes in Lake Skadar/Shkodra brought to light valuable scientific information and insight: (a) a significant number of charophyte taxa were determined (30), which shows this lake to be the important charophyte diversity centre in the Balkan Peninsula; (b) new finding sites of certain charophytes were found; and (c) the endemic species *Chara ohridana*, unobserved so far, was recorded. However, it was also noted that some species disappeared from once abundant finding sites (e.g. Plavnica), as a result of anthropogenic activity, i.e. the use of attractive parts of the lake for touristic purposes. According to data from 1979 and 1980, eight mixed plant communities were described at the Plavnica site, in which 14 species of charophytes from the genera *Nitella* (5), *Tolypella* (2) and *Chara* (5) were registered and 1 species of the genus *Nitellopsis* [14]. From 2001 to 2017, the presence of only two species of the genus *Nitella* (*N. confervacea*, *N. opaca*), two species of the genus *Chara* (*C. virgata* and *C. vulgaris*) and one species of the genus *Tolypella* (*Tolypella prolifera*) was observed at the same site. The factors endangering the flora of Lake Skadar/Shkodra include the urbanization of the coastal area, secondary eutrophication of the lake by chemicals used in agriculture and industrial zones, disposal of waste arising from intensive and extensive tourism, activation of waterways, and drying out of aquatic plant habitats.

In order to safeguard the diversity of charophytes and the overall floristic composition of the lake, it is of *utmost importance to urgently undertake protective activities*: (1) preserve the area of natural coastal vegetation, (2) control and prevent the inputs of wastewater into the drainage basin of the lake, (3) avoid/limit the use of sublacustrine springs for water supply, and (4) control and prevent introduction of invasive species. These measures are absolutely fundamental to the restoration and maintenance of the richness of charophytes in Lake Skadar/Shkodra, which then also witness for the clean water of the lake.

Acknowledgments We are indebted to Dr. Ingeborg Soulié-Märsche (Université de Montpellier-II) for her constructive and precious assistance in the interpretation of the micropaleontological investigations of fossil charophytes found in the Albanian part of Skadar/Shkodra basin. We also wish to express our gratitude to Professor Vladimir Stevanović for his valuable comments and advice. The expert technical assistance of Ms. Milica Petrović Đurić is gratefully appreciated, and we thank Dr. Dag Hjermann (Norwegian Institute for Water Research) for his help in making the map of localities. A. Vesić was supported by The Ministry of Education, Science and Technological Development of Serbia (Projects Nos. 173030 and 172001).

References

1. Petrović G (1981) Chemical investigation of water and sediments of Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University of Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 68–96
2. Beeton A (1981) Physical conditions of Lake Skadar and its Basin. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University of Veljko Vlahović, Institute of Biological and Medicine Research, Titograd, Montenegro, pp 15–17
3. Lasca N, Radulović V, Ristić R, Cherkauer D (1981) Geology, hydrology, climate and bathymetry of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University of Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 17–38
4. Nedeljković R (1959) Skadarsko jezero – studija organske produkcije u jednom karstnom jezeru. Doktorska disertacija, Prirodno-matematički fakultet Univerziteta u Beogradu
5. Lakušić R, Pavlović D (1981) Assitiations of Lake Skadar aquatic vegetation. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University of Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 125–133
6. Radulović V (1983) Prilog poznavanju položaja i veličine sliva Skadarskog jezera i njegovo hranjenje i pražnjenje vodama. In: Ivanović B (ed) Skadarsko jezero, radovi sa simpozijuma. CANU Naučni skupovi, Titogad 9, pp 45–56
7. Walter H, Lieth H (1967) Klimadiagramm – Weltatlas. VEB Gustav Fischer, Jena
8. Blaženčić J, Blaženčić Ž (1986) Flora i vegetacija algi razdela *Charophyta* u planinskim jezerima Crne Gore. CANU, Glasnik Odeljenja prirodnih nauka 5:187–203
9. Radović I, Radović I, Radović D, Jakšić P, Džukić G, Stevanović V, Bulić Z, Bušković V (2008) Skadar lake region and “Target species” species of Europea conservation concern. In: III international symposium of ecologists of Montenego – the book of abstracts and programme, pp 32–34
10. Vilhelm J (1912) Zweiter Beitrag zur Kenntnis der Charophytenflora von Montenegro und Bulgarien. Hedwigia 53:23–35
11. Pulević V (2006) Botaničari i Crna Gora. Prirodnjački muzej Crne Gore, Posebna Izdanja, Knjiga 2, Podgorica

12. Lakušić R, Pavlović D (1976) Vegetacija Skadarskog jezera. Glas Republ Zav Zašt Prir – Prirod Muz 9:45–50
13. Blaženčić J (1984) Rasprostranjenje i ekologija vrste *Nitella gracilis* (Smith) Ag. (Nitellaceae) u Jugoslaviji. Glasn Inst Bot Bašte Univ Beograd 18:31–36
14. Blaženčić J, Blaženčić Ž (1983) Fitocenološka studija zajednica *Charetum fragilis Corillion* 1957 i *Chareto-Nitellopsidetum obtusae* J. Blaž. ass. Nova kod Plavnice, na Skadarskom jezeru. Glas Rep Zavoda Zašt Prir – Prirod Muz, Titograd 16:7–13
15. Blaženčić J, Blaženčić Ž (1983) Prilog poznavanju Charophyta Skadarskog jezera. In: Ivanović B (ed) Skadarsko jezero, radovi sa simpozijuma, Titograd, 30 Octobar–01 Novembar 1983. CANU Naučni skupovi, Titograd 9, pp 259–264
16. Blaženčić J, Blaženčić Ž (2003) An overview of the existing data on living charophytes (Charales) of the Balkan peninsula. Acta Micropalaeontol Sin 20(2):103–110
17. Blaženčić J, Blaženčić Ž, Cvijan M, Stevanović B (1990) Systematics and biogeographic studies of charophytes in Yugoslavia. Cryptogam Algol 1(4):249–256
18. Blaženčić J, Blaženčić Ž, Ljaljević M (1996) Jezera Nacionalnih parkova prethodne Jugoslavije – riznice diverziteta Charophyta. Ekologija Beograd 31(2):37–48
19. Blaženčić J, Stevanović B, Blaženčić Ž, Stevanović V (2006) Red data list of Charophytes in the Balkan. Biodivers Conserv 15:3445–3457
20. Blaženčić J, Stevanović B, Blaženčić Ž, Stevanović V (2006) Distribution and ecology of charophytes recorded in the West and Central Balkans. Cryptogam Algol 27(4):311–322
21. Blaženčić J, Cvijan M (1980) *Nitellopsis* Hy (*Tolypellopsis* Mig.) – novi rod za floru Jugoslavije iz razdela Charophyta. Glas Rep Zavoda Zašt Prir – Prirod Muz 13:7–13
22. Krause W (1990) Zum Neufund der *Chara kokeilli* A. Br. im Skutarisee. Carinthia II 180(100):705–713
23. Biberdžić V, Dragićević S, Blaženčić J (2006) *Ricciocarpos natans* (L.) Corda. A new liverwort for the flora of Montenegro. Natura Montenegrina 5:9–14
24. Talevska M, Petrović D, Milošević D, Talevski T, Marić D, Talevska A (2009) Biodiversity of macrophyte vegetation from Lake Prespa, Lake Ohrid and Lake Skadar. In: XI anniversary scientific conference with interntional attendance. 120 years of academic education in biology, 45 years faculty of biology. “Biology-Traditions and Challenges”, Sofia, vol 23, pp 931–935
25. Blaženčić J, Stevanović B (2015) Katalog harofita (Charales) Crne Gore. Crnogorska akademija nauka i umjetnosti, Odjeljenje prirodnih nauka 10:1–51
26. Kashta L (1994) Kontribut per algofloren e ujrave te embla te Shqiperise. Bul Shk Nat 1:63–67
27. Kashta L (2009) Flora harofite (Charophyta) e rajonit të Shkodrës. Universiteti i Shkodrës “Luigj Gurakuqi”, Bul Shk, Ser. Shk Nat 59:97–106
28. Rakaj M, Kashta L (1999) Te dhena mbi algat e gjelbra (*Chlorophyta*) te Liqenit te Shkodres. Studime Biologjike 1:107–118
29. Rakocevic-Nedovic J, Rakaj M (2001) Algae. In: Pulevic V, Hadžiablahovic S, Kasom G, Rakocevic-Nedovic J, Nikcevic S, Pešic V, Ražnatovic A, Cirovic R, Saveljic D, Buškovic V, Dhora D, Kashta L, Sokoli F, Haxhiu I, Bino T, Bego F, Smajlaj R, Rakaj M (eds) Biodiversity database of the Shkodra/Skadar Lake. Checklist of species. The Regional Environmental Center for Central and Eastern Europe, Szentendre. Activity 3.2.1
30. Zeneli V, Kashta L (2016) Some Charophyta (Charales) from coastal temporary ponds in Velipoja area (North Albania). J Environ Sci Eng B 5:69–77
31. Kashta L, Rakaj M (2014) Macrophytes of lakes Prespa and Shkodra. Final report for Albania. In: Initial characterisation of Lakes Prespa, Ohrid and Shkodra/Skadar. Implementing the EU water framework directive in South-Eastern Europe. Deutsche Gesellschaft für Zusammenarbeit (GIZ) GmbH, Bonn
32. Zeneli V, Kashta L (2014) Ecological status assessment of Shkodra Lake using aquatic macrophytes. Int J Ecosyst Ecol Sci 4(3):457–480
33. Kashta L, Rakaj M, Zeneli V (2015) The diversity of aquatic macrophytes in the transboundary lakes of Shkodra, Ohrid and Prespa - Albanian part. Bul Shk Nat Universiteti i Tiranës 20:28–39
34. Peveling R, Brämick U, Densky H, Parr B, Pietrock P (eds) (2015) Initial characterisation of Lakes Prespa, Ohrid and Shkodra/Skadar. Implementing the EU water framework directive in South-Eastern Europe. Deutsche Gesellschaft für Zusammenarbeit (GIZ) GmbH, Bonn

35. Ristić J, Vizi O (1981) Synopsis survey of the dominant macrophytes in Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University of Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 68–96
36. Janković MM (1983) Kasaronja (*Trapa* L.) na Skadarskom jezeru i potreba njene zaštite. Skadarsko jezero Zbornik referata sa Simpozijuma o Skadarskom jezeru u organizaciji Crnogorske akademije nauka i umjetnosti, Titograd. 30–31.X i 1.XI 1980
37. Mazzini I, Gliozzi E, Galaty M, Bejko L, Sadori L, Soulie-Märsche I, Koci R, van Welden A, Bishati S (2016) Holocene evolution of Lake Shkodra: multidisciplinary evidence for diachronic landscape change in northern Albania. Quat Sci Rev 136:85–95
38. Mazzini I, Gliozzi E, Koci R, Zanchetta G, Soulie Märsche I, Baneschi I, Sadori L, Giardini M, Van Welden A, Bushati S (2014) Historical evolution and Middle to Late Holocene environmental changes in Lake Shkodra (Albania): new evidences from micropaleontological analysis. Palaeogeogr Palaeoclimatol Palaeoecol 419:47–59
39. Soulie-Märsche I (1989) Etude comparee de gyrogonites de Charophytes actuelles et fossiles et phylogenie des genres actuels, Revised edition. Imprimerie des Tilleuls, Millau
40. Soulie-Märsche I, Benammi M, Gemayel P (2002) Biogeography of living and fossil *Nitellopsis* (Charophyta) in relationship to new finds from Morocco. J Biogeogr 29:1–9
41. Corillion R (1957) Les Charophycées de France et d'Europe Occidentale. Bull Soc Sci Bretagne 32:1–499
42. Corillion R (1975) Flora des Charophytes (Characees) du Massif Armoricain et des contrees voisines d'Europe occidentale. In: Flore et vegetation du Massif Armoricain IV, Paris, pp 1–214
43. Wood RD, Imahori K (1964) A revision of the Characeae. II. Iconograph of the Characeae (with 394 icones). Verlag Von J. Cramer, Weinheim
44. Wood RD, Imahori K (1965) A revision of the Characeae. I. Monograph of the Characeae. J. Cramer, Weinheim
45. Gollerbah MM, Krasavina LK (1983) The determinant of the freshwater algae of the USSR. Charophytes - Charophyta, vol 14. Nauka, Leningrad
46. Krause W (1997) Charales (Charophyceae). In: Ettl H, Gärtner G, Heynig H, Mollenhauer D (eds) Süswasserflora von Mitteleuropa, vol 18. Gustav Fischer, Jena, Stuttgart, pp 1–202
47. Schubert H, Blindow I (2003) Charophytes of the Baltic Sea. The Baltic Marine Biologists publication, vol 19. A. R. G. Gantner Verlag Kommandigesellschaft, Ruggell
48. Cirujano S, Cambra J, Sánchez Castillo PM, Meco A, Flor Arnau N (2008) Flora Ibérica. Algas continentales. Carófitos (Characeae). Real Jardín Botánico, Madrid
49. Bazzichelli G, Abdelahad N (2009) Alghe d'aqua dolce d'Italia. Flora analitica delle Caroficee. Universita degli Studi di Roma 'La Sapienza', Roma
50. Tutin TG, Heywood VH, Burges NA, Moor DM, Valentine DH, Walters SM, Webb DA (eds) (1964–1980) Flora Europaea 1–5. Cambridge University Press, Cambridge
51. Josifović M (ed) (1970–1977) Flora SR Srbije I-IX. Srpska akademija nauka i umetnosti, Beograd
52. Pavletić Z (1968) Flora mahovina Jugoslavije. Institut za Botaniku Sveučilišta u Zagrebu, Zagreb
53. Petrov S (1975) Bryophyta Bulgarica clavis diagnostic. Academia Scientiarum Bulgaririca, Sofija
54. Kahle D, Wickham H (2013) ggmap: spatial visualization with ggplot2. R J 5(1):144–161
55. Core Team R (2017) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna
56. Blaženčić J, Blaženčić Ž, Lakušić D, Ranđelović V (1998) Phytogeographycal and ecological characteristics of the charophytes of the eadst Adriatic coast. Arch Biol Sci Belgrade 50(2):119–128
57. Bailly G, Schaefer O (2010) Guide illustré des Characées du nord-est de la France. Conservatoire Botanique National de Franche-Comté
58. Rakočević J (2000) Epifitske silikatne alge Skadarskog jezera. Magistarska teza. Biološki fakultet, Univerzitet u Beogradu, Beograd

59. Rakočević-Nedović J (2001) Epifitske silikatne alge Skadarskog jezera (Crna Gora, Jugoslavija). Poljoprivreda i šumarstvo 47(3–4):127–138
60. Rakočević-Nedović J (2002) Struktura i sezonska dinamika epifitskih dijatomskih zajednica na Plavnici (Skadarsko jezero). Natura Montenegrina 1:59–76
61. Urbaniak J, Ganka M, Blaženčić J (2008) *Nitella tenuissima* - a rare charophyte in Central and Southern Europe. Cryptogram Algol 29(2):161–171
62. Blaženčić J, Blaženčić Ž (2002) Rare and threatened species of charophytes (Charophyta) in Southeast Europe. Phytol Balcan 8(3):315–326
63. Kashta L, Perçini D, Molla O (2013) Data on the diversity and ecology of charophyte algae in Lake Ohrid. Bul Shk Nat Universiteti i Tiranës 15:142–150
64. Trajanovska S (2009) Taxonomy, ecology and status of charophyte flora (Charophyta) in the Ohird Lake. Docotral disertation, Faculty of natural sciences, Institut of Biology, University "Св. Кирил и Методиј", Skopje
65. Blaženčić J, Blaženčić Ž (2013) Charophytes of the Baćina lakes and surrounding freshwater localities (Dalmatia, Croatia). In: 4th Croatian botanical symposium with international participation. Book of abstracts, Split, 27–29 September 2013
66. Alegro A, Stanković S, Šegota V, van de Weyer K, Blaženčić J (2016) Macrophytic vegetation in the oligotrophic Mediterraean Lake Vrana (Island of Cres, Northern Adrisatic) – new insight after 50 years. Bot Serb 40(2):137–144
67. Koumpli-Sovantzi L (1997) The charophyte flora of Greece I. Flora Mediterr 7:173–177
68. Ionescu-Teculescu V (1970) Data asupra ecologiei unor Characeae din zona inundabilă a Dunării. Analele Univeritatii Bucuresti. Biol Vegetală 19:183–192
69. Blaženčić J, Blaženčić Ž, Cvijan M, Stevanović B (1991) Recherches ecologiques sur les Charophytes recoltes dans le Parc national des lacs des Plitvice. Bull Soc Fr Actual Bot 138(1):15–24
70. Filarszky N (1934) Enumeratio specierum et formarum Characearum in regionibus oppida Szeged hucusque cognitarum. Folia Cryptog 1(10):1307–1316
71. Urbaniak J, Blaženčić J (2012) SEM study of oospore characteristics in endemic and endangered Balkan Charopphytes. Cryptogam Algol 33(3):277–288
72. Langangen A (2010) Some charophytes (Charales) collected on the island of Evia, Greece in 2009. Flora Mediterr 20:149–157
73. Temniskova D, Stoyneva M (2015) Algae. Critically endangered. *Chara kokeilii* A.Braun, *Tolypella intricate* (Roth) Leonh. In: Golemansky V (ed) Red data book Republic of Bulgaria, Vol. 1. Plant and Fungi. Bulgarien Academy of Sciences, Mynistry of Environment and Waters of Bulgaria, Sofia
74. Lj K (1936) Prinos poznavanju haraceja Ohridskog jezera i okoline. Acta Bot Inst Bot Univ Zagreb 11:63–84
75. Blaženčić J, Blaženčić Ž (1999) Doiran Lake charophytes. God Zb Biol 52:83–92
76. Pukacz A, Pelechaty M, Pelehata A (2013) The relation between charophytes and habitat differentiation in temperate lowland lakes. Pol J Ecol 61(1):105–118
77. Melzer A (1999) Aquatic macrophytes as tools for lake management. Hydrobiologia 395:181–190
78. Penning WE, Mjelde M, Dudley B, Hellsten S, Hanganu J, Kolada A, van den Berg MS, Poikane S, Phillips G, Willby N, Ecke F (2008) Classifyng aquatic macrophytes as indicators of eutrophication in European lakes. Aquat Ecol 42(2):237–251

The Diversity of the Flora and Vegetation of Lake Skadar/Shkodra

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Contents

Abstract Research on the vascular flora of the Lake Skadar basin started in the middle of the nineteenth century when the German botanist Wilhelm Ebel visited this area in 1841. Based on the available literature and our unpublished data, a total of 1,396 taxa from 131 families and 588 genera have been reported from the area of the Lake Skadar National Park. The chorological structure showed that the Mediterranean-Sub-Mediterranean (28.7%) and Eurasian (24.9%) groups dominate. A phytogeographical analysis of the biological spectrum of the vascular flora revealed that hemicryptophytes (33.6%) and therophytes (32.4%) are most numerous. One element that is characteristic of the vascular flora of Lake Skadar basin is the high percentage of endemic species including a large number of *locus classicus* sites. Moreover, 40 species and subspecies that are endemic, and 42 species that are subendemic in the Balkan Peninsula were recorded in the flora of the Lake Skadar area. An analysis of the vegetation of Lake Skadar revealed the presence of 134 plant communities classified in 65 alliances, 48 orders and 30 classes. There are 50 taxa of vascular plants protected at the national and international level and 23 European

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 203–238, DOI 10.1007/698_2018_236,
© Springer International Publishing AG 2018, Published online: 19 May 2018

Natural Habitat Types (Annex I of the Habitat Directive) that exist in the area of the Lake Skadar National Park.

Keywords Diversity, Endemism, Lake Skadar/Shkodra, Vascular flora, Vegetation

1 Introduction

Research on the flora of the Lake Skadar/Shkodra area started in the middle of the nineteenth century when the German botanist Wilhelm Ebel [1] visited Montenegro. In 1844, Ebel published a paper in which he listed 494 taxa from the herbarium material he collected from the wider area of Lake Skadar/Shkodra (Mount Rumija) describing six taxa new to science [2]. In 1873, the Serbian botanist Josif Pančić [3] studied the flora of Lake Skadar and its surroundings. At the end of the nineteenth century (1886), the area of Lake Skadar and Podgorica was visited by Ignac Szyszyłowicz [4] on his journey to the Prokletije Mountains. Subsequently, the Czech botanist Bohuslav Horák visited Montenegro in July 1898, and published an article [5] with some floristic data from the Lake Skadar area. The famous Italian geographer and botanist Antonio Baldacci visited the area of Lake Skadar several times (1891, 1892 and 1894) [6, 7] and provided a significant contribution to the knowledge of Montenegrin vascular flora. He discovered two plant species new to science (*Edraianthus wettsteinii* Halácsy & Bald., *Asperula baldaccii* (Halácsy) Ehrend.) from Mount Rumija, located in the hinterland of Lake Skadar.

The most famous researcher of Montenegrin flora, the Czech botanist Josef Rohlena (1874–1944), in the period 1901–1906, visited Montenegro six times, including the area of Lake Skadar/Shkodra. Between 1903 and 1929, Rohlena published the results of his research in many articles and debates [8–15]. The greatest amount of data on the vascular flora of the area of Lake Skadar was published by Rohlena in 1942 in his famous work 'Conspectus Florae Montenegrinae' [16]. Altogether, about 200 taxa as species, subspecies, varieties and forms were described by Rohlena, including some taxa whose *locus classicus* is located within the Lake Skadar protected area. Of these taxa, *Minuartia mesogitana* subsp. *velenovskyi* is known.

At the beginning of the twentieth century, information on the flora and vegetation of the Lake Skadar/Shkodra area was provided by Beck [17] and Adamović [18], following by the Austrian botanist Janchen [19]. Another Austrian botanist, Cufodontis [20, 21] described a new taxon *Cymbalaria microcalyx* subsp. *ebelii* based on material collected by Wilhelm Ebel from the area of Lake Skadar.

A more comprehensive study on the aquatic and semiaquatic flora and vegetation of Lake Skadar was carried out in 1949 by Černjavski et al. [22]. Significant contributions – primarily related to the aquatic vegetation of the Lake and its surroundings – were also made by Lakušić and Pavlović [23, 24] and Lakušić [25]. Recently, Sead Hadžiablahović [26] in his PhD dissertation elaborated on the flora and aquatic vegetation of Lake Skadar/Shkodra.

In addition to the above-mentioned studies, the flora and vegetation of the Montenegrin part of Lake Skadar were the subject of numerous studies [27–83]. Likewise, the flora and vegetation of the Albanian side of Lake Skadar were the subject of analyses [84–109] which increased our knowledge of the vascular flora of the overall lake. Moreover, we should mention several papers that cited Lake Skadar as part of the distribution of certain species [110–113].

This chapter gives an overview of the richness and endemism of the vascular flora of the Lake Skadar area and makes a contribution to phytosociological studies by listing the plant communities that are present in the protected area of Lake Skadar.

2 The Characteristics of the Flora and Vegetation of the Lake Skadar/Shkodra Area

The great diversity of the vascular flora of the Lake Skadar/Shkodra basin can be explained by its geographical position in a karst terrain in the outer part of the Dinaric Alps. Biogeographically, the area of Lake Skadar is located between the biome of evergreen Eu-Mediterranean forests and the biome of temperate deciduous xerothermal Sub-Mediterranean forests, i.e. at the boundary between the subtropical and temperate zonobiomes of the northern hemisphere [25]. Therefore, the high plant diversity in the Lake Skadar/Shkodra area is the result of a range of geographical, geomorphological, pedological and climatic factors.

The geographical position of the area of Lake Skadar/Shkodra results in the presence of specific flora and vegetation. The strong influence of the Mediterranean Sea (*Sub-Mediterranean impact*) caused the dominant presence of Mediterranean-Sub-Mediterranean floral elements and plant communities. On the other hand, *Eu-Mediterranean impact* is reflected in the presence of most of the typical Eu-Mediterranean floral elements of temperate evergreen forests (*Quercus ilex*, *Laurus nobilis*, *Pistacia lentiscus*, *Olea europaea* and *Arbutus unedo*) in the vascular flora of the Lake Skadar area. Some of these species are not present only as individual specimens, but in certain parts of the lake basin they form typical Eu-Mediterranean plant communities.

The climate of the Lake Skadar area belongs to the Sub-Mediterranean perhumid type (type V sensu [114], type 1.2 sensu [115]). This type of climate is characteristic of the entire hinterland of the Montenegrin and Albanian coast and in a climazonal sense which corresponds to the vegetation of the amphiadriatic low-altitude calcareous thermophilous oak and oriental hornbeam forests of the *Carpinion orientalis* alliance. This alliance in the Lake Skadar area is represented by the following plant communities: *Querco-Carpinetum orientalis* (= *Rusco-Carpinetum orientalis* Blečić and Lakušić 1966), *Phyllireo-Carpinetum orientalis*, *Quercetum trojanae* and *Carpino orientalis-Quercetum virgilianae*. Compared to the other parts of the Sub-Mediterranean area of Montenegro and Albania, the climate of the Lake Skadar area is somewhat milder in winter and has characteristics of the perhumid Mediterranean climate that is limited to the coastal part of Montenegro and Albania. In a climazonal sense, this climate type corresponds to the vegetation of the evergreen forests and 'makija' of *Arbuto unedonis-Laurion nobilis* and *Quercion ilicis* alliances. In support of the later statement is the fact that the elements of evergreen vegetation – *Q. ilex*, *L. nobilis*, *A. unedo*, *Myrtus communis*, *P. lentiscus* or the fragments of *Lauretum nobilis* and *Fraxino orni-Quercetum ilicis* communities – survive around the northern rim of the Lake (Bolje Sestre and Poseljani) as well as on the islands of Kom, Mala and Velika (Velja) Čakovica.

The distribution of Southern Europe mountain group species is caused by the position of Mount Rumija (an *Oro-Mediterranean impact*) which surrounds the lake on the southern side and represents a natural barrier, separating the Adriatic Sea from Lake Skadar. In the vascular flora of the Lake Skadar basin, the Southern Europe mountain chorological group is represented by many endemic species such as *Crepis bertiscea*, *Crocus dalmaticus*, *Fritillaria messanensis* subsp. *gracilis*, *Hieracium heterogynum*, *M. mesogitana* subsp. *velenovskyi*, *Moltkia petraea*, *Ramonda serbica*, *Silene tommasinii* and various others.

The basin of Lake Skadar is an important refuge for many relict plant species: *Carpinus orientalis*, *Castanea sativa*, *L. nobilis*, *Ostrya carpinifolia*, *Quercus trojana*, *Paliurus spina-christi* and so on. Moreover, this area has been an important refuge for many endemic or endemic/relict plant species such as *Cymbalaria ebelii* (Fig. 1), *Edraianthus dalmaticus*, *F. messanensis* subsp. *gracilis*, *M. mesogitana* subsp. *velenovskyi*, *M. petraea*, *R. serbica*, *Succisella petterii* (Fig. 1), *Vincetoxicum huteri* (Fig. 2) and others.

3 The Richness of the Vascular Flora of the Lake Skadar/Shkodra Area

Based on the available literature, and our unpublished data, we count 1,396 taxa (1,299 species and 97 subspecies) and 7 hybrids from 131 families and 588 genera inhabiting the area of Lake Skadar.

Pteridophyta includes 23 taxa, from 11 genera, 9 families and 3 classes, what represent about 1.6% of the total vascular flora of the Lake Skadar area. Gymnospermae are represented by only 6 species from 4 genera and 3 families (0.4% of the total vascular flora of the Lake Skadar area), of which 4 species (*Pinus halepensis*, *Pinus nigra*, *Pinus pinaster* and *Cupressus sempervirens*) are cultivated and naturalized.

Magnoliophyta (Angiospermae) are the most abundant group in the Lake Skadar/Shkodra area. Magnoliopsida (Dicotyledones) are represented by 1,049 taxa (of which 116 are introduced aliens) from 96 families and contribute 75.1% of the total vascular flora of this area. On the other hand, Liliopsids (Monocotyledones) are represented by 23 families and 318 taxa (of which 27 are introduced aliens) that represent 22.8% of the total flora of the Lake Skadar area.

The most abundant families are *Poaceae* with 135 species and 11 subspecies (10.4% of the total number of species accounted for in the vascular flora of the Lake Skadar area) and *Asteraceae* with one taxa less.

Fig. 1 Endemics of Skadar Lake basin: (**a**) *Scilla lakusicii* Šilić, (**b**) *Succisella petterii* (J. Kerner & Murb.) G. Beck, (**c**) *Campanula austroadriatica* D. Lakušić & Kovačić, (**d**) *Cymbalaria ebelii* (Cuf.) Speta, (**e**) *Edraianthus tenuifolius* (Waldst. & Kit.) A. DC., (**f**) *Scorzonera doriae* Degen & Bald. Photos by S. Hadžiablahović

Five families each have more than 50 taxa (in parentheses, the number of taxa given as species + subspecies + hybrids): *Fabaceae* (96 + 12), *Lamiaceae* (54 + 10 + 1×), *Brassicaceae* (58 + 3), *Apiaceae* (52 + 3) and *Scrophulariaceae* (47 + 7 + 2×). The greatest number of genera (in parentheses) were recorded for the families (>10% of the total number of genera recorded for the vascular flora of the

Fig. 2 Endemics of lake Skadar basin: (**a**) *Vincetoxicum huteri* Vis. & Ascherson, (**b**) *Ramonda serbica* Pančić. Photos by S. Hadžiablahović

Lake Skadar area) *Poaceae* (72) and *Asteraceae* (64), followed by the families (>5% of the total number of genera) *Brassicaceae* (34), *Apiaceae* (33) and *Fabaceae* (31).

The most abundant genera (in parentheses, the number of species + subspecies) in the vascular flora of Lake Skadar are *Trifolium* (28 + 2), *Carex* (23), *Euphorbia* (19 + 2), *Ranunculus* (17 + 1) and *Veronica* (15). Moreover, an additional 11 genera (*Galium*, *Silene*, *Allium*, *Geranium*, *Verbascum*, *Vicia*, *Juncus*, *Crepis*, *Rumex*, *Campanula* and *Lathyrus*) each contains 10 or more species.

A phytogeographical analysis of the biological spectrum of the vascular flora revealed that hemicryptophytes (33.6%) and therophytes (32.4%) are the most numerous followed by geophytes (11.2%), phanerophytes (9.5%), chamaephytes (5.9%), hydrophytes (4.5%), scandentophytes (2.2%) and parasitophytes (0.7%). The classification of life forms followed the system of Raunkiaer [116], revised by Mueller-Dombois and Ellenberg [117] and elaborated by Stevanović [118].

The phytogeographical analysis of the vascular flora of the Lake Skadar/Shkodra area showed that the Mediterranean-Sub-Mediterranean group (28.7% of the total number of taxa) and the Eurasian group (24.9%) dominate. Other chorological groups are represented as follows: Cosmopolitan (9.5%), Mediterranean-Pontic (9.2%), Adventive (9%), South-European Mountain (6.3%), Central-European (6%), Holarctic (5.8%) and Pontic-South Siberian (0.6%). The phytogeographical analysis was done according to Stevanović [118].

4 Balkan Endemics and Balkan Subendemics in the Vascular Flora of the Lake Skadar/Shkodra Area

The region of the Dinaric Alps is characterized by a high percentage of endemic species [119]. According to Turrill [120], there are 1,754 endemic plant species that inhabit the Balkan Peninsula, meaning that almost 27% of the total flora (6,750 species) is endemic. In Montenegro, 223 species plant taxa endemic to the Balkans were found, what represent around 12% of the total flora of the country [121].

This large number of plant taxa endemic and/or subendemic to the Balkan is characteristic of the vascular flora of the Lake Skadar area. Altogether, 40 species and subspecies endemic to the Balkan Peninsula have been recorded in the flora of the Lake Skadar area (Table 1). An analysis of the biological spectrum of the Balkan endemic flora revealed that hemicryptophytes are most numerous with 18 taxa, followed by chamaephytes with 13 and therophytes with 6 taxa. In the chorological structure of the endemic flora of the Lake Skadar area, the South-European Mountain group dominates with 22 taxa.

A large number of Balkan endemic species were found on the slopes of Mount Rumija and are characteristic of the vegetation of rock crevices and screes (*C. ebelii*, *R. serbica*, *M. petraea*, *Teucrium ardunii*, *Stachys menthifolia*, *Seseli globiferum*, *Cardamine rupestris*, *C. bertiscea*, *Edraianthus tenuifolius* and *Campanula austoadriatica*). Other species like *Onosma stellulata*, *Sideritis romana* subsp. *purpurea*, and *V. huteri* are characteristic of the vegetation of Mediterranean grasslands and herblands, while *Succisella petterii* is characteristic of wet meadows. Moreover, 42 plant taxa are subendemic (Table 2) – in addition to being found in the Balkan peninsula these taxa are also present in one or two neighbouring countries. Therefore, the total number of taxa of these two categories (Balkan endemics + Balkan subendemics) in the vascular flora of the Lake Skadar area was counted as 82.

Some of the endemic plant taxa were described from the *loci classici* located within the border of the Lake Skadar/Shkodra Protected Area. *M. mesogitana* subsp. *velenovskyi* was described by Rohlena (as *Alsine tenuifolia* var. *velenovskyi*) from Godinje near Virpazar [9]; *C. ebelii* (Fig. 1) was described by Georg Cufodontis (as *Linaria microcalyx* subsp. *ebelii*) from the material collected by W. Ebel on Vranjina island [20]. The *locus classicus* of *F. messanensis* subsp. *gracilis*, a taxon originally described as *Lilium gracile* by Ebel [2], is Sutorman on Mount Rumija. Of the above-mentioned species, *M. mesogitana* subsp. *velenovskyi* is endemic to the Balkans, and *F. messanensis* subsp. *gracilis* is subendemic to the Balkans (it is also present in Italy [122]), while *C. ebelii* is endemic to the area of the Lake Skadar/ Shkodra basin (Montenegro and Albania). On the other hand, some plant species were described from Mount Rumija and their *loci classici* lie outside the border of the Lake Skadar Protected Area. This group of endemics includes *E. wettsteinii*, *A. baldaccii* and *Gymnospermium scipetarum*.

Moreover, there are two more plant taxa described from the Lake Skadar Protected Area: *Quercus robur* subsp. *scutariensis* and *Trapa longicarpa* subsp. *scutariensis*. The latter taxon originally described by Janković [35] is cited in 'The Euro + Med PlantBase' but without specifying the subspecies (subsp. *scutariensis*), while 'The Plant List' mentioned '*T. longicarpa*' as an unresolved name. On the other hand, *Q. robur* subsp. *scutariensis* described by Černjavski et al. [22] is not cited in any of the relevant taxonomic plantbases such as 'The Euro + Med PlantBase', 'The Plant List', 'IPNI' and 'Flora Europea'.

Table 1 Review of Balkan endemic taxa in the vascular flora of the Lake Skadar area

No	Taxa	Locality	LF	Chorological group
1.	*Bupleurum glumaceum* Sibth. & Sm.	Rijeka	T	MED-SUBM
2.	*Bupleurum karglii* Vis.	Rijeka	T	SEM
3.	*Campanula austroadriatica* D. Lakušić & Kovačić	Donji Murići, Rijeka, Virpazar,	Ch	MED-SUBM
4.	*Cardamine rupestris* (O.E. Schulz) K. Malý	Between Riječani and Komarno	T/H	MED-SUBM
5.	*Cerastium ligusticum* Viv. subsp. *trichogynum* (Möschl) P. D. Sell & Whitehead	Donji Murići	T	MED-SUBM
6.	*Chaerophyllum coloratum* L.	Rijeka, Vitoja, Virpazar	T	MED-SUBM
7.	*Clinopodium alpinum* (L.) Kuntze subsp. *majoranifolium* (Mill.) Govaerts	Božaj, Virpazar, Vranjina	H	MED-SUBM
8.	*Crepis bertiscea* Jáv.	Boljevići	H	SEM
9.	*Crocus dalmaticus* Vis.	Virpazar	G	SEM
10.	*Cymbalaria ebelii* (Cuf.) Speta	Godinje, Virpazar, Vranjina	Ch	MED
11.	*Cynoglossum pustulatum* Boiss. subsp. *parvifolium* (Vis.) Sutorý	Virpazar	H	SEM
12.	*Cytisus tommasinii* Vis.	Virpazar	Ch	SEM
13.	*Dianthus ciliatus* Guss. subsp. *dalmaticus* (Čelak.) Hayek	Godinje, Virpazar, Vranjina	Ch	MED-SUBM
14.	*Edraianthus dalmaticus* DC.	Rijeka	Ch	SEM
15.	*Edraianthus tenuifolius* (Waldst. & Kit.) A. DC.	Boljevići, Obida, Rijeka, Virpazar	Ch	SEM
16.	*Eryngium palmatum* Pančić & Vis.	Rijeka	H	SEM
17.	*Erysimum linearifolium* Tausch	Rijeka, Virpazar, Vranjina	Ch	SEM
18.	*Hieracium heterogynum* (Froel.) Gutermann	Rijeka, Virpazar, Vranjina	H	SEM
19.	*Leucanthemum rohlenae* (Horvatić) Vogt & Greuter	Plavnica, Virpazar	H	MED
20.	*Micromeria longipedunculata* Bräuchler	Godinje, Rijeka, Virpazar, Vranjina	Ch	SEM
21.	*Minuartia mesogitana* (Boiss.) Hand.-Mazz. subsp. *velenovskyi* (Rohlena) McNeill	Virpazar	T	SEM
22.	*Moltkia petraea* (Tratt.) Griseb.	Godinje, Obida, Rijeka, Virpazar	Ch	SEM
23.	*Onosma stellulata* Waldst. & Kit.	Virpazar	H	SEM
24.	*Petteria ramentacea* (Sieber) C. Presl	Godinje, Rijeka, Virpazar	NP	MED-SUBM
25.	*Ramonda serbica* Pančić	Donji Murići	H	SEM
26.	*Scilla lakusicii* Šilić	Rijeka, Virpazar	G	SEM

(continued)

Table 1 (continued)

No	Taxa	Locality	LF	Chorological group
27.	*Scorzonera doriae* Degen & Bald.	Godinje, Virpazar	H	MED
28.	*Seseli globiferum* Vis.	Virpazar, Vranjina	H	MED
29.	*Sesleria robusta* Schott, Nyman & Kotschy subsp. *skanderbeggii* (Ujhelyi) Deyl	Donji Murići, Godinje	H	SEM
30.	*Sideritis romana* L. subsp. *purpurea* (Bentham) Heywood	Dodoši, Drušići, Rijeka, Virpazar	H	MED
31.	*Silene tommasinii* Vis.	Rijeka, Virpazar	Ch	SEM
32.	*Stachys menthifolia* Vis.	Godinje, Rijeka, Virpazar, Vitoja	H	MED-SUBM
33.	*Stachys recta* L. subsp. *baldaccii* (K. Malý) Hayek	Limljani	H	SEM
34.	*Succisella petterii* (J. Kerner & Murb.) G. Beck	Gostilj, Mataguži, Plavnica, Zbelj	H	SEM
35.	*Tanacetum cinerariifolium* (Trev.) Schultz Bip.	Murići, Godinje, Rijeka, Virpazar	Ch	MED
36.	*Teucrium ardunii* L.	Rijeka, Virpazar	Ch	MED-SUBM
37.	*Trifolium dalmaticum* Vis.	Boljevići, Poseljani	T	MED
38.	*Trifolium pignantii* Fauché & Chaub.	Boljevići, Virpazar	H	MED-SUBM
39.	*Verbascum niveum* Ten. subsp. *visianianum* (Reichenb.) Murb.	Godinje, Gornje Blato, Rijeka	H	SEM
40.	*Vincetoxicum huteri* Vis. & Ascherson	Virpazar, Vranjina	H	SEM

LF Life forms, *NP* nanophanerophytes, *Ch* chamaephytes, *H* hemicryptophytes, *G* geophytes, *T* therophytes

Chorological groups: *MED–SUBM* Mediterranean–Sub-Mediterranean, *SEM* South-European Mountain

5 Protected and Rare Species in the Vascular Flora of the Lake Skadar/Shkodra Area

One element that is characteristic of the vascular flora of the Lake Skadar basin is the presence of a large number of endemic species, some of them being protected at the international and national level. Information on the national and/or international conservation status of certain plant species and plant communities in the area of Lake Skadar/Shkodra has been the subject of several studies [80, 107, 123, 124]. In Table 3, we list the protected plant taxa of the vascular flora of the Lake Skadar area.

According to the IUCN Red List Categories and Criteria (IUCN 2012a), one fern species (*Marsilea quadrifolia*) is defined as threatened (Vulnerable) at the European level [125]. After a long time, this species was recently discovered in the area of

Table 2 Review of the Balkan subendemic taxa in the vascular flora of the Lake Skadar area

No	Taxa	Locality	LF	Chorological group
1.	*Acanthus hungaricus* (Borbás) Baen.	Boljevići, Hum	H	SEM
2.	*Allium guttatum* Steven subsp. *dalmaticum* (A. Kern. ex Janch.) Stearn	Virpazar	G	MED-SUBM
3	*Anchusella cretica* (Mill.) Bigazzi, E. Nardi & Selvi	Limljani, Podhum, Rijeka, Virpazar, Vranjina	T	SEM
4.	*Anthriscus sylvestris* (L.) Hoffm. subsp. *fumarioides* (Waldst. & Kit.) Spalik	Podhum	H	MED-SUBM
5.	*Asperula scutellaris* Vis.	Rijeka, Šestani, Virpazar	Ch	SEM
6.	*Athamanta ramosissima* Spreng.	Boljevići	Ch	MED-SUBM
7.	*Ballota hispanica* (L.) Benth.	Boljevići, Godinje, Rijeka	Ch	MED-SUBM
8.	*Bunium alpinum* Waldst. & Kit. subsp. *montanum* (Koch) P. W. Ball	Godinje, Rijeka	H	SEM
9.	*Bupleurum veronense* Turra	Limljani, Rijeka, Virpazar	T	SEM
10.	*Campanula versicolor* Andrews	Bobija	H	SEM
11.	*Carduus nutans* L. subsp. *micropterus* (Borbás) Hayek	Dodoši, Malo Blato, Rijeka	H	MED-SUBM
12.	*Centaurea jacea* L. subsp. *weldeniana* (Rchb.) Greuter	Gostilj, Rijeka, Virpazar, Zbelj	H	SEM
13.	*Colchicum hungaricum* Janka	Donji Murići	G	SEM
14.	*Cota macrantha* (Heuff.) Boiss.	Virpazar	H	SEM
15.	*Cota segetalis* (Ten.) Holub	Godinje	T	MED-SUBM
16.	*Cymbalaria muralis* P. Gaertn., B. Mey. & Scherb. subsp. *visianii* D. A. Webb	Seljani	Ch	MED-SUBM
17.	*Edraianthus graminifolius* (L.) DC.	Skadar Lake	Ch	SEM
18.	*Euphorbia glabriflora* Vis.	Skadar Lake	Ch	SEM
19.	*Fritillaria messanensis* Rafin. subsp. *gracilis* (Ebel) Rix	Rijeka, Virpazar	G	SEM
20.	*Genista sericea* Wulfen	Boljevići, Godinje, Virpazar	Ch	SEM
21.	*Iris pallida* Lam.	Rijeka	G	MED
22.	*Leucanthemum ircutianum* DC. subsp. *leucolepis* (Briq. & Cavill.) Vogt & Greuter	Rijeka	H	MED-SUBM
23.	*Marrubium incanum* Desr.	Podhum, Virpazar, Vranjina	H	MED-SUBM
24.	*Malva thuringiaca* (L.) Vis. subsp. *ambigua* (DC.) Valdés	Gostilj, Plavnica, Virpazar	H	MED-SUBM
25.	*Micromeria cristata* (Hampe) Griseb. subsp. *cristata*	Seoca village	Ch	SEM

(continued)

Table 2 (continued)

No	Taxa	Locality	LF	Chorological group
26.	*Onosma echioides* (L.) L. subsp. *dalmatica* (Scheele) Peruzzi & N. G. Passal.	Boljevići, Godinje, Rijeka, Virpazar, Vranjina	Ch	MED-SUBM
27.	*Ornithogalum exscapum* Ten.	Đuravci	G	MED-SUBM
28.	*Parvotrisetum myrianthum* (Bertol.) Chrtek	Drušići, Rijeka, Šestani	T	MED-SUBM
29.	*Petrorhagia obcordata* (Margot & Reuter) Greuter & Burdet	Balabani, Gostilj	T	MED-SUBM
30.	*Picris hispidissima* (Bartl.) Koch	Boljevići, Godinje	H	MED-SUBM
31.	*Rhamnus orbiculatus* Bornm.	Godinje, Virpazar	NP	MED-SUBM
32.	*Salvia amplexicaulis* Lam.	Hum	H	MED-SUBM
33.	*Satureja subspicata* Bartl. ex Vis.	Rijeka	Ch	SEM
34.	*Scabiosa webbiana* D. Don	Rijeka	H	MED-SUBM
35.	*Scorzonera villosa* Scop.	Boljevići, Virpazar	G/H	SEM
36.	*Silene gigantea* L.	Skadar Lake	H	SEM
37.	*Stachys recta* L. subsp. *subcrenata* (Vis.) Briq.	Limljani	H	SEM
38.	*Tamarix dalmatica* Baum	Boljevići, Rijeka, Virpazar	NP	MED
39.	*Tragopogon balcanicus* Velen.	Boljevići, Limljani	H	MED-SUBM
40.	*Verbascum nigrum* L. subsp. *abietinum* (Borbás) I. K. Ferguson	Rijeka, Boljevići	H	SEM
41.	*Verbascum glabratum* Friv.	Rijeka, Šestani	H	SEM
42.	*Verbascum samniticum* Ten.	Bobija, Dodoši, Obida	H	SEM

Lake Skadar ([83]; Hadžiablahović, unpublished). On the other hand, records of some species from the Lake Skadar basin are still uncertain. The species *E. dalmaticus* was recorded from Rijeka Crnojevića but this record is not confirmed by findings of this species after that [79].

Baldellia ranunculoides is defined as 'Near threatened' at the World level [126]. *Najas flexilis* is categorized as VU (Vulnerable) on IUCN Red List of Europe. Recently, this species was discovered from Lake Skadar on the basis of leaf fragment found on the water surface [26].

Twenty-five plant species that inhabit the Lake Skadar area are listed in Annex II of the CITES Convention while nine species (*M. quadrifolia*, *E. dalmaticus*, *Anacamptis pyramidalis*, *Himantoglossum caprinum*, *Caldesia parnassifolia*, *Galanthus nivalis*, *N. flexilis*, *R. serbica* and *Ruscus aculeatus*) are listed in Annex II, IV and V of the Habitat Directive.

Table 3 Protected taxa (species and subspecies) of vascular flora in the Lake Skadar area

Taxon	Prot MNE	IUCN RL world	IUCN RL Europe	HD annex	Bern annex	CITES annex
Marsileaceae						
Marsilea quadrifolia L.	+			II/IV	I	
Fagaceae						
Quercus robur L. subsp. *scutariensis* Černj.	+					
Polygonaceae						
Persicaria decipiens (R. Br.) K. L. Wilson	+					
Ranunculaceae						
Baldellia ranunculoides		NT	NT			
Caryophyllaceae						
Minuartia mesogitana (Boiss.) Hand.-Mazz. subsp. *velenovskyi* (Rohlena) Mc Neill	+					
Aquifoliaceae						
Ilex aquifolium L.	+					
Rhamnaceae						
Rhamnus intermedius Steudel & Hochst	+					
Apiaceae						
Chaerophyllum coloratum L.	+					
Eryngium palmatum Vis. & Pančić	+					
Primulaceae						
Cyclamen hederifolium Aiton	+					II
Asclepiadaceae						
Vincetoxicum huteri Vis. & Ascherson	+					
Lamiaceae						
Micromeria longipedunculata Bräuchler	+					
Dipsacaceae						
Succisella petterii (J. Kerener & Murb.) G. Beck	+					
Plantaginaceae						
Cymbalaria ebelii (Cufod.) Speta	+					
Campanulaceae						
Edraianthus dalmaticus (A. DC.) A. DC.				II/IV		
Asteraceae						
Crepis bertiscea Jáv.	+					
Cyperaceae						
Cyperus michelianus (L.) link			NT			
Orchidaceae						
Anacamptis coriophora (L.) R. M. Bateman, Pridgeon & M. W. Chase	+					II

(continued)

Table 3 (continued)

Taxon	Prot MNE	IUCN RL world	IUCN RL Europe	HD annex	Bern annex	CITES annex
Anacamptis morio (L.) R. M. Bateman, Pridgeon & M. W. Chase subsp. *caucasica* (K. Koch) H. Kretzschmar, Eccarius & H. Dietr.	+					II
Anacamptis morio (L.) R. M. Bateman, Pridgeon & M. W. Chase subsp. *morio*	+					II
Anacamptis morio (L.) R. M. Bateman, Pridgeon & M. W. Chase subsp. *picta* (Loisel.) Jacquet & Scappat.	+					II
Anacamptis palustris (Jacq.) R. M. Bateman, Pridgeon & M. W. Chase	+					II
Anacamptis papilionacea (L.) R. M. Bateman, Pridgeon & M. W. Chase	+					II
Anacamptis pyramidalis (L.) L. C. M. Richard	+			II/IV		II
Dactylorhyza incarnata (L.) Soó subsp. *incarnata*	+					II
Gymnadenia conopsea (L.) R. Br.	+					II
Himantoglossum caprinum (M. B.) Sprengel	+			II/IV		II
Limodorum abortivum (L.) Swartz	+					II
Neotinea tridentata (Scop.) R. M. Bateman, Pridgeon & M. W. Chase	+					II
Ophrys apifera Hudson	+					II
Ophrys bertolonii Moretti	+					II
Ophrys scolopax Cav. subsp. *cornuta* (Steven) E. G. Camus	+					II
Ophrys sphegodes Miller subsp. *sphegodes*	+					II
Orchis pauciflora Ten.	+					II
Orchis provincialis Balb.	+					II
Orchis quadripunctata Cyr. ex Ten.	+					II
Orchis simia Lam.	+					II
Platanthera bifolia (L.) L. C. M. Richard	+					II
Serapias lingua L.	+					II
Serapias vomeracea (Burm. fil.) Briq. subsp. *vomeracea*	+		LC			II
Spirantes spiralis (L.) Chevall	+		LC			II
Alismataceae						
Caldesia parnassifolia (L.) Parl.	+		NT	II/IV	I	
Potamogetonaceae						
Potamogeton acutifolius link			NT			

(continued)

Table 3 (continued)

Taxon	Prot MNE	IUCN RL world	IUCN RL Europe	HD annex	Bern annex	CITES annex
Colchicaceae						
Colchicum hungaricum Janka	+					
Amaryllidaceae						
Galanthus nivalis L.	+		NT	V		II
Narcissus poeticus L. subsp. *radiiflorus* (Salisb.) Baker	+				I	
Iridaceae						
Iris tuberosa L.	+					
Najadaceae						
Najas flexilis (Willd.) Rostk. & W. L. E. Schmidt	+		VU B2ab (iv)	II/IV	I	
Gesneriaceae						
Ramonda serbica Pančić	+		LC	IV	I	
Asparagaceae						
Ruscus aculeatus L.				V		
Scilla lakusicii Šilić	+					
Lythraceae						
Trapa natans L.	+		NT		I	
Trapa longicarpa M. Jank.			DD			
Utriculariaceae						
Utricularia vulgaris L.	+		LC			

6 The Vegetation of the Lake Skadar/Shkodra Area

An analysis of the vegetation of Lake Skadar revealed the presence of 134 plant communities classified into 65 alliances, 48 orders and 30 classes (see Appendix). The names of the syntaxa are given according to the International Code of Phytosociological Nomenclature [127]. The synaxonomic position of the higher taxa (Classis, Ordo and Alliance) of the vegetation of the Lake Skadar/Shkodra area follows Mucina et al. [128].

The dominant climazonal vegetation in the Lake Skadar area is represented by Sub-Mediterranean deciduous forests which are mainly present in the southern and western part of the Lake basin. Here, two dominant thermophilic deciduous plant communities are present: one (*Querco-Carpinetum orientalis*) (Fig. 3a) composed of the downy oak and the Oriental hornbeam, and the second, a community of the Macedonian oak (*Q. trojanae*). Smaller areas are occupied by the following

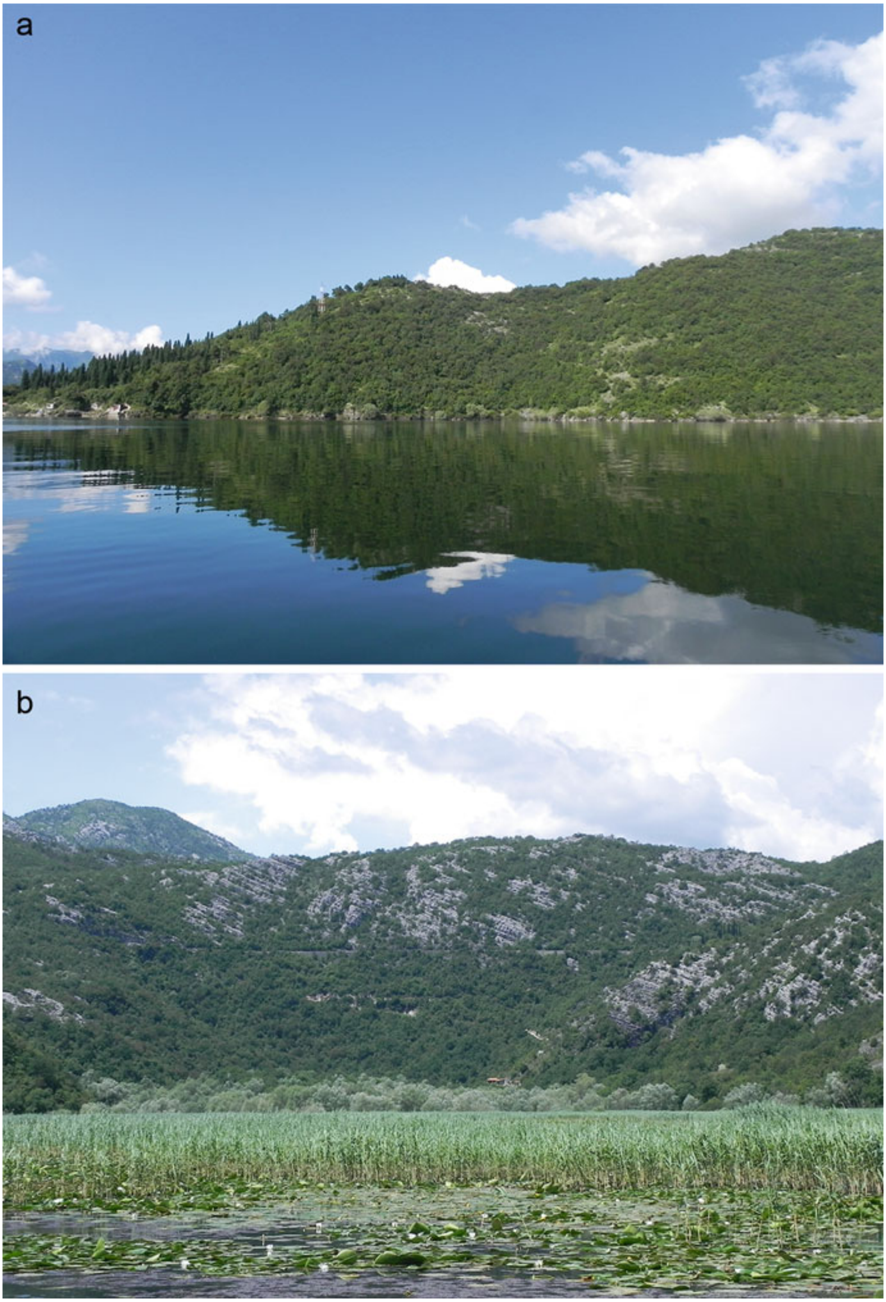

Fig. 3 Vegetation of Lake Skadar: (**a**) Ass. *Querco-Carpinetum orientalis*, (**b**) Ass. *Phragmitetum australis*. Photos by S. Hadžiablahović

communities: *C. orientalis-Q. virgilianae*, *Seslerio-Ostryetum carpinifoliae*, *Quercetum cerridis* and *Quercetum confertae-cerridis.*

In the southern and western parts of the Lake Skadar area, different degradation stages of the *Querco-Carpinetum orientalis* are present. Here, intrazonal scrub and woodlands vegetation with a characteristic community (*Rhamno-Paliuretum*) of *P. spina-christi* and the Balkan endemic *Rhamnus intermedius* are also present.

The vegetation of Sub-Mediterranean rocks present on degraded habitats is often defined as the final stage of degradation. This is also the case for the vegetation of zonal steppe grasslands which is dominantly represented by different plant communities of the order of *Scorzonero-Chrysopogonetalia (Stipo-Salvietum officinalis*, *Asphodelo-Chrysopogonetum grylli*, *Bromo-Chrysopogonetum grylli*, *Salvio-Phlomidetum fruticosae* and so on).

In the zone of climazonal vegetation (*Querco-Carpinetum orientalis*) of the Lake Skadar area, especially in the area of Virpazar and Vranjina, communities with *C. sempervirens* and *P. halepensis* can be found. These two species have been introduced, but seemed to be well adapted to the existing climatic conditions and they are spreading naturally by forming well-developed plant communities.

In the southern part of Lake Skadar (Ostros Krajina), on acidic soil a well-developed community of chestnut and Hungarian oak (*Querco confertae-Castanetum*) is present. This community has significance from the conservation point of view, is listed in the Habitat Directive (9260 Chestnut Forests) and forms a part of the NATURA 2000 network.

Around the northwestern part of the basin (Poseljani, Bolje Sestre), fragments of the vegetation of evergreen forests of the flowering ash and the holm oak (*F. orni-Q. ilicis*) are present while fragments of evergreen forests of the laurel (*L. nobilis*) are present on the islands of Kom, Mala and Velika (Velja) Čakovica. These laurel communities on the islands of Lake Skadar represent low-growing facies and as such are identified in the context of Natura 2000 (5310 *L. nobilis* thickets).

Azonal alluvial and swamp forests and scrub vegetation in the flooding zone of Lake Skadar are represented by many communities that occupy large areas of the northern shore of the lake. The community of black alder (*Alnus glutinosa*) is present mainly along the banks of the River Morača at its mouth into Lake Skadar. On the other hand, the floodplain forest of the white willow (*Salix alba*) and the narrow-leafed ash (*Fraxinus angustifolia* subsp. *oxycarpa*) are dominantly present in large areas around the northern part of the lake from Pohumski Bay to Žabljak Crnojevića and the village of Dodoši. The community of pedunculate Skadar oak (*Q. robur* subsp. *scutariensis*) is extremely degraded and their remains are present mostly in fragments of the pastures in the meadows around the village of Gostilj. Around the western part of the lake along the shoreline, there is a narrow belt with chaste tree (*Viticetum agni casti*) which in the bays is replaced by a community of white willow (*S. alba*) and narrow-leafed ash (*F. angustifolia* subsp. *oxycarpa*) or their fragments.

Freshwater aquatic submerged vegetation in the Lake is represented by many associations. The communities *Potamogetonetum lucentis*, *Najadetum marinae* and

Najadetum minoris are mainly present in Podhum Bay while *Ceratophylletum demersi* occurs in shallow water mostly in the eastern part of the lake. The communities of *Potamogetonetum perfoliati*, *Potamogetono- Vallisnerietum* and *Ceratophyllo demersi-Vallisnerietum spiralis* occupy the largest area of aquatic submerged vegetation of the lake. The flotant aquatic vegetation mainly occurs in the near-shore zone of the lake covering a large area as well. This vegetation is mostly represented by communities of yellow water-lily and European white water lily (*Nymphaeo albae-Nupharetum luteae*) (Fig. 4a), a community of European white water lily (*Nymphaeetum albae*) and a community of water caltrop (*Trapetum natantis*) (Fig. 5b).

Fig. 4 Vegetation of Lake Skadar: (**a**) Ass. *Nymphaeo albae-Nupharetum luteae*, (**b**) Ass. *Salicetum albo-fragilis*. Photos by S. Hadžiablahović

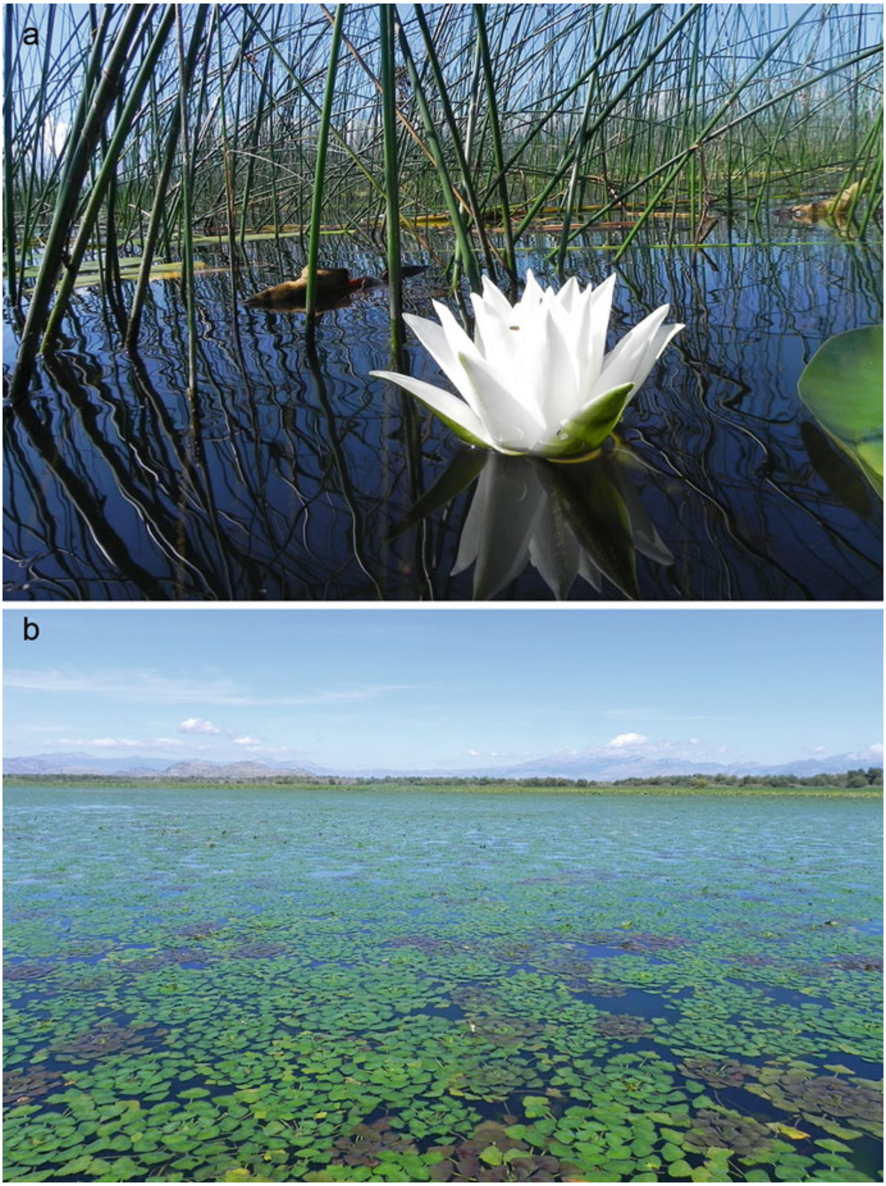

Fig. 5 Vegetation of Lake Skadar: (**a**) Ass. *Scirpetum lacustris*, (**b**) Ass. *Trapetum natantis*. Photos by S. Hadžiablahović

The vegetation of the freshwater springs, shorelines and swamps of the Lake is represented with many associations. It is predominantly represented by a community of common reed (*Phragmitetum australis*) and a community of lakeshore bulrush (*Scirpetum lacustris*). Both communities occupy large areas in the near-shore zone of the lake.

There are many NATURA 2000 habitats in Lake Skadar National Park that contribute to the special biological value of this area. Altogether, there are 23 European Natural Habitat Types (Annex I of the Habitat Directive) that occur in the Lake Skadar area, including 2 Priority Habitat Types (types in danger of disappearance and whose natural range mainly falls within the territory of the European Union), being Habitats 6220 and 91AA (see Table 4). This list also includes a habitat with *Platanus orientalis*, present along the banks of the River Morača at its mouth into Lake Skadar. This latter habitat is listed in the 'Catalog of EU habitats of Montenegro' [81] but without additional phytocoenological information.

Table 4 List of Natura 2000 habitat types occurring in Lake Skadar/Shkodra (Interpretation Manual of European Union Habitats – EUR28 2013) [129]

Code	Natura 2000 habitat types
3130	Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
3150	Natural eutrophic lakes with *Magnopotamion* and *Hydrocharition* type vegetation
3240	Alpine rivers and their ligneous vegetation with *Salix elaeagnos*
3260	Water courses of plain to montane levels with the *Ranunculion fluitantis* and *Callitricho-Batrachion* vegetation
3280	Constantly flowing Mediterranean rivers with *Paspalo-Agrostidion* species and hanging curtains of *Salix* and *Populus alba*
3290	Intermittently flowing Mediterranean rivers of the *Paspalo-Agrostidion*
5310	*Laurus nobilis* thickets
6220	*Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*
62A0	East Sub-Mediterranean dry grasslands (*Scorzoneretalia villosae*)
6420	Mediterranean tall humid herb grasslands of the *Molinio-Holoschoenion*
8130	Western Mediterranean and thermophilous scree
8210	Calcareous rocky slopes with chasmophytic vegetation
91F0	Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*)
91M0	Pannonian-Balkanic turkey oak – sessile oak forests
91AA	*Eastern white oak woods
9250	*Quercus trojana* woods
9260	*Castanea sativa* woods
9280	*Quercus frainetto* woods
9290	Cupressus forests (*Acero-Cupression*)
92A0	*Salix alba* and *Populus alba* galleries
92C0	*Platanus orientalis* and *Liquidambar orientalis* woods (*Platanion orientalis*)
92D0	Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*)
9340	*Quercus ilex* and *Quercus rotundifolia* forests

The priority habitat types are marked with an asterisk

Appendix

Syntaxonomic list.

Zonal and Intrazonal Vegetation

Vegetation of the Nemoral Forest Zone

Zonal Temperate Broad-Leafed Forests

Quercetea pubescentis Doing-Kraft ex Scamoni et Passarge 1959

Quercetalia pubescenti-petraeae Klika 1933

Fraxino orni-Ostryion Tomažić 1940

Seslerio autumnalis-Ostryetum carpinifoliae Horvat et Horvatić ex Horvat et al. 1974

Carpinion orientalis Horvat 1958

Querco-Carpinetum orientalis Horvatić 1939
(= *Rusco-Carpinetum orientalis* Blečić & Lakušić 1966)
Carpino orientalis-Quercetum virgilianae Trinajstić 1988
Quercetum trojanae Em 1958
Phyllireo-Carpinetum orientalis Fukarek 1966
Cupressus sempervirens comm.
Pinus halepensis comm.

Quercion confertae Horvat 1958

Quercetum confertae-cerridis Rudski (1940) 1949
Quercetum cerridis meditteraneo-montanum Lakušić et Kutleša 1976

Quercetea robori-petraeae Br.-Bl. et Tx. ex Oberd. 1957

Quercetalia roboris Tx. 1931

Castaneo-Quercion petraeae Soó 1964

Querco confertae-Castanetum montenegrinum Černjavski, Grebenščikov et Pavlović 1949

Intrazonal Scrub and Woodlands of the Nemoral Zone

Crataego-Prunetea Tx. 1962

Paliuretalia Trinajstić 1978

Paliuro-Petterion P. Fukarek 1962

Rhamno-Paliuretum Trinajstić 1996

Intrazonal Boreo-Temperate Grasslands and Heath

Sedo-Scleranthetea Br.-Bl. 1955

Sedo-Scleranthetalia Br.-Bl. 1955

Scabioso-Trifolion dalmatici Horvatić et N. Ranđelović in N. Ranđelović 1977

Trifolium dalmaticum comm.

Molinio-Arrhenatheretea Tx. 1937

Arrhenatheretalia elatioris Tx. 1931

Cynosurion cristati Tx. 1947

Lolietum perennis Gams 1927
Lolietum multiflorae Dietl et Lehmann 1975

Molinietalia caeruleae Koch 1926

Calthion palustris Tx. 1937

Calthetum laetae Krajina 1933
Epilobio-Juncetum effusi Oberd. 1957
Equisetetum palustris Steffen 1931

Bromion racemosi Tx. in Tx. et Preising ex de Foucault 2009

Bromus racemosus and *Vulpia ligustica* comm.

Trifolio-Hordeetalia Horvatić 1963

Molinio-Hordeion secalini Horvatić 1934

Alopecurus rendlei comm.

Holoschoenetalia Br.-Bl. ex Tchou 1948

Molinio-Holoschoenion Br.-Bl. ex Tchou 1948

Scirpoidetum holoschoeni Br.-Bl. ex Tchou 1948
Agrostis stolonifera comm.

Vegetation of the Steppe Zone

Zonal Steppe Grasslands

Festuco-Brometea Br.-Bl. et Tx. ex Soó 1947

Scorzoneretalia villosae Kovačević 1959

Chrysopogono grylli-Koelerion splendentis Horvatić 1973

Bromo-Chrysopogonetum grylli Černjavski, Grebenščikov et Pavlović 1949
Satureio subspicatae-Poetum bulobosae Černjavski, Grebenščikov et Pavlović 1949
Satureio-Edrianthetum Horvat 1942
Asphodelo-Chrysopogonetum grylli Horvatić (1936) 1958
Salvio-Phlomidetum fruticosae Barbagallo, Brullo et Fagotto 1979
Stipo-Salvietum officinalis Horvatić (1956) 1958
Schoenus nigricans comm.
Opuntia vulgaris comm.

Vegetation of the Mediterranean Zone

Zonal Mediterranean Forests and Scrub

Quercetea ilicis Br.-Bl. ex A. Bolós et O. de Bolòs in A. Bolòs y Vayreda 1950

Quercetalia ilicis Br.-Bl. ex Molinier 1934

Arbuto unedonis-Laurion nobilis Rivas-Mart. et al. 1999

Lauretum nobilis adriaticum Lakušić 1983 n.n.

Quercion ilicis Br.-Bl. ex Molinier 1934

Fraxino orni-Quercetum ilicis Horvatić (1956) 1958

Intrazonal Mediterranean Scrub

Nerio-Tamaricetea Br.-Bl. et O. de Bolòs 1958

Tamaricetalia africanae Br.-Bl. et O. de Bolòs 1958

Tamaricion dalmaticae Jasprica et Kovačić

Vitici-Tamaricetum dalmaticae Horvatić 1960

Intrazonal Mediterranean Grasslands and Herblands

Lygeo sparti-Stipetea tenacissimae Rivas-Mart. 1978

Cymbopogono-Brachypodietalia ramosi Horvatić 1963

Cymbopogono-Brachypodion ramosi Horvatić 1963

Chrysopogoni-Airetum capillaris Horvatić (1956) 1958
Brachypodio ramosi-Hyparrhenietum hirtae Horvatić 1961

Helianthemetea guttati Rivas Goday et Rivas-Mart. 1963

Helianthemetalia guttati Br.-Bl. in Br.-Bl. et al. 1940

Helianthemion guttati Br.-Bl. in Br.-Bl. et al. 1940

Helianthemetum guttati Br.-Bl. (1931) 1940

Poetalia bulbosae Rivas Goday & Rivas-Martínez in Rivas Goday & Ladero 1970

Vulpio ciliatae-Crepidion neglectae Poldini 1989

Festuco pseudovinae-Poetum bulbosae Horvat 1956

Vulpietalia Pignatti 1953

Vulpio-Lotion Horvatić 1963

Vulpio ligusticae-Dasypiretum villosii Fanelli 1998

Azonal Vegetation

Alluvial Forests and Scrub

Alno glutinosae-Populetea albae P. Fukarek et Fabijanić 1968

Populetalia albae Br.-Bl. ex Tchou 1949

Populion albae Br.-Bl. ex Tchou 1949

Salici-Populetum albae (Tüxen 1931) M. Drees 1936
Periploco-Populetum albae Černjavski, Grebenščikov et Pavlović 1949

Platanion orientalis I. Kárpáti et V. Kárpáti 1961

Platanetum orientalis Horvat, Glavač et Ellenberg 1974

Lauro nobilis-Fraxinion angustifoliae I. Kárpáti et V. Kárpáti 1961

Periploco-Quercetum scutariensis Černjavski, Grebenščikov et Pavlović 1949
Carici remotae-Fraxinetum oxycarpae Pedrotti 1970 corr. Pedrotti 1992
Amorpha fruticosa comm.

Salicetea purpureae Moor 1958

Salicetalia purpureae Moor 1958

Salicion eleagno-daphnoidis (Moor 1958) Grass 1993

Salicetum eleagno-purpureae Sillinger 1933

Salicion albae Soó 1951

Salicetum albo-fragilis Moor 1958

Tamaricetalia ramosissimae Borza et Bos caiu ex Dolțu et al. 1980

Tamaricion parviflorae I. Kárpáti et V. Kárpáti 1961

Viticetum agni-casti Lakušić 1972
Rubo-Viticetum agni-casti Lakušić et al. 1980
Tamarici-Salicetum amplexicaulis (Karpati 1961) Em

Swamp Forests and Scrub

Alnetea glutinosae Br.-Bl. et Tx. ex Westhoff et al. 1946

Alnetalia glutinosae Tx. 1937

Alnion glutinosae Malcuit 1929

Alnetum glutinosae Malcuit 1929
Robinia pseudoacacia comm.

Vegetation of Rock Crevices and Screes

Adiantetea Br.-Bl. et al. 1952

Adiantetalia Br.-Bl. ex Horvatić 1934

Adiantion Br.-Bl. ex Horvatić 1934

Eucladio-Adiantetum capillus-veneris Br.-Bl. 1931

Polypodietea Jurko et Peciar ex Boşcaiu, Gergely et Codoreanu in Rațiu et al. 1966

Anomodonto-Polypodietalia serrati O. de Bolòs et Vives in O. de Bolòs 1957

Polypodion serrati Br.-Bl. in Br.-Bl. et al. 1952

Polypodietum cambrici Br.-Bl. in Br.-Bl., Roussine et Négre 1952

Asplenietea trichomanis (Br.-Bl. in Meier et Br.-Bl. 1934) Oberd. 1977

Centaureo dalmaticae-Campanuletalia pyramidalis Trinajstić ex Terzi et Di Pietro 2016

Centaureo dalmaticae-Campanulion Horvatić 1934

Campanulo-Moltkeetum petraeae Horvatić 1963
Asplenio-Cotyledonetum horizontalis Horvatić 1963

Moltkeetalia petreae Lakušić 1968

Edraianthion Lakušić 1968

Cheilanthes fragrans-Ramonda serbica comm.

Cymbalario-Parietarietea diffusae Oberd. 1969

Tortulo-Cymbalarietalia Segal 1969

Cymbalario-Asplenion Segal 1969

Cymbalaria ebelii comm.

Thlaspietea rotundifolii Br.-Bl. 1948

Stipetalia calamagrostis Oberd. et Seibert in Oberd. 1977

Stipion calamagrostis Jenny-Lips ex Br.-Bl. 1950

Stipetum calamagrostidis Br.-Bl. 1918

Freshwater Aquatic Vegetation

Lemnetea O. de Boòs et Masclans 1955

Lemnetalia minoris O. Bolòs & Masclans 1955

Lemnion minoris O. Bolòs & Masclans 1955

Lemno minoris-Riccietum fluitantis Šumberová et Chytrý in Chytrý 2011
Spirodel(*etum*)*a polyrhiza*(*e*) (Kelhofer 1915) W. Koch em. R. Tx. & A. Schwabe 1974 in R. Tx.1974

Utricularion vulgaris Passarge 1964

Lemno-Utricularietum Soó 1947

Stratiotion Den Hartog et Segal 1964

Hydrocharietum morsus ranae van Langedonk 1935
Ceratophylletum demersi Corillion 1957

Potamogetonetea Klika in Klika et Novák 1941

Potamogetonetalia Koch 1926

Potamogetonion Libbert 1931

Najadetum marinae Fukarek 1961
Najadetum minoris Ubrizsy 1961
Potamogetonetum lucentis Hueck 1931
Potamogetonetum denso-nodosi de Bolós 1957
Potamogetonetum pusilli von Soó 1927
Sparganio emersi-Potamogetonetum pectinati Carstensen ex Hilbig 1971
Potamogetonetum perfoliati Miljan 1933
Potamogetono-Valisnerietum Br.-Bl. 1931
Ceratophyllo demersi-Vallisnerietum spiralis Lazić 2006
Potamogetono pectinati-Myriophylletum spicati Rivas Goday 1964 corr. Conesa 1990

Nymphaeion albae Oberd. 1957

Nupharetum pumilae Miljan 1958
Nymphaeo albae-Nupharetum luteae Nowiński 1927
Nymphaeetum albae Vollmar 1947
Nymphoidetum peltatae Bellot 1951
Potamogetono natantis-Polygonetum natantis Knapp et Stoffers 1962
Trapetum natantis Kárpáti 1963
Potametum crispi Soó 1927

Callitricho hamulatae-Ranunculetalia aquatilis Passarge ex Theurillat in Theurillat et al. 2015

Ranunculion aquatilis Passarge 1964

Hippuridetum vulgaris var. *fluviatilis* Julve & Catteau 2007
Ranunculetum trichophylli (Soó 1949) Julve 2006

Vegetation of Freshwater Springs, Shorelines and Swamps

Littorelletea uniflorae Br.-Bl. et Tx. ex Westhoff et al. 1946

Littorelletalia uniflorae Koch ex Tx. 1937

Littorellion uniflorae Koch ex Klika 1935

Eleocharetum acicularis Koch 1926

Isöeto-Nanojuncetea Br.-Bl. et Tx. in Br.-Bl. et al. 1952

Nanocyperetalia Klika 1935

Nanocyperion Koch 1926

Cyperetum flavescentis Koch ex Aichingeer 1933
Ludwigietum palustris Lakušić et Pavlović 1976
Ludwigia palustris-Persicaria decipiens comm.

Verbenion supinae 1951

Verbenetum supinae Sunding 1972
Menthetum pulegii Lakušić 1973

Phragmito-Magnocaricetea Klika in Klika et Novák 1941

Phragmitetalia Koch 1926

Phragmition communis Koch 1926

Phragmitetum australis Savič 1926
Typho angustifoliae-Phragmitetum australis (Tüxen & Preising 1942) Rivas-Martínez, Báscones, T. E. Díaz, Fernández-González et Loidi 1991
Scirpo lacustris-Phragmitetum australis Koch 1926
Amorpha fruticosa-Phragmites australis comm.
Eleocharito palustri-Hippuridetum vulgaris Passarge 1955
Scirpetum lacustris Chouard 1924
Iridetum pseudoacori Krzywanski 1974

Typhion laxmannii Nedelcu 1968

Typhaetum angustifoliae (All. 1922) Pign. 1943
Typhetum latifoliae Lang 1973

Bolboschoenetalia maritimi Hejný in Holub et al. 1967

Scirpion maritimi Dahl et Hadač 1941

Bolboschoenetum maritimi Eggler 1933

Magnocaricetalia Pignatti 1953

Magnocaricion elatae Koch 1926

Caricetum elatae Koch 1926
Cladietum marisci (Allorge 1922) Zobrist 1935

Cyperetum longi Micevski 1957

Magnocaricion gracilis Géhu 1961

Caricetum vulpinae Nowiński 1927

Nasturtio-Glycerietalia Pignatti 1954

Glycerio-Sparganion Br.-Bl. et Sissingh in Boer 1942

Glycerietum maximae Hueck 1931
Nasturtietum officinalis Gilli 1971
Sparganio-Cyperetum longi Horvatić 1939
Sparganietum erecti Roll 1938
Sparganietum emersi Mirkin, Gogoleva et Konov 1985
Beruletum erectae Roll 1938
Veronicetum beccabungae Philippi 1973

Phalaridion arundinaceae Kopecký 1961

Phalaridetum arundinaceae Libb. 1931

Oenanthetalia aquaticae Hejný ex Balátová-Tuláčková et al. 1993

Oenanthion aquaticae Hejný 1948 ex Neuhäsl 1959

Oenanthetum aquaticae Soó ex Nedelcu 1973
Menthetum aquaticae Lakušić & Pavlović 1976
Rorippetum amphibiae Psrg. (1960) 1964

Eleocharito palustris-Sagittarion sagittifoliae Passarge 1964

Eleocharitetum palustris Schennikow 1919
Butometum umbellati Philippi 1973

Anthropogenic Vegetation

Chenopodietea Br.-Bl. in Br.-Bl. et al. 1952

Brometalia rubenti-tectorum (Rivas Goday et Rivas-Mart. 1973) Rivas-Mart. et Izco 1977

Hordeion murini Br.-Bl. in Br.-Bl. et al. 1936

Hordeetum murini Libbert 1933

Chenopodietalia Br.-Bl. in Br.-Bl. et al. 1936

Chenopodion muralis Br.-Bl. in Br.-Bl. et al. 1936

Chenopodietum albi Solm. in Mirk. et al. 1986

Sisymbrietea Gutte et Hilbig 1975

Sisymbrietalia sophiae J. Tx. ex Görs 1966

Atriplicion Passarge 1978

Erigeron canadensis comm.

Digitario sanguinalis-Eragrostietea minoris Mucina, Lososová et Šilc in Mucina et al. 2016

Eragrostietalia J. Tx. ex Poli 1966

Eragrostion Tx. in Oberd. 1954

Digitarietum sanguinalis Poldini 1980
Eragrostis minor comm.
Cynodon dactylon comm.

Polycarpo-Eleusinion indicae Čarni et Mucina 1998

Eleusinetum indicae (Pignatti 1953) Oberdorfer 1971

Eragrostio-Polygonion arenastri Couderc et Izco ex Čarni et Mucina 1998

Polygonum aviculare comm.
(= *Polygonetum arenastri* Gams 1927 corr. Láníková in Chytrý 2009)

Polygono-Poetea annuae Rivas-Mart. 1975

Polygono arenastri-Poetalia annuae Tx. in Géhu et al. 1972 corr. Rivas-Mart. et al. 1991

Polygono-Coronopodion Sissingh 1969

Poetum annuae Gams 1927

Artemisietea vulgaris Lohm., Prsg. & Tx. 1950

Onopordetalia acanthii Br.-Bl. & R.Tx. ex Klika & Hadač 1944

Onopordion acanthii Br.-Bl. & al. 1936

Onopordetum acanthii Br.-Bl. 1936

Agropyretalia intermedio-repentis T. Müller et Görs 1969

Convolvulo arvensis-Agropyrion repentis Görs 1967

Sorghum halepense comm.

Carthamnetalia lanati Brullo & Marceno 1985

Silybo mariani-Urticion piluliferae Sissingh ex Br.-Bl. et O. de Bolòs 1958

Carduo-Silybetum mariani Trinajstić 1979

Elytrigio repentis-Dittrichietalia viscosae Mucina ined.

Inulo viscosae-Agropyrion repentis Biondi et Allegrezza 1996

Cynodono dactyloni-Dittrichietum viscosae Černjavski, Grebenščikov et Pavlović 1949

Epilobietea angustifolii Tx. et Preising ex von Rochow 1951

Convolvuletalia sepium Tx. ex Moor 1958

Senecionion fluviatilis Tx. ex Moor 1958

Mentho longifolii-Pulicarietum dysentericae Slavnić 1958
Roripetum austriacae Oberd. 1957

Bidentetea Tx. et al. ex von Rochow1951

Bidentetalia tripartitae Br.-Bl. et Tx. ex Klika et Hadač 1944

Bidention tripartitae Nordhagen 1940 ex Klika et Hadač 1944

Bidentetum tripartitae Koch 1926

Chenopodion rubri (Tx. in Poli et J. Tx. 1960) Hilbig et Jage 1972

Mentha pulegium-Xanthium italicum comm.

Paspalo-Heleochloetalia Br.-Bl. ex Rivas Goday 1956

Paspalo-Agrostion semiverticillati Br.-Bl. in Br.-Bl. et al. 1952

Paspaletum paspaloidis Černjavski, Grebenščikov et Pavlović 1949
Paspalum dilatatum comm.
Sporobolus indicus comm.

References

1. Ebel W (1842) Reise in Montenegro. Monastber Verh Ges, Berlin, pp 132–141
2. Ebel W (1844) Zwolf Tage in Montenegro und ein Blick auf Dalmatien, Konigsberg, S. I–IV, 1–176 and I–XXXIX
3. Pančić J (1875) Elenchus Plantarum vascularium quas aestate a 1873 in Crna Gora. Belgradi, pp 1–106

4. Beck G, Szyszyłowcz I (1888) Plantae à [sic] Dre Ign. Szyszyłowicz in Itinere per Cernagoram et in Albania adjacente anno 1886 lectae. Universitatis Jagellonicae, Cracoviae
5. Horák B (1900) Zweiter Beitrag zur Flora Montenegro's. Osterr Bot Zeitschr 50:156–164. 208–212
6. Baldacci A (1892) Altre notizie intorno alla flora del Montenegro. Malpighia 6:6–123. Genova
7. Baldacci A (1894) Contributo alla conoscenza della flora dalmata, montenegrina, albanese, epirota e greca. Nuovo Gior Not Ital (Nuova serie) 1(2):90–103
8. Rohlena J (1902) Erster Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wisss Prag, pp 1–26
9. Rohlena J (1902) Zweiter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss Prag, pp 1–37
10. Rohlena J (1903) Dritter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss Prag, pp 1–71
11. Rohlena J (1904) Vierter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss Prag 38:1–208
12. Rohlena J (1906) Beitrag zur Flora von Montenegro (Originaldiagnosen). Feddes Reppert 3(36/37):145–149
13. Rohlena J (1912) Fünfter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss Prag, pp 1–143
14. Rohlena J (1931–32) Achter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss Prag, Tr II 35:1–29
15. Rohlena J (1933–34) Neunter Beitrag zur Flora von Montenegro. Sitz-Ber Böhm Ges Wiss, Prag, pp 1–20
16. Rohlena J (1941–42) Conspectus florae Montenegrinae. Preslia, XX-XXI. VČBS Praha, pp 1–505
17. Beck G (1901) Die Vegetationsverhältnisse illyrischer Länder. W. Engelmann, Leipzig
18. Adamović L (1913) Građa za floru Kraljevine Crne Gore. Rad JAZU (Zagreb) 195:1–96
19. Janchen E (1919) Beitrag zur Floristik von Ost-Montenegro. Österr Bot Zeitschr 68(5–7):77–98. 166–179, 254–286, 327–340
20. Cufodontis G (1936) Revisione monografica della *Linaria* appartenenti alla sez. *Cymbalaria* Chaw. Arch Bot (Forli) 12:54–81. 135–158, 233–254
21. Cufodontis G (1947) Die Gattung *Cymbalaria* Hill. Nachträge und Zusammenfassung. Bot Not (Lund) 107:135–156
22. Černjavski P, Grebenščikov O, Pavlović Z (1949) O vegetaciji i flori Skadarskog područja. Glasnik Prirodnjačkog muzeja, Ser B, knj 1–2:5–91
23. Lakušić R, Pavlović D (1976) Vegetacija Skadarskog jezera. Glas Rep Zavoda Zašt Prir, Titograd 9:45–50
24. Lakušić R, Pavlović D (1981) Association of Lake Skadar aquatic vegetation. In: Beeton AM, Karaman SG (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 125–133
25. Lakušić R (1983) Ekosistemi Skadarskog jezera i njegove okoline. In: Ivanović B (ed) Skadarsko jezero, radovi sa simpozijuma CANU, Naučni skupovi, Titograd, knj, vol 9, pp 101–112
26. Hadžiablahović S (2015) The pattens of diversity of Flora and vegetation of Skadar Lake in Montenegro. Disertation, Faculty of Sciences, University of Sarajevo, Bosnia and Herzegovina (in Bosnian)
27. Pantocsek J (1874) Adnotationes ad floram et faunam Hercegovinae, Crnagorae et Dalmatiae. Verh Verein Naturk (Presburg) 2:1–143
28. Gross L, Kneucker A (1902) Unsere Reise nach Istrien, Dalmatien, Montenegro, der Herzegovina und Bosnien im Juli und August 1900. Algem Bot Zeitschr, pp 151–153
29. von Hayek A (1917) Beitrag zur Kenntnis der Flora des albanisch-montenegrinischen Grenzgebietes. Akad Wiss Math-Nat Kl 94:127–210
30. Košanin N (1929) Die Verbreitung der *Castanea sativa* im Königreiche SHS. Bull Inst Bot Univ Beograd 1(2):191–198

31. Černjavski P (1931) Rezultati analize polena u mulju Skadarskog jezera. (Die resultate der Pollenanalyse im Schlamme des Skutarisees). Glasn Skop Nauč Društva 9(3):67–78
32. Černjavski P (1935) Pollenanalytische Untersuchungen der Gebrigsseen in der Balkangewässern. Verhandlungen der Inter Vereinigung für teoretische und angwandte Limnologie 7(1):142–153
33. Janković M (1953) Značaj pedoloških uslova za razvoj plodova kod vodene biljke *Trapa natans* L. na Skadarskom jezeru. (Die Bedeutung der pedologischen Bedigungen fürdie Fruchtentwicklung der Wasserpflanze *Trapa natans* L. am Skutari-See). Arh Biol Nauka, Beograd 5(1–2):79–98
34. Janković M (1957) Rezultati biometrijske analize roda *Trapa* L. u Jugoslaviji. (Ergebnisse der variations-statistischen Analyse der Gattung *Trapa* L. in Jugoslawien). Glasn Prir Muz Srpske Zem, Beograd, Ser B 10:161–218
35. Janković M (1957) Übersicht der Systematik der Gatung *Trapa* L. in Jugoslawien. Glasn Prir Muz Srpske Zem, Beograd, Ser B 10:83–159
36. Janković M (1959) Prilog pitanju sistematske vrednosti pojedinih organa oraška *Trapa* L. (Beitrag zur Frage 'Sistematische Werte' einzelner Organe del' Wassemuss – *Trapa* L.) Glasn Prir Muz, Beograd, Ser B 14:185–211
37. Janković M (1964) Neka razmatranja u vezi sa problemom forme 'robur' u okviru populacija vrste *Quercus robur* L. na teritoriji Jugoslavije. (Einige Betraehtungen im Beuzug auf das Problem del' Form 'robur' im Rahmen del' Populationen del' Art *Quercus robur* L. auf dem Territorium Jugoslawiens). Glasn Prir Muz, Beograd, Ser B 19:95–105
38. Janković M (1983) Kasaronja (*Trapa* L.) na Skadarskom jezeru i potreba njene zaštite. In: Ivanović B (ed) Skadarsko jezero, radovi sa simpozijuma, vol 9. CANU, Naučni skupovi Titograd, Knjiga, pp 65–270
39. Fukarek P (1956) Prilog poznavanju šumskih zajednica u kojima se javlja poljski jasen (*Fraxinus angustifolia* Vahl.) Šum List 80(1–2):30–40
40. Fukarek P (1963) Rasprostranjenost i druge fitohorološke karakteristike poljskog jasena (*Fraxinus angustifolia* Vahl). In: Naučno društvo SR Bosne i Hercegovine – Djela XX, vol 4. Sarajevo, pp 1–99
41. Slavnić Ž (1958) O vegetaciji sveze *Senecion fluviatilis* Tx. u Jugoslaviji. (Ueber die Vegetation des Verbrandes *Senecion fluviatilis* Tx. in Jugoslawien). Zbor Prir Nauke Mat Srpske Novi Sad 15:153–172
42. Höpflinger F (1964) Beiträge zur Flora von Skutari (Nordalbanien). Sonderabdruck aus den "Mitt des Natur, Vereines für Steierm" 94:92–107
43. Gigov A (1965) Kratak pregled kvartarne flore i vegetacije. Glasn Muz Lova Beograd 5:103–152
44. Gigov A (1984) Postglacijalni (Virm III) areal rasprostranjenja lužnjaka (*Quercus robur* L.) na Balkanskom poluostrvu. Radovi Akad Nauka Umjet Bosne Herceg 76(23):79–83. Sarajevo
45. Janković M, Bogojević R, Stefanović K (1969) Lovorova (*Laurus nobilis*) žbunasta vegetacija na Skadarskim ostrvima i njen značaj za problem granica rasprostranjenosti mediteranske vegetacije u našim submediteranskim područjima. In: III Kongres biologov Jugoslavije (Knjiga plenarnih referatov in povzetkov), pp 130–131
46. Aalto M, Hãmet-Ahti L, Rauuhijãvi R, Suominen J, Taarna K, Uotila M, Uotila P, Vitikaineno O (1972) Jugoslavian retki 11-25 VI 1971 (Botanical excursion to western Yugoslavia in 11 25 VI 1971, including a list of the collected vascular plants). Helsingin Yliopiston kasvimuseon monisteita 5:46
47. Janković M, Blaženčić J (1973) Uporedna studija strukture endokarpa plodova različitih vrsta roda *Trapa* L. i njen ekološki značaj. Glasnik Bot zavoda i Bašte Univ u Beogradu 8(1–4):81–116
48. Šmarda J (1968) Výsledky biogeografických cest do Jugoslávie v letech 1964–1967, II Výsledky botanických cest do Jugoslávie v letech 1964–1967, vol 9. Československá Akademie věd, Geografický ústav Brno, Zaprávy o vědecké činnosti, Brno, pp 1–128
49. Lakušić R (1969) *Utricularia vulgaris* L. nova karnivorna biljka u flori Crne Gore. Glas Rep Zavoda Zašt Prir – Prir Muz, Titograd 2:85–86

50. Pulević V (1970) *Euphorbia dendroides* L. i *Euphorbia wulfenii* Hoppe u flori Crne Gore. Glas Rep Zavoda Zašt Prir – Prir Muz, Titograd 3:67–69
51. Pulević V (1973) Prilog flori Crne Gore. Glas Rep Zavoda Zašt Prir – Prir Muz, Titograd 6:77–83
52. Pulević V (2005) Građa za vaskularnu floru Crne Gore. Republički Zavod za zaštitu prirode Crne Gore, Podgorica
53. Lakušić R, Pavlović D (1973) Pet novih vrsta u flori Crne Gore. Glas Rep Zavoda Zašt Prir – Prir Muz, Titograd 6:59–61
54. Blečić V, Lakušić R (1976) Prodromus biljnih zajednica Crne Gore. Glas Rep Zavoda Zašt Prir – Prir Muz 9:57–98
55. Pulević V, Mijušković M (1977) Korovska flora na nasipu željezničke pruge preko Skadarskog jezera. Jugosl Sav Herb Željezn, Zagreb, pp 119–124
56. Leute G (1978) Ergenbisse einer botanischen Sammel reise durch das Sudliche Jugoslawien im Jahre 1969. Ann Naturhistor Mus (Wien) 81:75–105
57. Šilić Č (1979) Monografija rodova Satureja L., *Calamintha* Miller, *Micromeria* Bentham, *Acinos* Miller i *Cliniopodium* L. u flori Jugoslavije. Zemaljski muzej Bosne i Hercegovine – Posebno izdanje, Sarajevo
58. Šilić Č (1991/1992) *Scilla lakusicii* sp. nov. – nova vrsta genusa *Scilla* L. i njeni srodnički odnosi sa vrstom *S. litardierei* Breistr. Glasn Muz Bosne i Herceg 30:29–41
59. Adams SM (1981) Aqutic macrophytes of Lake Skadar. In: Karaman SG, Beeton AM (eds) The biota and limnology of Lake Skadar. Univerzitet Veljko Vlahovic, Podgorica, pp 115–116
60. Ivković O (1981) Rasprostranjenje adventivne vrste *Lepidium virginicum* L. 1753 (Capparidales, Brassicaceae) u Jugoslaviji. Fragm Herb Jugosl, Zagreb 10(2):5–13
61. Ivković O (1982) Novi nalazi adventivne vrste *Eleusine indica* (L.) Gaertn. 1788 (Poales, Poaceae) u Jugoslaviji. Matica Srpska – Zbor Prir Nauka. Novi Sad 63:77–81
62. Lee K (1981) Initial application of a *Myriophyllum* production model to litoral zone of Lake Skadar. In: Beeton AM, Karaman SG (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 133–138
63. Ristić J, Vizi O (1981) Synoptic survey of the dominant Macrophytes in Lake Skadar. In: Beeton AM, Karaman SG (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 117–125
64. Čuturilo S, Ratković B (1983) Prilog proučavanju ekoloških uslova razvoja drezge – *Myriophyllum spicatum* L. na Skadasrkom jezeru. In: Ivanović B (ed) Skadarsko jezero, radovi sa simpozijuma. CANU, Naučni skupovi, Knjiga, vol 9, pp 212–229
65. Parolly G (1991–1992) Die Orchideenflora Montenegros. Mitt Bl Arbeitskr Heim Orch Baden-Württ 24(2):141–391
66. Vizi O (1997) Neki efekti eutrofizacije Skadarskog jezera na primjeru makrofitske vegetacije. Prirodne vrijednosti i zaštita Skadarskog jezera. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera, vol 44. CANU, Naučni skupovi, Knjiga, pp 299–308
67. Hadžiablahović S (2002) *Plantago intermedia* Godr. u flori Crne Gore. In: Proceeding of the 7th symposium on flora of Southeastern Serbia and neighbouring regions, Dimitrovgrad, pp 19–21
68. Hadžiablahović S (1994/95, 2004) The contribution to the Flora of Montenegro. Glas Rep Zavoda Zašt Prir 27–28:7–17
69. Hadžiablahović S (2005) Contribution to the Flora of Montenegro and FR Yugoslavia. Hacquetia 4(1):103–110
70. Hadžiablahović S (2006) Floristic and chorological addition of the vascular flora of Montenegro. In: Pešić V, Hadžiablahović S (eds) Proceedings of the symposium, II international symposium of ecologists of Montenegro, Kotor, 20–25 Sept 2006, pp 93–100
71. Hadžiablahović S (2010) The vascular flora of Ćemovsko polje (Montenegro). Natura Montenegrina 9(1):7–143

72. Hadžiablahović S (2012) *Vicia loiseleurii* (M. B.) D. Litvinov (Leguminosae) in the flora of Montenegro. Natura Montenegrina 11(3):425–431
73. Petrović D (2004) Floristička studija planine Sutorman. Magistarski rad, Biološki fakultet Univerziteta u Beogradu
74. Petrović D (2011) Floristička i vegetacijska studija planine Rumije. Doktorska disertacija, Prirodno-matematički fakultet Univerziteta u Podgorici
75. Biberdžić V (2007) *Caldesia parnassifolia* (L.) Parl. new species in Montenegrin flora. Natura Montenegrina 6:151–152
76. Hadziablahović S, Sokoli F, Kashta L (2001) Biodiversity database of the Shkodra/Skadar Lake (checklist of species)
77. Hadžiablahović S, Karaman V, Bulić Z (2003) *Solanum eleagnifolium* Cav. A new neotophyt in the flora of Montenegro. In: II congress of ecologists of the Republic of Macedonia, Ohrid
78. Hadžiablahović S, Redžić S, Bulić Z, Trakić S (2011) Chorological additions to the flora of Montenegro. Glas Rep Zavoda Zašt Prir 31–32:95–100
79. Bubanja N, Stevanović V, Lakušić D (2007) *Edraianthus dalmaticus* A. DC. (Campanulaceae) in Montenegro. Natura Montenegrina 6:19–25
80. Petrović D, Stešević D, Vuksanović S, Hadžiablahović S, Kasom G, Dragićević S, Mačić V, Karaman M, Bušković V, Borija I, Biberdžić V, Bubanja N (2009) Important plant areas in Montenegro. IPA Programe, p 65
81. Petrović D, Hadžiablahović S, Vuksanović S, Mačić V, Lakušić D (2012) Catalogue of habitat types of EU importance of Montenegro
82. Petrović D, Stešević D (2011) Shift of the western boundary of the distribution area of *Micromeria cristata* (Hampe) Griseb. and *Steptorhamphus tuberosus* (Jacq.) Grossh. Acta Bot Croat 70(2):259–267
83. Đurišić S (2018) *Marsilea quadrifolia* L. (Marsileaceae) a new report for the flora of Montenegro. Natura Montenegrina (in press)
84. von Grimburg CG (1871) Beiträge zur Flora Albaniens. Verhandlungend k Zoolisch-Botanischen gesellschaft in Wien 21:1345–1352
85. Höhnel F (1893) Beitrag zur Kenntnis der Laubmoosflora des Küstenstriches vom Görzer Becken bis Scutari in Albanien. Österr Bot Zeitschrr 43(12):403–412
86. Baldacci A (1901) Rivista della collezione botanica fatta nel 1897 nell'Albania settentrionale. Mem Accad sci Isti Bologna ser V t 9
87. Janchen E (1920) Vorarbeiten zur einer Flora der Umgebung von Skodra in Nord-Albanien. Österr Bot Zeitschr 59:128–146. 169–186, 199–207, 230–261
88. Bertram H (1930) Nje ekskursion botanik deri ne Shiroke. Hylli i Drites, 7, 8, 9, 11. Shkoder
89. Schütt B (1945) Die Pflanzenwelt von Nordalbanien, des westlichen Montenegro und der westlichen Šar. Manuscript, aufbewahrt im Übersee-Museum, Bremen
90. Karpati I (1962) Überblick der zönologischen und ökologischen verhältnisse der Auenwälder des Westbalkans. Int Vereinigung für vegetationskunde Ostalpin-Dinarische Sektion Mitteilungen der Ostalpin-dinarischen Pflanzensoziologischen Arbeits – Gemeinschaft 2:101–106. + X tabelle
91. Karpati I, Karpati V (1961) Die Zönologischen verhältnisse der auenwälder Albaniens. Acta Bot Sci Hungary 7:235–301
92. Ruci B (1983) Te dhena mbi vegjetacionin dhe floren e Liqenit te Shkodres. Buletin i Shkencave Natyrore Tirane 3–4:109–113
93. Ruci B (1985) Konsiderata mbi bimësisnë dhe florën e rrethit të Shkodrës. Dizertacion, Tiranë, p 666
94. Ruci B, Vangjeli J (1996) Te dhena mbi vegjetacionin e ujrave te embla dhe floren hidro e higrofile te Shqiperise. Uji-Pasuri e madhe kombetare. Studimi dhe administrimi i burimeve ujore te Shqiperise. Konference shkencore kombetare, Tirane, pp 171–176
95. Kashta L (1999) Perhapja e disa bimeve te rralla dhe te kercenuara ne Liqenin e Shkodres. Bio Eko 2:7–10
96. Kashta L (1999) Rreth perhapjes se *Trapa natans* L. ne Liqenin e Shkodres. Bio Eko 1:1–2

97. Kashta L (2000) Mbi perhapjen e disa bimeve te rralla dhe te kercenuara nehidrobiotope ne afersi te liqenit te Shkodres. Bio Eko 3:12–16
98. Kashta L (2007) Aquatic macrophytes in Lake Shkodra-Buna River wetlans complex. In: Pinna M, Uricchio VF, Aresta M, Bsset A (eds) Rivers and citizens. Cross-border experiences in environmental protection and sustainable development. Lecce, pp 82–93
99. Kashta L, Dhora D, Rakaj M (1997) Lista (Checklist) e bimeve dhe kafsheve te Liqenit te Shkodres – pjesa shqiptare. Sector of Bio-ecology for Shkodra Lake, p 24
100. Kashta L, Rakaj M (1999) Disa specie te reja per floren hidrofile te rrethit te Shkodres. Bio Eko 1:5–7
101. Kashta L, Rakaj M (1999) *Hydrocharis morsus ranae* L. (Hydrocharitaceae) dhe *Hydrocotyle vulgaris* L. (Umbelliferae) – specie te reja per floren e Liqenit te Shkodres. Bio Eko 2:11–13
102. Kashta L, Rakaj M (2001) Mbi perhapjen e disa bimeve te rralla dhe tekercenuara ne liqenin e Shkodres dhe ne hidrobiotope ne afersi te tij. In: Konferenca Kombetare e Biologjise, Tirane, 26–27 Prill. Studime Biologjike
103. Kashta L, Rakaj M (2003) First announcement of *Caldesia parnassifolia* (Bassi) Parlatore (Alismataceae) – a new species for the flora of Albania. Studime Biologjike, Tirane 7:90–96
104. Rakaj M (2009) New aquatic macrophytes for the flora of Albania from the Lake Shkodra, Drini and Buna basins. J Int Environm Application Science 4(3):278–284
105. Rakaj M (2011) Floristic and chorological records of monocots of Lake Shkodra. Ref No 014. In: Proceeding book ICE_2011 of international conference of ecosystems, Tiranë, 4–6 June 2011, pp 65–70
106. Rakaj M, Kashta L (2010) The threatened and rare plant species of the Lake Shkodra – Delta Buna Hydrological System. In: BALWOIS 2010, Ohrid, Republic of Macedonia, 25, 29 May 2010
107. Rakaj M, Kashta L (2011) Rare and threatened plant asociations and species of Lake Shkodra – Delta Buna wetland complex./Liqeni i Shkodres – gjendja dhe perspektivat, vol 2. CANU/ASHSH, Podgorica, Shkoder, pp 23–35
108. Rakaj M, Hyseni G (2012) Specie të reja makrofitesh për Liqenin e Shkodres dhe Shqipërinë. Bul Shkencor Ser Shkencave Nat (Shkodër) 62:70–79
109. Fanelli G, De Sanctis M, Gjeta E, Mullaj A, Attorre F (2015) The vegetation of the Buna river protected landscape (Albania). Hacquetia 14(2):129–174
110. McNeill J (1963) Taxonomic studies in the Alsinoideae: II. A revision of the species in the orient. Notes Roy Bot Gard Edinburgh 24:241–404
111. Speta F (1986) Heterokarpie, Dehiszenz, Heterospermie und basifixe Samen bei *Cymbralaria* Hill. (Scrophulariaceae) und systematische Schlußfolgerungen. Phyton, Annales Rei Botanicae, Horn 26(1):23–57
112. Kučera J, Marhold K, Lihová J (2010) *Cardamine maritima* group (Brassicaceae) in the amphi-Adriatic area: a hotspot of species diversity revealed by DNA sequences and morphological variation. Taxon 59(1):148–164
113. Lakušić D, Liber Z, Nikolić T, Surina B, Kovačić S, Bogdanović S, Stefanović S (2013) Molecular phylogeny of the *Campanula pyramidalis* species complex (Campanulaceae) inferred from chloroplast and nuclear non-coding sequences and its taxonomic implications. Taxon 62(3):505–524
114. Walther H, Leith H (1964) Klimadiagram. Weltatlas. VEB Gustav Fischer, Jena
115. Stevanović V, Stevanović B (1995) Osnovni klimatski, geološki i pedološki činioci biodiverziteta kopnenih ekosistema Jugoslavije. In: Stevanović V, Vasić V (eds) Biodiverzitet Jugoslavije. Biol fak Univerziteta u Beogradu, Ekolibri, Beograd, pp 75–95
116. Raunkiaer C (1934) The life forms of plants and statistical plant geography. Clarendon, London
117. Mueller-Dombois D, Ellenberg H (1974) Aims and methods of vegetation ecology. Wiley, New York

118. Stevanović V (1992) Floristička podela teritorije Srbije sa pregledom viših horiona i odgovarajućih flornih elemenata. In: Sarić MR (ed) Flora Srbije, vol 1. Srpska akademija nauka, Belgrade, pp 47–56
119. Anačkov G, Caković D, Stešević D, Vuksanović S, Mačić V, Tomović G (2016) Diversity of vascular flora of Boka Kotorska Bay. In: Joksimović A, Djurović M, Semenov AV, Zonn IS, Kostianoy AG (eds) The Boka Kotorska bay environment. Springer International Publishing, Cham
120. Turrill WB (1929) The plant life of the Balkan peninsula. A phytogeographical study. Clarendon, Oxford
121. Stevanović V, Jovanović S, Lakušić D, Niketić M (1995) Diverzitet vaskularne flore Jugoslavije sa pregledom vrsta od međunarodnog značaja. In: Stevanović V, Vasić V (eds) Biodiverzitet Jugoslavije sa pregledom vrsta od međunarodnog značaja. Ecolibri, Biološki fakultet, Beograd, pp 183–217
122. Peruzzi L, Innangi M, Tatino F, Santangelo A (2017) *Fritillaria messanensis* subsp. *gracilis* (Liliaceae), a new record for the Italian flora (S Italy). Phytotaxa 307(2):167–170
123. Službeni glasnik Crne Gore (2006) Rješenje o stavljanju pod zaštitu pojedinih biljnih i životinjskih vrsta. Br 76/06
124. Shuka L, Kashta L, Xhulaj M (2008) Evaluation of potential transboundary important plant areas of the North Albania. Natura Montenegrina 7(3):425–439
125. García Criado M, Väre H, Nieto A, Bento Elias R, Dyer R, Ivanenko Y, Ivanova D, Lansdown R, Molina JA, Rouhan G, Rumsey F, Troia A, Vrba J, Christenhusz MJM (2017) European red list of lycopods and ferns, vol 4. IUCN, Brussels, p 59
126. Lansdown RV (2014) *Baldellia ranunculoides*. The IUCN red list of threatened species 2014: e. T164327A42332261. https://doi.org/10.2305/IUCN.UK.2014-1.RLTS.T164327A42332261.en
127. Weber HE, Moravec J, Theurillat JP (2000) International code of phytosociological nomenclature. J Veg Sci 11:739–768
128. Mucina L, Bültmann H, Dierßen K et al (2016) Vegetation of Europe: hierarchical floristic classification systemof vascular plant, bryophyte, lichen, and algal communities. Appl Veg Sci 19(Suppl 1):3–264
129. Interpretation manual of European Union Habitats – EUR28 (2013)

The Zooplankton of Lake Skadar/Shkodra: Species Diversity and Abundance

Spase Shumka, Maria Špoljar, and Orhideja Tasevska

Contents

Abstract The most common groups of freshwater metazooplankton in Lake Skadar/Shkodra are rotifers, copepods, and cladoceran microcrustacean. Rotifers dominate in the zooplankton and consist of about 58% of the entire zooplankton species, while Copepoda and Cladocera are represented by 29 and 54 species, respectively. The copepod and cladoceran species found in the lake are common in the wider region with specific presences in different lake areas. The presence of rotifers in the plankton of Lake Skadar shows a clear difference in terms of both abundance and composition. During different periods of investigation, a clear similarity in the horizontal distribution of the zooplankton was revealed and it reflects the major water movements in Lake Skadar/Shkodra. The water movements

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 239–254, DOI 10.1007/698_2018_237,
© Springer International Publishing AG 2018, Published online: 11 May 2018

and flow from the north to the south are sufficiently large and show only minor modifications due to the local winds. In a situation of limited investigation or vegetation influences (in the extensively developed northern and southeastern zones of the lake), it is apparent that the main drivers in determining the diversity and horizontal distribution of zooplankton in Lake Skadar/Shkodra have to be explained by the movement of the water masses, the influence of river inflows, differences in temperature values, the low nutrient content, and the differences in nutrient content.

Keywords Abundance, Diversity, Lake Skadar/Shkodra, Trophic state, Zooplankton

1 Introduction

The abundance and quality of the world's freshwater resources are declining rapidly [1]. The primary reasons for such circumstances are a combination of pollution, unsustainable land use, the overutilization of freshwater resources, climate change, anthropogenic disruption of hydrological habitat connectivity, and the introduction of alien species. These threats combined with the importance of freshwater for human development suggest that freshwater ecosystems and the biodiversity they support are, and will remain, among the most endangered globally [2]. Furthermore, in terms of current climate change issues [3], the Balkan Lakes and Mediterranean islands are the most vulnerable. In this context, due to the interrelationship among different biota communities and a variety of abiotic factors, changes in zooplankton are reflected in their abundance, biomass, and species structure [4].

Zooplankton organisms comprise crucial elements of the structure and function of freshwater ecosystems, not only as consumers of primary production grazing on algae, bacteria, protozoa, and other invertebrates [5] but also as food items for the juvenile stages of several fish species. Thus, zooplankton occupies a key position in the food web architecture [6]. Moreover, its sensitivity to both natural and man-made changes makes zooplankton quite suitable for assessing alterations in the trophic dynamics and the ecological state of aquatic ecosystems related to changes in nutrient loading and climate [7–9]. In this sense, changes in zooplankton abundance, species diversity, and community composition can provide important indications of environmental change or disturbance and several studies have shown its usefulness as an indicator of changes in trophic dynamics and the ecological state of lakes related to changes in nutrient loading and climate [10, 11] due to the fact that these communities are highly sensitive to environmental variation [12].

Similar to other large Balkan Lakes, such as Lake Ohrid and Lake Prespa, the history of zooplankton surveys in Lake Skadar/Shkodra starts from the end of nineteenth century [13]. Basically, they were taxonomic and descriptive investigations, while later on, in the second half of the twentieth century, systematic approaches emphasizing the particularities and richness of zooplankton in one specific karstic Mediterranean lake began to appear. An overview of zooplankton research in Lake Skadar was provided by Petković [14]. Amongst those researchers who have significantly contributed to the research of the zooplankton of Lake Skadar, we should mention Richard [15] with his work dedicated to Cladocera, [16] and who also published papers on Copepoda [17] and Cladocera [18–20], Nedeljković [20] for Rotifera, Petkovski [21] for his fundamental work on Cladocera and Copeoda, and Živković [22–24] for Rotifera, Protozoa, and Cladocera. The interdisciplinary approach to Lake Skadar completed by the publication of the book "The Biota and Limnology of Lake Skadar" in 1981 considered various aspects of the composition, development, and spatial distribution of zooplankton through various published investigations by Stevan Petković, John Gannon, and Richard Stemberger [25–28]. Recent studies done on the Albanian side of the lake were carried out by Spase Shumka [14, 29] who provided data on the zooplankton from the Albanian side of Lake Skadar and gave valuable information on the impact of the eutrophication process on zooplankton abundance and diversity. The abovementioned studies provide important background information by suggesting that there are significant particularities in the zooplankton community and the food webs of Lake Skadar. Lake Skadar is a shallow unstratified lake with a relatively short water residence time that influences the pattern of zooplankton distribution.

According to several studies [25, 26, 30, 31], rotifers dominate in the Lake Skadar/Shkodra zooplankton consisting of about 58% of the entire zooplankton species, while Copepoda and Cladocera showed the presence of 54 and 29 species, respectively.

2 The Diversity of Lake Skadar/Shkodra Zooplankton

The three common groups of freshwater metazooplankton in Lake Skadar/Shkodra are copepods, cladocerans, and rotifers. The copepod and cladoceran species that occur in Lake Skadar are dominantly widespread species present in other nearby lacustrine systems, Ohrid and Prespa Lakes.

The presence of rotifers in the plankton of the littoral and the central part of the lake shows a clear difference in their abundance and composition. Actually, rotifers are the most diverse metazooplankton group in Lake Skadar/Shkodra. The number of rotifers in Lake Skadar/Shkodra has been determined as 205 taxa [25, 26, 32], 44 of them being reported from pelagic zooplankton [32].

2.1 *Copepods*

Copepod crustaceans in the Lake Skadar zooplankton are represented by three suborders: calanoids, cyclopoids, and harpacticoids. The latter comprises exclusively meiobenthic species that are very rarely found in plankton samples [22]. Calanoids are exclusively planktonic and in Lake Skadar they are represented by four taxa: *Neolovenulla alluaudi*, *Eudiaptomus coeruleus*, *Eudiaptomus drieschi*, and *Eudiaptomus vulgaris*. On the other hand, cyclopoids are the only copepods in the pelagic metazooplankton of Lake Skadar/Shkodra, with 14 species dominated by *Macrocyclops albidus*, *Eucyclops lilljeborgi*, *Eucyclops macruroides*, *Eucyclops serrulatus*, *Paracyclops affinis*, *Paracyclops fimbriatus*, *Thermocyclops crassus*, and *Mesocyclops leuckarti*. Gannon and Stemberger [27] reported the presence of the following Harpacticoid species: *Ectinosoma abrau*, *Nitokra hibernica*, *Canthocamptus staphylinus*, *Attheyella crassa*, *Paracamptus schmeili*, and *Nannopus palustris* from the lake.

According to Gannon and Stemberger [28], the population of *E. drieschi* occurred throughout the year in different lake zones. In the Albanian part of the lake, this species dominates, showing the greatest dominance along the shoreline of the lake [14]. Petković [31] and Gannon and Stemberger [28] reported that *E. drieschi* is lacking in the river mouths and littoral zones, with one peak of abundance in October in the pelagial part of the lake, while in the near shore zone the peak of abundance occurred in spring time. Some studies [14, 28, 31] suggest that there seems to be a tendency for the greatest numbers to occur near the bottom and at intermediate depths. However, occasionally the highest densities of *E. drieschi* were recorded in the surface water layer or there was a uniform vertical distribution.

The copepod *M. leuckarti* was present throughout the lake and dominates in the pelagial part of the lake. This species has not been observed at the mouth of the River Morača [31], and in a limited numbers has been recorded in the upper part of the River Buna/Bojana [14]. A specific particularity of the lake is the presence of copepodites and nauplii in all sampling seasons, suggesting that their reproduction continues throughout the year [30, 31].

2.2 Cladocera

Cladocera are represented in Lake Skadar/Shkodra by 54 species [30] belonging to seven families. According to Petković [31], two species of *Daphnia*, *Daphnia cucullata* and *Daphnia hyalina*, occur in Lake Skadar. Based on the published literature, *D. cucullata* is the dominant species among cladocerans [14, 28, 31]. The peak of *Daphnia* abundance was registered in the open part of lake [31].

The greatest abundance of *Diaphanosoma brachyurum* during periods of 1972–1977 and 2010–2013 was registered in the central part of the lake, and less in the littoral part of the lake, particularly in the vegetated areas.

2.3 Rotifera

Rotifera represent the most diverse group of Lake Skadar/Shkodra zooplankton (Table 1 and Fig. 1). During both periods of investigation, the dominant recorded

Table 1 List of zooplankton species collected in the period of 1972–1977 [28] and 2011–2013 [14]

Rotifera	
Adineta steineri (Bartos 1951)	*Lepadella ovalis* (Muller 1786)
Ascomorpha ecaudis (Perty 1850)	*Lepadella patella* (Muller 1773)
Anuraeopsis fissa (Gosse 1851)	*Lepadella rhomboides* (Gosse 1886)
Ascomorpha ovalis (Carlin 1943)	*Lepadella triptera* (Erenberg 1830)
Ascomorpha saltans (Bartsch 1870)	*Monommata aequalis* (Ehrenberg 1832)
Asplanchna priodonta (Gosse 1850)	*Monostyla bulla* (Gosse 1851)
Brachionus angularis (Gosse 1851)	*Monostyla closterocerca* (Schmarda 1895)
Brachionus diversicornis (Daday 1883)	*Monostyla hamata* (Stokes 1896)
Brachionus calyciflorus (Pallas 1776)	*Monostyla lunaris* (Ehrenberg 1832)
Brachionus calyciflorus f. amphiceros	*Mytilina crassipes* (Luchs 1912)
Brachionus dimidiatus (Bryce 1931)	*Mytilina mucronata* (Ehrenberg 1832)
Brachionus falcatus (Zacharias 1898)	*Mytilina ventralis* (Ehrenberg 1832)
Brachionus forficula (Wierzejski 1891)	*Notholca acuminata* (Ehrenberg 1832)
Brachionus havanaensis (Rousselet 1911)	*Notholca foliacea* (Ehrenberg 1838)
Brachionus plicatus (Muller 1786)	*Notholca squamula* (Muller 1786)
Brachionus qudridentatus (Hermann 1783)	*Philodina megalotrocha* (Ehrenberg 1832)
Brachionus urceolaris (Muller 1773)	*Platyias quadricornis* (Ehrenberg 1832)
Cephalodella forficula (Ehrenberg 1831)	*Ploesoma hudsoni* (Imhof 1891)
Cephalodella gibba (Ehrenberg 1832)	*Ploesoma truncatum* (Levander 1894)
Cephalodella misgurnus (Wulfert 1937)	*Polyarthra dolichoptera* (Delson 1925)
Collotheca mutabilis (Hudson 1885)	*Polyarthra dolichoptera* (Delson 1925)
*Collotheca pelag*ica (Rousselet 1893)	*Polyarthra major* (Bueckhardt 1900)
Colurella adriatica (Ehrenberg 1831)	*Polyarthra minor* (Voigt 1904)
Colurella uncinata (O. F. Muller 1773)	*Polyarthra remata* (Skorikov 1896)
Conochiloides exiguus (Ahlstrom 1938)	*Polyarthra trygla* (Ehrenberg 1834)
Conochilus hippocrepis (Schrank 1830)	*Polyarthra vulgaris* (Carlin 1943)
Conochilus unicornis (Rousselet 1892)	*Pompholyx complanata* (Gosse 1851)
Dicranophorus forcipatus (Muller 1786)	*Pompholyx sulcata* (Hudson 1885)
Dipleuchlanis propatula (Gosse 1886)	*Rotaria rotatoria* (Pallas 1766)
Dissotrocha aculeata (Ehrenberg 1832)	*Squatinella rostrum* (Schmarda 1846)
Epiphanes macrourus (Barrois and Daday 1894)	*Squatinella tridentatus* (Muller 1786)
Euchlanis dilatata (Ehrenberg 1832)	*Notommata copeus* (Ehrenberg 1834)
Euchlanis meneta (Myers 1930)	*Scaridium longicaudum* (Muller 1786)
Filinia longiseta (Ehrenberg 1834)	*Synchaeta kitina* (Rousselet 1832)
Filinia terminalis (Plate 1886)	*Synchaeta oblonga* (Ehrenberg 1832)
Filinia opoliensis (Zacharias 1898)	*Synchaeta pectinata* (Ehrenberg 1832)
Gastropus hyptopus (Ehrenberg 1838)	*Synchaeta stylata* (Wierzejski 1893)
Gastropus stylifer (Imhof 1891)	*Testudinella incisa* (Hennann 1773)
Hexarthra mira (Hudson 1871)	*Testudinella mucronata* (Gosse 1886)
Kellicottia longispina (Kellicott 1879)	*Testudinella patina* (Hermann 1783)
Keratella cochlearis (Gosse 1851)	*Testudinella pseudoliptica* (Bartos 1887)

(continued)

Table 1 (continued)

Keratella hiemalis (Carlin 1943)	*Testudinella truncata* (Gosse 1886)
Keratella quadrata (Muller1786)	*Trichocerca bicristata* (Gosse 1887)
Keratella ticinensis (Callerio 1921)	*Trichocerca birostris* (Minkievicz 1900)
Keratella valga (Ehrenberg 1832)	*Trichocerca capucina* (Wie and Zach1893)
Lecane bulla (Gosse 1851)	*Trichocerca cylindrica* (Imhof 1891)
Lecane curvirostris (Yamamoto 1941)	*Trichocerca iernis* (Gosse 1887)
Lecane elasma (Harring and Myers 1926)	*Trichocerca longiseta* (Schrank 1802)
Lecane elsa (Nitzsch 1827)	*Trichocerca myersi* (Hauer 1931)
Lecane flexilis (Gosse 1886)	*Trichocerca porcellus* (Gosse 1886)
Lecane luna (Muller 1776)	*Trichocerca pusilla* (Lauterborn 1898)
Lecane nana (Murray 1913)	*Trichocerca rattus* (Muller 1776)
Lecane quadridentata (Ehrenberg 1832)	*Trichocerca rectangularis* (Evens 1947)
Lecane obtuse (Hauer 1889)	*Trichocerca rousseleti* (Voigt 1902)
Lecane obtuse (Hauer 1889)	*Trichocerca similis* (Wierzejski 1893)
Lophocaris salpina (Ehrenberg 1834)	*Trichocerca stylata* (Gosse 1851)
Lophocharis oxysternon (Gosse 1851)	*Trichocerca weberi* (Jennings 1903)
Lepadella ehrenbergi (Perty 1850)	*Trichotria pocillum* (Muller 1776)
Cladocera	
Branchinecta ferox (Milne-Edwards 1840)	*Monospilus dispar* (Sars 1862)
Chirocephalus carnuntanus (Brauer 1877)	*Oxyurella tenuicaudis* (Sars 1862)
Bosmina longirostris (O. F. Müller 1776)	*Phrixura rostrata* (Koch 1841)
Ceriodaphnia reticulata (Jurine 1820)	*Pleuroxus aduncus* (Jurine 1820)
Daphnia cucullata (Sars 1862)	*Pleuroxus laevis* (Sars 1862)
Daphnia hyalina (Leydig 1860)	*Pleuroxus trigonellus* (O. F. Müller 1776)
Simocephalus serrulatus (Koch 1841)	*Pleuroxus truncatus* (O. F. Müller 1785)
Scapholeberis mucronata (O. F. Müller 1776)	*Chydorus piger* (Sars 1862)
Acroperus harpae (Baird 1835)	*Chydorus globosus* (Baird 1843)
Alona affinis (Leydig 1860)	*Chydorus sphaericus* (O. F. Müller 1776)
Alona guttata (Sars 1862)	*Anhistropus emarginatus* (Sars 1862)
Alona rectangula (Sars 1862)	*Pseudochydorus globosus* (Baird 1843)
Alona diaphana (King 1889)	*Rynchotalona falcata* (Sars 1862)
Alona quadrangularis (O. F. Müller 1776)	*Rhyncotalona rostrata* (Koch 1841)
Alonella exigua (Lilljeborg 1853)	*Leptodora kindti* (Focke)
Alonella nana (Baird 1843)	*Ilyocryptus agilis* (Kurz 1878)
Camptocercus rectirostris (Schoedler 1862)	*Ilyocryptus sordidus* (Liévin 1848)
Chydorus sphaericus (O. F. Müller 1776)	*Lathonura rectirostris* (O. F. Müller 1785)
Eurycercus lamellatus (O. F. Müller 1776)	*Macrothrix hirsuticornis* (Nor and Brad 1867)
Paracantha truncata (O. F. Müller 1776)	*Macrothrix laticornis* (Jurine 1820)
Camptocercus rectirostris biserratus (Schoedler 1862)	*Moina micrura* (Kurz 1875)
Graptoleberis testudinaria (Fischer 1848)	*Moina rectirostris* (Leydig 1860)
Leydigia acanthocercoides (Fischer 1854)	*Diaphanosoma brachyurum* (Liévin 1848)
Leydigia leydigi (Schoedler 1862)	*Sida crystallina* (O. F. Müller 1776)

(continued)

Table 1 (continued)

Copepoda – Calanoida	
Neolovenulla alluaudi (Guer *et*. Rich 1890)	*Eudiaptomus drieschi* (Poppe and Mrazek 1895)
Eudiaptomus coeruleus (Fischer 1853)	*Eudiaptomus vulgaris* (Schmeil 1896)
Harpacticoida	
Ectinosoma abrau (Kritschagin 1877)	*Attheyella crassa* (Sars 1863)
Nitokra hibernica (Brady 1880)	*Paracamptus schmeili* (Mrazek 1893)
Canthocamptus staphylinus (Jurine 1820)	*Nannopus palustris* (Brady 1880)
Cyclopida	
Macrocyclops albidus (Jurine 1820)	*Thermocyclops crassus* (Fischer 1853)
Eucyclops lilljeborgi (Sars 1918)	*Thermocyclops hyalinus* (Rehberg 1880)
Eucyclops macruroides (Lilljeborg 1901)	*Mesocyclops leuckarti* (Claus 1857)
Eucyclops serrulatus (Fischer 1851)	*Microcyclops varicans* (Sars 1863)
Paracyclops affinis (Sars 1863)	*Cryptocyclops bicolor* (Sars 1863)
Paracyclops fimbriatus (Fischer 1853)	*Speocyclops montenegrinus* (Petkovski 1971)
Ectocyclops phaleratus (C. L. Koch 1838)	

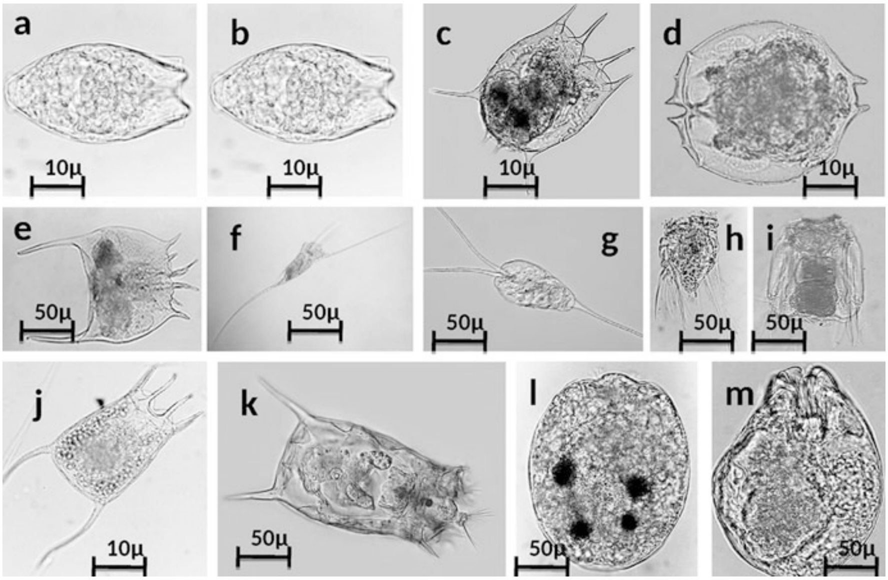

Fig. 1 The Rotifers of Lake Skadar/Shkodra: *Anuraeopsis fissa* (**a**, **b**), *Brachionus calyciflorus* (**c**), *Brachionus angularis* (**d**), *Brachionus quadridentatus* (**e**), *Kellicottia longispina* (**f**), *Filinia longiseta* (**g**), *Hexarthra mira* (**h**), *Polyarthra major* (**i**), *Keratella quadrata* (**j**, **k**), *Ascomorpha ecaudis* (**l**), and *Gastropus stylifer* (**m**). Original photographs taken by S. Shumka

species were *Synchaeta stylata*, *Polyarthra major*, *Polyarthra euryptera*, *Anuraeopsis fissa fissa*, *Pompholyx complanata*, *Lecane bulla*, *Lecane luna*, *Lecane lunaris*, *Trichocerca pusilla*, *Filinia longiseta*, *Keratella cochlearis*, *Keratella quadrata*, *Brachionus angularis*, *Brachionus diversicornis*, and *Brachionus calyciflorus*, a cosmopolitan mixture. The rotifer species assemblage was dominated by *Asplanchna priodonta*, *B. diversicornis*, and *B. calyciflorus f. amphiceros*, which comprised 25–30% of the total abundance [14].

2.4 Protozoa

Protozoa have rarely been included in studies of the zooplankton communities [5]. According to Dhora [32], there are 44 species that occur in the zooplankton structure in Lake Skadar/Shkodra. Most of these species belong to Ciliophora. The most abundant protozoa species are: *Monodinium* sp., *Codonella cratera*, *Chilodonella uncinata*, *Colpoda steini*, *Colpoda cucullus*, *Urotricha* sp., *Coleps* sp., *Dexiostoma campylum*, *Vorticella campanula*, *Vahlkampfia guttula*, *Vahlkampfia tachypodia*, *Vahlkampfia vahlkampfii*, *Vanella mira*, and so on [32].

2.5 Mollusca

In addition to the abovementioned groups and species, the planktonic lamellibranch, *Dreissena carinata* is part of the zooplankton with an increased abundance in the spring–summer period of the year [28]. Their presence and high invasiveness rate has been revealed in several reservoirs in the basin of the River Drini (Shumka, unpublished data). The former records of *Dreissena polymorpha* from Lake Skadar refer to *D. carinata* [33].

3 The Spatial Patterns and Population Dynamics of the Zooplankton

In most pelagic systems, the spatial variations that appear in the horizontal plane are closely correlated with those that develop in the vertical plane [4]. Organisms that concentrate at different depths in the water column tend to be transported to different locations by water currents. There is a strong correlation between the horizontal distribution of the zooplankton and the direction of the prevailing wind [34]. The importance of major water movements as vital in providing a basic understanding of the Lake Skadar/Shkodra ecosystem and plankton distribution was investigated in the period 1971–1977 [35, 36].

A central issue in understanding spatial patterns of zooplankton communities is identifying the local abiotic and biotic environmental conditions that drive them [37]. Abiotic factors driving variation in freshwater zooplankton communities between lakes include water chemistry such as nutrient concentration, pH level, conductivity, and turbidity [37, 38], hydrology for example, winds and wind induced currents [39], temperature [37, 40], and lake morphometry [41].

The first investigations of spatial patterns, population dynamics, and the influence of regional hydrology on the zooplankton of Lake Skadar/Shkodra were undertaken in the period 1972–1977 [28]. The investigation was basically focused on the effects of the lake tributaries on both the species composition and the horizontal distribution of limnetic rotifers and crustacean plankton on the Montenegrin side of the lake (Fig. 2). Later on in the period 2008–2013 [14], a similar approach mostly focused on limnetic rotifers was used for the Albanian side of the lake (Fig. 3). There is no joint approach by both sides for an integrated approach of entire ecosystem, while the lake itself experiences strong seasonal fluctuations in water level, where the influence of rivers and tributaries is of great importance.

These studies [14, 28] showed that rotifers were most abundant (183–315.2 individuals/L) in the upper reaches of Vučko Blato and in the vegetated area close to the city of Shkodra, while the lowest abundance (<10–18.3 individuals/L) occurred at the mouth of the River Morača and in the central part of the lake on the Albanian side. Species such as *K. cochlearis f. tecta*, *Brachionus* spp., and *A. fissa* were most prevalent in Vučko Blato, near Virpazar and in the vegetated area close to the city of Shkodra. There were no records of the presence of *K. cochlearis f. tecta* from the central and open part of the lake. *Polyarthra remata* dominates in Vučko Blato and in the vegetated area close to Shkodra, while *K. cochlearis f. microcantha*, *Pleosoma truncatum*, and *Synchaeta* spp. were all most prevalent in mid-lake localities [14, 28].

Crustacean plankton were generally low in abundance (0–36.5–74.22 individuals/L) [14, 28] and show a similar pattern of distribution to rotifers. Crustaceans were more abundant in the northeast (10.3–12.2 individuals/L) and southwest (14.5–19.3 individuals/L) parts of the lake. On the other hand, according to Gannon and Stemberger [28], the lake water mixed with the River Morača inflow was nearly devoid of crustacean plankton. Low abundance of *E. drieschi* was found in the River Morača influx, while relatively high abundance was reported in the southwest part of the lake (16.3 individuals/L) [28]. The cladoceran *Diaphanosoma* and *Bosmina* were present in all localities with an increased abundance in Vučko Blato, along the southern shore between Virpazar and Raduš [28] and in the southeastern and southwestern parts of the lake [28]. *D. cucullata* and *D. hyalina* were recorded in the southwestern and northwestern parts of the lake [28].

The part of lake that is affected by the water of the River Morača exhibited the lowest densities of rotifer and crustacean plankton. This pattern was observed in both the spring and the autumn season [28]. Obviously, the lower temperature and higher turbidity affect the growth and reproduction of rotifers and crustacean plankton near river mouths and outflows [28].

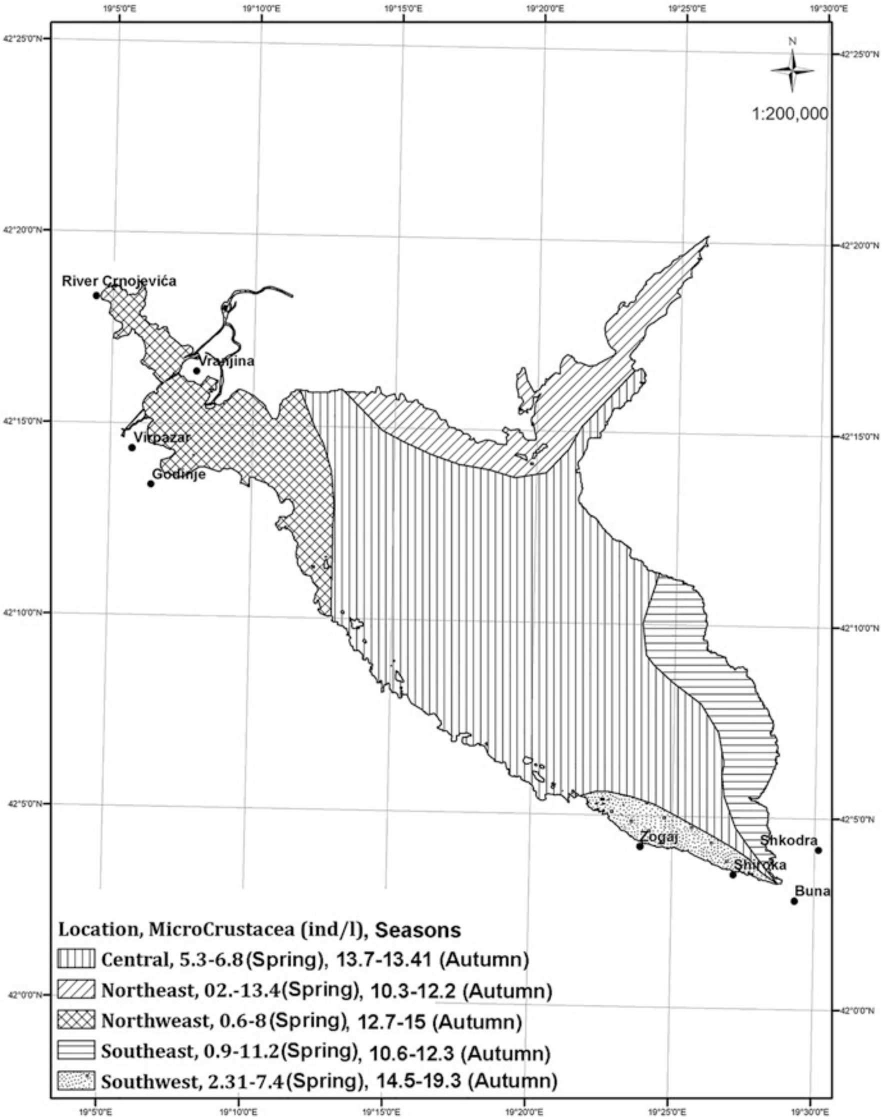

Fig. 2 Spatial distribution of microcrustacea during spring and autumn for the surveyed periods

As was noted for the composition revealed in the autumn, the abundance of crustacean plankton was low (0.1–13.6 individuals/L). Based on the available data, the greatest abundance values on the Albanian side were in the southwest of the lake (12.2 individuals/L) [14], while during the investigations of 1972–1977 on the Montenegrin side, the lake water mixed with inflow from the River Morača contained extremely low numbers of microcrustaceans and in those conditions

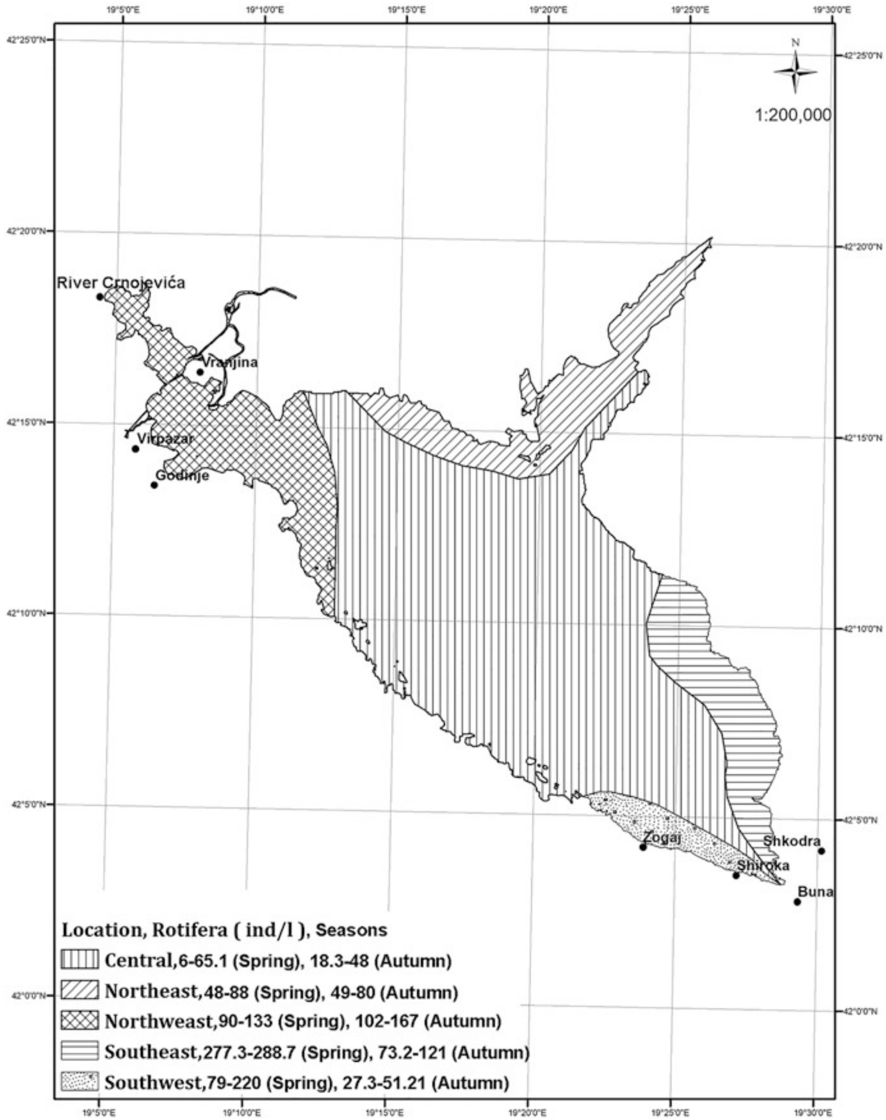

Fig. 3 The spatial distribution of rotifers during spring and autumns for the surveyed periods

extended for a considerable distance into the main part of the lake [28]. A lower number of crustaceans were also detected in the central part of the lake on the Albanian side (0.9 individuals/L). The River Morača affects breeding activity as nauplii and females carrying eggs or spermatophores were present in a high number in the southeastern part of the entire lake but not in areas affected by the River Morača [28].

A similar pattern was observed for two other cyclopid copepods, *M. leuckarti* and *Thermocyclops hyalinus.* Both species were present in a low density (0–0.1–1.6 individuals/L) and reached their highest value in those areas not affected by the River Morača (3 individuals/L).

The highest abundance of Cladocera (8.5 individuals/L) was observed in the southwestern part of the lake [14], while the lowest abundance was observed in the zones influenced by river inflows [28]. *Bosmina longirostris* comprised over 86% of the total microcrustaceans [28].

In summary, a greater diversity and biomass of zooplankton was observed in the littoral zone than in the open part of the lake's water [22, 23]. The relatively large numbers of littoral rotifers and crustacean species in the plankton reflect the extensiveness of the littoral zone and a relatively high degree of exchange between littoral and limnetic water [14].

According to Ganon and Stemberger [28], the low diversity of planktonic Crustacea in Lake Skadar/Shkodra may be partially explained by its comparative small and shallow limnetic zone. The second factor that affects crustacean plankton diversity relates to intensive predation by planktivorous fish [28]. The impact of these factors on the planktonic Crustacea in Lake Skadar/Shkodra is poorly investigated.

Another factor that leads to seasonal similarity in the horizontal distribution of zooplankton in Lake Skadar is related to the major water movements in Lake Skadar/Shkodra [28]. The main direction of the water movements and flow from north to south is relatively large and receives only minor modifications from the local winds.

There are other factors that influence the diversity and abundance of zooplankton in Lake Skadar/Shkodra but their impact is almost unknown. These factors include the impact of aquatic vegetation in the (extensively developed) northern and southeastern zones of the lake, pollution, especially by heavy metals, and the ongoing process of eutrophication. Further research is needed to estimate the impact of these factors on community changes in the zooplankton of Lake Skadar/Shkodra.

4 Variations in the Zooplankton Species Structure and Their Potential Use as Bioindicators of the Trophic State of the Lake

The investigation of the factors that determine plankton biomass has been one of the main issues in freshwater ecology since the eutrophication debate started in the early 1960s [10, 11]. In case of Lake Skadar/Shkodra, anthropogenic eutrophication is caused by using lake, rivers, and streams as recipients for urban, agricultural, and industrial waste. It has become clear that phosphorus can usually be considered the main limiting nutrient in freshwater systems and that the phosphorus supply sets an upper boundary for the phytoplankton biomass in lakes [42].

Bioindicator approaches using aquatic organisms and their responses to evaluate the trophic state have often been neglected in favor of chemical and physical techniques. Many studies have shown that the trophic state is an important factor in determining the distribution of rotifer communities in various aquatic ecosystems [42, 43].

Several studies have provided lists of rotifer species indicative of different trophic states [27, 44, 45]. However, one widely accepted community index based on rotifers has not yet been developed [46]. Duggan et al. [47] found that the trophic state was the main driver of rotifer distribution, and they developed a quantitative bioindicator index using the composition of the rotifer community in order to infer trophic lake index values.

Among zooplankton, rotifers are widely used as an indicator of eutrophic water conditions. The *B. calyciflorus*, *Trichotria tetractis*, and *F. longiseta* species are used as indicators of eutrophication [48]. Due to the fact that parthenogenetic reproduction and population length are very broad, lakes have been seen as convenient for eutrophication for the species of *Keratella* sp., *Brachionus* sp., *F. longiseta*, and *T. tetractis* [48]. *B. calyciflorus*, *B. angularis*, *K. quadrata*, *K. cochlearis*, *L. luna*, *Pompholyx sulcata*, *F. longiseta*, genus *Trichocerca*, *B. longirostris*, *Chydorus sphaericus*, and *Daphnia cucullata* (Cladocera) are among the species that are characteristic of eutrophic water [48]. Furthermore, other authors [49–52] have reported that species of *Brachionus quadridentatus*, *Notholca squamula*, *Lepadella patella*, *L. bulla*, *B. longirostris*, *Alona rectangula*, *Cyclops vicinus*, and *Acanthocyclops robustus* represent known indicator species of eutrophication.

Several studies [48–52] have listed rotifer and crustacean planktonic species as good indicators of eutrophication. Many of these species occur in lake areas which are being heavily influenced by anthropogenic impact.

The littoral part of the water in Lake Skadar/Shkodra, characterized by high nutrient content [14], were dominated by the following species: *B. angularis*, *B. diversicornis*, *Brachionus falcatus*, *Brachionus forficula*, *A. fissa*, *P. sulcata*, *P. complanata*, *Trichocerca capucina*, *Trichocerca cylindrica*, *T. pusilla*, *F. longiseta*, *K. cochlearis*, *Keratella ticinensis*, *K. quadrata*, *and Polyarthra trygla*. These species were less common in the open part of the water. Species of *Brachionus*, primarily *B. angularis* and *B. diversicornis*, comprised 35%, 15%, and 10% of the total rotifer density, respectively, at a sequence of localities stretching from the littoral to the open part of the water [28]. These species have previously been reported as good indicators of a eutrophic state [27, 44, 45]. *B. angularis*, *B. quadridentatus*, *K. quadrata*, *T. capucina*, *P. complanata*, *P. sulcata*, *F. longiseta*, and *F. terminalis* are characteristic of eutrophic water bodies.

Sládecek [46] mentioned that *Ascomorpha ovalis*, *K. cochlearis*, *K. quadrata*, *A. fissa*, *T. capucina*, and *F. longiseta* are characteristic inhabitants of mesotrophic to eutrophic waters, while Gannon and Stemberger [27] stated that *A. ovalis*, *Conochilus coenobasis*, *Conochilus dossuarius*, *Conochilus unicornis*, *Polyarthra dolichoptera*, and *Synchaeta longipes* are associated with a low trophic state. Our records show that *A. ovalis*, *Ascomorpha saltans*, *S. stylata*, *Synchaeta pectinata*, *Synchaeta oblonga*, *Synchaeta kitina*, *P. major*, *P. trygla*, *C. unicornis*, and *A. fissa* are characteristic of mesotrophic water conditions in Lake Skadar/Shkodra (Shumka, unpublished data).

Among the thirteen species of the family Lecanidae, *L. bulla*, *Lecane curvirostris*, *Lecane elasma*, *L. luna*, *Lecane quadridentata*, and *L. lunaris* were most common [28]. This genus in Lake Skadar/Shkodra includes both freshwater and saline species as the result of the connection between Lake Skadar/Shkodra and the Adriatic Sea by means of the River Buna (Shumka, unpublished data).

Surveys on both the Montenegrin and the Albanian side of the lake [14, 28] have confirmed that the greatest abundance (>183 individuals/litre) was recorded in the more eutrophic part of lake (Vučko Blato) and the lake areas that exhibit significant anthropogenic pressure, including Virpazar and the shore area of Shkodra. Characteristic species that are prevalent in these areas include *K. cochlearis f. tecta*, *A. fissa*, and *Brachionus* spp. [14, 28], which are indicators of increased eutrophic conditions.

Acknowledgements This work was partly funded by the Ministry of Education and Science of Albania (MASH) under the ALIW (Use of aquatic livings as indicator of water quality) project (contract n 212.10) and contributes of the Agricultural University Tirana, Albania.

References

1. Brown LR, Flavin C, French H (2000) State of the world 2000. The Worldwatch Foundation, New York
2. Palmer MA, Reidy Liermann CA, Nilsson C, Flörke M, Alcamo J, Lake PS, Bond N (2008) Climate change and the world's river basins: anticipating management options. Front Ecol Environ 6:81–89
3. Markovic D, Savrina F, Carrizo O, Oskar K, Walz A, David W (2017) Vulnerability of European freshwater catchments to climate change. Glob Chang Biol 23:3567–3580
4. Bruks L, Lodge M, Jepesen E, Lauridsen T (2002) Diel horizontal migration of zooplankton: costs and benefits of inhabiting the littoral. Freshw Biol 47:343–365
5. Russell RH, Ksenia NK, Alexei IP (2010) Zooplankton community patterns in the Chukchi Sea during summer 2004. Deep Sea Res II Top Stud Oceanogr 57(1–2):27–39
6. Dagg M, Benner R, Lohrenz S, Lawrence D (2004) Transformation of dissolved and particulate materials on continental shelves influenced by large rivers: plume processes. Cont Shelf Res 24:833–858
7. Hoffmann W (1977) The influence of abiotic environmental factors on population dynamics in planktonic rotifers. Arch Hydrobiol 8:77–83
8. Ferrara O, Vagaggini D, Margaritora FG (2002) Zooplankton abundance and diversity in Lake Bracciano, Latium, Italy. J Limnol 61(2):169–175
9. Preston ND, Rusak JA (2010) Homage to Hutchinson: does inter-annual climate variability affect zooplankton density and diversity? Hydrobiologia 653:165–177
10. Lampert W, Sommer U (1997) Limnoecology – the ecology of lakes and streams. Oxford University Press, Oxford, 382 pp
11. Caroni R, Irvine K (2010) The potential of zooplankton communities for ecological assessment of lakes: redundant concept or political oversight? Biol Environ Proc R Ir Acad B 110(1):35–53
12. Jeppesen E, Christoffersen K, Landkildehus F, Lauridsen T, Amsinck S, Riget F, Søndergaard M (2001) Fish and crustaceans in northeast Greenland lakes with special emphasis

on interactions between Arctic charr (*Salvelinus alpinus*), Lepidurus arcticus and benthic chydorids. Hydrobiologia 442:329–337
13. Shumka S (2001) Feeding relations of *Eudiaptomus gracilis* (SARS) and influence on some parameters of their life cycle in Lake Ohrid. Verh Int Ver Limnol 27:3708–3711
14. Shumka S (2014) Rotifers in the littoral zone of Lake Shkodra/Skadar (Albania-Montenegro) as a tool for determining water quality. Int Res J Biol Sci 3(3):71–77
15. Richard J (1897) Entomostraces recucillis par M. le Directeur Steindachner dans les lacs de Janina et Scutari. Ann k k Hofmus, Wien, 12
16. Steuer A (1900) Die Diaptomiden des Balkans zugleich ein Beitrag zur Kenntnis des Dioptomus vulgaris Schmeil. Situnzber. Keis Akadder Wiss Mathem Natur Classe, CIX B, Abr 1:1–10
17. Veršcagin GJ (1912) Cladocera Skutarijskogo ozera (Cernogorija). Raboti laborat Zoll kabineta imperator Varšav Univ, 23 pp
18. Parenzan P (1931) Cladoceri D'Albania con brevi notizie morfologische ed hidrobiologische et idrobiologische sui grandi laghi albanesi. Atti dell Academia Veneto Trentino Istriana 22:16–47
19. Parenzan P (1931) Una nuova varieta di *Bosmina longirostris* del lago di Scutari. Atti dell Academia Veneto Trentino Istriana 21:31–43
20. Nedeljković R (1959) Skadarsko jezero: studija organske prodikcije u jednom karsnom jezeru. Posebno izd Biol Inst 4:1–56
21. Petkovski T (1961) Zur Kenntnis der Crustaceen des Skadar (Scuteri) Sees. Acta Mus Macedonici Sci Nat 8(2):29–52
22. Živković A (1974) Nova vrsta Rotatoria *Platyias bicornis* sp.n. u Skadarskom jezeru. Arch Biol Nauka 26(3–4):193–195
23. Živković A (1975) Zooplankton and microfauna of the vegetative area of Skadar Lake. In: Limnological investigations of Skadar Lake, Progress Rept., 1973. Smithsonian Institution, pp 89–106
24. Milovanović D, Živković A (1965) Plankton Skadarskog jezera (1957 do 1958). Zbornik radova Bioloskog Instituta 8(4):21–28
25. Petković S (1978) The contribution to the better knowledge of ecology and distribution of *Brachionus sessilis* Varga 1957 (Rotatoria). Poljoprivreda i šumarstvo 24(2):17–37
26. Petković S (1973) Prilog poznavanju faune Rotatoria Crne Gore IIa.-Fam.Trichotriidae. Glas Republ Zavoda Zašt Prirod – Prirodnjačkog muzeja Titograd 5:129–134
27. Gannon JE, Stemberger RS (1978) Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans Am Microsc Soc 97:16–35
28. Gannon J, Stemberger R (1981) Impact of influent rivers in the distribution of zooplankton in Skadar Lake. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 199–216
29. Shumka S, Kostoski G (2017) *Dreissena* invasion: predictable patterns driven by invasion history – towards cascade reservoirs of Drini River in the northern Albania. In: Pešić V (ed) The book of abstracts and programme of 7th international symposium of ecologists of Montenegro, ISEM7, Sutomore, 4–7 Oct 2017
30. Petković S (1981) Zooplankton-general introduction. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 191–192
31. Petković S (1981) Seasonal abundance and distribution of planktonic Crustacea. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 192–199
32. Dhora D (2016) Liqeni i Shkodres. Shkoder, 163 pp
33. Pešić V, Glöer P (2018) The diversity and conservation status of the molluscs of Lake Skadar/Shkodra. In: Pešić V, Kostianoy AG, Karaman GS (eds) The Skadar/Shkodra Lake environment. Springer, New York

34. George D, Winfield I (2000) Factors influencing the spatial distribution of zooplankton and fish in Loch Ness, UK. Freshw Biol 43:557–570
35. Lee K (1981) Application of mathematical modeling in studying of Lake Skadar circulation patterns. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 56–65
36. Byron GT (1981) Growth rate of crustacean zooplankton in Skadar Lake. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 217–219
37. Bartrons M, Einarsson E, Nobre R, Herren C, Webert C, Brucet S, Ives I (2015) Spatial patterns reveal strong abiotic and biotic drivers of zooplankton community composition in Lake Mývatn, Iceland. Ecosphere 6(6):1–21
38. Pourriot R, Tifnouti A, Rougier C (1994) Spatial distribution of zooplankton in a natural reservoir: the Lalla-Takerkoust in Morocco. Arch Hydrobiol 130:113–127
39. Rennella AM, Quirós R (2006) The effects of hydrology on plankton biomass in shallow lakes of the Pampa Plain. Hydrobiologia 556:181–191
40. Winder M, Schindler D (2004) Climate change uncouples trophic interactions in an aquatic ecosystem. Ecology 85:2100–2106
41. Jeppesen E, Nõges P, Davidson TA et al (2011) Zooplankton as indicators in lakes: a scientific-based plea for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD). Hydrobiologia 676(1):279–297
42. Schindler DW (1978) Factors regulating phytoplankton production and standing crop in the worlds freshwaters. Limnol Oceanogr 23:478–486
43. Ejsmont-Karabin J (1995) Rotifer occurrence in relation to age, depth and trophic state of quarry lakes. Hydrobiologia 313–314:21–28
44. Mäemets A (1983) Rotifers as indicators of lake types in Estonia. Hydrobiologia 104:357–361
45. Berzins B, Pejler B (1989) Rotifer occurrence and trophic degree. Hydrobiologia 182:171–180
46. Sládecek V (1983) Rotifers as indicators of water quality. Hydrobiologia 100:169–201
47. Duggan I, Green J, Shiel R (2004) Distribution of rotifers in North Island, New Zealand, and their potential use as bioindicators of lake trophic state. Hydrobiologia 446–447:155–164
48. Ruttner-Kolisko A (1974) Handbook of plankton rotifers, biology and taxonomy. Die Binnengewasser Stuttgart 26(1):144
49. Bozkurt A, Tepe Y (2011) Zooplankton composition and water quality of Lake Gölbaşı (Hatay-Turkey). Fresenius Environ Bull 20:166–174
50. Špoljar M, Tomljanovic T, Lalic I (2011) Eutrophication impact on zooplankton community: a shallow lake approach. Holist Approach Environ 1(4):131–142
51. Tasevska O, Špoljar M, Gušeska D, Kostoski G (2017) Summer rotifer assemblages in three reservoirs in the Republic of Macedonia. Acta Zool Bulg Suppl 8:77–84
52. Gazonato Neto AJ, Silva LC, Saggio AA, Rocha O (2014) Zooplankton communities as eutrophication bioindicators in tropical reservoirs. Biota Neotropica 14(4):1–12

The Diversity of the Zoobenthos Communities of the Lake Skadar/Shkodra Basin

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 255–294, DOI 10.1007/698_2017_234,
© Springer International Publishing AG 2018, Published online: 13 May 2018

Abstract Zoobenthos is an important component of the aquatic ecosystems of the Lake Skadar basin and represents a reliable bioindicator of environmental degradation. In Lake Skadar, the zoobenthos communities exhibit different patterns with regard to abundance and community composition in the nearshore and the open lake zones. The greatest diversity of benthic invertebrates was generally found in the nearshore environment. Oligochaeta, Chironomidae, and mollusks dominated in the macrozoobenthos of Lake Skadar. The lake meiobenthos is less studied and is dominated by ostracods, copepod, and cladoceran species. The current knowledge of the diversity of the 22 zoobenthic groups from Lake Skadar and its basin are summed up here. Lake Skadar has experienced gradual eutrophication and the impact of nonnative species over the past several decades that have affected the zoobenthos communities. Continuous monitoring of the zoobenthos communities is recommended for inclusion in the ongoing national and transboundary Lake Skadar assessment projects.

Keywords Diversity, Endemism, Lake Skadar basin, Macrozoobenthos, Meiobenthos

1 Introduction

Benthic invertebrates are numerically important components of the Lake Skadar ecosystem and represent reliable bioindicators of environmental degradation [1, 2]. However, the ecology of the invertebrate assemblages of Lake Skadar has received little attention, and thus the ecology of the lake's zoobenthos still remains unknown. In the early period of the study of the zoobenthos of Lake Skadar, research was focused on the ecology and distribution of selected groups of benthic animals in the lake such as oligochaetes [3], chironomids [4], and mollusks [5]. The first detailed study of the zoobenthos of Lake Skadar was provided by Nedeljković in 1959 [6]. After that, the lake's zoobenthos were studied by Karaman and Nedić [7] from 1972 to 1977 as a result of the scientific project "Limnological Investigations of Lake Skadar" conducted between the Biological Institute in Titograd (today Podgorica) and the Smithsonian Institute (USA). Within the framework of the same project, Jacobi [8] studied the zoobenthos from the sublacustrine springs of Lake Skadar.

The large lake surface as well as the large variety of habitats in its basin, i.e., lentic and lotic waters, pools, and springs, greatly contributes to the high diversity of the zoobenthos in the Lake Skadar basin. Due to its low depth, Lake Skadar does not show vertical stratification [7]. Generally two zones, the nearshore and the open lake zone, can be separated in the lake itself. These two zones exhibited different patterns in zoobenthos abundance and community composition. The highest diversity was found in the nearshore environment where the habitat complexity is the greatest. Moreover, benthic communities in the nearshore environment show larger regional differences in terms of abundance and community composition than those communities that inhabit the open lake zone. This is partly influenced by the large number of sublacustrine springs in the nearshore, which significantly contribute to the overall biodiversity of Lake Skadar.

2 Abundance and Community Composition

The zoobenthos of Lake Skadar is not uniform and is constituted of meiobenthos (animals with a body length from 0.3 mm up to 4 mm) and macrozoobenthos (from a few millimeters to centimeters). The lake meiobenthos includes nematodes, ostracods, harpacticoids, true bottom copepod and cladoceran species, tardigrades, and meiobenthic oligochaetes but also juvenile stages of typical macrobenthic organisms such as oligochaetes, mollusks, and insect larvae. The level and intensity of meio- and macrobenthos production differ and generally depend on the trophic state, depth, and size of the lake [9]. For example, in large lakes, the ratio of meiobenthic to macrobenthic production of macrobenthos is on average 50–61% [9].

The macroinvertebrate communities of Lake Skadar are dominated by Oligochaeta and Chironomidae [6, 7]. Mollusks dominate at certain localities, primarily in the sublacustrine springs [8, 10]. Other groups of benthic animals are represented by a smaller abundance in the lake [7]. Taxonomically diverse Ephemeroptera and Trichoptera dominate the communities of the small nearby streams and tributaries of Lake Skadar where large amounts of coarse particulate organic matter were observed. Moreover, the abundance of Hirudinea and Crustacea is greater on stony than on soft substrates. On the other hand, the organically enriched tributaries were rich in oligochaetes, mollusks, and filter-feeding taxa (Hydropsychidae, Simuliidae). In the nearby springs, many of which fall below the water level of the lake during high water periods, hydrobiid snails and gammarid amphipods dominate [11].

The mean density of the macroinvertebrate communities in Lake Skadar varies between different localities and lake zones from a few tens of individuals to up to 13,000 individuals per m^2 [1, 7, 12]. The benthic density depends on a number of factors including the lake zones, types of bottom, and the presence of vegetation. In the open part of the lake, benthic communities show a lower density than in the littoral zone with two peaks of abundance that occurred in the winter and the summer [7].

In the littoral zone, benthic densities differ in the vegetated and in the open water localities [7]. The macrozoobenthic communities in the vegetated part show higher abundance and one peak of abundance in the winter. In the open water littoral localities, the density of the macroinvertebrate community is lower, and two peaks of abundance occur in the winter and the summer [7]. This is in agreement with Zivkovic [13] who found a higher diversity and biomass of zooplankton in the littoral vegetation than in the open water areas of the lake. The inundation zone communities are dominated by *Chironomus plumosus* larvae where the abundance in some organically enriched localities exceeds 13,000 ind/m^2 [12].

The diversity, density, biomass, and distribution of macroinvertebrate communities in the sublacustrine springs depend on their physical and bathymetric characteristics. The survey conducted by Jacobi [8] showed that the maximum depth of the occurrence for several macrobenthic taxa in the sublacustrine springs of Lake Skadar varies: the snail *Radix auricularia*, water mites, the isopod *Asellus aquaticus*, the larvae of phantom midges (*Chaoborus crystallinus*), coenagrionid dragonflies, and some mayflies (*Caenis* sp.) are present up to a depth of 10 m, while leeches and some mollusks (*Theodoxus fluviatilis*, *Unio* sp.) are found up to 20 m down, the snail *Pyrgula annulata*, the tubificid worms *Psammoryctides barbatus*, and *Potamothrix hammoniensis* up to 45 m in depth, and the chironomids *Chironomus plumosus* and *Polypedilum convictum* and the amphipods *Echinogammarus scutarensis* and *Synurella ambulans* were found at depths of 53 m [8]. Moreover, there are differences in the depths at which the highest density and biomass of the macrozoobenthic community were detected. In sublacustric spring at Raduš (Fig. 1), most species (19) were found at a depth of 4 m with the highest density detected at a depth of 17 m, while the largest biomass was measured at a depth of 6 m [8].

3 The Diversity of Benthic Groups in the Lake Skadar Basin

3.1 *Freshwater Jellyfish and Hydra (Cnidaria)*

Cnidaria are represented by two species: one autochtonous (the brown hydra *Hydra oligactis*) and one alien species (freshwater jellyfish *Craspedacusta sowerbii*) [14, 15].

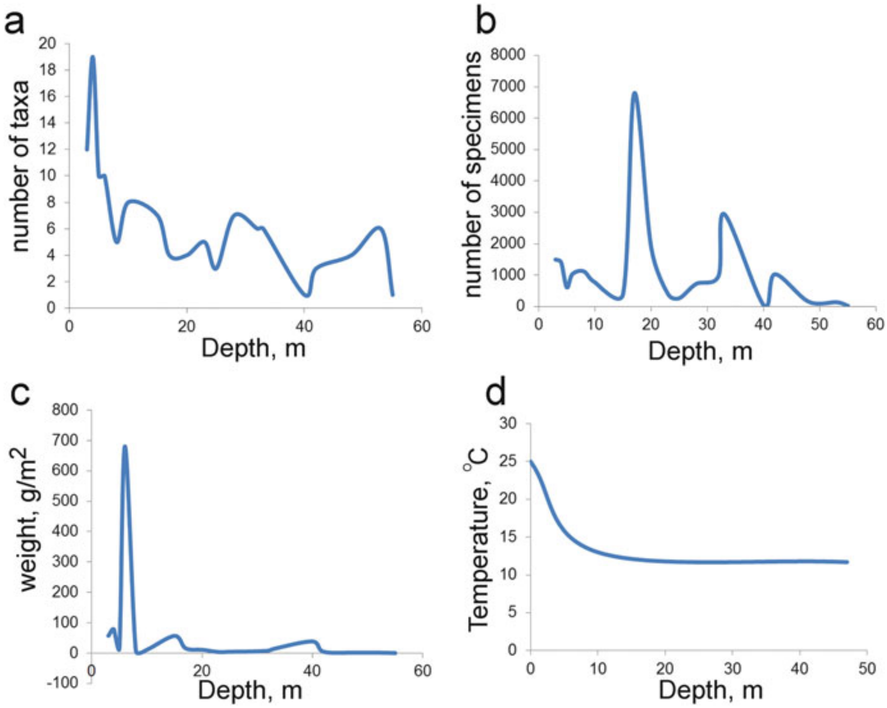

Fig. 1 (**a–c**) Zoobenthos in the sublacustrine spring at Raduš. (**a**) Relationship between depths and diversity (number of taxa). (**b**) Relationship between depths and density (number of specimens/m^2). (**c**) Relationship between depths and biomass (weight g/m^2). (**d**) Relationship between depths and water temperature (Data taken from [8])

3.2 Freshwater Sponges (Porifera)

Sponges are represented by one species *Spongilla lacustris* [14].

3.3 Flatworms: Turbellarians and Temnocephalans (Platyhelminthes)

Freshwater planarians were found in the surrounding streams and springs as well as in the lake itself associated with the sublacustrine environment. The polypharyngeal *Crenobia alpina montenigrina* and some unidentified species of the genera *Dugesia*, *Dendrocoelum*, and *Polycelis* are present (Pešić, unpublished).

Scutariellid temnocephalidan (Scutariellidae) are usually found as external symbionts on crayfish, and in the Lake Skadar basin, they are represented by one species, *Scutariella didactyla*. This species was originally described from shallow-water vegetation near the mouth of the River Morača into Lake Skadar attached to the moor snipe *Atyaephyra desmaresti* [16].

3.4 Nemerteans (Nemertea)

Phylum Nemertea is poorly known in Montenegro, and there is only one species reported from Lake Skadar: *Prostoma graecense* [17].

3.5 Gastrotricha

The first data on the freshwater gastrotrich fauna of Lake Skadar was provided by Petković [15] who reported one species, *Chaetonotus similis*. Recently Kolicka et al. [18] described a new species, *Chaetonotus antrumus* (Chaetonotida) from Obodska Cave. This species appear to prefer finer sediments with high organic matter content [18].

3.6 Horsehair Worms: Gordioidea (Nematomorpha)

The horsehair worm fauna of the Lake Skadar basin is poorly known, and there is only a record of one species, *Gordius villoti* (syn. *G. montenegrinus*) existing [19]. Additional horsehair worm species (*Gordius aquaticus*, *G. pesici*, and *Spinochordodes bacescui*) have been reported from the central and southern parts of Montenegro [20, 21] and can be expected to be found in the Lake Skadar basin. All gordiids are parasites and can be found free-living in late summer in various freshwater habitats [21].

3.7 Freshwater Bryozoans (Bryozoa)

Freshwater bryozoans are represented by *Plumatella repens* and *Cristatella mucedo* [15]. They grow as a colony attached to aquatic vegetation, stones, and also to organic or artificial firm substrata.

3.8 Freshwater Snails and Mussels (Mollusca: Gastropoda and Bivalvia)

Mollusks are diverse and abundant in Lake Skadar and its associated water bodies and represent an important component in the food chains of the Lake Skadar ecosystem [10]. A total of 53 freshwater mollusk species, 10 species of Bivalvia, and 43 species of Gastropoda have been found in the Lake Skadar basin and Lake Šasko [10]. A detailed study of the diversity and ecology of this ecologically important group of benthic invertebrates including the history of research of the Lake Skadar mollusks was provided by Pešić and Glöer [10]. Most of the species that are present in Lake Skadar itself and its associated lentic water bodies are present in various types of standing water habitats over the Lake Skadar catchment basin [10, 22].

The greatest diversity and endemism among the freshwater snails inhabiting the flowing and ground waters of the Lake Skadar catchment area are related to hydrobiid snails (Hydrobioidea). Altogether there have been 30 species of hydrobiid gastropods recorded so far from the Lake Skadar catchment area, of which 27 species occur in the Montenegrin part of the basin, while 7 species are known from Albania (Table 1). The boundary between the Adriatic and the Black Sea catchment area is determined by the distribution of the species of the genus *Bythinella* which are absent from the Adriatic drainage area, with the exception of one locality in the upper part of the River Morača, near the watershed of the two drainage sea areas [24].

The largest number of hydrobiid species in the Lake Skadar catchment area is inhabitants of subterranean habitats [25–28]. Access and sampling from these habitats are difficult, and therefore subterranean hydrobiids have been collected mainly as empty shells in strong karst springs, and very few living animals have ever been found. Around 82% of the hydrobioid species that inhabit the Lake Skadar catchment area are known only from type localities, while 33% are known only from empty shells. Most of the subterranean species have been collected from a few localities (Vitoja, Pričelje, Tunjevo, Taban), where they were washed and brought together from various geographically isolated areas (thanatocoenosis).

The most diverse genera whose members inhabit hypogean habitats are *Plagigeyeria* with seven nominal taxa (three species and five subspecies) and *Paladilhiopsis* with three species (Fig. 2). The systematic status of some species like *Plagigeyeria zetaprotogona* is still unclear [29]. In running waters and springs, snails of the genus *Radomaniola* dominate with four species [30]. *Radomaniola curta* is the most abundant snail species in many of the running waters of the Lake Skadar catchment area. It is likely that the number of *Radomaniola* is overestimated as the molecular analysis done by Falniowski et al. [31] showed the presence of a few additional molecularly evident groups at the species level from the Lake Skadar drainage system.

Most of the hydrobiid species that live in the surface waters are inhabitants of spring habitats. Many of the springs in the Lake Skadar catchment area are threatened by human

Table 1 List of hydrobiid snails (Hydrobiidae) occurring in the Lake Skadar catchment basin (MN Montenegro, AL Albania)

Species	Distribution	Habitat	Red List category (after [23])
Radomaniola curta *R. curta curta* *R. curta anagastica*	MN, AL, MN, AL, MN	Springs, high- and middle-order streams	Least concern
Radomaniola lacustris	MN	Sublacustrine springs	Critically endangered
Radomaniola elongata	MN	Springs	Critically endangered
Radomaniola montana	MN	Springs	Least concern
Vinodolia gluhodolica	MN	Subterranean	Endangered
Vinodolia matjasici	MN	Subterranean	Critically endangered
Vinodolia zetaevalis	MN	Springs, high-order streams	Data deficient
Vinodolia scutarica	MN	Sublacustrine springs	Endangered
Vinodolia vidrovani	MN	Springs	Least concern
Bracenica spiridoni	MN	Subterranean	Endangered
Bracenica vitojaensis	MN	Subterranean	
Arganiella tabanensis	MN	Subterranean	
Antibaria notata	MN	Springs	Least concern
Islamia montenegrina	MN	Subterranean	
Iverakia hausdorfi	MN	Subterranean	
Bythiospeum demattiai	MN	Subterranean	
Lanzaia pesici	MN	Subterranean	
Litthabitella chilodia	MN	Springs	Least concern
Saxurinator hadzii	MN	Subterranean	Data deficient
Saxurinator orthodoxus	MN	Subterranean	Critically endangered
Montenegrospeum bogici	MN	Subterranean	
Zeteana ljiljanae	MN	Subterranean	
Paladilhiopsis prekalensis	AL	Subterranean	
Paladilhiopsis szekeresi	AL	Subterranean	
Paladilhiopsis wohlberedti	AL	Subterranean	
Plagigeyeria lukai	MN	Subterranean	
Plagigeyeria montenigrina	MN	Subterranean	Critically endangered
Plagigeyeria zetaprotogona *P. zetaprotogona zetaprotogona* *P. zetaprotogona vitoja* *P.zetaprotogona pageti* *P. zetaprotogona zetadidyma* *P. zetaprotogona zetatridyma*	MN, AL MN MN, AL MN MN MN	Subterranean	Endangered
Karucia sublacustrina	MN, AL	Sublacustrine springs	
Pyrgula annulata	MN, AL	Lake	Least concern

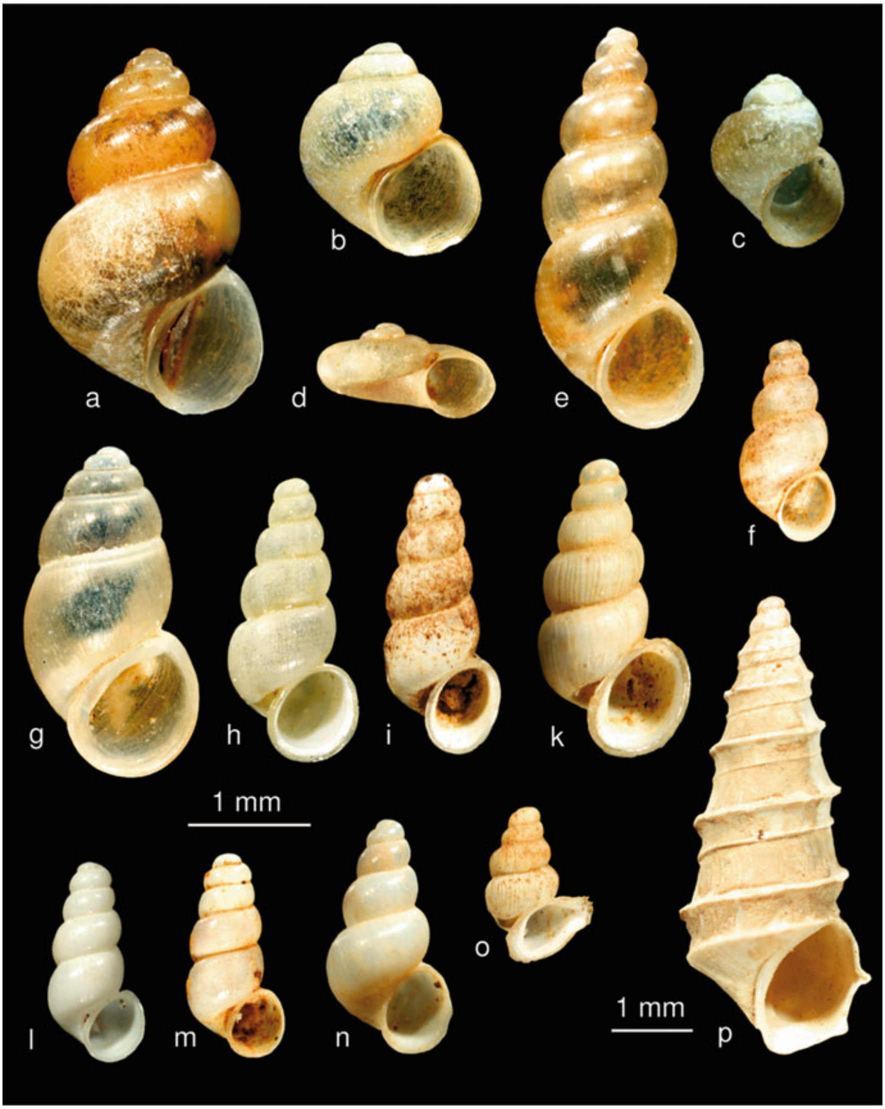

Fig. 2 (**a**) *Radomaniola curta*, (**b**) *R. montana*, (**c**) *Antibaria notata*, (**d**) *Arganiella tabanensis*, (**e**) *Vinodolia zetaevalis*, (**f**) *Bythiospeum demattiai*, (**g**) *Litthabitella chilodia*, (**h**) *Montenegrospeum bogici*, (**i**) *Iverakia hausdorfi*, (**k**) *Zeteana ljiljanae*, (**l**) *Paladilhiopsis prekalensis*, (**m**) *Paladilhiopsis szekeresi*, (**n**) *Paladilhiopsis wohlberedti*, (**o**) *Plagigeyeria lukai*, (**p**) *Pyrgula annulata* (Photos by P. Glöer)

impact (e.g., capture for use as drinking water sources) or even destroyed by draining or cattle trampling. Moreover, there are many intermittent springs in the Lake Skadar catchment basin that host snail assemblages differing from those in the perennial springs.

Snails constitute a major faunistic component in many springs, and due to their poor dispersal characteristics, they are more susceptible to climatic changes and human impact. For this reason, further conservation planning and management is required to protect the spring environments of the Lake Skadar catchment area [32].

3.9 Aquatic Worms (Oligochaeta)

Most of the investigations of Oligochaeta in Montenegro have been conducted in the region of Lake Skadar. In 1931, Černosvitov published the first taxonomical data on aquatic worms from Lake Skadar [33]. Later on, papers on the taxonomy, faunistics, and ecology of oligochaetes were published by Hrabě [34], Šapkarev [3], Karaman [35], Kerovec and Mršić [36], Janković and Jakovčev [37], Đukić [38], and Jabłońska and Pešić [39]. All these investigations were sporadic. The first comprehensive study regarding the taxonomy, ecology, and use as bioindicators in water and sediment quality assessment for oligochaetes was provided by Danijela Šundić in 2007 [40] which resulted in a number of papers published thereafter [1, 41–43].

A total of 35 species of Oligochaeta belonging to the families Naididae (Naidinae and Tubificinae), Lumbriculidae, and Criodriliidae have been recorded so far from Lake Skadar (Table 2). For the entire Oligochaeta fauna of Montenegro, a total of 82 species and subspecies are known, meaning that Lake Skadar is home to around 43% of the species known across the country. Among them, three species, *Spirosperma scodraensis*, *Tubificidarum hrabei*, and *Trichodrilus montenegrinus*, are endemic to Lake Skadar. The tubificid worms dominated Oligochaeta fauna of Lake Skadar. The most abundant species in Lake Skadar (in order of their abundance) are *Limnodrilus hoffmeisteri*, *Potamothrix hammoniensis*, *Psammoryctides barbatus*, *Potamothrix prespaensis*, *Aulodrilus pluriseta*, and *Limnodrilus udekemianus*. Their density ranged from 355 ind/m^2 (*Limnodrilus udekemianus*) to 3,466 ind/m^2 (*Limnodrilus hoffmeisteri*). The most frequently occuring species in Lake Skadar is *Potamothrix hammoniensis* [1, 43].

A comparative analysis of the abundance of oligochaete species from 1975 to 2005, in different seasons, showed an increasing trend over a period of 30 years (Fig. 3). Moreover, for the same period, there is evidence of an increasing trend in the total biomass of Oligochaeta in Lake Skadar. In 1975, the population density was more or less even at all the investigated sites in all the seasons. As was shown in Fig. 3, the total number of individuals was significantly higher in the spring and the autumn in 2004, while, in 2005, the total abundance was higher in all three seasons in comparison to the results of the investigation conducted in 1975. It is likely this might be the consequence of the impact of various hydrological, meteorological, and pollution factors on the seasonal dynamic of oligochaete abundance in Lake Skadar. The total abundance of the oligochaete population was the highest during the summer season in 2007 at the sampling site of Vranjina – 4,399.97 ind/m^2. In addition, significant abundance was also recorded at Kamenik (2,244.40 ind/m^2) and in the middle of the lake (1,777.71 ind/m^2).

Table 2 List of Oligochaeta species from Lake Skadar (endemic species are marked with an asterisk)

Taxon	Reference
Aulophorus furcatus	[1, 37, 41, 43]
Dero obtusa	[1, 37, 41, 43]
Nais barbata	[1, 37, 41, 43]
Nais communis	[1, 37, 41, 43]
Nais elinguis	[1, 41, 43]
Nais pseudobtusa	[1, 35, 36, 41, 43]
Nais variabilis	[1, 37, 41, 43]
Ophidonais serpentina	[1, 41, 43]
Stylaria lacustris	[1, 39, 41, 43]
Vejdovskyella comata	[1, 37, 43]
Pristina aequiseta	[1, 37, 41, 43]
Pristina breviseta	[1, 35–37, 41, 43]
Pristina rosea	[1, 37, 41, 43]
Aulodrilus limnobius	[1, 34, 36, 42, 43]
Aulodrilus pigueti	[1, 34, 36, 37, 42, 43]
Aulodrilus pluriseta	[1, 37, 42, 43]
Embolocephalus velutinus	[1, 42, 43]
Ilyodrilus templetoni	[1, 42, 43]
Isochaetides michaelseni	[1, 38, 42, 43]
Limnodrilus claparedeianus	[1, 39, 42, 43]
Limnodrilus hoffmeisteri	[1, 3, 33–39, 42, 43]
Limnodrilus profundicola	[1, 38, 42, 43]
Limnodrilus udekemianus	[1, 3, 34–38, 42, 43]
Potamothrix hammoniensis	[1, 35–39, 42, 43]
Potamothrix prespaensis	[1, 3, 33–36, 42, 43]
Potamothrix vejdovskyi	[1, 38, 42, 43]
Psammoryctides albicola	[1, 39, 42, 43]
Psammoryctides barbatus	[1, 3, 33–38, 42, 43]
Spirosperma ferox	[1, 42, 43]
*Spirosperma scodraensis**	[1, 34–36, 39, 42, 43]
Tubifex nerthus	[1, 38, 42, 43]
Tubifex tubifex	[1, 33, 35–38, 42, 43]
*Tubificidarum hrabei**	[1, 35, 36, 43]
*Trichodrilus montenegrinus**	[1, 35, 36, 43]
Criodrilus lacuum	[1, 35, 42, 43]

3.10 Freshwater Leeches (Hirudinea) and Crayfish Worms (Branchiobdellida)

The research of leeches in Lake Skadar has a relatively long tradition starting with the paper by Blanchard in 1905 [45]. Based on the available literature (see [46] for a review of leech research in Montenegro), the fauna of the leeches of Lake Skadar is represented by

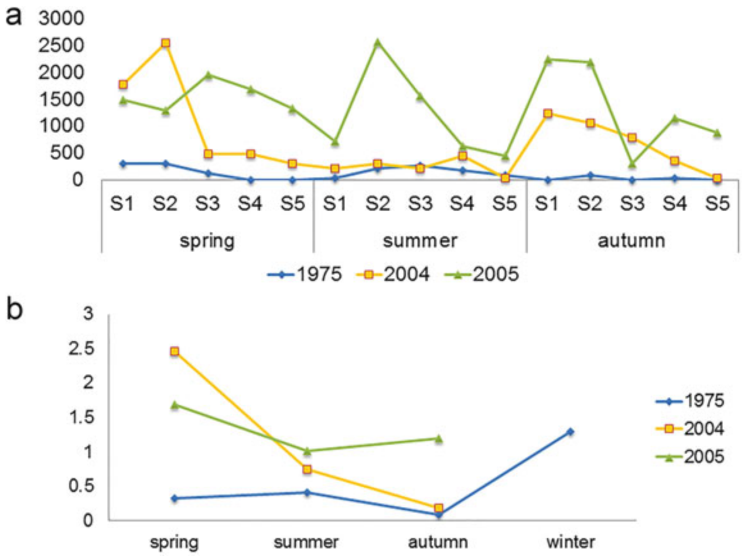

Fig. 3 (**a**) Seasonal fluctuations in the abundance of the oligochaete population in Lake Skadar (S1, Kamenik; S2, Vranjina; S3, middle of the lake; S4, Plavnica; and S5, Raduš). Data compiled from [1, 7, 40, 44]. (**b**) Seasonal fluctuations in the biomass of oligochaetes in Lake Skadar. Data compiled from [7, 40, 44]

15 species. For the entire leech fauna of Montenegro, a total of 29 species and subspecies is known [46] meaning that Lake Skadar is home to 52% of all Montenegrin leech species.

Most of the leech species inhabit the lake, but some species are only reported from the sublacustrine environment (*Glossiphonia paludosa*, *G.* cf. *pulchella*) [46]. Two species *Dina dinarica* and *Trocheta dalmatina* inhabit nearby springs [46]. There are no endemic species. The status of the population of *Glossiphonia* cf. *pulchella* from Lake Skadar, a species known only from the littoral zone of Lake Ohrid, is still not resolved and will require the application of molecular techniques. As recently demonstrated by Grosser et al. [47], the records of *Glossiphonia nebulosa* from Lake Skadar [46, 48] refer to *G. balcanica*, a species recently described from Kosovo and Montenegro. This species occurs in small- to medium-sized fast running waters but also in large standing waters such as Lake Skadar [48].

Branchiobdellid annelids or crayfish worms are usually found as ectosymbionts on crayfish populations. The knowledge of their ecology and dispersion in Lake Skadar is still limited. Gelder [49] reported *Branchiobdella hexodonta* in the gill chambers and *B. pentodonta* on the ventral thorax and abdomen of *Austropotamobius torrentium* collected from the River Crnojevića.

3.11 Spiders and Mites (Chelicerata: Aranea and Acari)

The diving bell spider (*Argyroneta aquatica*) is the only spider known to live its entire life under water. In Lake Skadar this species was recorded in the shallow northern part of the lake (Pešić, unpublished).

In the various aquatic habitats of the Lake Skadar basin, mites (Acari) are represented by two clades, Halacaroidea and Hydrachnidia (true water mites). Some other Acari clades, like acaridid and oribatid mites which include hygrophilous species, can be regularly found in some freshwater habitats such as temporary pools or hyporheic interstitial. In aquatic samples from the nearby streams, oribatid species (*Trimalaconothrus major*, *Hydrozetes lemnae*) can regularly be found (Pešić, unpublished). Pešić [50] recorded *Schwiebea cavernicola* (Acari, Acaridida) from underground waters of the Lake Skadar basin. Halacarid mites colonize various benthic habitats, underground and lentic or slowly flowing waters, mosses, sand filters, vascular plants such as epifauna but can also be found in the gill chamber of crustaceans. Altogether 19 halacarid species in 9 genera have been recorded so far from the Balkan Peninsula [51]. At least five halacarid mite species (*Lobohalacarus weberi*, *Parasoldanellonyx typhlops*, *Soldanellonyx chappuisi*, *S. monardi*, and *S. visurgis*) were found in the underground waters of Lake Skadar catchment area [52]. *Lobohalacarus weberi* is the most frequent and abundant species in the interstitial waters in the Lake Skadar basin. On the other hand, the "true water mites" (Hydrachnidia) includes 53 species from Lake Skadar [53]. There are 190 water mite species known from Montenegro [54, 55], diversified to occupy almost all the freshwater habitats of the Skadar Lake catchment. A detailed study on the diversity and ecology of this diverse and ecologically important group of benthic invertebrates in Lake Skadar is provided in this book by Zawal and Pešić [53].

3.12 Microcrustaceans

Microcrustaceans are common in Lake Skadar and its associated waterbodies and can be found at the bottom but also free in the open water as part of the plankton community. They are one of the main parts of the lake meiobenthos. Our present knowledge of the meiobenthos of Lake Skadar is much weaker than of the macrozoobenthos. The cladoceran and copepod crustaceans in Lake Skadar are usually studied as the part of the zooplankton communities [56]. Petković [56] mentioned that around one third (107 species) of the 355 species of Lake Skadar microfauna can be found in the plankton, while the main part of the species that lives in the lake (248 species) are benthic and inhabit primarily the littoral zone which has well-developed macrophyte vegetation. Cladocerans (water fleas) are most abundant in the inundated zones of Lake Skadar where they feed mainly on detritus, bacteria, and algae. Petković [56] listed 54 species of cladoceran crustaceans for Lake Skadar.

Copepods are a diverse and rather abundant component of the Lake Skadar meiobenthos. Petković [56] listed 15 species of copepod crustaceans from Lake Skadar. The fauna of copepods from the Lake Skadar catchment area has been intensively studied by Tomo Karanović who described the great diversity of this group from different habitats, especially from underground water [57]. Most of the harpacticoid copepods that inhabit underground water habitats are endemic to the Lake Skadar drainage basin: these include *Nitocrella longa* described from the Sutimska Jama cave near Podgorica [58]; *Moraria jana*, *Ceuthonectes petkovskii*, *Elaphoidella montenegrina*, and *E. gordani* from several caves in southern Montenegro [59, 60]; and *E. uva* from a spring and a well near Podgorica [61].

3.12.1 Seed Shrimps (Ostracoda)

Ostracods in the Lake Skadar basin are diverse and inhabit various habitats, but they are more common in the soft sediment. Their eggs can survive in dry sediment for some years. The first study on living ostracods in Lake Skadar was done by Trajan Petkovski [62] who reported nine ostracod species including two species new to science: *Candona montenegrina* and *Limnocythere scutariense*. Both species were found exclusively in Lake Skadar at depths of between 2.5 and around 6 m. Later on, several ostracod species were reported by Ivana Karanović [63] from various habitats around Lake Skadar including the endemic *Pseudocandona regisnikolai* described from Gornje Malo Blato, Lake Skadar (see [64] for an overview). The autecology of the ostracods from Lake Skadar is poor and needs further research. Ostracods were found mainly in the littoral of Lake Skadar, and they represent an important component in the diet of fish [56].

The ostracods in the Lake Skadar catchment basin inhabit a diverse spectrum of aquatic habitats: periodic streams (*Eucandona breuili*, *Fabaeformiscandona fabaeformis*, *Typhlocypris prespica*), artificial reservoirs and lakes (*Cypria exculpta*, *Typhlocypris marchica*, *Candona candida*), streams (*Candona bimucronata*, *Typhlocypris albicans*, *Eucypris pigra*), rivers (*Paralimnocythere karamani*), springs (*Eucypris* cf. *virens*, *Psychrodromus fontinalis*, *Eucandona brevicornis*, *Candona neglecta*, *C. altoides*, *Candonopsis kingsleii*, *Typhlocypris lobipes*, *Heterocypris reptans*), puddles (*Typhlocypris pratensis*), and underground waters (*Trapezicandona hvarensis*, *Pseudocypridopsis clathrata*) [64]. Endemic species from the Lake Skadar catchment basin includes *Trajancandona natura* (a cave in Cetinje), *T. particular* (Sutimska Jama cave in Podgorica), *Pseudocypridopsis petkovskii* (Sutimska Jama cave in Podgorica), *Leptocythere pseudoproboscidea* (Mareza spring), *Candona forma* (Malo Oko spring, Sotonići), and *Candonopsis mareza* (Mareza spring) [64].

Recently Mazzini et al. [65] studied the ostracod assemblages recovered from the SK13 sediment core in order to reconstruct the changes in the biodiversity and the palaeoenvironmental evolution of Lake Skadar over the last 4,500 years. They found 13 ostracod species including 5 species (*Candona* ex gr. *bimucronata*, *C. meridionalis*, *Paralimnocythere georgevitschi*, *Metacypris cordata*, and *Cyclocypris* sp.) reported for the first time from Lake Skadar [65].

3.12.2 Fairy Shrimps (Anostraca) and Tadpole Shrimps (Notostraca)

Branchiopods inhabit various types of temporary pools with eggs that are drought tolerant and capable of surviving dry periods. Based on the available literature, four species (*Branchinecta ferox*, *Branchipus schaefferi*, *Chirocephalus carnuntanus*, and *C. diaphanous*) of fairy shrimps (Anostraca) are present in the Lake Skadar basin [66, 67]. *Chirocephalus diaphanous* is the most common and abundant species of large branchiopods in the temporary pools in the Lake Skadar basin [66]. Tadpole shrimps (Notostraca) are represented by one species of *Triops cancriformis* [66]. This species inhabits small shallow temporary pools but can also be found in larger ponds rich in submerged vegetation [67].

3.13 Malacostraca (Decapoda, Mysida, Amphipoda, Isopoda)

One of the first papers providing data on malacostracan fauna from Lake Skadar is the report by Mrázek [68] from his faunistic expedition to Montenegro in 1902. He mentioned the presence and provided information on the ecology of two decapod shrimp species, *Palaemon antennarius* (as *Palaemonetes varians*) and *Atyaephyra desmaresti* (as *Caridina desmaresti*). Just a year later, Brožek [69, 70] performed extensive morphometric studies upon the local population of the latter shrimp species. Over the following century, numerous subsequent works contributed to our knowledge of the local malacostraca, and the most recent summary was provided by Gordan Karaman [71].

Altogether, there are 34 species from four malacostracan orders that have been recorded so far from the Lake Skadar basin (Table 3). The most numerous and speciose group are amphipods, totalling 21 species belonging to six families. The family Niphargidae includes ten predominantly stygobiotic and locally endemic species, occasionally found also in springs (e.g., *Niphargus vranjinae*). The stygobiotic elements are *Metohia carinata* and *Typhlogammarus mrazeki*, belonging to the family Typhlogammaridae as well as *Bogidiella montenegrina* of the family Bogidiellidae. Both families are typically subterranean, and the first is known only from the Balkan Peninsula and the Caucasus, while the second has an almost worldwide distribution, excluding southern Africa, Australia, and Antarctica [72]. The members of the family Crangonyctidae, *Synurella ambulans* and *S. intermedia montenegrina*, live primarily in ground waters but are occasionally found also in surface springs and streams. By contrast, the five species of Gammaridae noted from the area are predominantly epigean and inhabit various habitats – from springs (including sublacustrine springs) and streams with underground water supplies in the case of the locally endemic *Laurogammarus scutarensis* to springs, streams, and the lake itself in the case of the more generalist *Gammarus roeselii*.

Table 3 List of Malacostraca species from the Lake Skadar area. L, lake; Sp, springs; St, streams; and Sg, subterranean

Name	Habitat	Lake Skadar basin endemics
Order Decapoda		
Atyaephyra desmaresti	L, Sp, St	
Astacus astacus	St	
Austropotamobius torrentium	St, Sp	
Austropotamobius italicus meridionalis	St, Sp	
Palaemon antennarius	L, Sp	
Potamon fluviatile	L, St	
Troglocaris prasence	Sg	
Troglocaris hercegovinensis	Sg	
Order Mysidacea		
Diamysis lacustris	L	+
Order Isopoda		
Asellus aquaticus	L, St, Sp	
Proasellus anophtalmus	Sp	
Monolistra sp.	Sp	
Sphaeromides virei montenegrina	Sg	+
Order Amphipoda		
Niphargus asper	Sg	+
Niphargus bilecanus	Sg	
Niphargus sketi	Sg	+
Niphargus inclinatus	Sg	+
Niphargus vulgaris	Sg	+
Niphargus podgoricensis	Sg	+
Niphargus polymorphus	Sg	
Niphargus vranjinae	Sg	+
Niphargus zorae	Sg	+
Niphargus kusceri	Sg, Sp	+
Laurogammarus scutarensis	Sp, St	+
Echinogammarus veneris	Sp, St	
Echinogammarus thoni	Sp, St	
Gammarus roeselii	Sp, St, L	
Gammarus balcanicus	Sp, St	
Hadzia gjorgjevici cristata	Sg	
Metohia carinata	Sg	
Typhlogammarus mrazeki	Sg	
Synurella ambulans	St, Sp, Sg	
Synurella intermedia montenegrina	Sp, Sg	
Bogidiella montenegrina	Sg	+

Four species of aquatic isopods have been recorded from the Skadar Lake basin so far, including the widespread morphospecies of water louse, *Asellus aquaticus*, frequently present in the coastal habitats of the lake itself as well as in the rivers and spring systems with accumulates of organic material. On the other hand, *Monolistra (Typhlosphaeroma)* sp. is a spring inhabitant, while *Proasellus anophtalmus* is widespread in the subterranean waters in the vicinity of Podgorica. The exclusively stygobiotic *Sphaeromides virei montenegrina* is endemic to the Lake Skadar area, where it was recently rediscovered, 60 years after its description, and belongs to the family Cirolanidae [73]. This predominantly marine family includes some 50 species that have colonized the subterranean waters in the area formerly covered by the Tethys Ocean in Europe, North Africa, and North America [74].

The eight decapod species recorded from the Lake Skadar basin include two species of shrimp, three crayfishes, and one crab. Two widespread shrimp species, *Palaemon antennarius* and *Atyaephyra desmaresti*, are common inhabitants of the lake, its tributaries, and the associated spring systems, occurring predominantly between the macrophytes. On the other hand, the crayfishes, *Astacus astacus*, *Austropotamobius torrentium*, and *A. italicus meridionalis*, occur exclusively in the tributaries and spring areas, avoiding the lake, where the water temperature fluctuates greatly throughout the year [75]. The latter subspecies was recently reported from the area by Rajković et al. [76] based on morphometric and molecular parameters. The crab, *Potamon fluviatile*, is found commonly all around the lake, including in the tributaries and spring areas.

Finally, mysids are represented by one species, the recently redescribed *Diamysis lacustris*, which is endemic to the Lake Skadar system [77]. It may be found all over the lake area and also in the associated spring systems, where it occurs among the aquatic vegetation.

It is important to mention that recent molecular studies on Balkan malacostracans have revealed substantial cryptic diversity within the conventionally described morphospecies. For example, it appeared that some widespread morphospecies are represented in the Lake Skadar basin by highly divergent lineages, and possibly by cryptic or pseudocryptic species, endemic to the southern Balkans, as is seen in the cases of *Gammarus roeselii* and *Asellus aquaticus* [78, 79]. Others, such as the local lineages of *Gammarus balcanicus*, *Atyaephyra desmaresti*, or *Palaemon antennarius*, are most probably endemic only to the Lake Skadar basin ([80], own unpublished data). Even in the case of the locally endemic *Laurogammarus scutarensis*, different spring systems in the lake basin seem to be inhabited by already divergent cryptic lineages ([81], own unpublished data). Thus, the diversity and endemicity of the Skadar malacostracans may be even higher that is currently believed.

The biology and ecology of the malacostracan species in the Lake Skadar basin have hardly been studied. The only species whose life cycle has been thoroughly analyzed is the locally endemic amphipod *Laurogammarus scutariensis* [82].

To summarize, due to the variety of available habitats and the karstic character of the area, the malacostracan fauna in the Lake Skadar basin is rich and diverse, including both epigean and stygobiotic species. There is a rather large share of local endemics, particularly in subterranean waters. Taking into account that many of the local isolated springs and caves remain underexplored, we can expect to supplement the species list in the future.

Most of the malacostracans have poor dispersal abilities, and some of them are endemic only to particular spring systems and caves. Thus, they are highly susceptible to climatic changes and human impact. For this reason, further conservation planning and management is required to protect the spring and subterranean environments of the Lake Skadar catchment area.

3.14 Mayflies (Ephemeroptera)

The history of studies on mayflies in the Lake Skadar basin started with the paper by Puthz in 1974 [83] who reported two species, *Siphlonurus lacustris* and *Cloeon dipterum* from a swamp near the “Zeta” railway station. Recently, Kovács and Murányi [84] have published two additional species, *Cloeon simile* and *Caenis strugaensis*. All these species, including *Caenis horaria* (Kovács and Murányi, unpublished), are characteristic of standing water habitats and occur in the lentic sections of the various running waters of the Lake Skadar basin (Table 4). The larvae of *Siphlonurus lacustris*, *Cloeon dipterum*, and *C. simile* live on roots and the submerged hanging portions of riparian plants, while *Caenis* larvae can be found in the different substrates (Fig. 4).

The fauna of the sublacustrine springs (Bajzë and Omarë in the Albanian part of the lake, Karuč and Vitoja spring in Montenegro) includes species that inhabit the lake itself (*Siphlonurus lacustris*, *Cloeon dipterum*, *C. strugaensis*) but also a group of lotic species that were not found in the lake. The latter group includes *Ephemera lineata* with larvae developing in the substrate of the rhitral section and *Baetis liebenauae* whose larvae inhabit sections with dense submerged vegetation. The highest number of mayflies in the sublacustrine springs was found in the Karuč (*Cloen dipterum*, *Ephemera lineata*, *Caenis strugaensis*) and Omarë (*Baetis liebenauae*, *C. dipterum*, *C. strugaensis*) springs, while two species (*Siphlonurus lacustris*, *C. dipterum*) were found in the spring at Vitoja and one species in the Bajzë spring (*S. lacustris*).

Among the tributaries of Lake Skadar, the Rivers Cem/Cijevna, Morača, and Zeta are characterized by diverse mayfly communities (Table 4). As these rivers and their tributaries arise in the surrounding high mountains, several high mountain taxa – *Ameletus inopinatus*, *Baetis alpinus*, *B. lutheri*, *B. muticus*, *Ephemera danica*, *Ecdyonurus*, *Epeorus*, and *Rhithrogena* species – can be found even in their lowland sections, together with typical lowland taxa such as *Baetis fuscatus*, *Heptagenia longicauda*, and *Potamanthus luteus* [84–89]. On the other hand, the mayfly fauna of the River Bojana/Buna is very poorly known, and hitherto only two species *Baetis libenauae* and *Ephemerella ignita* have been found.

Two mayfly species were originally described from the Lake Skadar catchment area: *Siphlonurus abraxas*, so far known only from Montenegro, and *Ephemera zettana*, a Mediterranean species, also recorded in Albania, Bosnia and Herzegovina, Croatia, and Italy [90]. *Siphlonurus abraxas* was described from the lower River Morača near Bioče, while further specimens were collected from Rujela Stream along the Podgorica–Tuzi road [86]. Subimagoes emerge in late May, while the imagoes were collected in mid-June [86]. *Ephemera zettana* was described from the River Zeta [89], but the most published records of imagoes come from oligotrophic

Table 4 List of mayfly species from the Lake Skadar catchment area (new data are marked with an asterisk, with a question mark sign for doubtful data)

Taxa	Distribution
Ameletus inopinatus	Morača river basin [85]
Siphlonurus abraxas	Morača river basin [86]; Lake Skadar area (Rujela Stream [86])
Siphlonurus lacustris	Lake Skadar area (Bajzë*, Vitoja spring*, Lake Skadar [83]); Cem/Cijevna river basin*
Baetis alpinus	Cem/Cijevna river basin*; Morača river basin* [85]
Baetis fuscatus	Cem/Cijevna river basin*; Morača river basin [85]
Baetis libenauae	Lake Skadar area (Omarë*); Buna/Bojana river basin*; Mareza channel*
Baetis lutheri	Cem/Cijevna river basin [84]; Morača river basin [85]; Zeta river basin*
Baetis muticus	Morača river basin* [85]; Zeta river basin*
Baetis rhodani	Cem/Cijevna river basin*; Morača river basin* [85]; Zeta river basin*
Baetis vernus	Morača river basin [85]
Centroptilum luteolum	Morača river basin [85]
Cloeon dipterum	Lake Skadar area (Karuč spring*, Vitoja spring*, Omarë*, Skadar Lake* [83])
Cloeon simile	Lake Skadar [84]
Ecdyonurus fluminum?	Morača river basin [85]
Ecdyonurus helveticus	Morača river basin [85]
Ecdyonurus venosus	Morača river basin [85]
Ecdyonurus zelleri?	Morača river basin [85]
Heptagenia longicauda	Morača river basin [85]
Epeorus assimilis	Cem/Cijevna river basin*; Morača river basin * [85]; Zeta river basin*
Epeorus yougoslavicus	Morača river basin [87, 88]
Rhithrogena diaphana?	Morača river basin [85]
Rhithrogena semicolorata	Morača river basin [85]
Habroleptoides confusa	Morača river basin* [85, 88]
Habrophlebia fusca	Morača river basin [85]; Zeta river basin [88]
Paraleptophlebia submarginata	Cem/Cijevna river basin*; Morača river basin* [85]
Ephemera danica	Cem/Cijevna river basin*; Morača river basin* [85]
Ephemera lineata	Lake Skadar area (Karuč spring*); Mareza channel*
Ephemera zettana	Zeta river basin [89]
Potamanthus luteus	Morača river basin [85]
Ephemerella ignita	Buna/Bojana river basin*; Cem/Cijevna river basin*; Morača river basin* [85]; Zeta river basin*
Serratella ikonomovi	Cem/Cijevna river basin [84]; Morača river basin [84]
Torleya major	Cem/Cijevna river basin*; Morača river basin* [85]; Zeta river basin [88]
Caenis horaria	Mareza channel*; Lake Skadar*
Caenis macrura	Morača river basin [85]
Caenis strugaensis	Lake Skadar area (Karuč spring*, Omarë*, Lake Skadar [84])

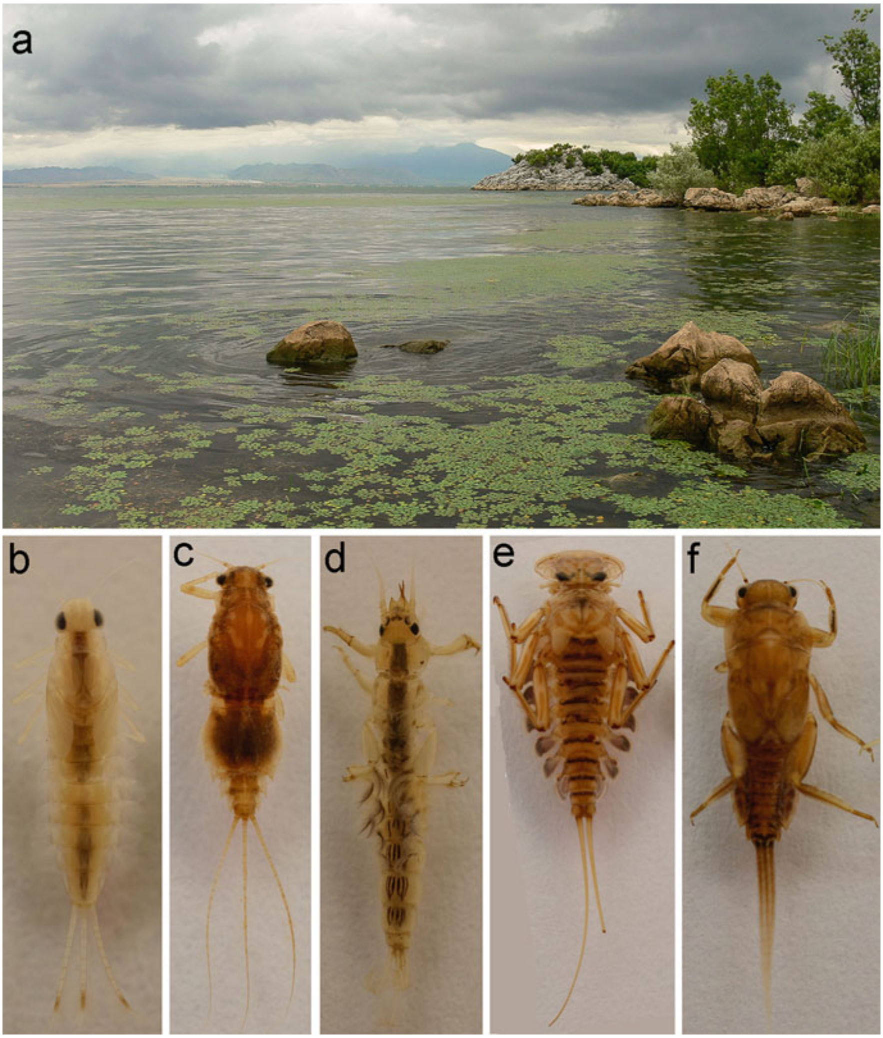

Fig. 4 (**a**) Bes, Skadar Lake, habitat of *Cloeon dipterum*, *C. simile*, *Caenis horaria*, *C. strugaensis* (Ephemeroptera), and *Lindenia tetraphylla* (Odonata). (**b**) *Cloeon simile.* (**c**) *Caenis strugaensis.* (**d**) *Ephemera lineata.* (**e**) *Epeorus yougoslavicus*. (**f**) *Serratella ikonomovi*. Photos by T. Kovács

lakes and larger rivers below 300 m above sea level. Imagoes were collected between the end of April and the end of June [90].

Two additional species which are of interest include the rare *Serratella ikonomovi* found in the Rivers Sjevernica and Cijevna in Montenegro [84] and *Caenis strugaensis* recently found in the lentic habitat of the Lake Skadar basin [84]. The first species is known from Bosnia and Herzegovina, Greece (Epirus), Kosovo, Macedonia, and Spain (Sierra Nevada), while *Caenis strugaensis* have been reported from Greece (Corfu), Italy

(Piemonte and Sardegna), and Macedonia (Lake Ohrid, Lake Prespa, and the River Crni Drim) [90].

3.15 Dragonflies (Odonata)

The history of studies on the dragonflies in Montenegro starting with the first paper by Stein in 1863 has been thoroughly discussed by Jović et al. [91] and later on by Knijf et al. [92] and Buczyński et al. [93]. The latest checklist of the Odonata of Montenegro was provided by Gligorović [94] who listed 67 dragonfly species from Montenegro.

Knijf et al. [92] stated that Lake Skadar has the greatest diversity of dragonflies in Montenegro. Lake Skadar is one of the parts of Montenegro whose odonatofauna is relatively well studied. The first data of the dragonflies of Lake Skadar was provided by Bertenov [95] who lists 16 species. Later on Dumont [96] lists 17 species, while Adamović [97] lists 29 species for the Lake Skadar area.

In the period between 2003 and 2013, there were as many as 16 papers on dragonflies on Montenegro (see [93] for the complete list), which also contain data on dragonfly species from Lake Skadar. Buczyński et al. [93] summarized the known data on the Odonata of Lake Skadar and stated that in the basin of the lake as many as 60 species of dragonflies occur. Later on two more papers with additional data on the dragonflies from the area of the Lake Skadar system were published by Kovács and Murányi [98, 99]. Recently, Buczyński et al. [100] report *Gomphus pulchellus* from Lake Skadar, increasing the number of species that inhabit the Lake Skadar basin to 61, which accounts for almost 90% of the odonatofauna of Montenegro. Moreover, Lake Skadar is home to several threatened and European protected species including *Lindenia tetraphylla* (Fig. 5) and *Cordulegaster heros* [92], both included in the Annexes of the Habitats Directive (Table 5).

Lake Skadar is probably the most important site for the conservation of *Lindenia tetraphylla* [92]. Imagoes and exuviae of this species were found in the rocky southern part of Lake Skadar where the number of exuviae reaches around 20 exuviae per 1 m^2 of boulders [92]. Knijf et al. [92] presume the Lake Skadar population is a source population for many of the observed individuals and acts as a source for many populations of *Lindenia tetraphylla* in the Mediterranean. For some species (*Epitheca bimaculata*, *Gomphus pulchellus*), Lake Skadar is at the border of its distribution area in Europe. *Cordulegaster heros*, *Gomphus schneiderii*, and *Caliaeschna microstigma* occur in the nearby tributaries of Lake Skadar [92]. Lake Šasko holds important populations of *Selysiothemis nigra* and *Lindenia tetraphylla* [92].

The ecology of the dragonflies of the Lake Skadar basin is poorly studied. The only exception is the fauna of the springs of the Lake Skadar basin including the sublacustrine springs in the lake itself [102]. Pešić et al. [102] showed that the Odonata larvae assemblages in the karstic springs of the Lake Skadar basin were comparably influenced by the environmental parameters acting on the level of

Fig. 5 Adult (**a**) and exuvia (**b**) *Lindenia tetraphylla* from Lake Skadar. Photos by T. Kovács

individual springs, principally the anthropogenic impact, and by disturbance factors such as permanence as well as by factors acting at the landscape level, including altitude and riparian vegetation. The maximum dragonfly diversity (23 species) was found in two sublacustrine springs in Lake Skadar [102]. This was explained by the large surface area and the standing water body nature of these springs, which is primarily induced by the location of these water bodies within the lake [102].

3.16 Water Beetles (Coleoptera)

A small number of papers have focused on the water beetles of Lake Skadar. Pavićević and Pešić [103] reported six species (*Hydroporus jonicus*, *H. palustris*, *H. tessellatus*, *Agabus bipustulatus*, *A. guttatus*, and *Ilybius pseudoneglectus*) from a flooded meadow near Virpazar, two species from one pond near Rijeka Crnojevića, and one species from Lake Šasko. Later on, Scheers [104] reported five species (*Graptodytes veterator*, *Hygrotus inaequalis*, *Laccophilus hyalinus*, *L. poecilus*, and *Noterus clavicornis*) from the littoral zone of Lake Skadar. Generally, the predaceous water beetle fauna of Lake Skadar is more diverse and abundant in the inundated zone of the lake and its associated small water bodies than in the main lake system. The hydradephagan fauna of Lake Skadar is dominated by the widespread palaearctic species. Those species with a more restricted distribution are mainly associated with the neighboring springs (*Hydroporus dobrogeanus* was found in a spring on the island of Vranjina [103]). In total, 14 species of diving beetles (Dytiscidae), 1 species of burrowing water beetles (Noteridae), and 1 species of whirligig beetle (Gyrinidae) (*Orectochilus villosus*) are known from Lake Skadar and its associated water bodies. This is a relatively small number of species for an ecosystem like Lake Skadar. Moreover, it is a small number in relation to the total number of hydradephagan species known for Montenegro (91 species [104]), which

Table 5 List of dragonfly species from the Lake Skadar basin that are threatened at the European and Mediterranean level (based on [101])

Species	Annex II. Habitats Directive	Annex IV. Habitats Directive	Red List of the Mediterranean basin	European Red List	Bern convention
Lestes macrostiogma			Near Threatened	Vulnerable	
Calopteryx splendens			Vulnerable	Least Concern	
Coenagrion ornatum	X		Near Threatened	Near Threatened	
Coenagrion pulchellum			Near Threatened		
Erythromma najas			Near Threatened		
Brachytron pratense			Near Threatened		
Caliaeschna microstigma			Near Threatened	Near Threatened	
Gomphus flavipes		X	Near Threatened	Least Concern	X
Gomphus pulchellus			Least Concern	Least Concern	
Gomphus schneiderii			Least Concern	Near Threatened	
Lindenia tetraphylla	X	X	Near Threatened	Vulnerable	X
Cordulegaster bidentata			Near Threatened	Near Threatened	
Cordulegaster heros	X	X	Vulnerable	Near Threatened	
Sympetrum vulgatum			Near Threatened		

highlights the need for further research on this diverse group of invertebrates in Lake Skadar.

Aquatic polyphagan assemblages dominated by the family Hydrophilidae are represented by six species in the Lake Skadar basin [105–107]. The fauna, being dominated by relatively widespread taxa (*Berosus signaticollis*, *Helochares obscurus*, *Enochrus nigritus*, and *Cymbiodyta marginella*), is mostly found in the inundated zone of Lake Skadar. In the surrounding streams, Elmidae and Hydraenidae can be found, some of them, such as *Ochthebius insidiosus* (Hydraenidae) described from Rijeka Crnojevića, being endemic [108].

3.17 Water Bugs (Hemiptera)

The aquatic Heteroptera of Montenegro have been studied only sporadically (see [109] for a historical review), and thus only a few papers contain data on the water bugs of Lake Skadar [110, 111]. Recently Gligorović et al. [111] collected ten water bug species from two sublacustrine springs in Lake Skadar. It is currently estimated that 37 water bug species occur in Montenegro [109] meaning that almost 30% of the known fauna of this group occurs in the sublacustrine springs of Lake Skadar. In the Lake Skadar basin, water bugs are found in different types of aquatic and semi-aquatic and in both lotic and lentic habitats but prevail in stagnant and slowly flowing waters [111]. Widespread polytopic species such as *Hydrometra stagnorum*, *Notonecta glauca*, and *Sigara lateralis* dominate in most habitats, but some water bug species like *Plea minutissima*, *Ranatra linearis*, and *Sigara falleni* favor deeper water bodies [111].

3.18 True Flies (Diptera)

True flies (Diptera, Insecta) are one of the most important and most diverse groups of benthic macroinvertebrate fauna. There more than 20 families known from Lake Skadar and its surrounding water bodies (in parentheses some characteristic genera/species from Lake Skadar area are given, Pešić unpublished): Athericidae (watersnipe flies, *Ibisia*, *Atherix*), Chironomidae (nonbiting midges), Dixidae (meniscus midges, *Dixa*), Blephariceridae (net-winged midges, *Blepharicera fasciata*), Ceratopogonidae (biting midges, *Culicoides*), Empididae (dagger flies, *Hemerodromia*), Psychodidae (sand flies), Simuliidae (blackflies, *Simulium*, *Prosimulium*), Thaumaleidae (solitary midges), Tabanidae (horse-flies), Chaoboridae (phantom midge), Culicidae (mosquitoes), Stratiomyidae (soldier flies, *Odontomyia*, *Stratiomys*, *Nemotelus*, *Oxycera*), Ptychopteridae (phantom crane flies, *Ptychoptera*), Ephydridae (shore flies), Syrphidae (Eristalinae, drone fly *Eristalis tenax*), Cylindrotomidae (long-bodied crane flies), Tipulidae (crane flies, *Tipula*, *Nephrotoma*), Limoniinae (*Antocha*, *Dicranomyia*), Pediciinae (*Dicranota*, *Pedicia occulta*), Empididae (dagger flies), Rhagionidae (snipe flies), Dolichopodidae (long-legged flies), and Sciomyzidae (marsh flies). Among them, Chironomidae, Chaoboridae, and Simuliidae were the most abundant dipteran families in the zoobenthos of Lake Skadar. In general, the diversity and ecology of most dipteran families in the Lake Skadar basin are poorly studied, and only a few groups have received attention in recent years. Some of these groups, like mosquitoes, sand flies, and horse-flies, are important vectors of diseases.

Phlebotomine sand flies (or "nevidi" as they are called by the local residents) are vectors of visceral leishmaniasis (VL). Ivović et al. [112, 113] collected six species of phlebotomine (*Phlebotomus papatasi*, *P. perfiliewi*, *P. tobbi*, *P. neglectus*, *P. kandelakii*, and *Sergentomyia minuta*) from area of the city of Bar. *P. neglectus* is the main VL vector in the district of Bar [113].

Horse-flies of the genus *Tabanus* are potential vectors of anthrax, while deer flies (genus *Chrysops*) are vectors of tularemia and loa loa. The larvae of many horse-fly species are known to develop in different water bodies. Krčmar et al. [114] collected three species of *Chrysops* (*caecutiens*, *flavipes*, *viduatus*), three species of *Hybomitra* (*ciureai*, *muehlfeldi*, *ukrainica*), six species of *Tabanus* (*autumnalis*, *bromius*, *eggeri*, *spectabilis*, *sudeticus*, *tergestinus*), and one species of *Haematopota* (*grandis*) and *Philipomyia* (*graeca*), respectively, in biotopes overgrown with reed and rushes on the shores of Lake Skadar [114].

Blackflies are pool feeders, and in the summer they are common, especially in the remnant pools of nearby streams. Adler and Crosskay [115] updated a total count of 16 species and 4 species complex (*rufipes*, *cryophilum*, *bezzii*, and *ornatum*) of blackflies for Montenegro.

Phantom midges (Chaoboridae) in Lake Skadar are represented by *Chaoborus crystallinus* [6]. The larvae of this species are predatory and feed selectively on small species of crustacean zooplankton; this can have a significant impact on the structuring of the zooplankton communities.

3.18.1 Chironomidae (Midges)

Chironomid midges represent an abundant, diverse, and widespread group of invertebrates inhabiting different types of freshwater ecosystems. Chironomid communities play an important role in the food chains of the Lake Skadar ecosystems. However, our knowledge of chironomid communities from Lake Skadar and its associated water bodies is still fragmentary. Based on the published literature [4, 7, 8, 116], 31 species of nonbiting midges from the lake itself and 24 species from springs have been reported so far. Gadawski et al. (unpublished) showed that this number is an underestimate and that the taxonomic diversity of nonbiting midges in the Lake Skadar basin is much higher. This phenomenon might be caused by the occurrence of cryptic species in some genera or rarely by misidentification among morphologically similar taxa.

DNA barcoding has proved to be a useful tool in separating morphologically similar species. Recently Gadawski et al. (unpublished) demonstrated that the list of species obtained from molecular identification is 30.8–33.8% larger than by traditional analysis based on morphological characters. The traditional species concept based on the morphological identification of adults revealed the presence of 83–86 species from Lake Skadar and the surrounding springs. Additionally, a number of species obtained from the analysis of pupal exuviae increased chironomid diversity to 106 species (Gadawski et al., unpublished). On the other hand, identification using DNA barcode techniques revealed around 120–130 chironomid species from Lake Skadar and the surrounding habitats, which is about 37–44 more than the number obtained by using traditional methods based on morphological characters (Gadawski, unpublished).

Ecological studies recently conducted by Gadawski et al. (unpublished) have shown that the chironomid communities that inhabit the shallow, littoral parts of Lake Skadar are more diverse than those that inhabit the open, deeper parts. It is likely that temperature is a limiting factor for the existence of many chironomid species which are restricted to the nearshore zone, in the springs or at the mouths of rivers. Chironomidae emergence occurs during the whole year, but the temperature influences the start of that emergence. During the winter, when the water temperature of the lake is similar to that of the springs and rivers, some of these species (e.g., *Chironomus annularius*, *Cricotopus sylvestris*, *Kiefferulus tendipediformis*, *Polypedilum nubeculosum*, *Polypedilum scaleanum*, *Tanytarsus usmäensis*) were found in both the nearshore and open lake zones (Gadawski et al., unpublished).

The *Polypedilum nubeculosum*, *Paratanytarsus natvigi*, *Cricotopus sylvestris*, and *Chironomus plumosus* group are the most abundant nonbiting midges that inhabit Lake Skadar (Gadawski et al. unpublished). Rich chironomid fauna was detected in the lake tributaries and nearby springs with at least 26 species being collected from the sampling sites along the River Morača (Gadawski et al., unpublished). The most abundant species at these localities was *Polypedilum nubeculosum* which was also the most abundant in the nearby springs. The other significantly abundant species include *Tanytarsus usmäensis*, *Chironomus riparius*, the *C. thummi* group, and *Procladius choreus*.

The presence of different types of substrates influences different chironomid communities as well as different types of feeding behavior. Collector-filterers dominate in different substrate types in Lake Skadar:

1. Sediments (e.g., *Chironomus plumosus*, *Chironomus annularius*, *Glyptotendipes pallens*)
2. Submerged substrata including wood (e.g., *Cladotanytarsus mancus*-agg., *Polypedilum sordens*)
3. Vascular plant tissues (e.g., *Polypedilum nubeculosum*, *Endochironomus tendens*) (Gadawski et al., unpublished)

The larvae of *Polypedilum nubeculosum*, the most abundant midge in Lake Skadar, are sediment inhabitants and are present across almost the entire lake.

By contrast, deposit-feeders (or collector-gatherers) dominate the northwestern shore on the organic soils that is saturated by minerals, permanently under water and covered by typical swamp vegetation. They feed on the fine particulate organic matter (FPOM) that accumulates in such places. Some collector-gatherers, such as *Chironomus plumosus* and *Chironomus annularius*, were collected from the sediment in the open part of Lake Skadar (Gadawski et al., unpublished data).

Scrapers dominate in places with coarse inorganic substrata, and they are characteristic of the southern and southwestern shoreline of Lake Skadar. Many Orthocladiinae, but also some Chironominae, feed as scrapers. The group of scrapers from Lake Skadar includes species mainly from the following genera: *Acricotopus*, *Corynoneura* (e.g., *C. gratias*), *Cricotopus* (e.g., *C. sylvestris*), *Limnophyes*, *Orthocladius*, *Parachaetocladius*, *Paratrichocladius*, and *Pseudosmittia* (Gadawski et al., unpublished).

Shredders dominate the chironomid assemblages in places with coarse particulate organic material such as living vascular plants (e.g., *Cricotopus*, *Endochironomus*, *Polypedilum*, and *Stenochironomus* species), submerged wood (e.g., *Stenochironomus*), macro- or colonial algae (e.g., *Cricotopus* or *Rheocricotopus*), and leaf litter (e.g., *Brillia* and some species of *Chironomus*) (Gadawski, unpublished). The larvae of *Paratanytarsus natvigi* live in the shallow part, near the lake edge where the water temperature is higher and vegetation is present (Gadawski et al., unpublished).

3.18.2 Culicidae (Mosquitos)

Several species of mosquitos (*Anopheles atroparvus*, *A. maculipennis*, *A. messeae*, *A. saccharovi*, *A. superpictus*, and *Coquillettidia buxtoni*) have been reported from the Lake Skadar basin as a result of investigations conducted within the framework of the project "Surveillance of invasive and native mosquito vectors and the pathogens they transmit in Montenegro – LOVCEN" [117]. Some of these species are potential vectors of malaria (*Anopheles saccharovi*, *An. maculipennis*), chikungunya virus and dengue virus (*Aedes albopictus*), and West Nile virus and Rift Valley fever virus (*Culex pipiens*). The larvae of *Anopheles saccharovi* live in shallow permanent water bodies with abundant surface vegetation. The larvae of other species regularly occur in the small temporary water bodies that appear after floods (*Ochlerotatus sticticus*) or in small natural and artificial containers, which is the case with the invansive Asian tiger mosquito (*Aedes albopictus*). The latter species has recently been reported from the Lake Skadar basin. It has been present in Montenegro since 2001 or perhaps even earlier, since the species was first reported in Albania in 1979 [118].

3.19 Alderflies (Megaloptera)

The alderfly fauna of the Lake Skadar basin is poorly studied. Alderfly larvae inhabit various freshwater environments, including lentic and lotic habitats [119]. Two alderfly species, *Sialis lutaria* and *S. fuliginosa*, have been found in the Lake Skadar basin (Pešić, unpublished data).

3.20 Stoneflies (Plecoptera)

The first Plecoptera record ever published from the Lake Skadar basin dates back only a century, when Aubert [120] described *Brachyptera dinarica* on the basis of a holotype male caught at Shkodër (Skadar) in February 1918. Unfortunately, nothing is known about its habitat and efforts by Murányi in 2011 [121] to recollect the species failed. After that, Zwick [122] in his revision of the Chloroperlidae provide data on *Chloroperla tripunctata* from the vicinity of Lake Skadar. During the 1970s, two more species were added from the Morača valley: *Leuctra graeca* [123] and *Capnioneura balkanica balkanica*, an endemic that inhabits spring habitats [124]. Kaćanski and Baumann [125] added 38 species from the Montenegrian part of the Lake Skadar catchment area, making the Morača valley into a relatively well-known area of stonefly faunistics. Later, two species (*Leuctra malcor* and *Nemoura asceta*) from the Albanian part of the Lake Skadar catchment area [126] and one species (*Taeniopteryx auberti*) from the Montenegrin part of the catchment area [127] were added. More recently, two new species of *Isoperla* and a *Perlodes* were described from the Montenegrian drainage area, also adding five species previously not reported from the area [128, 129]. Finally, new distribution and ecological data were added by Murányi et al. [130].

Together with our unpublished records of a further four species, there are 60 Plecoptera known from the Lake Skadar catchment area (Table 6). The identity of five of the previously reported species (marked with a question mark in Table 6) needs confirmation [127] due to revisionary work done after their publication. *Protonemura rauschi* (Theischinger, 1975) (one female and one pharate larva) and the genus *Zwicknia* (Murányi, 2014) (two females) are here reported as new to the fauna of Albania (collection data: Malësi e Madhe District, Gruemirë–Kurtë, side torrent of the Sheu River, 270 m, 42°12.267′N 19°34.079′E, 16.iv.2006, leg. Z. Erőss, Z. Fehér, A. Hunyadi, D. Murányi).

There are no published Plecoptera records from Lake Skadar, and recent efforts by D. Murányi did not yield any specimens (Murányi, unpublished). It seems likely that most of the lake is too warm to provide permanent habitat for stoneflies; however, some mature larvae drifting from the tributaries may emerge from the lake.

More than half of the stonefly species of the Lake Skadar catchment area are Balkan endemic or subendemic taxa, with the others showing European or Eurosiberian distribution. Most stonefly species in the Lake Skadar catchment area are restricted to cold crenal or rhitral habitats, but a few potamal taxa also occur in the Rivers Morača and Cijevna, and there are some species adapted to temporary waters. Surprisingly, in the huge lowland karst springs (okos) directly connected to Lake Skadar, only a single specimen of *Brachyptera tristis* has been found (Murányi and Kovács unpublished).

Nine species can be regarded as true crenal elements: *Taeniopteryx auberti* is a species found in large streams in most of its Central European range, but the Morača population was found exclusively in karst springs [127]. *Brachyptera tristis* is a Balkan endemic species, restricted mostly to the Dinaric ranges and found exclusively in huge karst springs at low to moderate elevations [131]. *Capnioneura balkanica balkanica* seems to be a winter-emerging endemic of the Morača valley and was found in different crenal habitats from karst spring outlets to small forest brooks [125]. *Leuctra jahorinensis* and *L. malcor* are narrow endemics of the Dinaric Mountains, both restricted to montane crenal habitats [131]. *Protonemura auberti* and *P. aestiva* belong to a Central European and Balkan species complex of crenal taxa [131]. In the Balkans, they seem to be connected to karst springs. *Nemoura asceta* is a widespread Balkan endemic species, connected to small, temporary spring brooks of low to high elevations [126]. *Isoperla pesici* is a widely distributed crenal species of the Central Balkans, which occurs in both small and large springs at different elevations [130] (Fig. 6).

Table 6 List of stonefly species from the Lake Skadar catchment area (new data are marked with an asterisk; a question mark indicates doubtful data)

Taxa	Distribution
Taeniopteryx auberti	Morača river basin
Taeniopteryx hubaulti?	Morača river basin
Brachyptera beali beali	Morača river basin, Sheu river basin*
Brachyptera dinarica	Lake Skadar area (Shkodër)
Brachyptera graeca	Morača river basin
Brachyptera helenica	Morača river basin, Sheu river basin*
Brachyptera risi	Morača river basin
Brachyptera seticornis	Morača river basin
Brachyptera tristis	Mareza spring, Morača river basin, Lake Skadar area (sublacustrine spring Syri i Hurdan*)
Capnioneura balkanica balkanica	Morača river basin
Zwicknia sp.	Sheu river basin*
Leuctra autumnalis	Morača river basin
Leuctra bronislawi	Morača river basin
L. carpathica?	Morača river basin
Leuctra digitata	Morača river basin
Leuctra fusca fusca	Morača river basin, Zeta river basin*
Leuctra graeca	Morača river basin
Leuctra hirsuta	Morača river basin, Zeta river basin
Leuctra inermis	Morača river basin
Leuctra jahorinensis	Morača river basin
Leuctra major	Morača river basin, Zeta river basin
Leuctra malcor	Cem/Cijevna river basin
Leuctra metsovonica	Bogë valley*
Leuctra mortoni feheri	Morača river basin, Zeta river basin*
Leuctra moselyi	Morača river basin
Leuctra olympia	Morača river basin
Leuctra prima?	Morača river basin
L. quadrimaculata	Morača river basin, Zeta river basin
Amphinemura sulcicollis	Morača river basin
Amphinemura triangularis	Cem/Cijevna river basin*, Morača river basin, Zeta river basin
Protonemura aestiva?	Morača river basin
Protonemura auberti	Morača river basin
Protonemura autumnalis	Morača river basin, Zeta river basin
Protonemura hrabei	Morača river basin
Protonemura intricata intricata	Bogë valley*, Cem/Cijevna river basin*, Morača river basin, Zeta river basin
Protonemura montana	Zeta river basin
Protonemura nitida	Morača river basin
Protonemura praecox praecox	Morača river basin

(continued)

Table 6 (continued)

Taxa	Distribution
Protonemura rauschi	Sheu river basin*
Nemoura asceta	Sheu river basin
Nemoura cinerea cinerea	Zeta river basin
Nemoura marginata	Morača river basin
Nemoura subtilis	Morača river basin
Nemoura uncinata	Morača river basin
Nemoura vinconi	Sheu river basin*
Nemurella pictetii	Zeta river basin
Besdolus illyricus	Morača river basin
Besdolus imhoffi	Cem/Cijevna river basin*, Morača river basin, Zeta river basin*
Perlodes floridus floridus	Morača river basin, Cem/Cijevna river basin
Perlodes intricatus	Morača river basin
Perlodes microcephalus	Morača river basin
Isoperla autumnalis	Morača river basin
Isoperla grammatica	Cem/Cijevna river basin*, Morača river basin
Isoperla pesici	Lake Skadar area (Godinje), Mareza spring, Morača river basin, Zeta river basin
Isoperla tripartita tripartita	Morača river basin
Chloroperla tripunctata	Morača river basin
Siphonoperla graeca	Morača river basin
Perla marginata?	Morača river basin
Perla pallida	Morača river basin
Dinocras megacephala	Cem/Cijevna river basin, Morača river basin

3.21 Caddisflies (Trichoptera)

Compared with northern part of Montenegro, the Trichoptera fauna of the Lake Skadar drainage basin has only been partially studied. For example, around 150 species have been confirmed for Mount Durmitor as a result of intensive studies done by Radovanović [132, 133], Krusnik [134], and Oláh [135]. The first study in the Lake Skadar drainage basin was conducted by Marinković-Gospodnetić [136] who recorded 48 species from the River Morača and its tributaries, with eight being reported from the River Plavnica, a northern tributary of Lake Skadar. Interestingly, Radovanović [133] did not find any caddisflies from Lake Skadar. Kumanski [137] collected four species (*Ecnomus tenellus*, *Phryganea grandis*, *Ceraclea dissimilis*, and *Athripsodes dalmatinus*) from the Albanian part of Lake Skadar near Zogaj. The Montenegrin part of Lake Skadar seems to be poorly studied. Jacobi [8] reported caddisfly larvae of *Triaenodes*, *Athripsodes*, and *Ecnomus* from the sublacustrine springs of Lake Skadar. Recently we found three species (material identified by

Fig. 6 The endemic stonefly *Isoperla pesici*. Photo by V. Pešić

W. Graf) from the littoral near Virpazar (*Limnephilus affinis*, *Halesus digitatus*) and Plavnica (*Limnephilus flavispinosus*).

Oláh and Kovacs [138] reported seven species (*Diplectrona atra*, *Rhyacophila tristis*, *Agapetus iridipennis*, *Silo nigricornis*, *Stenophylax mitis*, *Adicella filicornis*, and *Sericostoma schneideri*) from springs and streams on Mount Rumija and described a new species *Agapetus kampos* from Basa spring, Mount Rumija [138].

Caddisflies larvae were found in the littoral of Lake Skadar, sometimes in significant abundance. Janković and Trifunac [139] mentioned that Trichoptera are the dominant component in the diet of chub from Lake Skadar.

Trichoptera is an important part of the communities of the small nearby streams and tributaries of Lake Skadar where large amounts of coarse, particulate organic matter are present. In the upper part of the River Crnojevića, *Polycentropus flavomaculatus*, *Limnephilus lunatus*, and *Hydroptila forcipata* have been found (material identified by W. Graf).

3.22 Aquatic Caterpillars (Lepidoptera)

In the available literature, we found records of the brown China-mark *Elophila nymphaeata* moth of the family Crambidae from the vicinity of Lake Skadar [140]. The larvae of this species are entirely aquatic, feeding on water plants.

4 Main Threats

Lake Skadar faces various environmental stresses which can be attributed to changes in the lake environment, most notably the gradual eutrophication and the impact of nonnative species. In the last decade, Lake Skadar has experienced the progressive development of tourism followed by infrastructural development in some shoreline areas. The effect of these disturbances on the benthic communities in Lake Skadar is still understudied. In the 1970s, Lake Skadar was considered oligotrophic, but in the last three decades, the situation has changed [1]. Nutrient enrichment in Lake Skadar over the past 30 years has led to the gradual eutrophication of the lake. The change in the eutrophic level of the lake has been confirmed by investigations of the phytoplankton [141] and zoobenthos (Oligochaeta) [1]. These studies have shown the mesotrophic level of Lake Skadar. Generally, the diversity of macroinvertebrates increases with nutrient loading, but the effect is followed by the homogenization of the zoobenthos community [142]. It can be expected that fauna on stony substrates and in the nearshore zone is more sensitive to eutrophication than assemblages on soft bottoms and in the open lake zone, an area which shows much weaker regional differences.

Some studies [32, 82] have stressed that changes in the zoobenthos communities may, as a consequence, lead to species loss and the risk of introducing alien species, like the killer shrimp *Dikerogammarus villosus* [82].

Changes in the zoobenthos may represent good indicators of early changes in the lake ecosystem as a consequence of the eutrophication process and the impact of invasive species. Therefore, continuous monitoring of the zoobenthos communities is recommended as a point to include in national and transboundary biological assessment and conservation programs.

Acknowledgments The first author would like to thank Dr. János Oláh (Hungary) for his critical reading of the chapter section on caddisflies.

References

1. Šundić D, Radujković B (2012) Study on freshwater oligochaeta of Montenegro and their use as indicators in water quality assessment. Nat Montenegr 11:117–383
2. Vukašinović-Pešić V, Blagojević N (2018) Metal pollution: evidences from plants, aquatic invertebrates and fishes from the Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
3. Šapkarev J (1956) Contribution à la connaissance de la faune des oligochètes des trois grands lacs Yougoslaves, Prespa, Dojran et Skadar. Arch Sci Biol Belgrade 8(1–2):135–144
4. Janković (1974) Uticaj ekoloških faktora na rasprostiranje dominantnih vrsta Chironomidae Skadarskog jezera. Ekologija 9(2):175–197
5. Stein R, Kitchell J, Knezevic B (1975) Selective predation on carp (*Cyprinus carpio*) on benthic molluscs in Skadar Lake, Yugoslavia. J Fish Biol 7(3):391–399
6. Nedeljković R (1959) Skadarsko jezero: studija organske produkcije u jednom karsnom jezeru. Posebno Izd Biol Inst 4:1–156
7. Karaman G, Nedić D (1981) Zoobenthos of Skadar Lake. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 222–246
8. Jacobi GZ (1981) Zoobenthos from sublacustrine springs in Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 251–263
9. Kurashov EA (2002) The role of meiobenthos in lake ecosystems. Aquat Ecol 36:447–463

10. Pešić V, Glöer P (2018) The diversity and conservation status of the Molluscs of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
11. Šundić M, Pešić V (2007) Seasonal changes in the abundance of benthic assemblages in the spring on Vranjina island (Skadar Lake National Park). Glas Republ Zavoda Zašt Prirode 29–30:125–130
12. Janković M (1981) Quality of substrate as a factor of distribution of benthic organisms in Lake Skadar. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 263–276
13. Zivkovic A (1974) Zooplankton and microfauna of the vegetative area of Skadar Lake. In: Limnological investigation of Skadar Lake, Progress Report, 1973, Smithsonian Institution, Washington, pp 89–106
14. Milovanović D, Živković A (1965) Plankton Skadarskog jezera (1957–1958). Zbornik radova, Biološki institut SR Srbije 8(4):1–36
15. Petković S (1977) Nove vrste u fauni Skadarskog jezera. Glas Republ zavoda zašt prirode–Prirodnjačkog muzeja 10:31–36
16. Mrazek A (1907) Ein europischer Vertreter der Gruppe Temnocephaloidea. Sitz K Bhm Ges wiss Prag 11:1–7
17. Morisi A, Shestani L, Fenoglio S (2008) Qualità biologica delle acque del fiume Buna a monte e a valle dell'immissione del fiume Drin. Biol Ambient 22(1):50–53
18. Kolicka M, Gadawski P, Dabert M (2017) A new species of freshwater Chaetonotidae (Gastrotricha, Chaetonotida) from Obodska Cave (Montenegro) based on morphological and molecular characters. Eur J Taxon 354:1–30
19. Pešić VM, Ćurčić SB (2006) New records of hairworms (Nematomorpha) from Montenegro (SE Europe). Arch Biol Sci Belgrade 58:5P–6P
20. Pešić V, Schmidt-Rhaesa A (2008) First data on Serbian hairworms (Nematomorpha). In: Pavićević D, Perreau M (eds) Advances in the studies of the fauna of the Balkan Peninsula. Institute for Nature Conservation of Serbia, Belgrade, Monograph 22, pp 337–340
21. Schmidt-Rhaesa A (2010) Considerations on the genus Gordius (Nematomorpha, horsehair worms), with the description of seven new species. Zootaxa 2533:1–35
22. Glöer P, Pešić V (2008) The freshwater gastropods of the Skadar Lake with the description of *Valvata montenegrina* n. sp. (Mollusca, Gastropoda, Valvatidae). In: Pavićević D, Perreau M (eds) Advances in the studies of the subterranean and epigean fauna of the Balkan Peninsula, Institute for Nature Conservation of Serbia, Volume dedicated to the memory of Guido Nonvellier, Monograph 22, pp 325–332
23. Cuttelod A, Seddon M, Neubert E (2011) European red list of non-marine Molluscs. Publications Office of the European Union, Luxembourg
24. Glöer P, Pešić V (2010) The freshwater snails of the genus *Bythinella* Moquin-Tandon (Gastropoda: Rissooidea: Hydrobiidae) from Montenegro. Arch Biol Sci, Belgrade 62(2): 441–447
25. Pešić V, Glöer P (2013) *Montenegrospeum*, a new genus of Hydrobiid snails (Gastropoda: Risooidea) from Montenegro. Acta Zool Bulg 64(4):565–566
26. Glöer P, Pešić V (2014) New subterranean freshwater gastropods of Montenegro (Mollusca: Gastropoda: Hydrobiidae). Ecol Mont 1(2):82–88
27. Glöer P, Pešić V (2014) New subterranean freshwater gastropods of Montenegro (Mollusca: Gastropoda: Hydrobiidae), with description of one new genus and two new species. Ecol Mont 1(4):244–248
28. Boeters H, Glöer P, Pešić V (2014) *Arganiella tabanensis* n. sp. from Montenegro (Mollusca: Gastropoda: Hydrobiidae). Ecol Mont 1(3):131–139
29. Grego J, Glöer P, Erőss ZP, Fehér Z (2017) Six new subterranean freshwater gastropod species from northern Albania and some new records from Albania and Kosovo (Mollusca, Gastropoda, Moitessieriidae and Hydrobiidae). Subterr Biol 23:85–107

30. Radoman P (1982) Hydrobioidea a superfamily of Prosobranchia (Gastropoda), I. Sistematics, vol 547. Serbian Academy of Sciences and Arts, Beograd, (Dep. Sci. 57): 1–256, 12 pls
31. Falniowski A, Szarowska M, Glöer P, Pešić V (2012) Molecules vs morphology in the taxonomy of the *Radomaniola*/*Grossuana* group of Balkan Rissoiidea (Mollusca: Caenogastropoda). J Conchol 41(1):19–36
32. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281: 69–90
33. Černosvitov L (1931) Zur Kenntnis der Oligochaeten–Fauna des Balkans, III. Oligochaeten aus Montenegro und Süd Südserbien. Zool Anz 95:312–327
34. Hrabě S (1958) Die Oligochaeten aus den Seen Dojran und Skadar. Spisy vyd přír fak Masar university. Brno 397:337–354
35. Karaman S (1973) Beitrag zur Kenntnis der Oligochaetenfauna des Skadarsees. Zool Anz 190(5–6):351–358
36. Kerovec M, Mršić N (1981) Oligochaeta, III/1. Catalogus faunae Jugoslavie, Ljubljana
37. Janković M, Jakovčev D (1986) Study of the bottom fauna of the Lake Skadar in the area of Raduš. Acta Biol Iugosl Ekologija 21(1):1–14
38. Đukić N (1988) Aquaculture development possibility in Skadar Lake. Report of the International scientific cooperation between University Auburn (USA) and Institute for biological and medical investigations Podgorica. Ministry of Education and Science of Montenegro
39. Jabłońska A, Pešić V (2006) New data on aquatic Oligochaeta of Montenegro. In: Pešić V, Hadžiablahović S (eds) Proceedings of the symposium, II international symposium of ecologists of montenegro, Kotor, 20–25 Sept 2006, pp 25–29
40. Šundić D (2007) Diversity and bioindicator's potential of Oligochaeta of the Skadar Lake. Dissertation, University of Montenegro
41. Šundić D, Radujković BM, Krpo-Ćetković J (2011) Catalogue of naidinae and pristininae (Annelida: Oligochaeta: Naididae) with twenty species new for Montenegro. Zootaxa 2737:1–18
42. Šundić D, Radujković BM, Krpo-Ćetković J (2011) Catalogue of aquatic oligochaeta (Annelida: Clitellata) of Montenegro, exclusive of naidinae and pristininae. Zootaxa 1985:1–25
43. Šundić D (2012) Freshwater oligochaeta of Montenegro and their potential as biological indicators. Dissertation, University of Belgrade, Belgrade
44. Šundić D, Radujković B (2012) Pollution of the Skadar Lake. NGO Green Home
45. Blanchard R (1905) Hirudineen aus Montenegro. Sitzungsber Königl Böhm Ges Wiss Prag, pp 1–3
46. Grosser C, Pešić V, Gligorović B (2015) A checklist of the leeches (Annelida: Hirudinea) of Montenegro. Ecol Montenegrina 2(1):20–28
47. Grosser C, Pešić V, Berlajolli V, Gligorović B (2016) *Glossiphonia balcanica* n. sp. and *Dina prokletijaca* n. sp. (Hirudinida: Glossiphoniidae, Erpobdellidae) – two new leeches from Montenegro and Kosovo. Ecol Mont 8:17–26
48. Utevsky S, Utevsky A, Pešić V (2013) First record of *Glossiphonia nebulosa* (Hirudinida: Glossiphoniidae) from the Skadar Lake in Montenegro. Lauterbornia 76:123–125
49. Gelder SR (1999) Zoogeography of branchiobdellidans (Annelida) and temnocephalans (Platyhelminthes) ectosymbiotic on freshwater crustaceans, and their reactions to one another in vitro. Hydrobiologia 406:21–31
50. Pešić V (2007) First records of *Schwiebea cavernicola* Vitzthum, 1932 (Acari, Acaridida) in Serbia and Montenegro. Arch Biol Sci, Belgrade 59(1):7P–8P
51. Chatterjee T, Pavićević A, Pešić V (2010) New records of the halacarid mites (Acari*:* Halacaridae) from Croatia. Acta Biologica 17:85–89
52. Pešić V (2004) New records of Halacarid mites (Acari, Halacaroidea) from Crna Gora. In: Pešić V (ed) The biodiversity of the Biogradska Gora National Park. Monographs I. Department of Biology, University of Montenegro & Centre for Biodiversity of Montenegro, Montenegro, pp 96–103

53. Zawal A, Pešić V (2018) The diversity of assemblages of water mites from Lake Skadar and its catchment. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Berlin
54. Pešić V, Smit H, Gerecke R, Di Sabatino A (2010) The water mites (Acari: Hydrachnidia) of the Balkan peninsula, a revised survey with new records and descriptions of five new taxa. Zootaxa 2586:1–100
55. Pešić V, Bańkowska A, Goldschmidt T, Grabowski M, Michoński G, Zawal, A (2018) Supplement to the checklist of water mites (Acari: Hydrachnidia) from the Balkan peninsula. Zootaxa 4394(2):151–184
56. Petković S (1981) Zooplankton: general introduction. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 191–192
57. Karanović T (1998) Taxonomical, zoogeographical, and ecological study of Copepods (Crustacea, Copepoda) from Continental water in Adriatic drainage area of Montenegro. Dissertation, University of Novi Sad
58. Karanović T (2000) *Nitocrella longa* n. sp. (Crustacea, Copepoda, Harpacticoida) from subterranean waters of Montenegro (SE Europe). Mitt Mus Naturkunde Berl. Zoolog Reihe 76: 75–83
59. Karanović T (1997) Two new species of Harpacticoid Copepods (Copepoda, Harpacticoida, Canthocamptidae) from Montenegro (Balkan Peninsula). Bull zool Mus Univ Amsterdam 16:1–9
60. Karanović T (1998) Two interesting species of the genus *Elaphoidella* Chappuis, 1929 (Crustacea, Copepoda) from Balkan peninsula. Mém Biospéol 25:25–33
61. Karanović T (2001) *Elaphoidella* uva n. sp. (Crustacea, Copepoda) and two other interesting species of the genus *Elaphoidella* from Montenegro (SE Europe). Beaufortia 51(2):57–74
62. Petkovski T (1961) Zur Kenntnis der Crustaceen des Skadar (Shkodra) See. Acta Mus Maced Sci Nat 2(70):31–49
63. Karanović I (1998) The ostracod fauna (Ostracoda, Crustacea) from the Skadar Lake drainage basin. Disertation, University of Novi Sad
64. Karanović I (2012) Recent freshwater ostracods of the world. Springer, Berlin, Heidelberg
65. Mazzini I, Gliozzi E, Koci R et al (2015) Historical evolution and Middle to Late Holocene environmental changes in Lake Shkodra (Albania): new evidences from micropaleontological analysis. Palaeogeogr Palaeoclimatol Palaeoecol 419:47–59
66. Petkovski S (1993) Taksonomsko-morfološka i zoogeografsko-ekološka studija Anostraca (Crustacea: Branchiopoda) jugoslovenskih zemalja. Dissertation, University of Novi Sad
67. Petrov B, Petrov I (1997) The status of Anostraca, Notostraca and Conchostraca Crustacea: Branchiopoda in Yugoslavia. Hydrobiologia 359:29–35
68. Mrázek A (1903) Ergebnisse einer von Dr. Al. Mrázek im J. 1902 nach Montenegro unternommenen Sammelreise. Věstn Král České Společn Nauk, pp 1–24
69. Brožek A (1904) Variačně statistická zkoumání na Atyaëphyra desmarestii (Joly) z jezera Skadarského. Věstn Král České Společn Nauk, pp 1–71
70. Brožek A (1905) Variačně statistická zkoumání na Atyaëphyra desmarestii (Joly) z jezera Skadarského. II cást: Meristika a vnější organisace. Věstn Král České Společn Nauk, pp 1–69
71. Karaman GS (1997) Fauna of Amphipoda (Crustacea, Malacostraca) of Skadar Lake basin and its vicinity (228. Contribution to the Knowledge of the Amphipoda). In: Mijušković M (ed) Natural values and protection of Lake Skadar. CANU, Scientific Meetings, 44, pp 225–234
72. Coineau N, Stock JH (1986) Amphipoda: Bogidiellidae. In: Botosaneanu L (ed) Stygofauna mundi. E. J. Brill, Leiden, pp 412–422
73. Delić T, Sket B (2015) Found after 60 years: the hows and whys of *Sphaeromides virei montenigrina* (Crustacea: Isopoda: Cirolanidae) rediscovery in Obodska pećina, Montenegro. Natura Sloveniae 17(2):59–65

74. Botosaneanu L, Bruce N, Notenboom J (1986) Isopoda: cirolanidae. In: Botosaneanu L (ed) Stygofauna Mundi. E. J. Brill, Leiden, pp 574–580
75. Karaman GS (1981) Crustacea decapoda, mysidacea and amphipoda from Lake Skadar drainage basin. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 246–250
76. Rajkovic M, Petrovic A, Maguire I, Simic V, Simic S, Paunovic M (2012) Discovery of a new population of the species complex of the white-clawed crayfish, *Austropotamobius pallipes/ italicus* (Decapoda, Astacidae) in Montenegro, range extension, endangerment, and conservation. Crustaceana 85(3):333–347
77. Wittmann KJ, Ariani AP (2012) The species complex of *Diamysis* Czerniavsky, 1882, in fresh waters of the adriatic basin (NE Mediterranean), with descriptions of *D. lacustris* Băcescu, 1940, new rank, and *D. fluviatilis* sp. nov. (Mysida, Mysidae). Crustaceana 85(14):1745–1779
78. Sworobowicz L, Grabowski M, Mamos T, Burzyński A, Kilikowska A, Sell J, Wysocka A (2015) Revisiting the phylogeography of Asellus Aquaticus in Europe: insights into cryptic diversity and spatiotemporal diversification. Freshw Biol 60:1824–1840
79. Grabowski M, Mamos T, Bącela-Spychalska K, Rewicz T, Wattier RA (2017) Neogene paleogeography provides context for understanding the origin and spatial distribution of cryptic diversity in a widespread Balkan freshwater amphipod. Peer J 5:e3016
80. Jablońska A, Mamos T, Zawal A, Pešić V, Grabowski M (2015) An old endemic species of freshwater shrimps in the very young Skadar Lake. In: 13th international congress on the zoogeography and ecology of Greece and adjacent regions, October 7–11, Irakleio, Crete
81. Wrzesińska W, Hupało K, Jabłońska A, Mamos T, Zawal A, Pešić V, Grabowski M (2017) When DNA barcoding fails: a case of intergeneric mtDNA introgression in freshwater Balkan amphipods. In: 17th international colloquium on amphipoda, Sept 4–7, Trapani, Italy
82. Grabowski M, Bącela-Spychalska K, Pešić V (2014) Reproductive traits and conservation needs of the endemic gammarid *Laurogammarus scutarensis* (Schäferna, 1922) from the Skadar Lake system, Balkan Peninsula. Limnologica 47:44–51
83. Puthz V (1974) Einige Ephemeropteren aus Jugoslawien, vorwiegend aus Montenegro und Serbien (Insecta, Ephemeroptera). Acta Rer Natur Mus Nat Slov Bratislava 19(2):147–156
84. Kovács T, Murányi D (2013) New country data of some mayflies (Ephemeroptera) from Europe. Folia Hist-Nat Mus Matraensis 37:15–19
85. Filipović D (1981) Distribution and quantitative relationships of the fauna of Ephemeroptera in the Morača River. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 300–304
86. Jacob U (1986) *Siphlonurus abraxas* n. sp. ein neues Taxon der lacustris Gruppe aus Montenegro (Jugoslawien) (Ephemeroptera, Siphlonuridae). Reichenbachia 23(25):139–143
87. Petrovic A, Simic V, Paunovic M, Stojanovic B (2006) A new records of *Epeorus Yougoslavicus* (Šamal, 1935) [Ephemeroptera] in Serbia and Montenegro. Biotechnol Biotechnol Equip 20(2): 67–71
88. Putz V (1980) Ergebnisse der Albanien-Expedition 1961 des Deutschen Entomologischen Institutes. 94. Beitrag: Ephemeroptera. Beitr Entomol 30(2):343–355
89. Kimmins DE (1937) Some new Ephemeroptera. Ann Mag Nat Hist 10(19):430–440
90. Bauernfeind E, Soldán T (2012) The mayflies of Europe (Ephemeroptera). Apollo Books, Ollerup
91. Jović M, Lj A, Bedjanič M, Santovac S (2008) Rewiew of the fauna Odonata of Montenegro. Opusc Zool Flumin 224:1–26
92. De Knijf G, Vanappelghem C, Demolder H (2013) Odonata from Montenegro, with notes on taxonomy, regional diversity and conservation. Odonatologica 42:1–29
93. Buczyński P, Zawal A, Stępień E, Buczyńska E, Pešić V (2013) Contribution to the knowledge of dragonflies (Odonata) of Montenegro, with the first record of *Ophiogomphus cecilia* (Fourcroy, 1785). Ann Univ Mariae Curie Sklodowska Sectio C 68:57–71

94. Gligorović B (2015) Species account and data about Odonata in Montenegro. In: Boudot J-P, Kalkman VJ (eds) Atlas of the European dragonflies and damselflies. KNNV Publishing, Zeist
95. Bartenev AN (1912) Notice sur les odonates du Monténégro. Revue russe Ent 12:76–80
96. Dumont HJ (1997) Sur une collection d'odonates de Yugoslavie, avec notes sur la faune des teritores adjecents de Roumanie et de Bulgarie. Bull Annls Soc R Belge Ent 113:187–209
97. Adamović Ž (1996) Odonata taken and observed in Donji Ceklin, Montenegro. Acta Ent Serbica 1(1–2):39–48
98. Kovács T, Murányi D (2013) Larval data of *Caliaeschna microstigma* (Schneider, 1845) from the Balkan Peninsula, with contributions to its biology (Odonata: Aeshnidae). Folia Hist-Nat Mus Matraensis 37:21–28
99. Murányi D, Kovács T (2013) Contribution to the Odonata fauna of Albania and Montenegro. Folia Hist-Nat Mus Matraensis 37:29–41
100. Buczyński P, Tończyk G, Buczyńska E, Gadawski P, Michoński G, Zawal A (2017) On the occurrence of gomphus pulchellus Selys, 1840 (Odonata: Gomphidae) on the Balkan Peninsula. Acta Zool Bulg 69(1):43–47
101. Boudout JP, Kalkman VJ (eds) (2015) Atlas of the European dragonflies and damselflies. KNNV-Uitgeverij, Zeist
102. Pešić V, Gligorović B, Savić A, Buczyński P (2017) Ecological patterns of Odonata assemblages in karst springs in central Montenegro. Knowl Manag Aquat Ecosyst 418:3
103. Pavićević A, Pešić V (2011) Predaceous diving beetles (Coleoptera: Dytiscidae) from Montenegro with new records and description of the female of *Hydroporus macedonicus* Fery & Pešić, 2006. Arch Biol Sci 63(2):477–485
104. Scheers K (2016) An updated checklist of the water beetles of Montenegro (Coleoptera, Hydradephaga). Spixiana 39(2):205–212
105. Pešić V, Pavićević A (2005) New records of water beetles species of the Hydrophilidae (Coleoptera) from Montenegro (SE Europe). Acta Ent Serbica 8(1–2):91–94
106. Pešić V, Pavićević A (2005) New records of water beetles species of the Hydrophilidae (Coleoptera) from Montenegro. Part II. Acta Ent Serbica 8(1–2):99–102
107. Przewozny M, Jaskula R, Pešić V (2009) Re-discovery of *Hydrochus Flavipennis* and *Anacaena Globulus* in Montenegro (Coleoptera: Hydrochidae et Hydrophilidae). Lauterbornia 67:23–27
108. Jäch MA (1999) Revision of the Palearctic species of the genus *Ochthebius* Leach. XVI. Additional notes on the metallescens group (Coleoptera: Hydraenidae). Koleopterol Rundsch 69:83–98
109. Protić Lj (2016) Checklist of Heteroptera of Montenegro. Ecol Mont 7:350–393
110. Kment P, Bryja J, Jindra Z (2005) New records of true bugs (Heteroptera) of the Balkan Peninsula. Acta Entomol Slovenica 13(1):9–20
111. Gligorović B, Savić A, Lj P, Pešić V (2016) Ecological patterns of water bugs (Hemiptera: Heteroptera) assemblages in karst springs: a case study in central Montenegro. Oceanol Hydrobiol Stud 45(4):554–563
112. Ivović V, Ivović M, Miscević Z (2003) Sandflies (Diptera: Psychodidae) in the bar area of Montenegro (Yugoslavia). Ann Trop Med Parasitol 97(2):193–197
113. Ivović V, Depaquit J, Léger N, Urano A, Papadopoulos B (2004) Sandflies (Diptera: Psychodidae) in the bar area of Montenegro (Yugoslavia). 2. Presence of promastigotes in *Phlebotomus neglectus* and first record of *P. kandelakii*. Ann Trop Med Parasitol 98(4):425–427
114. Krčmar S, Mikuska J, Chvála M (2002) Tabanidae (Diptera) of Western and Central Balkans – Bosnia and Herzegovina, Serbia, Montenegro, Vojvodina, Kosovo and Macedonia. Acta Univ Carol Biol 46:305–320
115. Adler PH, Crosskey RW (2017) World blackflies (Diptera: Simuliidae): a comprehensive revision of the taxonomic and geographical inventory. http://www.clemson.edu/cafls/biomia/pdfs/blackflyinventory.pdf. Accessed 15 Oct 2017
116. Płóciennik M, Pešić V (2012) New records and list of non-biting midges (Chironomidae) from Montenegro. Biol Serb 34:36–50

117. LOVCEN Project (2015) Mosquitoes in Montenegro – check list end of 2015. http://project-lovcen.me/userfiles/01%20Mosquitoes%20in%20Montenegro%20-%20check%20list%20end%202015.pdf. Accessed 15 Oct 2017
118. Becker N, Petric D, Zgomba M, Boase C, Madon M, Dahl C, Kaiser A (2010) Mosquitoes and their control, 2nd edn. Springer, Heidelberg
119. Devetak D, Slavevska-Stamenković V, Sivec I (2016) Alderflies (Insecta: Megaloptera: Sialidae) from Serbia and Macedonia, with notes on their occurrence in the neighbouring Balkan countries. Acta Zool Bulg 68(1):39–42
120. Aubert J (1964) Quelques Plécoptères du Muséum d'Histoire naturelle de Vienne. Ann Nat Hist Mus Wien 67:287–301
121. Murányi D (2011) The genus *Brachyptera* Newport (Plecoptera: Taeniopterygidae) in the Peloponnes, Greece. Zootaxa 2977:61–68
122. Zwick P (1967) Revision der Gattung *Chloroperla* Newmann (Plecoptera). Mitt Schweiz Entomol Ges 40(1–2):1–26
123. Zwick P (1978) Steinfliegen (Plecoptera) aus Griechenland und benachbarten Ländern – 2. Teil. Mitt Schweiz Entomol Ges 51(3):213–239
124. Baumann RW, Kaćanski D (1975) A new species of *Capnioneura* from Yugoslavia (Plecoptera, Capniidae). Mitt Schweiz Entomol Ges 48(3–4):451–453
125. Kaćanski D, Baumann RW (1981) Notes on the plecoptera fauna of the Morača River drainage. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 304–307
126. Murányi D (2007) New and little-known stoneflies (Plecoptera) from Albania and the neighbouring countries. Zootaxa 1533:1–40
127. Murányi D (2008) The stonefly (Plecoptera) fauna of Montenegro. In: Pešić V (ed) The book of abstracts and programme, III. International symposium of ecologists of Montenegro, Herceg Novi, 8–10 Oct 2008
128. Murányi D (2011) Balkanian species of the genus *Isoperla* banks, 1906 (Plecoptera, Perlodidae). Zootaxa 3049:1–46
129. Kovács T, Vinçon G, Murányi D, Sivec I (2012) A new *Perlodes* species and its subspecies from the Balkan Peninsula (Plecoptera: Perlodidae). Illiesia 8(20):182–192
130. Murányi D, Kovács T, Orci KM (2016) Contribution to the taxonomy and biology of two Balkan endemic *Isoperla* Banks, 1906 (Plecoptera: Perlodidae) species. Zoosymposia 11:73–88
131. Graf W, Lorenz AW, Tierno de Figueroa JM, Lucke S, López-Rodriguez MJ, Davies C (2009) Plecoptera. In: Schmidt-Kloiber A, Hering D (eds) Distribution and ecological preferences of European freshwater organisms, vol 2. Pensoft, Sofia, 262 p
132. Radovanović M (1935) Trichoptera in Yugoslavia. Bull Mus Nat Hist BiH Sarajevo XLVII:73–84
133. Radovanović M (1953) Contribution to the study of Trichoptera in the Balkan peninsula, primarily in caves and mountain lakes. Bull SAN CCX 7:11–38
134. Krusnik C (1987) Trichoptera (Insecta). In: Fauna of Mt. Durmitor, Book 2. Montenegrian Academy of Science and Arts, Special edition, Book 21, Department of Natural Sciences, vol 13, pp 201–224
135. Oláh J (2011) New species and species records of Balkan Trichoptera. Folia Hist-Nat Mus Matraensis 35:111–121
136. Marinković-Gospodnetić M (1981) Trichoptera of the Morača and Plavnica river drainages. In: Beeton AM, Karaman GS (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Montenegro, pp 307–309
137. Kumanski K (1997) Contributions to the caddisfly fauna (Trichoptera) of the central-western part of the Balkan Peninsula. Lauterbornia 31:73–82
138. Oláh J, Kovacs T (2013) New species and records of Balkan Trichoptera II. Folia Hist-Nat Mus Matraensis 37:109–121
139. Janković D, Trifunac M (1978) Kompetitivni odnosi u ishrani ekonomski značajnih ciprinidnih vrsta riba u Skadarskom jezeru. Ekologija 13(2):111–112

140. Rebel H, Zerny H (1931) Die Lepidopterenfauna Albaniens (mit Berück sichtigung der Nachbargebiete). Denkschr Öst Akad Wiss 103:37–161
141. Rakočević-Nedović J, Hollert H (2005) Phytoplankton community and its pigment characteristics as trophic indexes of the Skadar Lake (Montenegro, Balkan). Environ Sci Pollut Res 12: 146–152
142. Donohue I, Jackson AL, Pusch MT, Irvine K (2009) Nutrient enrichment homogenizes lake benthic assemblages at local and regional scales. Ecology 90(12):3470–3477

The Diversity and Conservation Status of the Molluscs of Lake Skadar/Shkodra

Vladimir Pešić and Peter Glöer

Contents

Abstract Research on the aquatic molluscs of Lake Skadar has a long tradition, starting with the paper published by Küster in 1843. The Lake Skadar basin consists of the lake itself and a variety of nearby water bodies, including lotic waters, pools, and springs that are inhabited by diverse communities of freshwater molluscs. A total of 53 freshwater mollusc species, ten species of Bivalvia and 43 species of Gastropoda, have been found in the Lake Skadar basin and Lake Šasko, with 15 being endemic. Some of the basin's endemic species are common and relatively unconfined in terms of depths and zones. A characteristic feature of the lake is the presence of endemic species restricted to sublacustrine spring habitats. The lake's ongoing process of eutrophication, its use as a water supply, and the ecological disruption caused by non-native species are generally recognized as the main threats to the lake's mollusc fauna. Future research on the lake's gastropod fauna should focus on the application of molecular methods and including the endemic species in ongoing national and transboundary conservation programs.

Keywords Conservation, Diversity, Endemism, Lake Skadar basin, Molluscs

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 295–310, DOI 10.1007/698_2017_235,
© Springer International Publishing AG 2018, Published online: 29 April 2018

1 Introduction

Research on the aquatic molluscs of Lake Skadar began in 1843 with a paper published by Heinrich Carl Küster [1]. In 1852 Küster [2] described a new species, *Viviparus mamillatus* from a stream (Crnojevića, after Wohlberedt [3]) flowing into Lake Skadar. In 1864 Walderdorff [4] described *Neritina fluviatilis* v. s*cutarensis*. At the beginning of the twentieth century, Wohlberedt [3] described *Bithynia montenegrina* from the River Crnojevića and gave an overview of the mollusc fauna of Montenegro, listing six species from Lake Skadar: *Theodoxus fluviatilis f. scutarensis, Viviparus mamillatus, Valvata piscinalis, V. cristata, Radix ovata,* and *Stagnicola palustris*. After a long pause in research on Lake Skadar molluscs, Jaeckel et al. [5] published a paper listing 20 gastropod species in Montenegro, but unfortunately the locations of these species were not indicated, making it unclear whether any of these species were observed in the Lake Skadar basin.

The lake's zoobenthos and molluscs were studied from 1972 to 1977 by Karaman and Nedić [6] as a result of a scientific collaboration between the Biological Institute in Titograd (today Podgorica) and the Smithsonian Institute (USA) – the project was conducted within the framework of the project "Limnological Investigations of the Skadar Lake."

Stein et al. [7] published the first ecological data on the abundance of mollusc species in Lake Skadar. Covich and Knežević [8] studied size selective predation by fish on thin-shelled *Lymnaea auricularia* and *L. stagnalis* and the importance of floating *Trapa*-vegetation as a refuge for these species. Jacobi [9] provided the first data on the distribution and ecology of molluscs in the sublacustrine springs of Lake Skadar.

In the 1970s and 1980s the famous Serbian zoologist Pavle Radoman (1913–2007) studied hydrobiid snails in the Lake Skadar basin and described many new species and genera [10–13]. He systematized knowledge on the systematics, origin and zoogeography of hydrobiid gastropods in two large monographs [13, 14]. Although the lake itself was not a subject of his special interest, Radoman described two new species of hydrobiid snails (*Radomaniola lacustris* and *Vinodolia scutarica*) from Skadar Lake [11, 12]. Furthermore, he presented two hypotheses aimed at explaining the limnological origin of the extant Lake Skadar. In his first hypothesis, Lake Skadar was formed of "novo" in a dry plane from the springs (or rivers) on the site of a former marine gulf. In the second hypothesis, Lake Skadar is a remnant of a much broader interlinked lacustrine system, first brackish then freshwater, that was gradually fragmented and disappeared. The two scenarios, primarily introduced by Radoman [13] to explain the recent distribution of *Radomaniola lacustris* and *Vinodolia scutarica* in Lake Skadar, were recently reviewed by Pešić and Glöer [14].

On the Albanian side of Lake Skadar, the fauna of molluscs was the subject of a study conducted by Professor Dhimitër Dhora (Shkodra). In the period from 1985 to 2016 he published a number of papers on Lake Skadar molluscs [15–17]. Moreover, he published two books, in 2002 and 2004, in which he presented the results of his nearly four decades of work on Lake Skadar molluscs [18, 19]. Dhora and Welter-

Schultes [20] published the first checklist of the molluscs of Lake Skadar, in which they listed 27 species of gastropods and ten species of Bivalvia.

The next checklist of Lake Skadar molluscs was given by Božana Jovanović [21]. She provided valuable data on the ecology of molluscs on the Montenegrin side of the lake and listed 13 species of gastropods and four species of Bivalvia for Lake Skadar.

In the period 2007–2013, Peter Glöer (Hetlingen) and Vladimir Pešić (Podgorica) published a series of papers on gastropods from Lake Skadar. They describe ten new species that inhabit the Lake Skadar basin [22–26]. Pešić and Glöer [14] described a new genus and species, *Karucia sublacustrina* and published a checklist of Lake Skadar gastropods, listing 50 species that occur in the Lake Skadar basin.

As the results of their numerous field trips to Albania, Fehér and Erőss [27] reported several species from the Albanian side of Lake Skadar. The molluscs of Lake Skadar and its surroundings were the subject of research of Peter Reischütz (Vienna), who published several papers on the molluscs of Lake Skadar [28–30]. In addition to *Bithynia hambergerae*, which was described from the River Plavnica, a northern tributary of Lake Skadar [28], he described a new subspecies *Plagigeyeria zetaprotogona vitoja* from the spring at Vitoja [29], a large karstic spring located on the northeastern shore of Lake Skadar. The latter spring was the object of a study conducted by Glöer et al. [31] who described therein several subterranean species with empty shells including three species new to science (*Bracenica vitojaensis, Islamia montenegrina,* and *Lanzaia pesici*).

2 The Distribution and Species Richness of Lake Skadar Molluscs

The Lake Skadar basin consists of the lake itself and different waterbodies in its region, i.e. lotic waters, pools, and springs. The unclear separation of the lake itself from its surrounding waterbodies explains the differences in the number of species mentioned in the various checklists of Lake Skadar molluscs [e.g., 14, 20, 21].

Lake Skadar has a surface area that fluctuates seasonally from approximately 370–600 km^2 [32]. The northern and northeastern shore is shallow and at times of high water levels it represents an extensive semi-littoral zone. Springs that are numerous in the lake basin and important for its water balance can also be found within the lake (sublacustrine springs called “oko”) or lie along the margins. The sublacustrine springs are mainly located along the steep southwestern zone [32]. The most powerful springs are Karuč and Raduš Oko which have a depth of 60 m [32]. The springs that lie along the margins of the lake are mainly located on the northern and northeastern shore of the lake. During high water periods, these spring systems fall under the water level of the lake, and at that time they function as part of the lake's ecosystem [33]. Most of these springs burst at the border between the massive limestone and the alluvium of Lake Skadar [31]. The most powerful springs lying along the margins are those springs on the islands of Vranjina and the Vitoja spring.

Lake Skadar has one outlet, the River Bojana, but it receives the inflow of a number of rivers located mainly on the northern side of the lake (e.g., Plavnica, Gostiljska Rijeka, and Karatuna). As a result of heavy rain over several months, the flatlands on the northern and northeastern shores are flooded and the lower parts of the inflowing rivers fall under the water level of the lake [32]. Similarly, a large number of surrounding ponds and still water channels that are separated from the lake in the summer months function as parts of the lake's ecosystem during high water level periods.

Several studies have shown that molluscs are an important component in the food chains of the Lake Skadar ecosystem. Janković [34] mentioned that in the early summer the carp (*Cyprinus carpio* L) in Lake Skadar mainly feed on plants and snails in roughly equal quantities. Stein et al. [7] studied selective predation by carp (*Cyprinus carpio*) on molluscan prey in Lake Skadar. They proved that molluscs were present in the guts of at least one third of the 415 carp collected in the littoral zone of Lake Skadar. Although *Pyrgula annulata* was very common, the carp seldom fed on this snail, and the food most commonly consisted of *Valvata piscinalis*, which was far less represented (12% of the mollusc fauna by direct count). The "electivity" for the latter species was explained by the thinner shell in *Valvata piscinalis* which can be crushed more easily by the carp's pharyngeal teeth [7].

The first data on the abundance of molluscs in the benthos of Lake Skadar was published by Stein et al. [7], who mentioned the following species in order of their abundance: *Pyrgula annulata*, *Valvata piscinalis, Dreissena, Pisidium* (several species), *Viviparus viviparus* (=*mamillatus*), *Radix auricularia,* and *Amphimelania holandrii*. *Pyrgula annulata* was the most abundant in the open part of the lake as well as in the sublacustrine springs [6]. Covich and Knežević [8] mentioned that *Valvata piscinalis* and *Pyrgula annulata* were relatively abundant at localities with muddy substrates, while *Viviparus mamillatus* was more abundant in the rocky shallow water.

Janković [35] reported that molluscs can form up to 20% of the total epifauna biomass from *Trapa* beds. He mentioned that the abundances of Mollusca from *Trapa* substrate increased from September to November and reached a mean density of 200 ind./m^2 and a biomass of 1 g/m^2. Covich and Knežević [8] mentioned that the densities of *Lymnaea auricularia* ranged from 12–20 ind./m^2 in Vranjina to 24–36 ind./m^2 in Raduš, while the density of *L. stagnalis* (=*raphidia*) was relatively low with a maximum of 4 ind./m^2 in Raduš.

Jovanović [21] studied the abundance of molluscs by the quantitative method using an Ekman grab at 18 localities along the Lake Skadar shore. She found the highest abundance of molluscs around Grmožur Island at a depth of 5 m, while the smallest number of specimens were collected at the localities of Odrinska Gora and near the monastery on the island of Vranjina. The highest population density (3818.40 ind./m^2) was found for *Valvata piscinalis*, which was the most frequent species in her study, at Grmožur Island at the depth of 5 m, while *Pyrgula annulata* at the same site had a density of 1376.49 ind./m^2. Stein et al. [7] reported that the density of the *Pyrgula annulata* population was 2,570 ind./m^2, while *Valvata piscinalis* reached a maximum abundance of 570 ind./m^2.

The largest number of molluscs in Lake Skadar was found in the littoral zone at a depth of 0.5–2.5 m [21]. The exceptions were the sublacustrine springs in which molluscs were found at significantly greater depths. Jacobi [9] reported that in the Raduš Oko sublacustrine spring, *Theodoxus fluviatilis* was found at a depth of 15 m, while *Valvata piscinalis* and *Pyrgula annulata* were found at a depth of as much as 48 m. *Viviparus mamillatus* was found at a depth of 6 m in Raduš Oko and in Karuč at 25 m, both in a high population density, significantly contributing to the total community biomass which reaches 780 g/m^2 in Raduš and 175 g/m^2 in Karuč [9].

3 Diversity and Endemism of Gastropoda

For a long time it has been considered that the fauna of molluscs of Lake Skadar include no endemic species and that the lake is inhabited by widespread Central-European species (e.g., [20, 21]). Many of these species, often common, have been misidentified in the past and their presence in older molluscan literature on Lake Skadar might refer to the endemic species described later on [14].

A total of 43 gastropod species have been found in the Lake Skadar basin, 15 of them being endemic (Figs. 1 and 2, Table 1). If we exclude the seven subterranean species described only from empty shells from springs, 12 species are endemic to the Skadar Lake basin, including the neighboring Lake Šasko. Pešić and Glöer [14] stated that taking the surface area into account by using normalized endemic species area index [36] Lake Skadar exceeds such famous ancient lakes as Malawi and Titicaca. The largest number of endemic species belongs to the genus *Bithynia*. Glöer et al. [37] suggest that Lake Skadar might be a hot spot of evolution of this genus.

Most of the endemic species of the Lake Skadar basin are common and relatively unconfined in terms of depths or zones. *Bithynia radomani* inhabits the lake and the various types of lotic and standing waters in the Lake Skadar system. The shell of *Bithynia radomani* is similar to *B. tentaculata*, which in the past has often led to confusion, so the former records of *B. tentaculata* from the Lake Skadar basin should refer to *B. radomani*. Morphologically, *B. radomani* is similar to *B. montenegrina* and *B. hambergerae* that have a much narrower distribution in the Lake Skadar basin and are known only from one locality [14]. All three species can be distinguished by the dimensions of the shell and the features of the male reproductive system [14]. This complex should be studied using molecular techniques. The two remaining species of the genus, *Bithynia zeta* and *B. skadarskii* are more common. The latter species is known only from Lake Skadar. *Bithynia zeta* is known from Lake Skadar and one spring near the Adriatic coast in Montenegro but recently it was discovered in the River Drim, suggesting that the areal of this species is much larger [14].

Valvata montenegrina seems to be common in Lake Skadar. In the past this species was probably confused with *Valvata piscinalis*. The distinctiveness of these two

Fig. 1 Endemic gastropod species occurring in the Lake Skadar basin. (**a**) *Vinodolia scutarica* (Radoman, 1973); (**b**) *Radomaniola elongata* (Radoman, 1973); (**c**) *Radomaniola lacustris* (Radoman, 1983); (**d**) *Valvata montenegrina* Glöer and Pešić, 2008; (**e**) *Bithynia radomani* Glöer and Pešić, 2007; (**f**) *Bithynia hambergerae* A. Reischütz, N. Reischütz and P. L. Reischütz, 2008; (**g**) *Bithynia montenegrina* (Wohlberedt, 1909); (**h**) *Bithynia skadarskii* Glöer and Pešić, 2007; (**i**) *Bithynia zeta* Glöer and Pešić, 2007; (**j**) *Karucia sublacustrina* Glöer and Pešić, 2013; (**k**) *Gyraulus ioanis* Glöer and Pešić, 2007; (**l**) *Gyraulus meierbrooki* Glöer and Pešić, 2007. Photos by P. Glöer

species has been demonstrated by the application of molecular methods. Clewing et al. [38] studied the phylogeography of the Tibetan Plateau *Valvata* spp. and showed that their specimens from the Tibetan Plateau form a well-supported subclade with *V. montenegrina*, which is sister to the group of *V.* cf. *piscinalis*.

Planorbis vitojensis has been described from a pond, rich in macrophytic vegetation, near the Lake Skadar shore [26]. This species seems to be closely related to *Planorbis carinatus*, from which it differs in its higher number of prostate diverticules [26]. In the past, the latter species was incorrectly reported from the Lake Skadar basin and its records should probably refer to *Planorbis vitojensis* [14]. A similar situation is found in relation to *Gyraulus meierbrooki*, an endemic of the Lake Skadar basin, which has previously been misidentified as *G. albus*. Interestingly, *Gyraulus meierbrooki* lay egg-clutches in the functional umbilical area of their own shell, a reproduction strategy

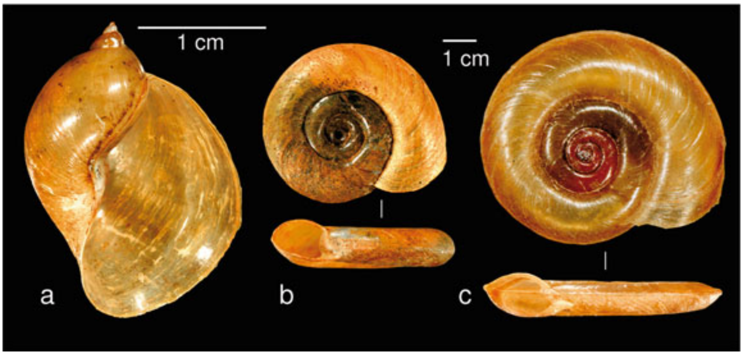

Fig. 2 Endemic gastropod species occurring in the Lake Skadar basin. (**a**) *Radix skutaris* Glöer and Pešić, 2007; (**b**) *Gyraulus shasi* Glöer and Pešić, 2007; (**c**) *Planorbis vitojensis* Glöer and Pešić, 2010. Photos by P. Glöer

also known in some other small-bodied planorbid or prosobranch species [39, 40]. Two other endemic species of the genus *Gyraulus*, *G. shasi* and *G. ioanis* inhabit Lake Šasko which belongs to the Lake Skadar water system. As stated by Pešić and Glöer [14], the former records of *Planorbis planorbis* from the Lake Skadar basin should be attributed to *Gyraulus shasi*.

Radix skutaris was described by Glöer and Pešić [24] and it is a common species in Lake Skadar. In the older molluscan literature on Lake Skadar, this species was probably confused with juveniles of *Radix auricularia* (Linnaeus, 1758) or even with *R. peregra* (Müller, 1774) [21].

Glöer and Pešić [25] described *Stagnicola montenegrinus* from Lake Skadar as a common species. Later on this species was found in Bulgaria [41] and Macedonia [42]. Recent research conducted by Schniebs et al. [43] by applying molecular techniques showed that specimens determined as *Stagnicola montenegrinus* can be interpreted as hybrids between *S. corvus* and another *Stagnicola* species, possibly *S. palustris* or *S. fuscus*. The latter species has not been reported from Lake Skadar, while the records of *Stagnicola palustris* in Lake Skadar [3, 20] are questionable because they were not based on anatomical determination. Likely, records of *Stagnicola montenegrinus* in Lake Skadar can be interpreted as a result of ancient hybridization or hybridization due to zoochory-mediated long-distance dispersal [43].

The highest proportion of endemic species was found in the springs located on the northern and northeastern shore of the lake. This can be explained by the relatively high number of subterranean species found in these springs (Fig. 3). Glöer et al. [31] reported six species of subterranean hydrobiid species from the Vitoja spring. In addition to the three new species, *Bracenica vitojaensis, Islamia montenegrina,* and *Lanzaia pesici*, known only from the *locus typicus*, they reported *Vinodolia matjasici* (originally described from a spring in village of Lipovik in the Lake Skadar drainage area) [44], *Plagigeyeria zetaprotogona* and *Bosnidilhia vreloana*, a species recently described from the subterranean waters of Banja Luka in Bosnia and Herzegovina [45]. All these species have been described from empty shells. The taxonomic status of some of these species

Table 1 List of molluscs occurring in the Lake Skadar basin

Taxa	Red list category (after [48])
Gastropoda	
Neritimorpha	
Theodoxus fluviatilis (Linnaeus, 1758)	Least concern
Caenogastropoda	
Viviparus mamillatus Küster, 1852	Data deficient
Amphimelania holandrii (Pfeifer, 1828)	Least concern
Bithynia zeta Glöer and Pešić, 2007	Endangered
Bithynia radomani Glöer and Pešić, 2007	Least concern
Bithynia skadarskii Glöer and Pešić, 2007*	Endangered
Bithynia montenegrina (Wohlberedt, 1909)*	Data deficient
Bithynia hambergerae A. Reischütz, N. Reischütz and P. L. Reischütz, 2008*	Data deficient
Radomaniola lacustris (Radoman, 1983)*	Critically endangered
Radomaniola elongata (Radoman, 1973)*	Critically endangered
Islamia montenegrina Glöer, Grego, Erőss and Fehér, 2015*	
Vinodolia scutarica (Radoman, 1973)*	Endangered
Vinodolia matjasici (Bole, 1961)	Critically endangered
Lanzaia pesici Glöer, Grego, Erőss and Fehér, 2015*	
Bracenica spiridoni Radoman, 1973	Endangered
Bracenica vitojaensis Glöer, Grego, Erőss and Fehér, 2015*	
Karucia sublacustrina Glöer and Pešić, 2013*	
Plagigeyeria zetaprotogona Schütt, 1960	Endangered
Pyrgula annulata (Linnaeus, 1767)	Least concern
Bosnidilhia vreloana Boeters, Glöer and Pešić, 2013	
Heterobranchia	
Valvata cristata O. F. Müller, 1774	Least concern
Valvata montenegrina Glöer and Pešić, 2008	Endangered
Acroloxus lacustris (Linnaeus, 1758)	Least concern
Galba truncatula (O. F. Müller, 1774)	Least concern
Stagnicola montenegrinus Glöer and Pešić, 2009	Near threatened
Radix auricularia (Linnaeus, 1758)	Least concern
Radix skutaris Glöer and Pešić, 2007*	Endangered
Lymnaea raphidia (Bourguignat, 1860)	
Physa acuta Draparnaud, 1805	Least concern
Bathyomphalus contortus (Linnaeus, 1758)	Least concern
Planorbarius corneus (Linnaeus, 1758)	Least concern
Planorbis vitojensis Glöer and Pešić, 2010*	
Gyraulus crista (Linnaeus, 1758)	Least concern
Gyraulus ioanis Glöer and Pešić, 2007*	Critically endangered
Gyraulus meierbrooki Glöer and Pešić, 2007*	Endangered
Gyraulus laevis (Alder, 1838)	Least concern
Gyraulus shasi Glöer and Pešić, 2007*	Critically endangered

(continued)

Table 1 (continued)

Taxa	Red list category (after [48])
Anisus vortex (Linnaeus, 1758)	Least concern
Hippeutis complanatus (Linnaeus, 1758)	Least concern
Segmentina nitida (O. F. Müller, 1774)	Least concern
Ferrissia fragilis (Tryon, 1863)	
Ancylus fluviatilis (O. F. Müller, 1774)	Least concern
Ancylus recurvus Martens, 1873	
Bivalvia	
Unionidae	
Anodonta cygnea (Linnaeus, 1758)	Least concern
Anodonta anatina (Linnaeus, 1758)	Least concern
Unio crassus Philipsson, 1788	Endangered
Unio mancus Lamarck, 1819 (syn. *U. elongatulus* Pfeiffer, 1825)	Near threatened
Unio pictorum (Linnaeus, 1758)	Least concern
Unio tumidus Retzius, 1788	Least concern
Microcondylaea bonellii (Ferussac, 1827)	Vulnerable
Dreissenidae	
Dreissena carinata (Dunker, 1853) (syn. *D. presbensis* Kobelt, 1915, *D. stankovici* Lvova and Starobogatov, 1982)	Near threatened
Sphaeriidae	
Musculium lacustre (Müller, 1774) (syn. *Sphaerium lacustre* (Müller, 1774)	Least concern
Pisidium casertanum (Poli, 1791)	Least concern

Endemic species of the Lake Skadar basin are marked by an asterisk

should be clarified by finding living animals and consequently through anatomical determination and the application of molecular techniques.

If we exclude subterranean species, the only point endemic species from Lake Skadar is *Radomaniola elongata* known only from its *locus typicus*, the spring on island of Vranjina [12]. The distinctiveness of this species was confirmed by Falniowski et al. [46] by applying molecular methods. The latter authors stressed that there are some molecularly evident groups at species rank within the genus *Radomaniola* in the Lake Skadar system, and potentially also in some springs adjacent to the lake, but as the molecular differentiation was not reflected in the morphology, making taxonomic decisions on these populations is not possible [46].

The species richness map based on the gastropod presence in the main part of the lake showed a relatively homogeneous distribution of gastropod species. Jovanović [21] mentioned that the largest number of mollusc species (eight species) was found at the localities near Virpazar and Vranjina, which are also the areas of highest anthropogenic pressure. Pešić and Glöer [14] stated that the largest diversity of species is found in the sublacustrine spring at Karuč where 17 species were found. This hotspot harbors more than 30% of the endemics of the Lake Skadar basin

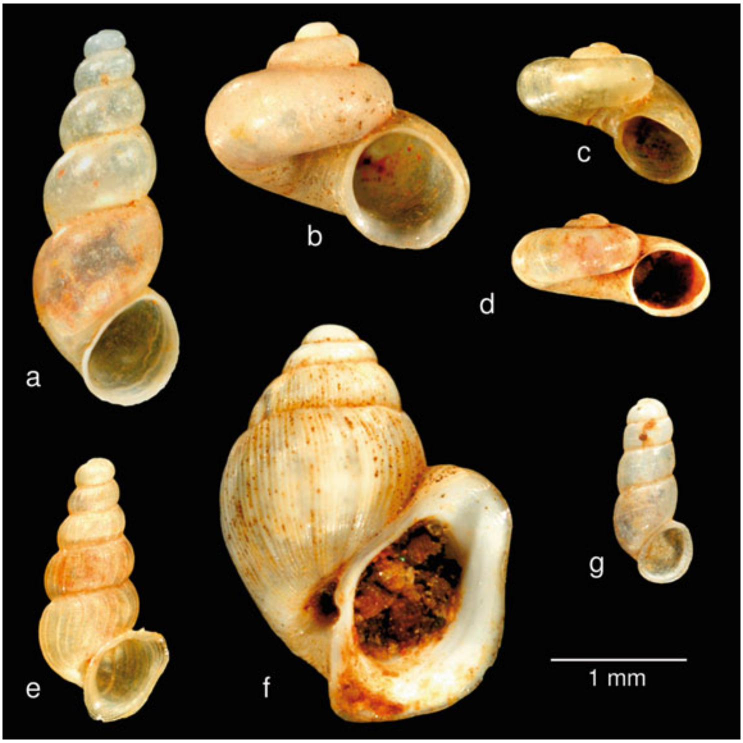

Fig. 3 Subterranean gastropod species found in the Lake Skadar basin. (**a**) *Vinodolia matjasici* (Bole, 1961); (**b**) *Islamia montenegrina* Glöer, Grego, Eröss and Fehér, 2015; (**c**) *Bracenica spiridoni* Radoman, 1973; (**d**) *Bracenica vitojaensis* Glöer, Grego, Eröss and Fehér, 2015; (**e**) *Lanzaia pesici* Glöer, Grego, Eröss and Fehér, 2015; (**f**) *Plagigeyeria zetaprotogona* Schütt, 1960; (**g**) *Bosnidilhia vreloana* Boeters, Glöer and Pešić, 2013. Photos by P. Glöer

including *Karucia sublacustrina* and *Radomaniola lacustris* which appear to be characteristic elements of sublacustrine springs.

The occurrence of endemic species in the sublacustrine springs is in contrast to earlier studies that stressed the absence of endemic taxa in this environment [9]. This was explained by the "non-isolated" nature of these springs and the fact that they are merely extensions of the lake [9]. *Karucia sublacustrina* was collected from Karuč and from two sublacustrine springs in the Albanian part of the lake and despite the intensive sampling in the lacustrine habitats around the type locality, it has not been collected outside the sublacustrine environment [14]. *Radomaniola lacustris* inhabits only the southwestern part of the lake [12], which is an area known to harbor many sublacustrine springs [14]. It seems probably that these two hydrobiid species require the specific environment associated with sublacustrine springs, a patchy system of porous stones or rocks, called "litoral interlithon" [36, 47].

4 The Conservation of Endemic Gastropods

The characteristic of the endemism of Lake Skadar is that many endemic species are common. Point endemics are restricted to a specific environment, associated with the subterranean environment or spring habitats. Based on the survey throughout the threat assessment of endemic gastropod species from Lake Skadar listed in the IUCN Red List of Threatened Species [48], it can be concluded that eutrophication and use as a water supply were generally recognized as the main threats to the endemic gastropod fauna of Lake Skadar. There is evidence of ongoing eutrophication in Lake Skadar [49] as the result of agricultural activities and pollution from sewage. However, the influence of eutrophication on endemic species in the lake has not yet been investigated. Interestingly, an increased number of gastropod species were observed in the areas of highest anthropogenic pressure (Vranjina, Virpazar, and Karuč).

If we exclude subterranean species, the greatest number of endemic species were found in a single biodiversity hotspot (the sublacustrine spring at Karuč) located near the steep southwestern shore. This site is endangered primarily due to the rapid process of eutrophication, as a result of the development of local fish farming, but also over recent years by the growing influence of tourism, and it requires a further conservation action plan to protect the endemic fauna. Pešić and Glöer [14] stated that prior to any conservation activities it is “necessary to assess the current status of the endemic species as well as to estimate the faunal change during the last decades.” In the case of the species inhabiting the subterranean environment this may be very difficult, if not impossible, as there is no standardized protocol as to how to collect these species and how best to achieve this. Most of the finds of underground species are based on empty shells (rarely living animals) that are thrown out from underground into the spring. The lack of a recent finding results in the fact that many subterranean species have been assumed to be critically endangered or even extinct. The subterranean species *Bracenica spiridoni* known from a single spring [10] was thought to be *extinct* [50], but it has recently been rediscovered in the Karuč spring [14].

It should be pointed out that conservation programs now largely advocate the use of genetic approaches to confirm the validity of taxa for which conservation activities are proposed. The preliminary phylogeographic study conducted by Vinarski et al. [51] shows that populations from Albania and Italy formerly assigned to the widely distributed *Lymnaea stagnalis* form a separate clade and should be attributed to *L. raphidia*. Any future research on the gastropod fauna of the Skadar Lake should focus on the application of molecular methods as well as on including endemic gastropods in the ongoing national and transboundary monitoring programs.

Most endemic species from Lake Skadar have already been included on the IUCN Red List of Threatened Species [48]. This list includes 34 gastropod species from the Lake Skadar basin, five of them evaluated as Critically Endangered, eight as Endangered, three as Data Deficient, and 17 as Least Concerns (see Table 1). Seven endemic gastropod species that occur in the Lake Skadar drainage basin (*Vinodolia scutarica, V. matjasici, V. zetaevalis, Radomaniola lacustris, R. elongata, Bracenica spiridoni,* and *Valvata montenegrina*) are protected in Montenegro by national legislation [52]. All of this provides a good legislative framework for the protection of the endemic gastropods in the Lake Skadar Lake as well as for future conservation activities.

5 Diversity and the Conservation of Bivalvia

Many studies have shown that freshwater mussels are particularly vulnerable due to the loss of habitat quality [48, 53]. They combine several life history traits (longevity, larvae parasitic on the gills of fishes and filter feeding) that make them susceptible to changes in environmental conditions. There are a number of freshwater mussels considered to be vulnerable at the European level [48] and protected under national or European regulation, but in Montenegro none of the freshwater mussels are protected or are subject to management measures [52].

The identification of freshwater mussels is still difficult, which in the past was the major problem in understanding which species inhabit Lake Skadar. According to the available literature [18, 20, 21] the bivalve fauna of Lake Skadar includes ten species: six species of Unionidae, one species of Dreissenidae, and two species of Sphaeriidae (Table 1). Most of these species have a wide range of Holarctic (*Musculium lacustre*), Palaearctic (*Unio pictorum*), European or Euro Siberian (*Unio crassus, U. tumidus, Anodonta cygnea*) distributions. Mediterranean fauna is represented by one species, *Microcondylaea bonellii* which is relatively limited to southern Europe and is considered to be possibly extinct in Lake Ohrid [54].

The ecology of Bivalvia in Lake Skadar is poorly studied, and data on population trends and factors that eventually lead to a decrease in the populations of mussels are entirely lacking. It is known that many species such as *Unio crassus* and *U. mancus* have suffered localized declines as a result of several major threat processes including water pollution, fragmentation, increased predation, and pressure by non-native species including the invasive zebra mussel (*Dreissena polymorpha*) [55]. In lake ecosystems such as Lake Skadar, these factors can lead to a decline or absence of fish hosts which ultimately leads to localized declines of the unionid species (Fig. 4).

In Lake Skadar only *Dreissena carinata* is present. In the past, this species has, in Lake Skadar, often been misidentified as *D. polymorpha* or even as *D. blanci* [19, 20]. Recent molecular research conducted by Wilke et al. [56] showed that the populations from Lake Skadar belong to *Dreissena carinata* (=*D. stankovici*). The latter authors suggested that the demographic expansion of *Dreissena carinata* in Lake Ohrid and its expansion into Lake Skadar started some 320,000–300,000 years ago. The two lakes are directly connected with each other via the River Drim which in the past is likely to have been the bridge for species exchange and their spreading [56].

Dreissena carinata is the only native *Dreissena* species in the Lake Skadar system and there is evidence of the spread of this species in various types of water bodies

Fig. 4 The duck mussel (*Anodonta anatina*) from the Plavnica River. Photo by V. Pešić

including the River Zeta and also in artificial lakes (including Lake Krupac and Lake Slano).

The invasive *Dreissena polymorpha* is only known from Lake Šasko. This is the only confirmed record of this species in the southwestern Balkans [56]. Preliminary results in Montenegro (Molloy et al. unpublished) show that there is no sign of the further expansion of *Dreissena polymorpha* in the area populated by the native *D. carinata*. However, the monitoring of this population is highly desirable as it is known that invasive *Dreissena* species have started a massive spread in Western Europe and North America from exactly this type of isolated area [56].

References

1. Küster HC (1843) Naturhistorische Reiseberichte aus Dalmatien und Montenegro, Teil V, Montenegro. Isis von Oken 654–656
2. Küster HC (1843) Die Gattungen *Paludina, Hydrocaena* und *Valvata*. Syst Conch Cab 1 (21):1–96
3. Wohlberedt O (1909) Zur Fauna Montenegros und Nordalbaniens. Mollusken, Käfer, Isopoden, Chilopoden, Diplopoden. Wiss. Mitt. Bosnien und Herzegowina, Wien, XI (Separat–Abdruck) 1–138 + 11 pl
4. Walderdorff R (1864) Systematisches Verzeichniss der im Kreise Cattaro (Süd-Dalmatien) mit Ausnahme der Biela-Gora und in einigen angrenzenden Theilen von Montenegro und türkisch Albanien vorkommenden Land- und Süsswasser-Mollusken. Verh k-k zool-bot Ges Wien 14:503–514
5. Jaeckel SV, Klemm W, Meise W (1958) Die Land- und Süsswasser-Mollusken der nördlichen Balkanhalbinsel. Abh Ber Staatl Mus Tierkd Dresden 23(2):141–205
6. Karaman G, Nedić D (1981) Zoobenthos of Skdar lake. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 222–246
7. Stein R, Kitchell J, Knezevic B (1975) Selective predation on carp (*Cyprinus carpio*) on benthic molluscs in Skadar Lake, Yugoslavia. J Fish Biol 7(3):391–399

8. Covich AP, Knežević B (1981) Size selective predation by fish on thin-shelled Gastropods (*Lymnaea*); the significance of floating vegetation (*Trapa*) as a refuge. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 276–277
9. Jacobi GZ (1981) Zoobenthos from Sublacustrine Springs in Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 251–263
10. Radoman P (1973) New classification of fresh and brackish water Prosobranchia from the Balkans and Asia minor. Pos Izdanja Prir Muz, Beograd 32:1–30
11. Radoman P (1973) *Anagasta* un nouveau genre Prosobranchia et sa speciation dans le basin du lac Skadar. Zool Anz 190:421–429
12. Radoman P (1982) Hydrobioidea a superfamily of Prosobranchia (Gastropoda), I. Sistematics. Mon Serb Acad Sci Arts 547(Dep Sci 57):2 + 256 p, 12 pl
13. Radoman P (1985) Hydrobioidea a superfamily Prosobranchia (Gastropoda), II. Origin, zoogeography, evolution in the Balkans and Asia minor. Monogr Inst Zool Belgrade 1:1–173
14. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
15. Dhora D (1975) Rezultatë te studimit të molusqeve te Liqenit të Shjodrës. Bulletini i Shkencave të Natyrës 1:65–69
16. Dhora D (1995) List of molluscs of Shkodra Lake. Bios 3:21–24
17. Dhora D, Welter-Schultes FW (1999) Mollusc cenoses from different environments in Albania. Schr Malakozool 13:61–65
18. Dhora D (2002) Studime mbi molusqet e Shiqipërisë. Camaj-Pipa, Shkodra
19. Dhora DH (2004) Mbi molusqet e Shiqipërisë. Camaj-Pipa, Shkodra
20. Dhora DH, Welter-Schultes FW (1996) List of species and atlas of the non-marine molluscs of Albania. Schr Malakozool 9:90–197
21. Jovanović B (1999) Fauna Mollusca Skadarskog jezera. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera. Crnogorska Akademija Nauka i Umjetnosti, Naučni skupovi, vol 44, pp 263–277
22. Glöer P, Pešić V (2007) The *Bithynia* species from Skadar Lake (Montenegro) (Gastropoda, Bithyniidae). Mollusca 25:85–91
23. Glöer P, Pešić V (2008) The freshwater gastropods of the Skadar Lake with the description of *Valvata montenegrina* n. sp. (Mollusca, Gastropoda, Valvatidae). In: Pavićević D, Perreau M (eds) Advances in the studies of the subterranean and epigean Fauna of the Balkan peninsula. Volume dedicated to the memory of Guido Nonvellier, monograph 22, Institute for Nature Conservation of Serbia, pp 325–332
24. Glöer P, Pešić V (2008) *Radix skutaris* n. sp., a new species from Montenegro (Gastropoda: Lymnaeidae). Mollusca 26:83–94
25. Glöer P, Pešić V (2009) *Stagnicola montenegrinus* n. sp., a new species of Montenegro (Gastropoda: Lymnaeidae). Mollusca 27:53–56
26. Glöer P, Pešić V (2010) The *Planorbis* species of the Balkans with the description of *Planorbis vitojensis* n. sp. (Gastropoda: Planorbidae). J Conchol 40:249–257
27. Fehér Z, Erőss Z (2009) Contribution to the Mollusca Fauna of Albania. Results of the field trips of the Hungarian Natural History Museum between 1992 and 2007. Schr Malakozool 25:3–21
28. Reischütz A, Reischütz N, Reischütz PL (2008) Ein Nachtrag zur Kenntnis der *Bithynia*-Arten von Montenegro (Gastropoda: Prosobranchia: Bythiniidae). Nachrichtenblatt der Ersten Vorarlberger Malakologischen Gesellschaft 15:41–43
29. Reischütz A, Reischütz PL (2008) Neue Hydrobiiden (Gastropoda, Prosobranchia, Hydrobiidae) aus dem Becken des Skutari-Sees (Montenegro/Albanien). Basteria 72:143–145
30. Reischütz A, Reischütz PL (2009) Ein Beitrag zur Kenntnis der Molluskenfauna von Montenegro. Beschreibung zweier neuer Arten der Gattung *Virpazaria* Gittenberger 1969. Nachrichtenblatt der Ersten Vorarlberger Malakologischen Gesellschaft 16:51–60

31. Glöer P, Grego J, Erőss ZP, Fehér Z (2015) New records of subterranean and spring molluscs (Gastropoda: Hydrobiidae) from Montenegro and Albania with the description of five new species. Ecol Mont 4:70–82
32. Beeton AM (1981) Physical conditions of Lake Skadar and its basin. Geberal introduction. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 15–17
33. Šundić M, Pešić V (2007) Seasonal changes in the abundance of benthic assemblages in the spring on Vranjina island (Skadar Lake National Park). Glas Republ Zavoda Zašt Prirode – Prirodnjačkog muzeja 29–30:125–130
34. Janković D (1983) Ishrana šarana (*Cyprinus carpio* L.) u Skadarskom jezeru. Skadarsko jezero, Radovi sa Simpozijuma CANU, Naučni skupovi, vol 9, pp 211–229
35. Janković D (1972) Proučavanje fitofilne faune Skadarskog jezera. Ekologija 7:168–181
36. Albrecht C, Wilke T (2008) Lake Ohrid: biodiversity and evolution. Hydrobiologia 615:103–140
37. Glöer P, Albrecht C, Wilke T (2007) Enigmatic distribution pattern of the Bithyniidae in the Balkan region (Gastropoda: Rissooidea). Mollusca 25:101–110
38. Clewing C, Viktor von Oheimb P, Vinarski M, Wilke T, Albrecht C (2014) Freshwater mollusc diversity at the roof of the world: phylogenetic and biogeographical affinities of Tibetan plateau *Valvata*. J Molluscan Stud 80(4):452–455
39. Albrecht C (2006) Unusual reproductive strategy of pulmonate gastropods in the Balkan ancient Lake Prespa. Malakol Abh 24:57–63
40. Boeters H, Glöer P (2007) A contribution to the genus *Boetersiella* Arconada & Ramos 2001 in Spain with the description of *Boetersiella wolfi* n. sp. Heldia 5:85–88
41. Schniebs K, Glöer P, Georgiev D, Hundsdoerfer A (2012) First record of *Stagnicola montenegrinus* Glöer & Pešić, 2009 (Mollusca: Gastropoda: Lymnaeidae) in Bulgaria and its taxonomic relationship to other European lymnaeids based on molecular analysis. North-West J Zool 8:164–171
42. Glöer P, Stamenkovic VS, Hinic J (2017) The *Stagnicola* spp. of the republic of Macedonia with the first record of *Stagnicola fuscus* (C. Pfeiffer, 1821). Ecol Mont 11:6–8
43. Schniebs K, Glöer P, Vinarski MV, Hundsdoerfer AK (2016) A barcode pitfall in Palaearctic *Stagnicola* specimens (Mollusca: Lymnaeidae): incongruence of mitochondrial genes, a nuclear marker and morphology. N West J Zool 12(2):239–254
44. Bole J (1961) Nove Hidrobide (Gastropoda) iz podzemeljskih voda zahodnega Balkana. Biol Vestn 9:59–69
45. Boeters HD, Glöer P, Pešić V (2013) Some new freshwater gastropods from southern Europe (Mollusca: Gastropoda: Rissooidea). Folia Malacol 21(4):225–235
46. Falniowski A, Szarowska M, Glöer P, Pešić V (2012) Molecules vs morphology in the taxonomy of the *Radomaniola/Grossuana* group of Balkan Rissoiidea (Mollusca: Caenogastropoda). J Conchol 41(1):19–36
47. Hauffe T, Albrecht C, Schreiber K, Birkhofer K, Trajanovski S, Wilke T (2011) Spatially explicit analysis of gastropod biodiversity in ancient Lake Ohrid. Biogeosciences 8:175–188
48. Cuttelod A, Seddon M, Neubert E (2011) European red list of non-marine Molluscs. Publications Office of the European Union, Luxembourg
49. Rakočević-Nedović J, Hollert H (2005) Phytoplankton community and its pigment characteristics as trophic indexes of the Skadar Lake (Montenegro, Balkan). Environ Sci Pollut Res 12:146–152
50. Regnier C, Fontaine B, Bouchet P (2009) Not knowing, not recording, not listing: numerous unrecognized mollusk extinctions. Conserv Biol 23:1214–1221
51. Vinarski MV, Schniebs K, Glöer P, Hundsdoerfer AK (2012) Preliminary phylogeography of *Lymnaea stagnalis*: are there cryptic species of the great pond snail? XI international congress on medical and applied malacology. Abstracts Book, Rio de Janeiro, p 66
52. Službeni list RCG, br. 76/06 (2006) Rješenje o stavljanju pod zaštitu pojedinih biljnih i životinjskih vrsta. Official Gazette of the Republic of Montenegro, No 76/06
53. Lydeard C, Cowie RH, Ponder WF et al (2004) The global decline of nonmarine molluscs. Bioscience 54(4):321–330

54. Albrecht C, Bodon M, Cianfanelli S, Giusti F, Manganelli G (2011) *Microcondylaea bonellii*. The IUCN Red List of Threatened Species 2011: e.T155595A4805631. https://doi.org/10.2305/IUCN.UK.2011-2.RLTS.T155595A4805631.en. Downloaded on 7 August 2017
55. Byrne A, Moorkens EA, Anderson R, Killeen IJ, Regan EC (2009) Ireland red list no. 2 – non-marine Molluscs. National Parks and Wildlife Service, Department of the Environment, Heritage and Local Government, Dublin
56. Wilke T, Schultheiß R, Albrecht C, Bornmann N, Trajanovski S, Kevrekidis T (2010) Native *Dreissena* freshwater mussels in the Balkans: in and out of ancient lakes. Biogeosciences 7:3051–3061

The Diversity of Water Mite Assemblages (Acari: Parasitengona: Hydrachnidia) of Lake Skadar/Shkodra and Its Catchment Area

Andrzej Zawal and Vladimir Pešić

Contents

Abstract Water mites in the Lake Skadar catchment area inhabit a wide range of aquatic habitats, including lotic, lentic, interstitial, and temporary waters. Altogether 53 water mite species are known for Lake Skadar and its associated water bodies. The indicative feature of the water mite assemblage of Lake Skadar is the absence of water mites from a huge astatic zone of Lake Skadar and their poor representation in the shallow phytolittoral zone. It is very likely that this is caused by the fact that the fingerling of many commercial fish species in Lake Skadar and the mosquito fish and the topmouth gudgeon are present in a fairly large quantities in the flood plain inundated area and the phytolittoral zone of Lake Skadar. In addition, the following topics are addressed: (1) the diversity of water mites assemblages from spring habitats – the presence and share of crenobiontic species in the different spring types of the Lake

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 311–324, DOI 10.1007/698_2018_257,
© Springer International Publishing AG 2018, Published online: 1 June 2018

Skadar catchment area; (2) the communities colonizing the running water and the interstitial habitats of the Lake Skadar catchment area, respectively, and their similarities and differences; and (3) the impact of seasonal intermittence on water mite assemblages.

Keywords Diversity, Ecology, Endemism, Skadar Lake basin, Water mites

1 Introduction

Water mites are a significant component of freshwater ecosystems inhabiting a wide range of aquatic habitats, including lotic, lentic, interstitial, and temporary waters [1, 2]. They have a complex life cycle that includes two pupa-like resting stages (protonymph, between larva and deutonymph, and tritonymph, between deutonymph and adult) and three active stages (larva, deutonymph, and adults). The larvae are nearly always parasitic, while the deutonymphs and adults are predators of minute invertebrates [1]. Some recent studies have shown that water mites can be good indicators of the health of an ecosystem [2].

Research on the water mites of Lake Skadar catchment area began in 1903 when the Czech zoologist Thon [3] published the first list of 13 species based on material collected by Prof. Alois Mrázek. After that, Musselius [4] provided a list of seven water mite species from the Lake Skadar basin. Later on Karl Viets [5], in his survey on water mites from Yugoslavia, reported nine species from the Lake Skadar basin. After a long pause, research on water mites was restarted at the beginning of the twenty-first century through a series of papers published by Vladimir Pešić. In 2002, he published a paper on water mites from the stagnant water of the Lake Skadar system, listing 49 species [6]. In the period between 2001 and 2017, he published 17 papers, either alone or in coauthorship that also included data from the Lake Skadar catchment area [6–22]. All these papers and the water mite species recorded were compiled into two checklists published in 2010 [20] and recently in 2018 [23]. In addition, Bańkowska et al. [24] published a paper on the reproduction of selected water mite species from Lake Skadar and its catchment area.

This chapter gives an overview of the richness and endemism of the water mite fauna, and gives a contribution to the ecology of the water mite communities that inhabit the diverse habitats of the Lake Skadar catchment area.

2 Water Mite Assemblage of Lake Skadar

Altogether 53 water mites species are known from Lake Skadar and its associated water bodies [6, 23] (Table 1). This is still a small number of water mites for such a large lake as Lake Skadar, with diversified habitat and trophic characteristics. In Central Europe water mite communities of oligotrophic and mesotrophic lakes of a much smaller size include 50–60 species [25].

In the littoral zone of Lake Skadar, 37 species were found, while in the deeper open part of the lake, 12 water mite species were identified ([23]; Zawal et al.

Table 1 List of water mites (Acari, Hydrachnidia) occurring in Lake Skadar

Species	Littoral	Open part of the lake	Sublacustrine springs
Lebertia inequalis (Koch, 1837)	+		+
Lebertia longiseta (Bader, 1955)	+		+
Lebertia porosa (Thor, 1900)	+		+
Oxus angustipositus (K. Viets, 1908)			+
Oxus longisetus (Berlese, 1885)	+		+
Oxus ovalis (Müller, 1776)	+	+	+
Oxus strigatus (Müller, 1776)			+
Oxus setosus (Koenike, 1898)			+
Sperchon clupeifer (Piersig, 1896)			+
Teutonia cometes (Koch, 1837)	+		
Monatractides stadleri (Walter, 1924)	+		
Torrenticola amplexa (Koenike, 1908)	+		
Limnesia maculata (Müller, 1776)	+		
Limnesia undulata (Müller, 1776)	+		
Limnesia undulatoides (Davids, 1997)	+	+	
Hygrobates fluviatilis (Ström, 1768)	+		+
Hygrobates longipalpis (Hermann, 1804)	+		+
Hygrobates nigromaculatus (Lebert, 1879)		+	+
Hygrobates setosus (Besseling, 1942)			+
Atractides nodipalpis (Thor, 1899)			+
Unionicola crassipes (Müller, 1776)	+	+	+
Unionicola gracilipalpis (K. Viets, 1908)	+		
Unionicola minor (Soar, 1900)	+	+	+
Unionicola aculeata (Koenike, 1890)	+	+	+
Unionicola parvipora (Lundblad, 1920)	+		
Neumania deltoides (Piersig, 1894)	+		+
Neumania limosa (Koch, 1836)	+		
Neumania papillosa (Soar, 1902)	+		
Forelia cetrata (Koenike, 1895)	+		
Forelia liliacea (Müller, 1776)	+		+
Forelia variegator (Koch, 1837)	+		+
Piona coccinea (Koch, 1836)		+	+
Piona disparilis (Koenike, 1895)	+		+
Piona imminuta (Piersig, 1897)	+	+	
Piona pusilla (Neuman, 1875)	+		
Piona rotundoides (Thor, 1897)		+	+
Piona stjoerdalensis (Thor, 1897)			+
Pionopsis lutescens (Hermann, 1804)			+
Hydrochoreutes krameri (Piersig, 1896)	+		
Tiphys torris (Müller, 1776)	+		
Brachypoda versicolor (Müller, 1776)	+	+	+
Hexaxonopsis romijni (K. Viets, 1923)	+		

(continued)

Table 1 (continued)

Species	Littoral	Open part of the lake	Sublacustrine springs
Hexaxonopsis serrata (Walter, 1928)	+	+	+
Mideopsis roztoczensis (Biesiadka and Kowalik, 1979)			+
Stygohydracarus karanovici (Pešić, 2001)	+		
Arrenurus albator (Müller, 1776)		+	
Arrenurus buccinator (Müller, 1776)			+
Arrenurus claviger (Koenike, 1885)	+		
Arrenurus conicus (Piersig, 1894)			+
Arrenurus cylindratus (Piersig, 1894)	+		+
Arrenurus globator (Müller, 1776)	+		
Arrenurus sinuator (Müller, 1776)	+		
Arrenurus stjoerdalensis (Thor, 1899)			+

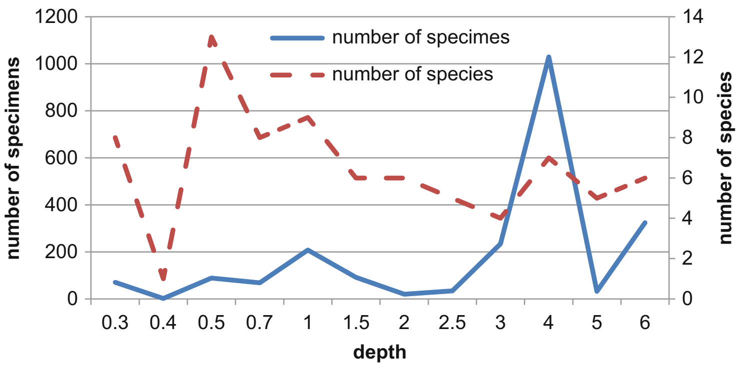

Fig. 1 The relationship between depth and water mite species richness (number of species) and abundance (number of specimens/sample), respectively, in Lake Skadar

unpublished). The most dominant species in the littoral zone of Lake Skadar are *Hygrobates longipalpis*, *Lebertia inequalis*, *Unionicola minor*, and *Lebertia porosa*, while in the deeper, open part of the lake and at the mouths of the main lake tributaries, *Unionicola aculeata* is the most abundant species.

The highest species richness in Lake Skadar occurred in the shallow littoral zone (0.3–1.5 m depth) and at a depth of 6 m, while the highest abundance was observed at a depth of 4 m (Fig. 1) with the highest average abundance recorded at the latter depth (Zawal et al. unpublished). In the sublacustrine springs, the highest water mite richness was observed in the shallow littoral zone (Fig. 2), while the average abundance per sample was highest at depths of 2 and 4 m, respectively (Zawal et al. unpublished). On the other hand, an analysis of the relationship between depth and the water mite assemblages that inhabit the mouths of lake tributaries revealed the highest average values of species richness and abundance at a depth of 1 m (Zawal et al. unpublished).

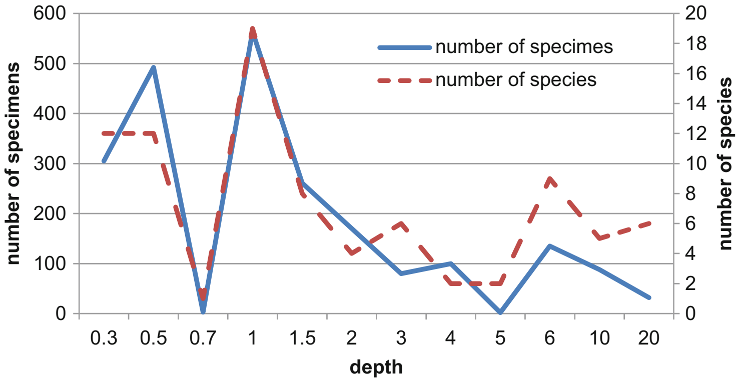

Fig. 2 The relationship between depth and water mite species richness (number of species) and abundance (number of specimens/sample), respectively, in the sublacustrine springs of Lake Skadar

The indicative feature of the water mite assemblages of Lake Skadar is the lack of many species that are characteristic for vernal astatic waters and small standing water bodies (*Eylais*, *Hydrachna*, *Hydryphantes*, *Hydrodroma*; Fig. 4a). It is a surprising finding considering that Lake Skadar has huge astatic and lake phytolittoral zones. In its astatic zone, almost no water mites were present, while in the phytolittoral zone, they were present in a very low number, and a large number of localities were completely absent (Zawal et al. unpublished). It is possible that this is caused by the high temperatures of the lake's water in the summer. The second, more likely, reason is that the fingerling of many commercial fish species (common carp, Prussian carp and yellow roach, for example) as well as the mosquito fish (*Gambusia affinis*) and the topmouth gudgeon (*Pseudorasbora parva*) is present in fairly large quantities in the phytolittoral and astatic zones of Lake Skadar. The latter two species, being an important fish invader in shallow lakes especially in the Mediterranean zone, can have an impact on macroinvertebrate assemblages [26]. Both species have a strong impact on chironomid larvae [27, 28] which are the main hosts for the larvae of the most abundant water mite species from Lake Skadar (*Unionicola aculeata, Hygrobates longipalpis*, *Lebertia inequalis*, and *Unionicola minor*).

Recent investigations by Zawal et al. (unpublished) have revealed that the abundance and richness of water mite assemblage in the shallow water of sublacustrine springs is higher than in the shallow littoral zone of the rest of the lake. The sublacustrine springs of Lake Skadar are characterized by a lower temperature, but also by a less numerous populations of mosquito fish and topmouth gudgeon in shallow water, suggesting that the density of fish can overcome other environmental variables in the shallow littoral of Lake Skadar as the main factor shaping water mite assemblages. Nevertheless, for one sound conclusion on this issue, additional laboratory and field experiments are required.

In the deeper, open part of the lake, typical representatives of lacustrine water mite fauna dominate (Table 1). *Unionicola aculeata* is the most abundant and frequent species. This widespread, planktivore species uses mussels (e.g., *Anodonta anatina*) as the site of oviposition and post-larval transformations [29].

The highest diversity of water mites was associated with sublacustrine environments. Thirty-two water mite species were found in the sublacustrine springs. *Unionicola aculeata*, *Hygrobates nigromaculatus*, *Lebertia porosa*, *Hygrobates fluviatilis*, and *H. longipalpis* are the most dominant species in the sublacustrine springs. However, none of the water mite species were found to be endemic to this habitat.

3 Water Mite Assemblage in Running Water

Water mite assemblages in the running waters of the Lake Skadar catchment area are mainly driven by substrate composition and anthropogenic impact. Many studies have shown that the differences between water mite assemblages are primarily a result of different substrate composition [30, 31]. On the other hand, water mite assemblage richness is probably related to the number of available habitats, rather than to habitat type.

In slowly flowing running waters dominated by fine particulate organic substrates, species that are typical for standing waters are more common. The water mite assemblage of the lower course of the River Crnojevića includes *Lebertia porosa*, *L. longiseta*, *Limnesia undulatoides*, *Neumania limosa*, *Unionicola aculeate*, *U. crassipes*, and *Arrenurus stjordalensis*. All these species, with the exception of *Arrenurus stjordalensis* for which this is the only record from the Balkans, are common in Lake Skadar [23].

Species that are common for standing waters have often been found in the marginal pools of rivers with a slower water flow and with well-developed vegetation [30, 31]. *Lebertia longiseta*, *Oxus strigatus*, and *Unionicola aculeata* were found in the lower course of the River Morača [23]. Occasionally, some species that occur in lentic habitats were collected in a more lotic environment, inhabiting areas along the shoreline with a reduced water flow. *Neumania imitata* and *Mundamela germanica* were found in the middle course of the River Zeta with typical rhitrobiontic species [12].

Rhitrobionts, a species that cannot live outside a lotic environment, dominate in river sections with a fast flow and coarse inorganic substrates. Some of these species tends to select microhabitats with weak flow, while others are more frequently found in those habitats with stronger flow conditions. In general, water mite species that inhabit lotic environments (and also species that inhabit spring habitats) are characterized by the reduction of swimming setae. Characteristic representatives of the rhitrobiontic fauna in the Lake Skadar catchment area include species which belongs to Hydryphantidae (particularly represented by many species of the genera *Protzia*), Sperchontidae (*Sperchonopsis verrucosa* and the species-rich genus *Sperchon*, Fig. 4h), Torrenticolidae (particularly represented by two species-rich genera *Torrenticola* and *Monatractides*), Lebertiidae (with one single genus *Lebertia*, Fig. 4f), Hygrobatidae (particularly two genera *Hygrobates* and *Atractides* with numerous species, Fig. 4e), Feltriidae (the genus *Feltria* with several species), and

Aturidae (with several genera including *Aturus*, *Axonopsis*, and *Woolastookia*). Among them, two species are endemic to Montenegro: *Torrenticola lukai* (Pešić, Valdecasas and Garcia-Jimenez, 2012) (Torrenticolidae) (Fig. 4j) [21] and *Atractides longisetus* Pešić, 2002 (Hygrobatidae) [10]. Both species inhabit middle order streams in the mountainous region of the Lake Skadar catchment area and do not occur in the Mediterranean region [20].

Hygrobates fluviatilis is the most frequent and abundant rhitrobiontic species in the running waters in the Lake Skadar catchment area. This is also the most abundant species found at moderately polluted sites. Other rhitrobiontic water mites are more sensitive to pollution caused by domestic waste water and generally avoid these sites or are present in low densities. *Torrenticola* (Fig. 4k) is one of the genera mainly restricted to clean streams [32] and often dominates in small clean streams with a sandy and gravel substrate.

4 Water Mite Assemblages in Springs

Springs are defined as spatially restricted habitats at the beginning of surface flow, which host specialized and often endemic or rare water mite taxa and greatly contribute to regional biodiversity [33]. Several studies have shown that among the biotic groups that inhabit springs, water mites include the highest number of crenobionts – species restricted to springs and not found in other habitat types [1, 34].

The Lake Skadar catchment area is characterized by a high number of springs hosting diverse and often abundant water mite communities. Most springs are rheocrenes, although limnocrenes are frequent in the lowlands, while helocrenes and rheohelocrenes are less well represented. The difference between these three spring types is reflected in the share of crenobionts in the water mite assemblage that inhabit the spring habitats of the Lake Skadar catchment area (Fig. 3). By contrast to interstitial, no taxonomically isolated clades of water mites are restricted to spring habitats, and generally these two faunas do not share a common species [35].

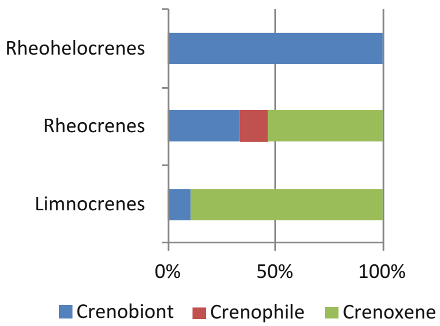

Fig. 3 Share of crenobiont, crenophile, and crenoxene water mite species in the springs of the Lake Skadar catchment area

At the European level, about one fifth of the 970 species of the European Hydrachnidia have a preference for spring habitats [34]. In the Lake Skadar catchment area, there are, altogether, 12 crenobiontic species – *Panisus michaeli*, *Protzia squamosa paucipora*, *Trichothyas jadrankae*, *Tartarothyas romanica*, *Lebertia schechteli*, *L. stigmatifera*, *L. separata*, *L. mediterranea*, *Atractides fonticolus*, *A. pennatus*, *Hygrobates marezaensis*, and *H. norvegicus* – found in the spring habitats [13, 16, 20, 22, 23, 36]. Among them, one species *Trichothyas jadrankae* Pešić, 2018 (Hydryphantidae) is endemic to the Lake Skadar basin. This rare species of polyacetabulate subgenus *Kashmirothyas* was described based on a single female collected from the mossy calcareous seepage near the stream that flowed into Lake Skadar [23]. Most of the abovementioned crenobionts were found in rheocrenes. Water mite assemblages in springs are mainly driven by the temperature and the substrate composition. Rheocrenic springs are generally characterized by a lower temperature and a coarse inorganic substratum. As expected for cold-stenothermic organisms, there is a correlation between the occurrence of many crenobiontic species and lower temperatures. *Atractides pennatus* is the most frequent crenobiont in the rheocrenes in the Lake Skadar catchment area but are usually collected in low densities. Three species, *Panisus michaeli* (Fig. 4g), *Hygrobates norvegicus*, and *Lebertia mediterranea*, have been collected in helocrenic and rheohelocrenic springs ([13, 20]; unpublished data). These two types of springs are characterized by the highest number of crenobionts [37], but the number of these habitats in the Lake Skadar catchment area is lower in comparison with those found in the rheocrene and limnocrene springs.

Limnocrenes are mainly dominated by crenoxenes, a taxa colonizing other types of habitats and only occasionally present in springs. These springs are mainly inhabited by standing water mites which have a preference for low temperatures [37]. Only two crenobionts *Tartarothyas romanica* and *Hygrobates marezaensis* were found in limnocrene springs in the Lake Skadar catchment area. In general, limnocrenes are characterized by a low number of spring specialists (Fig. 3). However, with regard to karstic lowland springs with a high discharge, that statement must be taken with caution. This type of limnocrene springs is characterized by well-developed aquatic vegetation, often dominated by *Berula erecta*, and offers more variety in microhabitats, providing both lotic and lentic sections. Moreover, the water temperature is much lower than in typical limnocrenes. The water temperature of the spring at Mareza is very stable throughout the year at 10°C ± 0.5 [38]. Recent studies using DNA-barcode techniques have shown that populations of some rhitrobiontic species such as *Hygrobates fluviatilis* that were frequently reported in karstic limnocrene springs represent genetically well-defined species [22]. *Hygrobates marezaensis* (Fig. 4l), an frequent and abundant species discovered in many of the strong karstic limnocrenes (the Mareza, Kraljičino Oko, Bolje Sestre, and Svinjiška Vrela springs) in the Lake Skadar catchment area, have previously been confused with the sympatric and more widespread *H. fluviatilis* [22].

In the lowland springs, especially those located near the lake shore, there are more species that are typical of standing waters. The most frequently collected species in the limnocrenes of the Lake Skadar catchment area were *Lebertia porosa*,

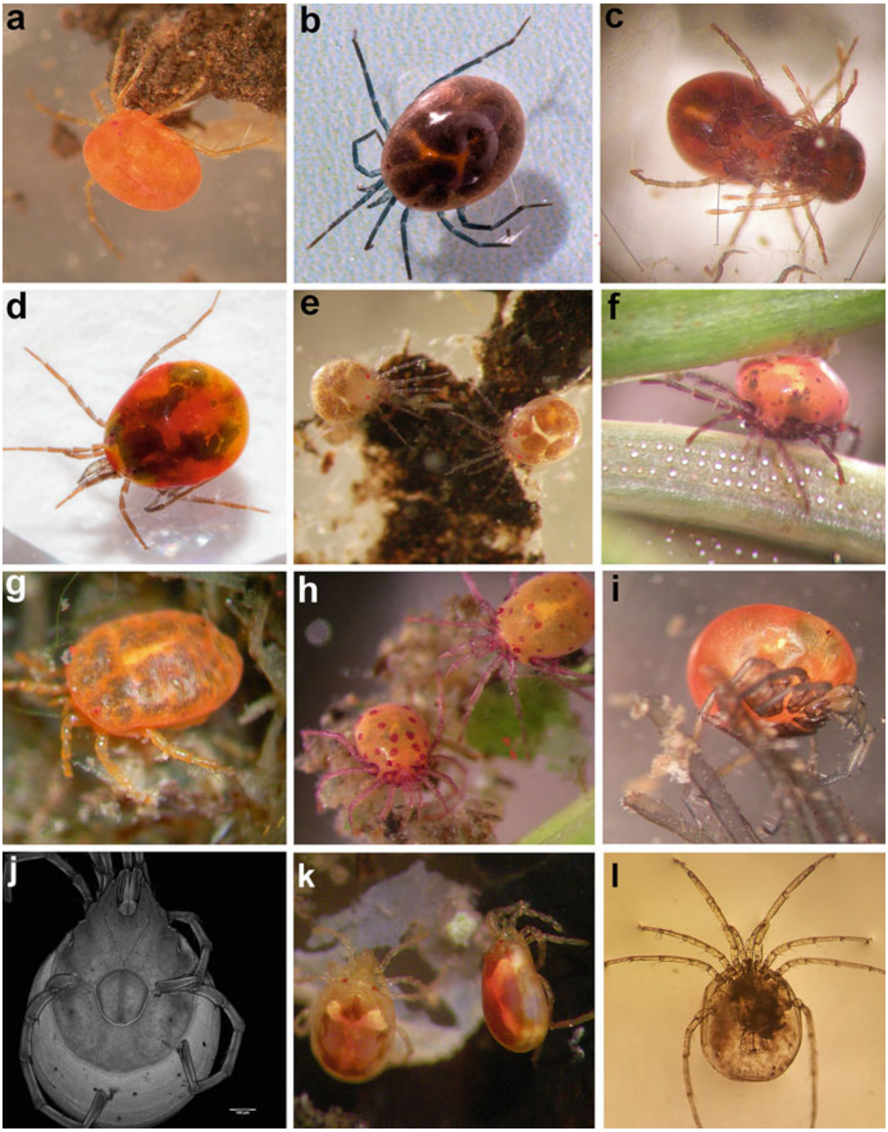

Fig. 4 (**a**) *Hydrodroma pilosa*, (**b**, **c**) *Piona* sp., (**d**) *Limnesia maculata*, (**e**) *Atractides* sp., (**f**) *Lebertia sparsicapillata*, (**g**) *Panisus michaeli*, (**h**) *Sperchon glandulosus*, (**i**) *Piona* sp., (**j**) *Torrenticola lukai*, (**k**) *Torrenticola elliptica*, (**l**) *Hygrobates marezaensis* (Photo by R. Gerecke (Fig. **a**, **c**, **e**–**i**, **k**), M. Gibson (Fig. **b**, **d**), A. Valdecasas and R. Garcia-Jimenez (Fig. **j**), V. Pešić (Fig. **l**))

L. inaequalis, and *Hygrobates longipalpis*. The composition of water mite assemblages in these springs is strongly influenced by local flooding events. Recent studies have shown that flooding results in a decrease in the number of crenobiontic species in the flooded in comparison with the non-flooded springs [39]. Many springs that lie along the Lake Skadar shoreline fall below the water level of Lake Skadar during a high water event [40]. Taking into account the fact that loss of crenobionts owing to climatic and land-use changes is expected in the future, priority must be given to the conservation of spring habitats in the Lake Skadar catchment area.

5 The Diversity of Water Mites in Interstitial Waters

Research conducted on a larger European or Palaearctic scale indicated the presence of many water mite clades that are exclusively bound to the hyporheic interstitial (see [1] for references). Studies on the hyporheic interstitial in the Lake Skadar catchment area have been conducted sporadically (see [20, 41] for an overview). However, this research demonstrated the presence of diverse hyporheic fauna. Most hyporheic water mite species found in the Lake Skadar catchment area were found in the superficial riverine gravel of the Rivers Zeta and Morača. The most abundant species collected from the interstitial dig of the River Zeta were *Feltria cornuta paucipora*, *Kongsbergia clypeata*, *Lethaxona pygmaea*, *Stygomomonia latipes*, and *Frontipodopsis reticulatifrons* [20].

On the other hand, only a few species have been reported from the interstitial of Lake Skadar. Pešić [7] described *Stygohydracarus karanovici* from the interstitial of Lake Plavsko in the northern part of Montenegro and from a single specimen of this species found in the zoobenthos of Lake Skadar. This specimen was collected on the rocky shore near sublucustrine springs and probably originates from the interstitial, thrown out by the spring water during heavy rain [7]. As with other typical members of the hyporheic interstitial fauna, this species has lateral eyes with lenses reduced and ocular pigmentation absent. Moreover, the water mites that are typical inhabitants of interstices in sand and gravel deposits are generally smaller and more slender (in comparison with their surface relatives). These mites are the opposite of a group of vermiformly elongated species (*Wandesia*, *Stygothrombium*) which are much larger and which prefer the spaces between gravel and larger stones and rocks. A functional approach based on the morphological features of these two groups can be a useful tool in distinguishing the interstitial communities inhabiting different substrate conditions.

Only a few species have been recorded from cave waters. Smit and Pešić [18] reported *Stygohydracarus subterraneus* from Sutimska Cave near Podgorica. On the other hand, halacarid mites are more frequent and abundant in cave waters (see [41, 42] for an overview of halacarid and hydrachnid mites of aquatic subterranean environment of the Lake Skadar Basin).

6 The Diversity of Water Mites in Temporary Waters

Temporary pools and streams dominate in Mediterranean and semiarid climatic conditions. There are a number of dry pools, intermittent rivers, and ephemeral streams in the Lake Skadar catchment area. The assemblages of water mites that inhabit these habitats are generally poorly studied. Pešić [6] collected seven species, *Hydrodroma descpiciens*, *Hydryphantes placationis*, *Hygrobates longipalpis*, *Piona carnea*, *P. damkoehleri*, *Tiphys ornatus*, and *Arrenurus globator*, from a temporary pool at Moromiš in the Valley of the River Zeta. All of these species have been found in temporary waters in other studies (see [43, 44] for additional information on the biology and habitat of the abovementioned species). These species in the pool at Moromiš were collected in springtime completing their life cycle before the pool disappeared [6].

Intermittent rivers and ephemeral streams (IRES) compose around half of all running waters globally [45], and their number increases every year. Water mite assemblages that inhabit separated pools are represented by typical lenitobiontic species, while the assemblage that inhabits the flowing phase of intermittent streams is mainly composed of lotic species. It is very likely that water mites avoid streams with an ephemeral flow. A weekly survey from January to June 2015 at three sites along the ephemeral reach of the Rimanić stream located in the valley of the River Zeta resulted in the collection of only three specimens of *Eylais planipons* (Pešić unpublished). On the other hand, rivers and streams with seasonal intermittence and with a subterranean flow which also persists during the summer contain richer assemblages of lotic water mites (e.g., *Lebertia variolata*, *Torrenticola ungeri*).

References

1. Davids C, Di Sabatino A, Gerecke R, Gledhill T, Smit H, Van der Hammen H (2007) Acari: Hydrachnidia I. In: Gerecke R (ed) Süßwasserfauna von Mitteleuropa, vol 7/2–1. Elsevier GmbN, Spektrum Akademischer Verlag, Munich, pp 241–376
2. Goldschmidt T (2016) Water mites (Acari, Hydrachnidia): powerful but widely neglected bioindicators – a review. Neotrop Biodivers 2:12–25
3. Thon K (1903) Über die in Montenegro von Dr. Mrázek gesammelten Hydrachniden. S B böhm Ges Wiss Prag II Cl 19:1–7
4. Musselius AA (1912) Einige Hydracarinen aus Montenegro. Varsava Prot Obsc jest 23 (3–4):95–97
5. Viets K (1936) Hydracarinen aus Jugoslavien (Systematische, ökologische, faunistische und tiergeographische Untersuchungen über die Hydrachnellae und Halacaridae des Süßwassers). Arch Hydrobiol 29:351–409
6. Pešić V (2002) Water mites (Acari, Actinedida) of the stagnant waters from the Skadar Lake drainage basin (Crna Gora, Yugoslavia). Acta Entomol Serb 5(1–2):131–152
7. Pešić V (2001) *Stygohydracarus karanovici* sp. n., and *Atractides inflatipes* Lundblad, 1956, two water mites species (Acari: Hydrachnidia) from Montenegro (SE Europe). Zootaxa 17:1–78
8. Pešić V (2002) First description of the male of *Atractides graecus* K. Viets, 1950 (Acari, Actinedida, Hygrobatidae) from Montenegro (Yugoslavia). Glasnik Sect Nat Sci Montenegrin Acad Sci Art (CANU) 14:177–182

9. Pešić V (2002) *Hydrodroma reinhardi* n. sp., a new species of water mites (Acari, Actinedida, Hydrodromidae) from the Mediterranean area. Aquat Insects 24(4):317–325
10. Pešić V (2002) Two interesting species of the genus Atractides Koch 1837 (Acari, Actinedida) from Crna Gora (Balkan peninsula). Lauterbornia 44:65–71
11. Pešić V (2003) On some very interesting water mite species (Acari, Actinedida) from Crna Gora (Montenegro), new for the Balkan peninsula and Mediterranean region. Natura Montenegrina 1:89–98
12. Pešić V (2003) New records of water mites (Acari: Hydrachnidia) from running waters from Montenegro and FYR Macedonia (SE Europe). Acta Entomol Serb 6(1/2):131–128
13. Pešić V (2003) New records of water mites (Acari, Hydrachnidia) from Yugoslavia. Arch Biol Sci, Belgrade 54(3–4):25P–26P
14. Di Sabatino A, Gerecke R, Smit H, Pešić V, Panesar A (2003) Water mites of the family Torrenticolidae (Acari, Actinedida, Hydrachnidia) from the eastern Mediterranean region. Arch Hydrobiol Suppl 139(3):1–39
15. Pešić V, Gerecke R (2003) Water mites of the genera Albaxona, Axonopsis, Barbaxonella and Erebaxonopsis (Acari, Hydrachnidia: Aturidae: Axonopsinae) from Central Europe and Mediterranean area. Arch Hydrobiol Suppl 139(4):563–576
16. Pešić V (2004) Some new and rare water mites (Acari: Hydrachnidia) from the Balkan peninsula. Glas Republ Zavoda Zašt Prirode - Prirodnjačkog muzeja 27–28:93–99
17. Pešić V (2004) Water mites (Acari: Hydrachnidia) of the Biogradska Gora National Park (Serbia and Crna Gora). In: Pešić V (ed) The biodiversity of the Biogradska Gora National Park. Monographies I, Department of Biology, University of Montenegro & Centre for Biodiversity of Montenegro, pp 65–86
18. Smit H, Pešić V (2004) New records of the families Arrenuridae, Nudomideopsidae and Athienemanniidae (Acari: Hydrachnidia) from Macedonia and Yugoslavia. Acta Entomol Serb 7(1–2):137–146
19. Baker R, Pešić V, Gerecke R, Hristovski N, Stojanovski S (2008) A comparative analysis of the water mite fauna (Acari) of three transboundary lakes in the Balkans. Lauterbornia 62:45–51
20. Pešić V, Smit H, Gerecke R, Di Sabatino A (2010) The water mites (Acari: Hydrachnidia) of the Balkan peninsula, a revised survey with new records and descriptions of five new taxa. Zootaxa 2586:1–100
21. Pešić V, Valdecasas A, Garcia-Jimenez R (2012) Simultaneous evidence for a new species of *Torrenticola* Piersig, 1896 (Acari, Hydrachnidia) from Montenegro. Zootaxa 3515:38–50
22. Pešić V, Asadi M, Cimpean M, Dabert M, Esen Y, Gerecke R, Martin P, Savic A, Smit H, Stur E (2017) Six species in one: evidence of cryptic speciation in the *Hygrobates fluviatilis* complex (Acariformes, Hydrachnidia, Hygrobatidae). Syst Appl Acarol 22(9):1327–1377
23. Pešić V, Bańkowska A, Goldschmidt T, Grabowski M, Michoński G, Zawal A (2018) Supplement to the checklist of water mites (Acari: Hydrachnidia) from the Balkan peninsula. Zootaxa 4394(2):151–184
24. Bańkowska A, Kłosowska M, Gadawski P, Michoński G, Grabowski M, Pešić V, Zawal A (2016) Oviposition by selected water mite (Hydrachnidia) species from Lake Skadar and its catchment. Biologia 71(9):1027–1033
25. Davids C, Ten Winkel EH, De Groot CJ (1994) Temporal and spatial patterns of water mites in Lake Maarsseveen I. Neth J Aquat Ecol 28(1):11–17
26. Preston DL, Hedman HD, Esfahani ER, Pena EM, Boland CE, Lunde KB, Johnson PTJ (2017) Responses of a wetland ecosystem to the controlled introduction of invasive fish. Freshw Biol 62(4):767–778
27. Declerck S, Louette G, De Bie T, De Meester L (2002) Patterns of diet overlap between populations of non-indigenous and native fishes in shallow ponds. J Fish Biol 61:1182–1197
28. Merkley SS, Rader RB, Schaalje GB (2015) Introduced Western Mosquitofish (Gambusia affinis) reduce the emergence of aquatic insects in a desert spring. Freshw Sci 34(2):564–573
29. Hevers J (1980) Biologisch-okologische Untersuchungen zum Entwickungszyklus der in Deutschland auf-tretenden Unionicola-Arten (Hydrachnellae, Acari). Arch Hydrobiol Suppl 57:324–373

30. Stryjecki R, Zawal A, Stępień E, Buczyńska E, Buczyński P, Czachorowski S, Szenejko M, Śmietana P (2016) Water mites (Acari, Hydrachnidia) of water bodies of the Krąpiel River valley: interactions in the spatial arrangement of a river valley. Limnology 17:247–261
31. Zawal A, Stryjecki R, Stępień E, Buczyńska E, Buczyński P, Czachorowski S, Pakulnicka J, Śmietana P (2017) The influence of environmental factors on water mite assemblages (Acari, Hydrachnidia) in a small lowland river: an analysis at different levels of organization of the environment. Limnology 18:333–343
32. van der Hammen H, Smit H (1996) The water mites (Acari: Hydrachnidia) of streams in the Netherlands: distribution and ecological aspects on a regional scale. Neth J Aquat Ecol 30(2–3):175–185
33. Pešić V, Dmitrović D, Savić A, von Fumetti S (2016) Studies on eucrenal-hypocrenal zonation of springs along the river mainstream: a case study of a karst canyon in Bosnia and Herzegovina. Biologia 71:809–817
34. Gerecke R, Martin P, Gledhill T (2017) Water mites (Acari: Parasitengona: Hydrachnidia) as inhabitants of groundwater-influenced habitats–considerations following an update of Limnofauna Europaea. Limnologica. https://doi.org/10.1016/j.limno.2017.11.008
35. Gerecke R, Stoch F, Meisch C, Schrankel I (2005) Die Fauna der Quellen und des hyporheischen Interstitials in Luxemburg. Unter besonderer Berücksichtigung der Acari, Ostracoda und Copepoda. Ferrantia 41:1–134
36. Gerecke R (1996) Untersuchungen über die Wassermilben der Familie Hydryphantidae (Acari, Actinedida) in der Westpalaearktis II. Die Wassermilben der Familie Hydryphantidae in den Mittelmeerländern -Systematik, Faunistik, Zoogeographie. Arch Hydrobiol Suppl 77(3–4):337–513
37. Gerecke R, Di Sabatino A (2007) Water mites (Hydrachnidia and Halacaridae) in spring habitats: a taxonomical and ecological perspective. In: Cantonati M, Bertuzzi E, Spitale D (eds) The spring habitat: biota and sampling methods. Museo Tridentino di Scienze Naturali, Trento (Monografi e del Museo Tridentino di Scienze Naturali 4). Marco Cantonati at Museo delle Scienze, Trento, pp 193–216
38. Grabowski M, Bącela-Spychalska K, Pešić V (2014) Reproductive traits and conservation needs of the endemic gammarid *Laurogammarus scutarensis* (Schäferna, 1922) from the Skadar Lake system, Balkan peninsula. Limnologica 47:44–51
39. Von Fumetti S, Dmitrović D, Pešić V (2017) The influence of flooding and river connectivity on macroinvertebrate assemblages in rheocrene springs along a third-order river. Fundam Appl Limnol 190(3):251–263
40. Šundić M, Pešić V (2007) Seasonal changes in the abundance of benthic assemblages in the spring on Vranjina island (Skadar Lake National Park). Glas Republ Zavoda Zašt Prirode – Prirodnjačkog muzeja 29–30:125–130
41. Pešić V, Karaman GS, Sket B (2018) The diversity and Endemism of Aquatic Subterranean Fauna of the Lake Skadar/Shkodra Basin. In: Pešić V, Kostianoy AG, Karaman GS (eds) The Skadar/Shkodra Lake environment. Springer, Berlin, Heidelberg
42. Pešić V, Gadawski P, Gligorović B, Glöer P, Grabowski M, Kovács T, Murányi D, Płóciennik M (2018) The diversity of the Zoobenthos communities of the Lake Skadar/Shkodra Basin. In: Pešić V, Kostianoy AG, Karaman GS (eds) The Skadar/Shkodra Lake environment. Springer, Berlin, Heidelberg
43. Di Sabatino A, Gerecke R, Gledhill T, Smit H (2010) Chelicerata: Acari II. In: Gerecke R (ed) Süßwasserfauna von Mitteleuropa, vol 7, 2–2. Elsevier GmbH, Spektrum Akademischer Verlag, Munich, pp 1–134
44. Gerecke R, Gledhill T, Pešić V, Smit H (2016) Chelicerata: Acari III. In: Gerecke R (ed) Süßwasserfauna von Mitteleuropa, vol Bd. 7/2–3. Springer, Heidelberg, pp 1–429
45. Stubbington R, Chadd R, Cid N, Csabai Z, Miliša M, Morais M, Munné A, Pařil P, Pešić V, Tziortzis I, Verdonschot RCM, Datry T (2017) Biomonitoring of intermittent rivers and ephemeral streams in Europe: current practice and priorities to enhance ecological status. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2017.09.137

Parasites of Lake Skadar

Branko Radujković and Danijela Šundić

Contents

Abstract During the period between 1964 and 1984, a total of 28 vertebrate host species from Lake Skadar were examined for parasites (18 fish, 3 amphibian, 2 reptilian and 5 bird species). The number of host individuals studied was about 10,522. The authors, who performed the investigations, stated 123 species of adult parasites, out of which 11 were proposed as the new species. Additionally, 25 more species were partly determined in adult or juvenile and larval stage. The studied parasite species from Lake Skadar belong to the following groups: apicomplexans, coccidians, trypanosomatids, myxozoans, monogeneans, digeneans, cestodes, nematodes, acanthocephalans, copepods and branchiurans. Some ecological features of the host-parasite interrelations, such as prevalence, abundance, host specificity and parasite life cycle, are discussed.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 325–338, DOI 10.1007/698_2018_266,
© Springer International Publishing AG 2018, Published online: 27 April 2018

Keywords Parasites, Fish, Amphibians, Reptilians, Birds, Lake Skadar, Montenegro

1 Introduction

In this paper all available data on parasites from Lake Skadar, published in the period from 1969 to 1984, were used. All host and parasite taxa names were validated using relevant and contemporary literature as well as taxonomic databases, such as Marić and Milošević [1], FishBase [2] (fish), Čađenović [3] (frogs), Radujković and Šundić [4, 5], Host-Parasite Database [6] and The Taxonomicon [7] (various parasites). For determination of level of parasitic specificity, two methods were used – according to Euzet and Combes [8] and Radujković et al. [9].

The first systematic research of the parasites of vertebrates from Lake Skadar began with Danilo Kažić in 1964, who published his first work in 1969 [10]. The complete results of these investigations were published by Kažić in 1970 [11]. From that year the interest in parasitic investigations of Lake Skadar has been increased. Several foreign researchers have published three significant papers during the period from 1970 to 1972: Ergens [12], Moravec and Ergens [13] and Ergens and Ryšavy [14].

As a result of cooperation between Biological Institute of Podgorica and Smithsonian Institution (Washington, USA), the comprehensive parasitological investigations were conducted within the project "Limnological investigations of the Lake Skadar." This enabled many Yugoslav and American scientists to take part in very intensive research and publish papers during 1977, 1978 and 1979 such as Kažić et al. [15], Kažić and Pulević [16], Kažić [17] and Mayberry et al. [18]. In addition, the most important contribution to the knowledge of parasitofauna of Lake Skadar was the publication of the monograph entitled *The Biota and Limnology of Lake Skadar* (1981), with several chapters concerning parasites [19–21]. Even afterwards, the authors published papers from the material collected during the intensive field work within the above-mentioned project [22–27].

2 Biodiversity of Parasites from Lake Skadar

The research of the parasites of Lake Skadar was carried out through several sampling campaigns, from 1964 to 1984. Some of them lasted one and some several years, and the field collection of host samples took place every month. The two largest sampling campaigns, by number of host species and sample size, were carried out between 1964 and 1969 (these results were published in 1970) and between 1967 and 1980 (results published in 1981). In the first sampling campaign, 8 species of fish hosts were examined, i.e. a total of 2,472 specimens (all parasitized with at least one parasite, extensity was 100%); in the second campaign, 9 species of fish hosts (5,152 specimens, 86.5% parasitized), 3 species of amphibians (175 specimens, 47% parasitized), 2 species of reptilians (11 specimens, 54.5% parasitized) and 5 bird species (74 specimens, 83% parasitized) (Table 1). In other sampling campaigns, between 1 and 5 host species were studied, most often at 1-year cycle.

2.1 Hosts

A total of 28 vertebrate hosts with 10,522 individuals were examined; 8,988 were found parasitized during the above-mentioned 20-year period (extensity was 85.42%). Among examined vertebrate hosts, 18 species were fishes, 3 amphibians, 2 reptiles and 5 birds.

Among fish hosts a total of 18 species from 5 orders and 5 families were investigated, as follows:

Alosa fallax (Lacepède, 1803) from order Clupeiformes and family Clupeidae

Anguilla anguilla (Linnaeus, 1758) (order Anguilliformes, family Anguillidae).

Salmo farioides Karaman, S. 1938 and *Salmo marmoratus* Cuvier, 1829 (order Salmoniformes, family Salmonidae).

Alburnoides ohridanus (Karaman, S., 1928).

Alburnus scoranza (Heckel & Kner, 1858).

Carassius auratus (Bloch, 1782).

Chondrostoma ohridanum Karaman, S. 1924.

Cyprinus carpio Linnaeus, 1758.

Gobio skadarensis Karaman, S., 1937.

Pachychilon pictum (Heckel & Kner, 1858).

Rhodeus amarus (Bloch, 1782).

Rutilus prespensis (Karaman, S., 1924).

Scardinius knezevici (Bianco & Kottelat, 2005) and *Squalius platyceps* (Zupančić, Marić, Naseka & Bogutskaya, 2010) (order Cypriniformes and family Cyprinidae).

Chelon labrosus (Risso, 1827), *Liza aurata* (Risso, 1810) and *Liza ramada* (Risso, 1810) (order Mugiliformes, family Mugilidae).

The amphibian hosts were represented with three species from order Anura and three families: *Pelophylax ridibundus* (Pallas, 1771) (fam. Ranidae), *Bombina variegata* (Linnaeus, 1758) (fam. Bombinatoridae) and *Bufo bufo* (Linnaeus, 1758) (fam. Bufonidae).

Two reptilian hosts *Mauremys caspica* (Gmelin, 1774) (order Chelonii (Testudines), fam. Geoemydidae) and *Natrix tessellata* (Laurenti, 1768) (order Squamata, fam. Colubridae) were also investigated.

Finally, the parasites from bird hosts in Lake Skadar were collected from five species, belonging to three orders and three families: *Podiceps cristatus* (Linnaeus,

Table 1 Overview of the results of parasitological investigations of some vertebrates from Lake Skadar, between 1969 and 1984 (A, number of host species examined; B, number of individuals examined; C, number of individuals parasitized; D, % of individuals parasitized; Ap, apicomplexans; Co, coccidians; Tr, trypanosomatids; Mx, myxozoans; Mo, monogeneans; Di, digeneans; Ce, cestodes; Ne, nematodes; Ac, acanthocephalans; Cp, copepods; Br, branchiurans; pi, partly identified adults, juveniles or larval?, no data)

Pisces															
					Number of parasite species recorded										
Year	A	B	C	D	Ap	Co	Tr	Mx	Mo	Di	Ce	Ne	Ac	Cp	Br
1969	5	?	?	?						7					
1970	8	2,472	2,472	100					2	14 + 5pi	6	6 + 7pi	2		
1970a	9	74	74	100					30						
1971	10	74	74	100								16			
1977	1	328	325	99.08					1	8 + 2pi	2 + 1pi	2 + 5pi	1		
1978	1	623	458	73.51					1	10	3	7	4	1	1
1978a	1	719	254	35.32						3					
1979	7	52	46	88.46	1										
1980	3	64	64	100						5 + 1pi	3	5	3		
1981	9	5,152	4,456	86.50	1	2	3	1	1	18 + 9pi	7 + 1pi	10 + 14pi	8	1	1
1983	1	623	555	89.08						2	3	5	5		
Anura															
1981	3	175	82	47						10		4	1		
Reptilia															
1981	4	11	6	54.5	2	1			–	–	–	–	–	–	–
Aves															
1981	5	74	62	83.78	1	1				9 + 1pi					
1983	3	40	30	75.00						6					
1984	3	41	30	73.17						6					

1758), *Podiceps ruficollis* Pallas, 1764, *Podiceps nigricollis* Brehm, 1831 (order Podicipediformes, fam. Podicipedidae), *Corvus cornix* Linnaeus, 1758 (order Passeriformes, fam. Corvidae) and *Phalacrocorax pygmaeus* (Pallas, 1773) (order Pelecaniformes, fam. Phalacrocoracidae).

2.2 Parasites

In parasitofauna of Lake Skadar, a total of 123 adult parasite species belonging to 11 groups (Table 1) were identified. Beside adults, juvenile and larval or partly identified parasites were also recorded in some groups (25 species). The highest parasitic diversity occurred in fish hosts. Namely, 91 parasites from 11 different groups were identified in fish hosts, as follows: apicomplexans (1 species), coccidians (2 species), trypanosomatids (3 species), myxozoans (1 species), monogeneans (32 species), digeneans (20 species +9 juveniles and larvals), cestodes (11 species +1 larval), nematodes (10 species +14 partly identified adults +8 juveniles), acanthocephalans (9 species), copepods (1 species) and branchiurans (1 species).

Other hosts harboured somewhat lower number of parasites. A total of 15 parasites from groups Digenea (10 species), Nematoda (4 species) and Acanthocephala (1 species) were identified from amphibian hosts; two apicomplexans and one coccidian species were found in reptilian hosts. The bird hosts were infested with 14 parasite species belonging to the following parasitic groups: Apicomplexa (1 species), Coccidia (1 species) and Digenea (12 species +1 partly identified).

2.3 New Species of Parasites Described from Lake Skadar

The investigation of monogeneans of Lake Skadar, conducted by Ergens in 1970, resulted in description of eight new species from genera *Dactylogyrus* and *Gyrodactylus* [12]. Five of them were found on *Pachychilon pictum*: *Dactylogyrus ivanovici* Ergens, 1970, *Dactylogyrus martinovici* Ergens, 1970, *Dactylogyrus petkovici* Ergens, 1970, *Dactylogyrus rosickyi* Ergens, 1970 and *Dactylogyrus sekulovici* Ergens, 1970; one from *Rutilus prespensis*, *Dactylogyrus erhardovae* Ergens, 1970; one from *Alburnoides ohridanus*, *Dactylogyrus rysavyi* Ergens, 1970; and one from *Cyprinus carpio*, *Gyrodactylus stankovici* Ergens, 1970.

Three other new species, *Haemohormidium* sp. n. (from *Natrix tessellata*) (apicomplexans), *Trypanosoma* sp. n. (from *Anguilla anguilla*) (trypanosomatids) and *Eimeria* sp. n. (from *Anguilla anguilla*) (coccidians), proposed by Ubelaker et al. [19] have not yet been described.

3 Ecology of Parasites from Lake Skadar

3.1 Parasites and Their Hosts

3.1.1 Number of Parasite Species per Host

One of the indicators of co-evolutionary interactions between parasites and hosts is the number of parasitic species hosted by a single host. Sometimes this number is large, as is the case with fish hosts in Lake Skadar.

The fish hosts in Lake Skadar harboured the highest number of parasite species. As it is shown in Fig. 1, the number of parasite species in fish hosts ranged from 21 in *Alburnus scoranza* and *Scardinius knezevici* to 28 in *Anguilla anguilla*. The number of parasite species in amphibian host *Pelophylax ridibundus* was 15, and in bird host *Podiceps cristatus* was 10 (Fig. 1).

3.1.2 Number of Parasite Groups per Host

Another indicator is the biodiversity of these parasites (Fig. 2). The fish hosts *Anguilla anguilla*, *Squalius platyceps* and *Pachychilon pictum* harboured seven groups of parasites: apicomplexans, trypanosomatids, coccidians, digeneans, cestodes, nematodes and acanthocephalans. The other two fish species, *Alburnus scoranza* and *Scardinius knezevici*, hosted four and five groups (monogeneans, digeneans, cestodes, nematodes, trypanosomatids). The amphibian host *Pelophylax ridibundus* harboured digeneans, nematodes and acanthocephalans; the bird – *Podiceps cristatus* – hosted only digeneans. The digeneans were the most represented parasite group, and their number, in all analysed vertebrate hosts, ranged from six species (in *Anguilla anguilla*) to ten (in *Alburnus*

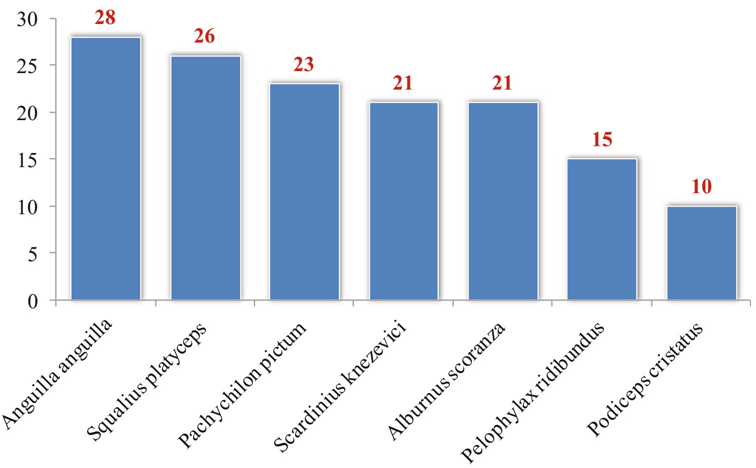


Fig. 1 The hosts with highest number of parasite species in Lake Skadar

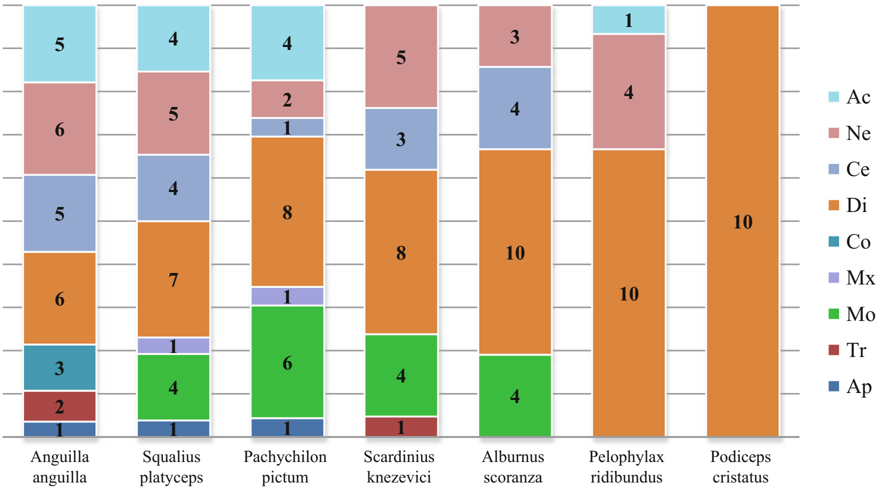


Fig. 2 The hosts harbouring different parasite groups in Lake Skadar (the abbreviations used in this figure are the same as those in Table 1)

scoranza, *Pelophylax ridibundus* and *Podiceps cristatus*). The number of nematode species ranged from three to six and monogeneans from four to six, while the number of other parasites was significantly lower (Fig. 2).

3.1.3 Number of Infested Hosts by Single Parasite Species

However, parasites can live in one, two or more hosts. The investigated parasites of Lake Skadar infested between three and ten species of hosts, from one to four families, i.e. the same number of orders. The digenean *Sphaerostoma globiporum* is characterized by its ability to infest ten species of hosts from even three orders (Table 2), then followed by *Pseudochetosoma salmonicola* (digeneans) with nine species (two families and three orders) and *Asymphylodora kubanica* (digeneans), *Rhabdospora telohani* (apicomplexans) and *Ligula intestinalis* (cestodes), all with seven species. Especially interesting species is *L. intestinalis* (plerocercoid), which develops as larva in many species of fish from four orders and, while as an adult, lives in a small number of birds.

3.2 Extensity of Parasitism

The prevalence of a parasite in the population of a particular host is an indicator of its success in survival and the development of lasting interactions with it. The largest extensity in Lake Skadar had larval forms, such as *Ichthyocotylurus pileatus* (metacercariae, from *Gobio skadarensis*) and *Hysterothylacium* sp. (larva, from *Alosa fallax*) with 96.03%

Table 2 Parasites with the highest number of hosts

Parasite group	Parasite name	Number of hosts infested	Host families
Digenea	*Sphaerostoma globiporum* (Rudolphi, 1802)	10	Clupeidae, Cyprinidae, Salmonidae
Digenea	*Pseudochetosoma salmonicola* Dollfus, 1951	9	Cyprinidae, Salmonidae
Digenea	*Asymphylodora kubanica* Issaitschikov, 1923	7	Cyprinidae
Apicomplexa	*Rhabdospora thelohani* Laguessé, 1895	7	Anguillidae, Cyprinidae
Cestoda	*Ligula intestinalis* (Linnaeus, 1758)	7	Anguillidae, Clupeidae, Cyprinidae, Salmonidae
Digenea	*Asymphylodora markewitschi* Kulakovskaja, 1947	6	Anguillidae, Cyprinidae
Cestoda	*Eubothrium crassum* (Bloch, 1779)	5	Anguillidae, Cyprinidae, Salmonidae
Acanthocephala	*Metechinorhynchus salmonis* (Müller, 1780)	5	Anguillidae, Cyprinidae, Salmonidae
Nematoda	*Philometra ovata* (Zeder, 1803)	4	Cyprinidae
Digenea	*Petasiger neocomansae* Fuhrmann, 1927	3	Podicipedidae
Nematoda	*Cosmocerca ornata* (Dujardin, 1845)	3	Ranidae, Bombinatoridae, Bufonidae

and 93.75%, respectively (Table 3). Some adults, such as digenean *Sphaerostoma globiporum* (from *Squalius platyceps*), 93.75%, and monogenean *Dactylogyrus sekulovici* (from *Pachychilon pictum*) with the level of extensity 83.33%, may also reach that high percentage.

3.3 Intensity of Parasitism

The intensity of parasitism is another indication of the success of a parasitic species and is measured by the total number of species in one host individual. This number should not be so high to kill the host, who is the source of food and shelter. When it comes to Skadar Lake parasites, the highest intensity has the digeneans of fish, especially their metacercariae: *Pronoprymna petrowi* from *Anguilla anguilla* (1,050), *Ichthyocotylurus pileatus* from *Gobio skadarensis* (469) and *Phyllodistomum elongatum* from *Alburnus scoranza* (439) (Table 4). The adult digeneans *Pronoprymna petrowi* and *Hemiurus appendiculatus*, both from *Alosa fallax*, had an intensity of 385 and 382. The monogenean, *Gyrodactylus medius* from *Cyprinus carpio*, had also a very high intensity of 298. Adult and larval nematodes were found in large numbers as well: *Hysterothylacium aduncum* from *Alosa fallax* (115) and *Raphidascaris* sp. larv. from *Pachychilon pictum* (500). Cestodes and acanthocephalans were found to be less numerous, except for *Bothriocephalus claviceps* from *Anguilla anguilla*, whose intensity was 138.

Table 3 The parasitic species with largest extensity

Parasitic group	Parasite species	Host	Extensity (%)
Monogenea	*Dactylogyrus sekulovici*	*Pachychilon pictum*	83.33
	Gyrodactylus medius	*Cyprinus carpio*	50.00
Digenea	*Ichthyocotylurus pileatus mtc.*	*Gobio skadarensis*	96.03
	Sphaerostoma globiporum	*Squalius platyceps*	93.75
Cestoda	*Caryophyllaeus laticeps*	*Cyprinus carpio*	66.70
Nematoda	*Hysterothylacium* sp. larv.	*Alosa fallax*	93.75
	Hysterothylacium squallii larv.	*Scardinius knezevici*	63.60
Acanthocephala	*Metechinorhynchus salmonis*	*Anguilla anguilla*	72.50
	Metechinorhynchus truttae	*Anguilla anguilla*	53.73

Table 4 The parasitic species with highest intensity (mtc, metacercariae)

Parasitic group	Parasite species	Host	Intensity
Monogenea	*Gyrodactylus medius*	*Cyprinus carpio*	298
	Dactylogyrus difformis	*Scardinius knezevici*	69
Digenea	*Ichthyocotylurus pileatus* mtc.	*Gobio skadarensis*	469
	Pronoprymna petrowi mtc.	*Anguilla anguilla*	1,050
	Phyllodistomum elongatum mtc.	*Alburnus scoranza*	439
	Pronoprymna petrowi	*Alosa fallax*	385
	Hemiurus appendiculatus	*Alosa fallax*	382
Cestoda	*Caryophyllaeus laticeps*	*Cyprinus carpio*	68
	Bothriocephalus claviceps	*Anguilla anguilla*	138
Nematoda	*Hysterothylacium aduncum*	*Alosa fallax*	115
	Raphidascaris sp. larv.	*Pachychilon pictum*	500
	Goezia ascaroides	*Anguilla anguilla*	65
Acanthocephala	*Metechinorhynchus salmonis*	*Anguilla anguilla*	27
	Metechinorhynchus truttae	*Anguilla anguilla*	55

3.4 Host Specificity

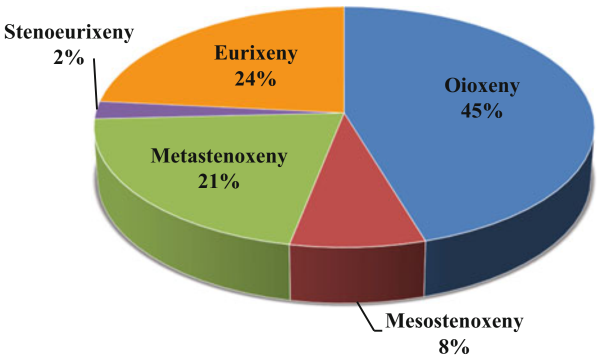
Host specificity is one of the best tools which can help to assess the level of complex relationships between the parasites and their hosts being the result of co-evolution in the given environment. Two approaches were used to treat the data on parasites and hosts from Lake Skadar – first formulated as a verbal definition by Euzet and Combes [8] and the second one by Radujković et al. [9]; in addition to the proposed five categories of parasitic specificity, the host specificity index (HSI) was calculated for each one, which allows a mathematical comparison of different cases (Table 5). The most characteristic parasites from three, i.e. five specificity categories and their HSI values, are shown in the table. Some authors classify the oioxenous (HSI = 1) and mesostenoxenous (HSI = 1.131) species in the so-called 'specialists' and species from other categories into 'generalists'. A total of 90% of parasites of Lake Skadar belong to three categories of parasitic specificity: oioxenous, 45%

Table 5 Host specificity of several characteristic parasite species of Lake Skadar (HSI, host specificity index)

Parasite and host	Host specificity after [8]	Host specificity after [9]
Dactylogyrus erhardovae	Oioxenous	Oioxenous, HSI = 1.0
Rutilus prespensis (f. Cyprinidae)		
Gyrodactylus stankovici	Oioxenous	Oioxenous, HSI = 1.0
Cyprinus carpio (f. Cyprinidae)		
Petasiger megacanthum	Stenoxenous	Mesostenoxenous, HSI = 1.131
Podiceps cristatus (f. Podicipedidae, o. Podicipediformes)		
Dactylogyrus vistulae	Stenoxenous	Metastenoxenous, HSI = 2.00048
Squalius platyceps (f. Cyprinidae)		
Alburnoides ohridanus (f. Cyprinidae)		
Rhabdospora telohani	Eurixenous	Eurixenous, HSI = 8.18
Anguilla anguilla (f. Anguillidae, o. Anguilliformes)		
Alburnoides ohridanus (f. Cyprinidae, o. Cypriniformes)		
Carassius auratus (f. Cyprinidae, o. Cypriniformes)		
Chondrostoma ohridanum (f. Cyprinidae, o. Cypriniformes)		
Pachychilon pictum (f. Cyprinidae, o. Cypriniformes)		
Rutilus prespensis (f. Cyprinidae, o. Cypriniformes)		
Squalius platyceps (f. Cyprinidae, o. Cypriniformes)		
Sphaerostoma globiporum	Eurixenous	Eurixenous, HSI = 12.10
Alosa fallax (f. Clupeidae, o. Clupeiformes)		
Alburnus scoranza (f. Cyprinidae, o. Cypriniformes)		
Chondrostoma ohridanum (f. Cyprinidae, o. Cypriniformes)		
Cyprinus carpio (f. Cyprinidae, o. Cypriniformes)		
Gobio skadarensis (f. Cyprinidae, o. Cypriniformes)		
Pachychilon pictum (f. Cyprinidae, o. Cypriniformes)		
Rutilus prespensis (f. Cyprinidae, o. Cypriniformes)		
Scardinius knezevici (f. Cyprinidae, o. Cypriniformes)		
Squalius platyceps (f. Cyprinidae, o. Cypriniformes)		
Salmo farioides (f. Salmonidae, o. Salmoniformes)		

(mainly monogeneans); eurixenous, 24% (mainly digeneans, especially larval forms); and metastenoxenous, 21%. The remaining two categories are significantly less represented in the parasitofauna of the lake (Fig. 3).

Fig. 3 Distribution of different host specificity categories in Lake Skadar



3.5 Life Cycle

Ubelaker et al. [19] mentioned only eight species that have an indirect life cycle, although this aspect has not been specifically studied. The indirect life cycle, which implies the existence of one or two intermediate and definitive hosts (in which adult forms develop), is characteristic for mentioned species from Lake Skadar (Table 6). The first intermediate hosts of nematodes can be oligochaetes, euphausiids and amphipods; for cestodes those are copepods (in which procercoids develop) and for digeneans different species of snails. The second intermediate hosts are fish from the families Cyprinidae, Anguillidae and Clupeidae, while the definitive hosts for all these parasites are various bird species.

Table 6 Life cycle of some parasites from Lake Skadar (N, nematodes; C, cestodes, D, digeneans, mtc.–metacercariae)

Parasite	Intermediate host 1	Intermediate host 2	Definitive host
Eustrongylides sp. (N)	Oligochaetes	*Gobio skadarensis*, fish	Birds
Anisakis sp. (N)	Euphausiid crustaceans	*Alosa fallax* fish	Birds
Streptocara sp. (N)	Amphipod crustaceans	*Gobio skadarensis*, fish	Birds
Schistocephalus sp. (C)	Copepod crustaceans (procercoid)	*Anguilla anguilla*, fish (plerocercoid)	Birds
Ligula intestinalis (C)	Copepod crustaceans (procercoid)	Cyprinid fish (plerocercoid)	Birds
Paradilepis scolecina (C)	Copepod crustaceans (procercoid)	Cyprinid fish (plerocercoid)	Birds
Ichthyocotylurus pileatus (D)	Snail	*Gobio skadarensis*, fish, mtc.	Birds
Clinostomum complanatum (D)	Snail	Cyprinid fish	Birds

4 Conclusions

The lack of data on parasite species of Lake Skadar for the last three decades is evident and imposes the necessity for the new parasitological investigations. The main directions of further research should be:

– Faunistical research with emphasis on uninvestigated species, both host and parasites, by using modern tools in its identification (molecular, DNA analysis)
– Ecological research – investigation of host specificity, prevalence, abundance, complete life cycles, etc.
– Pathogenicity of species – investigation of pathological effects of infestation in hosts, assessment of the risk of such an infestation on sustainable fishing, pisciculture and food chains; in particular, investigation of impacts of pathological effects on bird populations, since Lake Skadar is one of the most important wintering birds' habitats in Europe and International Important Bird Area.

References

1. Marić D, Milošević D (2011) Catalogue of the freshwater fishes (Osteichthyes) of Montenegro. In: Karaman G (ed) Fauna of Montenegro. Montenegrin Academy of Sciences and Arts, catalogues 5, book 4, Podgorica, 114 p
2. FishBase. http://www.fishbase.org/search.php. Accessed 4 Dec 2017
3. Čađenović N (2014) Catalogue of amphibian fauna of Montenegro (Crna Gora). In: Karaman G (ed) Fauna of Montenegro. Montenegrin Academy of Sciences and Arts, catalogues 10, book 9, Podgorica, 63 p
4. Radujković BM, Šundić D (2011) Catalogue of Parasitofauna of Montenegro. In: Karaman G (ed). Fauna of Montenegro. Montenegrin Academy of Sciences and Arts, catalogues 6, book 5, Podgorica, 300 p
5. Radujković BM, Šundić D (2014) Parasitic flatworms (Platyhelminthes: Monogenea, Digenea, Cestoda) of fishes from the Adriatic Sea. Nat Montenegr 13(1):7–280
6. Gibson DI, Bray RA, Harris EA (Compilers) (2005) Host-parasite database of the Natural History Museum, London. http://www.nhm.ac.uk/research-curation/scientific-resources/taxonomy-systematics/host-parasites/database/index.jsp
7. The Taxonomicon. http://taxonomicon.taxonomy.nl. Accessed 4 Dec 2017
8. Euzet L, Combes C (1980) Les problèmes de l'espèce chez les animaux parasites. In: Les problèmes de l'espèce dans le règne animal. Bull Soc Zool France 40(3):239–285
9. Radujković BM, Mitrović D, Čapuni I (2005) Host-specificity index proposal and its application to Adriatic and Mediterranean monogeneans. 5th international symposium on Monogenea, Guangzhou, China, p 111
10. Kažić D, Čanković M (1969) Parazitofauna riba Skadarskog jezera I. Neke kod nas neutvrđene vrste Trematoda Veterinaria 18:473–484
11. Kažić DM (1970) Endohelminths of economically most important fishes in the lake Skadarsko jezero. Biološki zavod Titograd, 128 p
12. Ergens R (1970) Parazitofauna ryb iz teritorii Cernogorii. I. Polyonchoinea (Monogenoidea) nekotoryh ryb Skadarskogo ozera i bolsogo Chernogo ozera. Poljoprivreda i šumarstvo 16 (1–2):149–186
13. Moravec F, Ergens R (1971) The parasite fauna of fishes from Montenegro II. Nematoda Poljoprivreda i Šumarstvo 17:1–18

14. Ergens R, Ryšavy B (1972) Cysticercoids of Cestodes (Dilepididae) from fishes of Lake Skadar. Folia Parasitol 19:215–216
15. Kažić D, Ubelaker JF, Čanković M (1977) Observations and seasonal variations of the helminth fauna of *Gobio gobio lepidolaemus* (Kessler, 1872), (Cyprinidae, Pisces) from Lake Skadar, Yugoslavia. Glas Republ zavoda zašt prirode – Prirodnjačkog muzeja, Titograd 10:5–29
16. Kažić DM, Pulević RD (1978) The contribution to the knowledge of bleak infection (*Alburnus albidus alborella* Filippi, 1884), (Pisces, Cyprinidae) by trematodes of genus *Phyllodistomum* from Skadar Lake, Yugoslavia. Glas Republ zavoda zašt prirode – Prirodnjačkog muzeja, Titograd 11:31–45
17. Kažić DM (1978) The endohelminths and seasonal dynamics of parasites of *Pachychilon pictum* (Heckel & Kner, 1858), (Cyprinidae, Pisces) from Skadar Lake. Glas Republ. zavoda zašt. prirode – Prirodnjačkog muzeja, Titograd 11:5–29
18. Mayberry FL, Marchiondo AA, Ubelaker JE, Kažić D (1979) *Rhabdospora thelohani* Laguessé, 1895 (Apicomplexa): new host and geographic records with taxonomic considerations. J Protozool 26(2):168–178
19. Ubelaker J, Kažić D, Mayberry L, Čanković M (1981) Parasitism of fishes and other vertebrates of Lake Skadar. In: Karaman G, Beeton A (eds) The Biota and Limnology of the Lake Skadar. Institut za biološka i medicinska istraživanja u SRCG, Biološki zavod, Titograd; Smithsonian institution, Washington, DC, USA, pp 356–383
20. Čanković M, Kažić D, Rozman M (1981) Recent results about investigations of Digenea of water birds from the family Podicipidae of lake Skadar. In: Karaman G, Beeton A (eds) The Biota and Limnology of the Lake Skadar. Institut za biološka i medicinska istraživanja u SRCG, Biološki zavod, Titograd; Smithsonian institution, Washington, DC, USA, pp 389–390
21. Rozman M (1981) Endohelminths of Anura from the area of lake Skadar. In: Karaman G, Beeton A (eds) The Biota and Limnology of the Lake Skadar. Institut za biološka i medicinska istraživanja u SRCG, Biološki zavod, Titograd; Smithsonian institution, Washington, DC, USA, pp 383–389
22. Kažić D, Ubelaker JF, Čanković M (1982) The Endohelminths of eel (*Anguilla anguilla*, Linnaeus, 1758) of Lake Skadar and some tributaries. Ichthyologia 14(1):41–53
23. Kažić D, Čanković M, Ubelaker JF (1983) The Endohelminths of eel (*Anguilla anguilla*, Linnaeus, 1758) of the Morača river. In: Ivanović B (ed) Lake Scutari, vol 9. Montenegrin Academy of Sciences and Arts, Titograd, 171–190 p
24. Kažić D (1983) Some characteristics of endohelminths of fish from Lake Sadar. In: Ivanović B (ed). Lake Scutari, vol 9. Montenegrin Academy of Sciences and Arts, Titograd, 155–164 p
25. Čanković M, Kažić D, Rozman M (1983) Helminthofauna of the water birds of the Podicipidae family on the Lake Skadar. Trematoda Digenea I. Veterinaria 32(2):171–179
26. Čanković M, Kažić D, Rozman M (1983) Helminthofauna of the water birds of the Podicipidae family on the Lake Skadar. Trematoda Digenea II. Veterinaria 32(2):181–193
27. Čanković M, Kažić D, Rozman M (1984) Helminthofauna of the water birds of the Podicipidae family on the Lake Skadar. Trematoda Digenea III. Veterinaria 33(1–2):33–44

The Diversity and Endemism of Aquatic Subterranean Fauna of the Lake Skadar/Shkodra Basin

Vladimir Pešić, Gordan S. Karaman, and Boris Sket

Contents

Abstract Based on the published data, approximately 90 stygobiotic species are known from aquatic subterranean environment of the Lake Skadar Basin. Crustacea are the most diverse faunistic group with 54 species, followed by Gastropoda and Acari with 22 and 12 species, respectively. Turbellaria are represented by two species, while Annelida are represented by one Hirudinea species. The highest number of stygobionts was stated for cave Obodska pećina. The largest number of stygobiotic species has been reported from cave waters, followed by springs and interstitial waters, while a lower number was found in wells. Crustacean Copepoda and Amphipoda are the most diverse in cave waters, while Hydrachnidia is the most diverse group in interstitial waters.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 339–362, DOI 10.1007/698_2018_303,
© Springer International Publishing AG 2018, Published online: 13 May 2018

Keywords Caves, Checklist, Endemism, Interstitial waters, Skadar/Shkodra Basin, Springs, Subterranean fauna, Wells

1 Introduction

The Lake Skadar Basin (Fig. 1) is characterized by a large amount of underground water, as the result of its location in the outer part of the Dinaric region, in the High Karst (*Visoki Krš*) zone [1]. On a large part of this area, especially in its western part

Fig. 1 The map of the studied area of the Lake Skadar catchment area. The location of the cave Obodska pećina is marked with a star

between the inland depression (Skadar Basin–the Zeta Valley–the Bjelopavlići Valley–Nikšić Polje) and the coastal region, regardless of the large precipitation, there are no significant perennial water bodies [1]. Most of the water is located in the underground, and the access to this environment, inhabited by many stygobiotic species, is often difficult and possible only through caves, wells, and surface springs [2]. Subterranean aquatic habitats include interstitial water beneath streams and rivers which exists at a depth of several centimeters or decimeters. The interstitial habitats and stygobiotic (interstitial) species that inhabit them are generally more accessible, but at the same time, they are more susceptible to the various anthropogenic threats, like pollution and sand and gravel extraction from the river banks.

Some specific subterranean habitats such as hypotelminorheic habitat and their associated outlets (seepage springs) and epikarst aquifer (the uppermost layer of karst which is more or less permanently saturated with the water that comes from the surface [3]) are poorly studied in the studied area.

There are several classifications of subterranean aquatic habitats [3, 4]. However, for the purpose of this paper, we classified habitats based on the information available in the literature sources (see under species richness and endemism of stygobiotic invertebrates in specific habitats). Another problem that exists with the available literature is that it often contains limited ecological information that does not always allow a reliable assignment of subterranean invertebrates to appropriate ecological categories. According to their occurrence in groundwater or surface water, aquatic invertebrates are generally classified in four categories following Sket [5]: (1) stygobiont (=aquatic troglobiont), species restricted to hypogean aquatic habitat and not found in other habitat types; (2) eustygophile a generally surface inhabitant able to produce permanent subterranean populations; (3) substygophiles, a common inhabitant of groundwaters which nevertheless needs to come outside for some functions (mainly for feeding); and (4) stygoxene (or accidental), species of surface habitats and only occasionally present in subterranean waters.

There is no checklist of stygobionts published for Montenegro and Lake Skadar catchment. Literature reviews of aquatic subterranean fauna of Montenegro have been published from different perspectives, including a focus on subterranean species in particular habitat [6] or focus on the obligate subterranean fauna at the level of Balkan Peninsula region [7]. Thus, the literature sources on subterranean animals in Montenegro remain highly dispersed. Sket et al. [7] mentioned that 1,460 entries (species/location) have been accumulated for terrestrial and aquatic subterranean fauna of Montenegro, which is less than for Bosnia and Hercegovina or Croatia, much less than for Slovenia (6,620), but higher than for Serbia and Macedonia.

Most of the studies and entries involving subterranean aquatic fauna refer to the Lake Skadar Basin. Some groups, like Amphipoda, Copepoda, and Ostracoda, seem to be relatively well studied. On the other hand, some groups escaped detailed taxonomical and faunistic studies – for example, there is lack of information on subterranean Turbellaria and especially of Oligochaeta.

The first paper on one subterranean invertebrate from Lake Skadar Basin was published at the beginning of the twentieth century when Schäferna [8] described *Typhlogammarus mrazeki* (Fig. 2) from the cave Lipska pećina. Since then, more than 60 papers on subterranean animals from the Lake Skadar Basin have been published. An analysis of literature sources on the subterranean aquatic fauna of the Lake Skadar Basin revealed the big difference in the amount of data in the group-specific knowledge.

In this analysis only papers listing stygobiotic species were included. Moreover we list only papers that contain new data, while reviews and syntheses based on previously published original papers were excluded. The results show that data on obligate subterranean fauna from aquatic environment of Lake Skadar Basin are unevenly distributed. Relatively few studies were reported on the fauna of subterranean waters prior to the 1940s, with most publications occurring from 2000 up to now (Fig. 3). Moreover, the analysis showed that group-specific knowledge is limited to a certain period of time. For many groups, even in the case of the Hydrachnidia (intensively studied by V. Pešić) or Copepoda (studied by T. Karanović), there are no data on subterranean species published in the last years. Only Amphipoda have been continuously studied by Gordan Karaman and Slovenian speleobiologists from 1960s up to 2000.

Fig. 2 *Typhlogammarus mrazeki* from Obodska pećina, the first stygobiotic species described from the Lake Skadar Basin. Photo: B. Sket

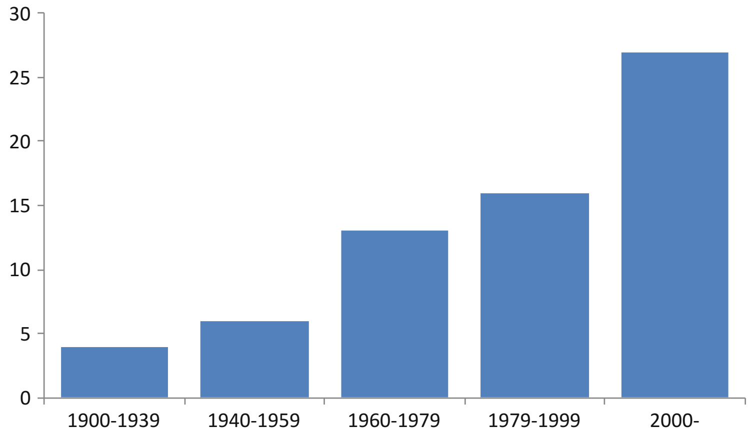

Fig. 3 Number of publications concerning subterranean aquatic fauna of the Lake Skadar Basin through time

2 Species Richness of Stygobiotic Species in Particular Taxonomic Groups

Approximately 90 stygobiotic species (Table 1) are known from aquatic subterranean environment of the Lake Skadar Basin. The subterranean fauna of the Lake Skadar Basin is part of subterranean fauna of Western Balkan which is recognized as by far the richest in the world in the share of stygobiotic species [78]. According to Sket et al. [7], the number of supposedly obligate aquatic subterranean species of the Balkan Peninsula tallies ca. >650 species, including 81 stygobiotic species known for Montenegro at the time of writing the paper (in 2004). The difference in comparison of our results is mainly because hydrachnid mites were not included in the census of obligate subterranean fauna by Sket et al. [7].

In the present checklist (Table 1), we included only taxa at the species level and the species which belong to stygobionts. However, it is possible that in compiling the list of stygobiotic species of the Lake Skadar Basin due to the lack of profound ecological data some species have been missed. Moreover, it is very likely that this list will be enriched by discovering new species, particularly if application of molecular techniques betrays some “cryptic” species.

Turbellaria seem to be one of the most poorly known groups of invertebrates in Montenegro. Subterranean Temnocephalida in the Lake Skadar Basin are represented by one species of the family Scutariellidae. *Troglocaridicola spelaeocaridis* live as epizootic and ectoparasitic species on cave shrimps of the genus *Troglocaris* in the cave Obodska pećina [79].

Table 1 List of stygobiotic species known in the Lake Skadar Basin

Taxa	Habitat	References
Turbellaria		
Crenobia anophthalma (Mrazek, 1907)	C	[10]
Troglocaridicola spelaeocaridis Matjašič, 1958	C	[11]
Gastropoda		
Arganiella tabanensis Boeters, Glöer & Pešić, 2014	SP	[12]
Bracenica spiridoni Radoman, 1973	SP	[13, 14]
Bracenica vitojaensis Glöer, Grego, Erőss & Fehér, 2015	SP	[15]
Bythiospeum demattiai Glöer & Pešić, 2014	SP	[16]
Bosnidilhia cf. *vreloana* Boeters, Glöer & Pešić, 2013	SP	[15]
Iglica absoloni (A.J. Wagner, 1914)	SP, C	[17, 18]
Islamia montenegrina Glöer, Grego, Erőss & Fehér, 2015	SP	[15]
Iverakia hausdorfi Glöer & Pešić, 2014	SP	[16]
Lanzaia pesici Glöer, Grego, Erőss & Fehér, 2015	SP	[15]
Lanzaia vjetrenicae Küscer 1933	SP	[19]
Montenegrospeum bogici (Pešić & Glöer 2012)	SP	[20, 21]
Paladilhiopsis prekalensis Grego, Glöer, Erőss & Fehér, 2017	C	[22]
Paladilhiopsis szekeresi Grego, Glöer, Erőss & Fehér, 2017	SP	[22]
Paladilhiopsis wohlberedti Grego, Glöer, Erőss & Fehér, 2017	SP	[22]
Plagigeyeria lukai Glöer & Pešić, 2014	SP	[23]
Plagigeyeria montenigrina Bole, 1961	C	[19]
Plagigeyeria zetaprotogona Schütt, 1960	SP, I	[22, 24, 25]
Saxurinator orthodoxus Schütt, 1960	SP	[24]
Saxurinator hadzii (Bole, 1961)	C, SP	[19]
Vinodolia gluhodolica (Radoman, 1973)	SP	[26]
Vinodolia matjasici (Bole, 1961)	SP	[18, 22, 27]
Zeteana ljiljanae Glöer & Pešić, 2014	SP	[23]

Annelida		
Dina absoloni Johansson 1913	C	[28, 29]
Hydrachnidia		
Albaxona lundbladi Motaş & Tanasachi, 1947	I	[30, 31]
Arrenurus haplurus K.Viets, 1925	I	[32]
Atractides pygmaeus (Motaş & Tanasachi, 1948)	I	[33]
Feltria cornuta paucipora Szalay, 1946	I	[30]
Frontipodopsis reticulatifrons Szalay, 1945	I	[30]
Kongsbergia clypeata Szalay, 1945	I	[30, 32]
Lethaxona pygmaea K.Viets, 1932	I	[32]
Neoacarus hibernicus Halbert, 1944	I	[30]
Stygohydracarus subterraneus Walter	C	[34]
Stygohydracarus troglobius Viets, 1932	W	[30]
Stygohydracarus karanovici Pesic, 2001	I, SF	[35]
Stygomomonia latipes Szalay, 1943	I	[30]
Copepoda		
Acanthocyclops venustus stammeri (Kiefer, 1930)	C, I, W	[36]
Bryocamptus pyrenaicus (Chappuis, 1923)	C, I	[36]
Ceuthonectes petkovskii Karanovic, 1999	C	[36, 37]
Diacyclops antrincola Kiefer, 1967	W	[36]
Diacyclops clandestinus (Kiefer, 1926)	SP, SF, C, I	[36]
Diacyclops disjunctus (Thallwitz, 1927)	C, I, W	[36]
Diacyclops hypnicola (Gurney, 1927)	I	[36]
Diacyclops karamani Kiefer, 1932	C	[36]
Diacyclops slovenicus Petkovski, 1954	C, W	[36]
Diacyclops skopljensis Kiefer, 1932	I	[36]
Diacyclops zschokkei (Graeter, 1910)	C, I, W	[36]

(continued)

Table 1 (continued)

Taxa	Habitat	References
Elaphoidella gordani Karanovic, 1998	C	[36, 38]
Elaphoidella montenegrina Karanovic, 1997	C	[36, 39]
Elaphoidella uva Karanovic, 2001	W, SP	[36, 40]
Eucyclops inarmatus Kiefer, 1932	C	[36]
Eucyclops subterraneus (Graeter, 1907)	SP	[36]
Hypocyclops montenegrinus (Karanovic, 2001)	SP	[36, 41]
Acanthocyclops gordani Petkovski, 1971	C	[36]
Metacyclops stammeri Kiefer, 1938	C	[36, 42]
Moraria jana Karanovic, 1997	C, SP	[39]
Nitocrella longa Karanovic, 2000	C	[36, 43]
Speocyclops demetiensis (Scourfield, 1932)	SF, C, I	[36]
Speocyclops hellenicus Lindberg, 1953	C, SP	[36]
Speocyclops italicus Kiefer, 1938	SP	[36]
Stygodiaptomus ferus Karanovic, 1999	C	[36, 44]
Ostracoda		
Candonopsis mareza Karanovic & Petkovski, 1999	SP	[45, 46]
Phreatocandona motasi Danielopol, 1978	I, W	[45]
Pseudocandona cavicola (Klie, 1935)	W	[45]
Pseudocypridopsis clathrata (Klie, 1936)	I, SP, C	[45, 47–49]
Pseudocypridopsis petkovskii Karanovic 2000	C	[45, 49]
Trajancandona natura Karanovic, 1999	C, W	[45, 50]
Trajancandona particula Karanovic, 1999	C	[45, 50]
Trapezicandona hvarensis (Danielopol, 1969)	W, SP	[45]
Typhlocypris skadari Karanovic, 2005	W	[51]
Isopoda		

Monolistra (*Typhlosphaeroma*) sp.	I	[52]
Proasellus anophthalmus (Karaman, 1934)	I, SP	[53, 54]
Sphaeromides virei montenigrina Sket, 1957	C	[55, 56]
Amphipoda		
Bogidiella montenigrina G. Karaman, 1997	C	[57]
Hadzia gjorgjevici crispata G. Karaman, 1969	I	[58, 59]
Metohia carinata Absolon, 1927	C, SP	[60–62]
Niphargus asper G. Karaman, 1972	W	[63]
Niphargus sketi G. Karaman, 1966	C, SP	[64, 65]
Niphargus bilecanus S. Karaman, 1953	C	Unpublished data (leg. T.Delić, Š. Borko, 1.2.2015)
Niphargus inclinatus G. Karaman, 1973	I	[66]
Niphargus vulgaris G. Karaman, 1968	SP	[67]
Niphargus podgoricensis S. Karaman, 1934	I, SP	[68, 69]
Niphargus polymorphus Fišer, Trontelj & Sket, 2006	C	[70]
Niphargus kusceri S. Karaman, 1950	C, I, SP	[69, 71, 72]
Niphargus vranjinae Karaman, 1967	SP	[73]
Niphargus zorae G. Karaman, 1967	C, I	[73]
Synurella intermedia montenegrina G. Karaman, 1974	I, SP, W	[74]
Typhlogammarus mrazeki (Schäferna, 1906)	C, SP	[8, 61, 64, 75, 76]
Decapoda		
Troglocaris (Spelaeocaris) prasence Sket & Zakšek, 2009 (syn. *T. pretneri* p.p.)	C	[77]
Troglocaris (Troglocaridella) hercegovinensis (Babić, 1922)	C	[77]

Abbreviations of habitat names: *C* caves, *I* interstitial waters, *SP* springs, *SF* surface waters, *W* wells. Species names follow Fauna Europaea [9]

The phylum Gastrotricha is represented by one, probably eustygophile species recently described from Obodska pećina [80].

The phylum Annelida is represented by only one stygobiotic species of Hirudinea (*Dina absoloni*, Fig. 4a). This species is also known from other parts of SE Dinarides – Croatia, Hercegovina, and Kosovo [28, 29, 81].

No systematic research of underground oligochaetes in Montenegro has been conducted. Only three Oligochaeta species are reported from cave and interstitial waters, but none of these is a stygobiont [82]. *Haplotaxis gordioides* discovered in Đalovića Cave [82] belongs to the group of eustygophiles.

Subterranean gastropods are represented by 22 stygobiotic species; most of them belong to the family Hydrobiidae. Stygobiotic gastropods have been collected most frequently in springs (20 species) as part of spring thanatocoenoses. As the results about one third of known hydrobiid stygobiotic species is known only from empty shells [83] which makes the taxonomic identification highly unreliable. Stygobiotic snails have been rarely found in interstitial waters, and no species have been recorded from wells. Three species *Plagigeyeria montenigrina* and *Saxurinator hadzii* (both from the cave Obodska pećina in Montenegro [19]) and *Paladilhiopsis prekalensis* (from Zhyla Cave in the Albanian part of the catchment [22]) have been collected within caves. One species, *Plagigeyeria zetaprotogona* has a wider distribution, while most others have been known only from type localities. There are five supposed subspecies of *Plagigeyeria zetaprotogona* which taxonomic status is still not resolved [22].

Water mites (Hydrachnidia) are represented by 12 species which inhabit almost exclusively interstitial waters (Table 1). Only one hydrachnid mite *Stygohydracarus subterraneus* has been reported from cave water [34]. Some water mites i.e., *Torrenticola ungeri*, *Monatractides madritensis*, and *Atractides oblongus*, have been found in interstitial waters through the Lake Skadar Basin, but they are considered as hyporheophilous [32]. Halacaroidea (halacarid mites) is represented with five probably eustygophile species, i.e., *Lobohalacarus weberi*, *Parasoldanellonyx typhlops*, *Soldanellonyx chappuisi*, *S. monardi*, and *S. visurgis*, which have been reported from caves, interstitial waters, and wells

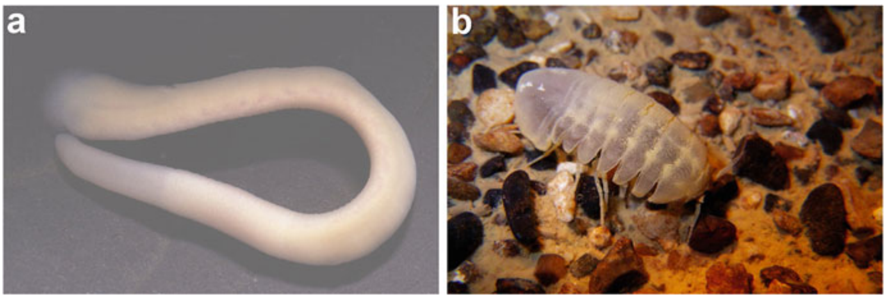

Fig. 4 (**a**) Absolon's leech (*Dina absoloni*), (**b**) underground aquatic isopod *Monolistra* sp. Photos by B. Sket

[84, 85]. *Lobohalacarus weberi* is the most dominant halacarid mite in interstitial waters and wells [83].

Crustacea, which usually dominate in subterranean waters of Balkan Peninsula [7], constitute 59% of all stygobiotic species in Lake Skadar drainage. Among them, Copepoda is the most diverse (25 species) followed by Amphipoda (15 species) and Ostracoda (9 species) (Table 1, Fig. 5).

Subterranean fauna of Copepoda has been intensively studied by Tomislav Karanović. In his dissertation, he listed 116 species and subspecies for the Adriatic drainage area of Montenegro [36], among which about a quarter are stygobionts. All these species, except two mixohaline species of *Halicyclops*, inhabit various subterranean habitats through the Lake Skadar Basin [36]. Most of the subterranean species belong to the order Cyclopoida (17), followed by Harpacticoida (7), while the order Calanoida is represented only by *Stygodiaptomus ferus*, known from the cave Šutimska Jama near Podgorica [44]. The latter cave is one of the hot spots of subterranean copepod diversity and harbors eight stygobiotic species [36].

Subterranean fauna of Ostracoda of Lake Skadar Basin has been intensively studied by Ivana Karanovic [45]. She listed nine stygobiotic species from caves, interstitial waters, and wells through the Lake Skadar Basin [45]. *Candonopsis mareza* is known only from Mareza, a large karst spring near Podgorica [46]. Two genera *Trajancandona* and *Pseudocypridopsis*, each with two species, respectively, are endemic for the Lake Skadar Basin [49, 50].

Subterranean aquatic isopods are recorded from various types of habitats such as caves, interstitial waters, and springs, but their diversity is still insufficiently studied. Only three taxa of aquatic stygobiotic isopods of three families Asellidae, Cirolanidae, and Sphaeromatidae have been recorded from the Lake Skadar catchment area (Table 1). Members of *Proasellus* (Asellidae) are found in interstitial waters and springs in the vicinity of Podgorica. The family Sphaeromatidae includes

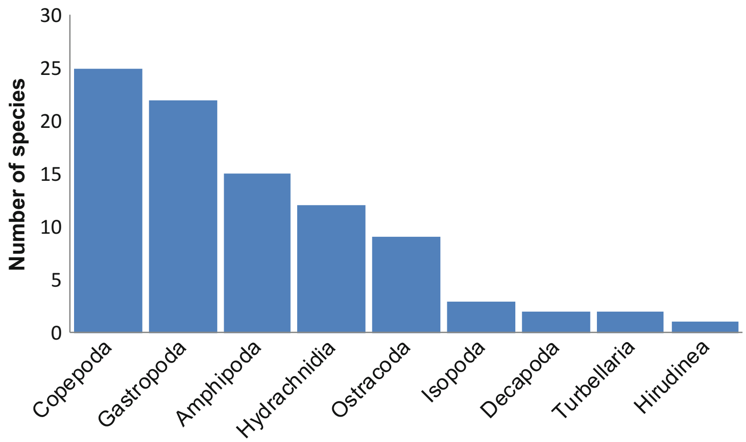

Fig. 5 Number of stygobiotic species from particular taxonomic groups

only one undescribed species of *Monolistra* (Fig. 4b), found in springs at the upper reaches of the Zeta river [52]. The biggest underground aquatic isopod in Montenegro, *Sphaeromides virei montenigrina* (Cirolanidae) (Fig. 6), described in the late 1950s based on a female specimen, recently was rediscovered in an underground lakelet in Obodska pećina, the only known locality of the subspecies [56].

Subterranean fauna of Amphipoda has been intensively studied by Gordan Karaman from the 1960s up to now. Amphipods are an important part of the aquatic subterranean fauna and include 15 stygobiotic species of 5 families: Bogidiellidae (1 species), Crangonyctidae (1 species), Gammaridae (2 species), Hadziidae (1 species), and Niphargidae (10 species). The highest number of stygobiotic species belongs to the genus *Niphargus* widely distributed in the cave waters with seven out of ten taxa endemic for Lake Skadar Basin. The five species (*Metohia carinata*, *Typhlogammarus mrazeki*, *Niphargus bilecanus*, *N. polymorphus*, and *N. kusceri*) have a wider distribution [86]. The spring-dwelling amphipod *Synurella ambulans* has been repeatedly observed in springs and subterranean waters in the area around Lake Skadar and Podgorica [86] and can be treated as eutroglophile species having troglomorphic and troglobiotic subterranean populations.

The shrimp family Atyidae is represented by two stygobiotic species of the genus *Troglocaris*, i.e., *T. hercegovinensis*, known with certainty only in eastern Hercegovina and southern Montenegro, and *T. prasence* known also from Bosnia and Herzegovina. Both inhabit here the cave Obodska pećina [77].

The mention of the cave salamander (*Proteus anguinus*) [6] from Montenegro is very questionable and is discussed in the biogeography paragraph. This species inhabits subterranean waters of the Dinarides, and it is known from Slovenia, the Trieste region in Italy, Croatia, and Bosnia and Herzegovina [87].

Fig. 6 The troglobiotic isopod *Sphaeromides v. virei*, a relative of *S. v. montenigrina*, found till now only in Obodska pećina. Photo B. Sket

3 Species Richness and Endemism of Stygobiotic Species in Particular Subterranean Habitats

Crustacea are the most diverse group in cave waters with Copepoda (18 species) representing almost 44% of the total stygobiotic species that inhabit this habitat. The most frequently collected copepod species in the cave waters of the Lake Skadar Basin is the harpacticoid *Bryocamptus pyrenaicus* [36]. Eight stygobiotic copepod species exclusively inhabit cave waters [36] (Table 1). Among them four species are endemics of the Lake Skadar drainage basin (South Dinaric region sensu Karanovic [36]), i.e., harpacticoids *Ceuthonectes petkovskii*, *Elaphoidella gordani*, and *E. montenegrina* and the calanoid *Stygodiaptomus ferus* [36].

The second group which is richly represented in cave waters is Amphipoda. By far the most diverse genus in the cave waters is *Niphargus* [88], but species of this genus have been collected in springs and interstitial waters also. The species of Bogidiellidae (*Bogidiella montenigrina*) have been reported only from cave waters (Table 1).

The four stygobiotic species of Ostracoda have been found in cave waters throughout the Lake Skadar Basin [45]. Among them three species are endemics known only from its *locus typicus*, i.e., *Pseudocypridopsis petkovskii* and *Trajancandona particula*, both described from the cave Šutimska Jama near Podgorica, and *T. natura* known from the cave Cetinjska pećina [49, 50].

The other groups are much less represented in cave waters. It is worth to note that all stygobiotic species known for the Lake Skadar Basin which belong to Turbellaria, Hirudinea (*Dina absoloni*), and decapod shrimp family Atyidae have been collected from cave waters.

From interstitial waters, altogether 28 stygobiotic species have been reported (Fig. 7). Most of them belong to true water mites Hydrachnidia (12 species) and Copepoda (8 species). Most frequent water mites in interstitial waters are *Stygomomonia latipes*, *Lethaxona pygmaea*, *Feltria cornuta paucipora*, *Kongsbergia clypeata*, and *Frontipodopsis reticulatifrons* [32]. Copepod species

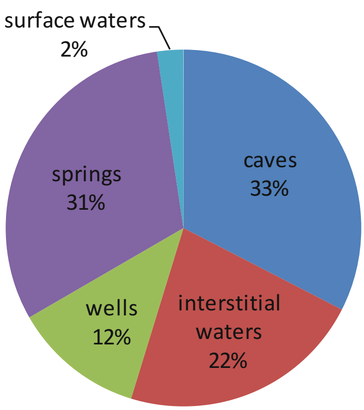

Fig. 7 Percentage of stygobiotic species in particular habitats of the Lake Skadar Basin

Diacyclops hypnicola and *D. skopljensis* are characteristic for interstitial water, and they are not found in other types of subterranean habitats [36]. The most frequent copepod species in interstitial water through the Lake Skadar Basin is *Diacyclops disjunctus* [36]. Interstitial fauna of the Lake Skadar Basin does not exhibit marked endemicity. Among the species which are typical inhabitants of hyporheic interstitial, only water mite *Stygohydracarus karanovici* is endemic for Montenegro [35].

The wells are separated in the special type of subterranean habitat, despite the fact that the wells represent access to interstitial waters. They contain specific fauna including typical stygobiotic species, although this habitat has been only scarcely studied [36]. Altogether 14 stygobiotic species have been reported from wells, most of them belong to Copepoda (6 species). The calanoid copepod *Mixodiaptomus tatricus* was reported from this type of habitat in the area of Lake Skadar Basin [36]. *Stygohydracarus troglobius*, the first described subterranean water mite collected by Stanko Karaman from a well near Skopje [89], is the only water mite found in the sample taken from wells of the Lake Skadar Basin [30]. The only endemic species found in this type of subterranean habitat is *Typhlocypris skadari* (Ostracoda) known from a well in Golubovci [51].

Additional field work and more intensive studies of stygobiotic species are highly needed for an appropriate evaluation of the richness and endemism of subterranean fauna in particular aquatic habitats of the Lake Skadar Basin. This is especially true for interstitial waters and wells which are threatened by pollution and other types of anthropogenic threats. For example, Karanović [36] in his dissertation mentioned that *Attheyella dentata*, a copepod species reported by Kiefer [90] from the spring of Ribnica river in Podgorica, probably has disappeared from the studied area as the results of competition with *A. wulmeri*, while some other species such as stygobiotic *Acanthocyclops gordani* is on the brink of extinction.

4 Fauna of the Cave Obodska Pećina

A locality with the richest number of aquatic troglobiotic species in Montenegro appeared to be the cave Obodska pećina (=Crnojevića pećina) near Rijeka Crnojevića, Cetinje. This is a periodic resurgence of waters sinking in Cetinjsko polje. Ponors (sinks) are ca 10 km upstream from the cave; besides the natural waste, they are draining also some urban waste from Cetinje [91, 92].

The influence of the surface hydrosystem is strongly seasonal; during dry months, the cave evidently contains only clear waters from the surrounding karst fissure system. Neither plant debris nor surface animals have been noticed at our visits. We were only visiting the cave in dry periods, when water is clear to slightly turbid (visibility 1 m [56]). Reportedly, during and after rainy periods, the water is muddy.

The first faunistic report on Obodska pećina was given by Remy [10]. He obtained "sous les pierres" Amphipoda, Mollusca, Turbellaria, and Spongiaria. Fortunately, with species names for Turbellaria, which were all trogloxene to eutroglophile, *Dendrocoelum nausicaae*, *Crenobia montenigrina*, and *Euplanaria* *lugubris*; neither the sessile(!) sponges nor any turbellarians were found again during our visits in recent times (after 1960). Novak [18] listed Amphipoda, Copepoda, and dipteran larvae (Chironomidae), besides a number of gastropods.

The only comparatively numerous animals were sometimes Gastropoda *Plagigeyeria*. At our first visits, we were always finding just one individual of crustaceans (shrimps or amphipods) only, but each time another species. In the very recent years, the numbers are slightly higher, but all animal species have been troglobiotic.

The faunistic list numbers 10 species of terrestrial and 13 species of aquatic troglobionts (Table 2). Stygobionts are very diverse but scarce in individual numbers, as it is a norm at poor resources. *Sphaeromides virei montenigrina*, after the first finding in the 1950s [55], was first found again in 2017 [56], in spite of a thorough search during more than ten visits to the cave. Also amphipods and shrimps have been found in scarce or single specimens. More numerous can be gastropods with two troglobiotic (*Plagigeyeria montenigrina*, *Saxurinator hadzii*) and one eutroglophile (*Litthabitella chilodia*) species.

The best represented group is Amphipoda with three *Niphargus* spp. [*N. kusceri* (Fig. 8), *N. bilecanus*, *N. polymorphus*] and two troglobiotic and troglomorphic species of Gammaridae (*Metohia carinata*, *Typhlogammarus mrazeki*). Isopoda are only represented by the abovementioned predatory species, while no *Monolistra* has ever been found. Decapoda are represented by two troglobiotic shrimp species [77], which is a comparatively rare case for one cave; their branchial cavities are infested by tiny epizoic or parasitic Temnocephalida flatworms (*Troglocaridicola spelaeocaridis*) [79].

5 Biogeographic Character of Troglobiotic Fauna of the Lake Skadar/Shkodra Basin

The troglobiotic fauna of the Dinaric (or West Balkan) area exhibits some characteristic patterns [93]. A *transdinaric* distribution can scarcely be perceived in Montenegrin species as it is mainly possible in eutroglophile species with a wide distribution on surface (like *Asellus aquaticus*; [94]). If *Proasellus karamani* occurs in caves as it does in the neighbor Hercegovina, this is such a species. An entirely troglobiotic transdinaric element is the isopod (Sphaeromatidae) genus *Monolistra* [52] with numerous endemic species between the Italian Alpino-Dinarides and the northernmost Albania, represented also in Montenegro. Transdinaric troglobiotic elements are also copepods *Metacyclops stammeri* and *Speocyclops italicus* [36].

Much more numerous are the evidenced narrowly endemic species, sometimes with single known localities. Such are numerous copepods and ostracods (i.e., *Ceuthonectes petkovskii*, *Elaphoidella gordani*, *E. montenegrina*, *Stygodiaptomus ferus*, *Pseudocypridopsis petkovskii*), but only seldom we can assure their endemicity with certainty since our knowledge of the local fauna is far too low for some

Table 2 Fauna of the cave Obodska pećina, mainly from SubBio (Ljubljana University); supposed status: *tx* trogloxene, *stp* subtroglophile, *etp* eutroglophile, *tb* troglobiont (incl. stygobiont)

Aquatic fauna	
Porifera	
Spongillidae	tx, etp
Turbellaria	
Dendrocoelum nausicaae O. Schmidt	tx, etp
Crenobia montenigrina Mrazek	tx, etp
Euplanaria lugubris O. Schmidt	tx, etp
Troglocaridicola spelaeocaridis Matjašič	tb
Gastrotricha	
Chaetonotus antrumus Kolicka	?etp
Gastropoda	
Litthabitella chilodia (Westerlund)	etp
Plagigeyeria montenigrina Bole	tb
Saxurinator hadzii (Bole)	tb
Vinodolia matjasici (Bole)	tb
Iglica absoloni (A.J. Wagner)	tb
(?) *Adriohydrobia* sp.	?etp
Amphipoda	
Metohia carinata Absolon	tb
Typhlogammarus mrazeki Schäferna	tb
Niphargus bilecanus S. Karaman	tb
Niphargus kusceri S. Karaman	tb
Niphargus polymorphus Fišer, Trontelj & Sket	tb
Niphargus sp.	
Isopoda	
Sphaeromides virei montenigrina Sket	tb
Decapoda	
Troglocaris hercegovinensis (Babić)	tb
Troglocaris prasence Sket & Zakšek	tb
Terrestrial fauna	
Gastropoda	
Agardhiella formosa (L. Pfeiffer, 1848)	tx
Agardhiella skipetarica (A.J. Wagner, 1914)	? tb
Spelaeodiscus obodensis Bole	? tb
Spelaeodiscus unidentatus Bole	? tb
Araneae	
Folkia mrazeki Nosek	tb
Stalita sp.	tb
Isopoda	
Cyphonethes herzegowinensis (Verhoeff)	tb
Diplopoda	
Apfelbeckia sp.	etp

(continued)

Table 2 (continued)

Brachydesmus subterraneus Heller	etp
Collembola	
Onychiuridae	
Heteromurus (*Verhoeffiella*) sp.	?tb
Coleoptera	
Anthroherpon sp.	tb
Neotrechus s. suturalis (Schaufuss)	tb
Laemostenus cavicola (Schaum)	etp
Speonesiotes sp.	tb
Diptera	
Limoniidae	stp
Mammalia	
Myotis blythii (Tomes)	stp
Myotis capaccinii (Bonaparte)	stp

Fig. 8 *Niphargus kusceri* is only one species from the diversity of its genus. Photo: T. Delić

conclusions. Narrowly endemic seems to be the ostracod genus *Trajancandona*. Less strictly endemic are the amphipod *Metohia carinata* [61] and the shrimp *Troglocaris (Spelaeocaris) prasence* [77], both known only from Montenegro and southern Hercegovina.

The prominent intra-Dinaric distribution areas or distribution patterns are the paralittoral, northwestern merodinaric, and southeastern merodinaric areas and the inappropriately named holodinaric area [93], corrected in [95].

Paralittoral are copepods *Diacyclops antrincola* and *Acanthocyclops gordani*. Species are spread along the Adriatic coast between Istra and Montenegro, with mixohaline and freshwater populations.

The *SE merodinaric* area includes the karst in the extreme NW of Albania, most of Montenegro, Bosnia and Herzegovina, Dalmacija, and the Croatian Lika, where its faunistic elements interdigitate with some NW merodinaric elements. In

Montenegro, a SE merodinaric element is the large amphipod *Typhlogammarus mrazeki*, both shrimp subgenera *Troglocaris (Troglocaridella)* and *T. (Spelaeocaris)*, isopod *Proasellus anophthalmus s. lat.*, and the troglobiotic leech *Dina absoloni*. Most probably SE merodinaric distribution exhibits also the diverse gastropod genus *Plagigeyeria*, with some more narrowly endemic species.

The *holodinaric area*, or distribution pattern, was named when we presumed that the absence of some elements in the far SE of Dinarides was fictitious, caused by our poor knowledge; we were supposing that some species or groups are factually present in the whole area of the Dinaric karst [93]. Nevertheless three copepod species, i.e., *Diacyclops karamani*, *D. slovenicus*, and *Eucyclops subterraneus* [36], exhibit the "classical" holodinaric distribution. It is worth to note that these are tiny animals which might be easily distributed through the fissure systems. Otherwise, it surprisingly appeared that the SE border of the distribution areas of some species or groups funnily coincided with the administrative NW border of Montenegro [95]. The most geographically illustrative examples are *Niphargus steueri s.l.* [96] and the shrimp subgenus *Troglocaris (Troglocaris)* [97]. The others are the polychaete *Marifugia*, the hydrozoan *Velkovrhia*, the bivalvian aggregate *Mytilopsis kusceri* (syn. *Congeria k.*), and the amphibian *Proteus* [78, 98].

There are a couple of reasons why we can hardly accept the presence of *Proteus* in Montenegro. Its presence in Montenegro has been only mentioned as an inscription to a figure [6]; no exact locality was given anywhere. The rostrum of shrimps from the Lake Skadar Basin is shortened, as it is in all shrimp populations where *Proteus* is absent [99]. Moreover, the dorsal spines of *Metohia carinata* in Obodska pećina are also reduced [61] which might be for the same reason as the shrimp's disarming. Most probably, the mention of *Proteus* in Montenegro [6] is a mistake.

Acknowledgments We thank Teo Delić for permission to use his photo.

References

1. Barović G, Spalević V, Pešić V, Vujačić D (2018) Physical and geographical characteristics of Skadar Lake Basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer International Publishing AG, Cham, Switzerland
2. Gunn J (ed) (2004) Encyclopedia of caves and karst science. Taylor & Francis, London, UK
3. Culver DC, Pipan T (2011) Shallow subterranean habitats: ecology, evolution, and conservation. Oxford University Press, Oxford
4. Gutjahr S, Schmidt SI, Hahn HJ (2014) A proposal for a groundwater habitat classification at local scale. Subterranean Biol 14:25–49
5. Sket B (2008) Can we agree on an ecological classification of subterranean animals? J Nat Hist 42(21–22):1549–1563
6. Ćurčić BPM, Decu V, Juberthie C (2008) Cave-dwelling invertebrates in Montenegro. In: Makarov SE, Dimitrijević RN (eds) Advances in arachnology and developmental biology. Papers dedicated to Prof. Dr. Božidar Ćurčić. Inst Zool, Belgrade; BAS, Sofia, Fac Life Sci, Vienna; SASA, Belgrade & UNESCO MAB Committee, Serbia. Vienna-Belgrade-Sofia, Monographs 12, pp 35–55

7. Sket B, Paragamian K, Tontelj P (2004) A census of the obligate subterranean fauna of the Balkan Peninsula. In: Griffith HI (ed) Balkan biodiversity. Kluwer Academic, Dordrecht, pp 309–322
8. Schäferna K (1906) O novem slepem blesivci *Typhlogammarus* n. sbg. Vestnik Kralovske Ceske Spolecnosti Nauk, Praha 26:1–25
9. Fauna Europea. http://www.faunaeur.org. Accessed 1 Feb 2018
10. Remy PA (1953) Description des grottes Yougoslaves. Glasnik Prirodnjačkog muzeja srpske zemlje, Beograd, B 5-6:175–232
11. Matjašič J (1959) Morfologija, Biologija in Zoogeografija evropskih Temnocefalov in Njihov sistematski pilozaj. Slovenska akad. Znanosti. Umetnosti, Ljubjana, Classes IV: Historia naturalis et medicina. Razprave Dissertationes V, pp 143–181
12. Boeters H, Glöer P, Pešić V (2014) *Arganiella tabanensis* n. sp. from Montenegro (Mollusca: Gastropoda: Hydrobiidae). Ecol Mont 1(3):131–139
13. Radoman P (1973) New classification of fresh and brackish water Prosobranchia from the Balkans and Asia minor. Prirodnjacki Muzej u Beogradu, Posebna Izdanja 32:3–30
14. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
15. Glöer P, Grego J, Erőss ZP, Fehér Z (2015) New records of subterranean and spring molluscs (Gastropoda: Hydrobiidae) from Montenegro and Albania with the description of five new species. Ecol Mont 4:70–82
16. Glöer P, Pešić V (2014) New subterranean freshwater gastropods of Montenegro (Mollusca: Gastropoda: Hydrobiidae), with description of one new genus and two new species. Ecol Mont 1(4):244–248
17. Bole J, Velkovrh F (1986) Mollusca from continental subterranean aquatic habitats. In: Botosoneanu P (ed) Stygofauna mundi, Leiden, pp 177–208
18. Novak T (1977) Po največjih črnogorskih jamah. Proteus 40(1):40–44
19. Bole J (1961) Nove hidrobide (Gastropoda) iz podzemeljskih voda zahodnega Balkana. (Neue Hydrobiiden (Gastropoda) aus den unterirdischen Gewässern Westbalkans). Biološki Vestnik 9:59–69
20. Pešić V, Glöer P (2012) A new species of *Bythiospeum* Bourguignat, 1882 (Hydrobiidae, Gastropoda) from Montenegro. Biol Nyssana 3:17–20
21. Pešić V, Glöer P (2013) *Montenegrospeum*, a new genus of Hydrobiid snails (Gastropoda: Risooidea) from Montenegro. Acta Zool Bulg 64(4):565–566
22. Grego J, Glöer P, Erőss ZP, Fehér Z (2017) Six new subterranean freshwater gastropod species from northern Albania and some new records from Albania and Kosovo (Mollusca, Gastropoda, Moitessieriidae and Hydrobiidae). Subterr Biol 23:85–107
23. Glöer P, Pešić V (2014) New subterranean freshwater gastropods of Montenegro (Mollusca: Gastropoda: Hydrobiidae). Ecol Mont 1(2):82–88
24. Schütt H (1960) Neue Höhlenschnecken aus Montenegro. Arch Molluskenkd 89(4–6):145–152
25. Reischütz A, Reischütz PL (2008) Neue Hydrobiiden (Gastropoda, Prosobranchia, Hydrobiidae) aus dem Becken des Skutari-Sees (Montenegro/Albanien). Basteria 72:143–145
26. Radoman P (1973) Anagasta un nouveau genre Prosobranchia et sa spéciation dans la bassin du lac Skadar. Zool Anz 190:421–429
27. Bole (1961) Nove vrste podzemeljskih polžev iz Črne Gore. II Jugoslovenski Speološki Kongres Zagreb, pp 205–207
28. Sket B (1968) K Poznavanju Favne Pijavk (Hirudinea) v Jugoslaviji, Zur Kenntnis der Egel-Fauna (Hirudinea) Jugoslawiens. Academia Scientiarum et Artium Slovenica Classis IV: Historia Naturaliset Medicina Diss 9(4):127–197
29. Grosser C, Pešić V, Gligorović B (2015) A checklist of the leeches (Annelida: Hirudinea) of Montenegro. Ecol Mont 2(1):20–28
30. Pešić V (1999) Contribution to the knowledge of Hydracarina (water mites) of Montenegro. Poljoprivreda i šumarstvo 45(3–4):83–96

31. Pešić V, Gerecke R (2003) Water mites of the genera A*lbaxona, Axonopsis, Barbaxonella* and *Erebaxonopsis* (Acari, Hydrachnidia: Aturidae: Axonopsinae) from Central Europe and Mediterranean area. Arch Hydrobiol 139(4):563–576
32. Pešić V, Smit H, Gerecke R, Di Sabatino A (2010) The water mites (Acari: Hydrachnidia) of the Balkan peninsula, a revised survey with new records and descriptions of five new taxa. Zootaxa 2586:1–100
33. Pešić V (2003) On some very interesting water mite species (Acari, Actinedida) from Crna Gora (Montenegro), new for the Balkan peninsula and Mediterranean region. Nat Monteneg 1:89–98
34. Smit H, Pešić V (2004) New records of the families Arrenuridae, Nudomideopsidae and Athienemanniidae (Acari: Hydrachnidia) from Macedonia and Yugoslavia. Acta Entomol Serb 7(1–2):137–146
35. Pešić V (2001) *Stygohydracarus karanovici* sp. n., and *Atractides inflatipes* Lundblad, 1956, two water mites species (Acari: Hydrachnidia) from (SE Europe). Zootaxa 17:1–7
36. Karanović T (1999) Taksonomska, Zoogeografska i Ekološka studija Kopepoda (Crustacea, Copepoda) kontinentalnih voda Jadranskog Sliva Crne Gore. Disertation, University of Novi Sad
37. Karanovic T (1999) *Ceuthonectes petkovskii*, a new species of harpacticoid copepod from Montenegro (Crustacea, Canthocamptidae). Bull Zool Mus Univ Amsterdam 16(14):97–102
38. Karanovic T (1998) Two interesting species of the genus Elaphoidella Chappuis, 1929 (Crustacea, Copepoda) from Balkan Peninsula. Mém de Biospéol 25:25–33
39. Karanovic T (1997) Two new species of harpacticoid copepods (Copepoda, Harpacticoida, Canthocamptidae) from Montenegro (Balkan Peninsula). Bull Zool Mus Univ Amsterdam 16:1–9
40. Karanovic T (2001) *Elaphoidella uva* n. sp. (Crustacea, Copepoda) and two other interesting species of the genus *Elaphoidella* from Montenegro (SE Europe). Beaufortia 51:57–74
41. Karanovic T (2001) Description of *Allocyclops montenegrinus*, spec. nov. and a revision of the genus *Allocyclops* Kiefer, 1932 (Crustacea, Copepoda, Cyclopoida). Spixiana 24(1):19–27
42. Karanovic T (1999) First record of *Metacyclops stammeri* Kiefer, 1938 from Balkan Peninsula (Crustacea, Copepoda). Spixiana 22:193–198
43. Karanovic T (2000) *Nitocrella longa* n. sp. (Crustacea, Copepoda, Harpacticoida) from subterranean waters of Montenegro (SE Europe). Mitt Mus Naturkunde Berl, Zoolog Reihe 76 (1):75–83
44. Karanovic T (1999) A new stygobitic Calanoida (Crustacea: Copepoda) of the genus *Stygodiaptomus* Petkovski, 1981 from the Balkan Peninsula. Proc Biol Soc Wash 112 (4):682–686
45. Karanović I (1999) Fauna Ostrakoda (Ostracoda, Crustacea) Sliva Skadarskog Jezera. Disertation, University of Novi Sad
46. Karanovic I, Petkovski T (1999) Two new species of the subfamily Candoninae (Ostracoda) from Montenegro (SE Europe). Crustaceana 72:603–616
47. Klie W (1936) Neue Ostracoden aus Jugoslavien. Glasnik Skopskog Naucnog Drustva 17:143–150
48. Karanovic I (1999) On *Pseudocypridopsis* n. gen., with a redescription of *Pseudocypridopsis* clathrata (Klie, 1936) and a first description of the male (Ostracoda, Cypridopsinae). Bull Zool Mus Univ Amst 17(1):1–6
49. Karanovic I (2000) *Pseudocypridopsis petkovskii* sp. nov., a stygobiont freshwater ostracod (Crustacea, Ostracoda, Cypridopsinae) from Montenegro (SE Europe). Mitt Hamb Zool Mus Inst 97:59–66
50. Karanovic I (1999) A new genus and two new species of Candoninae (Crustacea, Ostracoda) from Montenegro (SE Europe). Mém de Biospéol 26:47–57
51. Karanovic I (2005) On the genus *Typhlocypris* Vejdovsky, 1882 (Crustacea: Ostracoda: Candoninae), with description of two new species. Syst Biodivers 3(4):375–406

52. Sket B (1986) Isopoda: Sphaeromatidae. In: Botosaneanu L (ed), Stygofauna Mundi. A Faunistic, distributional and ecological synthesis of the world Fauna inhabiting subterranean waters (including the marine interstitial). E. J.Brill/Dr. W. Backhuys, Leiden, pp 423–427
53. Karaman S (1934) Beitrage zur Kenntnis des Isopoden-Familie Microparasellidae. Mitteilungen über Höhlen- und Karstforschung 1934:42–44
54. Sket B (1965) Ostliche Gruppe der Monolistrini (Crust., Isopoda) 2. Biologischer Tiel. Int J Speleol 1:249–267
55. Sket B (1957) Einige neue formen der Malacostraca (Crust.) aus Jugoslawien. Bull Scient 3 (3):70–71
56. Delić T, Sket B (2015) Found after 60 years: the hows and whys of *Sphaeromides virei montenigrina* (Crustacea: Isopoda: Cirolanidae) rediscovery in Obodska pećina, Montenegro. Natura Sloveniae 17(2):59–65
57. Karaman GS (1997) Contribution to the knowledge of the Amphipoda 217. *Bogidiella montenigrina*, *n. sp.* (Gammaridea, fam. Bogidiellidae), one new species from Crna Gora. The Montenegrin Academy of Sciences and arts, Glasnik of the section of natural. Sciences 11:29–44
58. Karaman GS (1969) XXI Beitrag zur Kenntnis der Amphipoden. Die Gattung *Hadzia* Kar. In: Jugoslawien. Acta Mus Macedonici Sci Nat 11(9):163–167
59. Karaman GS (1984) 133. Contribution to the knowledge of the Amphipoda. New data on a genus *Hadzia* S. Kar. In: Yugoslavia. Poljoprivreda i šumarstvo 30(1):13–31
60. Absolon K (1927) Les grandes amphipodes aveugles dans les grottes Balkaniques. Compte rendu de la 51e Session, Association Francaise pour l'Avancement des. Sciences 51:291–295
61. Karaman GS (1974) Contribution to the knowledge of the Amphipoda. Genus *Metochia* Abs. In: Yugoslavia and its relation to the genera *Typhlogammarus* Schaf. and *Accubogammarus* n. gen. Poljoprivreda i šumarstvo 20(1):43–57
62. Karaman GS (2000) On three interesting subterranean amphipods (Crustacea, Amphipoda) from Balkan Peninsula (contribution to the knowledge of the Amphipoda 238). Glasnik Odjeljenja prirodnih nauka, Crnogorska akademija nauka i umjetnosti 13:223–236
63. Karaman GS (1972) 37. Contribution to the knowledge of the Amphipoda. *Niphargus asper*, n. sp., Echinogammarus foxi (Schell.) and E. Stocki G. Kar. (fam. Gammaridae) from Yugoslavia. Acta Musei Macedoni 13:1–17
64. Sket B (1958) Einige interessante funde der Malacostraca (Crust.) aus der Herzegowina und Crna Gora. Bull Sci 4(2):53
65. Karaman GS (1966) III. Beitrag zur Kenntnis der Amphipoden aus Crna Gora. Arch Biol Sci Belgrade 18(2):29–30
66. Karaman GS (1973) XLVII. Contribution to the knowledge of the Amphipoda. Two new Niphargus species from Crna Gora (Montenegro), *N. inclinatus* n. sp. and *N. boskovici alatus* n. ssp. Period Biol 75(2):275–283
67. Karaman GS (1968) II. Beitrag zur Kenntis der Amphipodenfauna von Crna Gora (Montenegro). Fragmenta. Balcanica 4:109–118
68. Karaman S (1934) VI Beitrag zur Kenntnis jugoslawischer Suesswasseramphipoden. Zool Anz 107:325–333
69. Karaman GS (1984) 130. Contribution to the knowledge of the Amphipoda. Revision of the *Niphargus orcinus*-group, part I. (fam. Niphargidae). The Montenegrin Academy of Sciences and Arts: Glasnik of the Section of Natural. Sciences 4:7–79
70. Fišer C, Sket B, Trontelj P (2008) A phylogenetic perspective on 160 years of troubled taxonomy of Niphargus (Crustacea: Amphipoda). Zool Scr 37:665–680
71. Karaman GS (1967) IV. Beitrag zur Kenntnis der Niphargus-arten (Amphipoda, Gammaridea) aus Crna Gora (IV Prilog poznavanju amfipoda Amphipoda, Gammaridea) Crne Gore. Poljoprivreda i šumarstvo 13(1–2):1–12
72. Fišer C, Zagmajster M, Zakšek V (2013) Coevolution of life history traits and morphology in female subterranean amphipods. Oikos 122:770–778

73. Karaman GS (1967) I. Beitrag zur Kenntnis der Niphargus-arten (Amphipoda, Gammaridea) aus Crna Gora (Montenegro). Fragmenta. Balcanica 6:73–80
74. Karaman GS (1974) 58. Contribution to the knowledge of the Amphipoda. Genus *Synurella* Wrzes in Yugoslavia with remarks on its all world known species, their synonymy, bibliography and distribution (Fam. Gammaridae). Poljoprivreda i šumarstvo 20(2–3):83–133
75. Karaman GS (2001) Comparative analysis of Amphipoda fauna (Crustacea) from Bor region (Serbia) and Crna Gora (contribution to the knowledge of Amphipoda 240). Ekološkaistina 9:300–303
76. Karaman GS (2016) On two new or interesting Amphipoda from Italy and Montenegro (contribution to the knowledge of the Amphipoda 290). Ecol Mont 8:1–16
77. Sket B, Zakšek V (2009) European cave shrimp species (Decapoda: Caridea: Atyidae), redefined after a phylogenetic study; redefinition of some taxa, a new genus and four new *Troglocaris* species. Zool J Linn Soc 155:786–818
78. Sket B (1999) Diversity and singularity of hypogean fauna in the Dinaric region. Abstracts 14th international symposium biospeleology, Makarska, pp 21–25
79. Matjašič J (1990) Monography of the family Scutariellidae (Turbellaria, Temnocephalidea). SAZU, Ljubljana, pp 1–166
80. Kolicka M, Gadawski P, Dabert M (2017) A new species of freshwater Chaetonotidae (Gastrotricha, Chaetonotida) from Obodska Cave (Montenegro) based on morphological and molecular characters. Eur J Taxon 354:1–30
81. Grosser C, Pešić V, Lazarević P (2015) A checklist of the leeches (Annelida: Hirudinida) of Serbia, with new records. Fauna Balkana 3:71–86
82. Jablonska A, Pešić V (2011) Five aquatic Oligochaeta species new for the fauna of Montenegro. Turk J Zool 35:119–121
83. Pešić V, Gadawski P, Gligorović B, Glöer P, Grabowski M, Kovács T, Murányi D, M Płóciennik M (2018) The diversity of the Zoobenthos communities of the Lake Skadar/Shkodra Basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer International Publishing AG, Cham, Switzerland
84. Pešić V (2004) New records of Halacarid mites (Acari, Halacaroidea) from Crna Gora. In: Pešić V (ed) The biodiversity of the Biogradska Gora National Park. Monographs I, Department of Biology, University of Montenegro & Centre for Biodiversity of Montenegro, pp 96–103
85. Pešić V, Petrović D (2003) Second contributions to the knowledge of Halacarid mites (Acari, Halacaroidea) from Yugoslavia: the first finding of *Parasoldanellonyx typhlops* Viets, 1933, and new data of *Soldanellonyx chappuisi* Walter, 1917. Poljoprivreda i šumarstvo 48 (1–2):99–102
86. Karaman GS (1997) Fauna of Amphipoda (Crustacea, Malacostraca) of Skadar Lake Basin and its vicinity (228. Contribution to the Knowledge of the Amphipoda). In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera. CANU, Naučni skupovi, Knjiga 44, pp 225–234
87. Sket B (1997) Distribution of *Proteus* (Amphibia: Urodela: Proteidae) and its possible explanation. J Biogeogr 24:263–280
88. Karaman GS, Ruffo S (1986) Amphipoda: Niphargus-Group (Niphargidae sensu Bousfield, 1982). In: Botosaneanu L (ed) Stygofauna Mundi. A Faunistic, distributional and ecological synthesis of the world Fauna inhabiting subterranean waters (including the marine interstitial). E. J.Brill/Dr. W. Backhuys, Leiden, pp 514–534
89. Viets K (1932) Die erste stygobionte Wassermilbe. Arch Hydrobiol 23:677–684
90. Kiefer F (1937) Die freilebenden Ruderfusskrebse (Crustacea, Copepoda) Jugoslawiens. Bull Soc Sci Skopje 48:77–105
91. Ferk M (2008) Obodska pećina. Bilten jamarskega kluba Železničar 26:77–79
92. Radna grupa za vode (2012) Procjena ekološki prihvatljivog protoka za rijeku crnojevića. faza i: izvještaj o testiranju metodologija za potrebe izrade pravilnika o ekološki rihvatljivom protoku. http://www.greenhome.co.me/fajlovi/greenhome/attach_fajlovi/lat/glavne-stranice/2014/12/pdf/Procjena_ekoloki_prihvatljivog_protoka_za_Rijeku_Crnojevica.pdf. Accessed 8 Feb 2018

93. Sket B (1994) Distribution patterns of some Crustacea in the territory of former Yugoslavia. Hydrobiologia 287:65–75
94. Sket B (1994) Distribution of *Asellus aquaticus* (Crustacea: Isopoda: Asellidae) and its hypogean populations at different geographic scales, with a note on *Proasellus istrianus*. Hydrobiologia 287:39–47
95. Sket B, Zagmajster M (2006) Subterranean fauna of Montenegro: its biodiversity and biogeographical character. In: Pešić V, Hadžiabalahović S (eds) The book of abstracts and programme, II international symposium of ecologists of montenegro, Kotor, 20–25.09.2006, p 23
96. Fišer C, Zakšek V, Zagmajster M, Trontelj P, Sket B (2007) Taxonomy and biogeography of Niphargus steueri (Crustacea: Amphipoda). Limnology 8:297–309
97. Jugović J, Jalžić B, Prevorčnik S, Sket B (2012) Cave shrimps *Troglocaris* s. str. (Dormitzer, 1853), taxonomic revision and description of new taxa after phylogenetic and morphometric studies. Zootaxa 3421:1–31
98. Sket B (2005) Dinaric karst, diversity in. In: Culver DC, White WB (eds) Encyclopedia of caves. Elsevier Academic Press, Oxford, pp 158–165
99. Jugovic J, Prevorčnik S, Aljančič G, Sket B (2010) The atyid shrimp (Crustacea: Decapoda: Atyidae) rostrum: phylogeny versus adaptation, taxonomy versus trophic ecology. J Nat Hist 44 (41–42):2509–2533

The Ichthyofauna of Lake Skadar/Shkodra: Diversity, Economic Significance, Condition, and Conservation Status

Drago Marić

Contents

Abstract The freshwater ichthyofauna of Lake Skadar/Shkodra consists of 59 species belonging to 18 families (17 of which are native), including diadromous, euryhaline, and introduced ones. Of these, 44 are native to the watershed, whereas 15 are introduced. Seven species are endemic (now present): *Ninnigobius montenegrensis*, *Knipowitschia montenegrina*, *Barbatula zetensis*, *Rutilus albus*, *Gobio skadarensis*, *Salmo zetensis*, *Alosa* sp., and *Chondrostoma scodrense* – extinct (EW). The most diverse family is Cyprinidae with 24 (of which 16 are native = 36.3%) species, followed by Mugillidae (5), and Gobiidae (4).

Fish in this watershed have significant economic potential. The following species are fished and can be fished for the commercial purposes (economic fishery): Bleak (*Alburnus scoranza*), Carp (*Cyprinus carpio*), Skadar Rudd (*Scardinius knezevici*), Skadar Chub (*Squalius platyceps*), Goldfish (*Carassius auratus*), Ohrid Nase (*Chondrostoma ohridanum*), Eel (*Anguilla anguilla*), Spotted Roach (*Pachychilon pictum*), Yellow Roach (*Rutilus prespensis*), White Roach (*R. albus*), Mugilidae, species of the genus *Alosa*, Sea Bass (*Dicentrarchus labrax*), European Perch (*Perca fluviatilis*), and Flounder (*Pleuronectes flesus*) as well as scrap fish – others. In the past, as much as 1,500–2,000 tons used to be fished each year, whereas less than 1/3

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 363–382, DOI 10.1007/698_2018_238,
© Springer International Publishing AG 2018, Published online: 27 April 2018

of that catch has been landed recently. Presently, there are no precise records on catch, but some species like *Alosa* sp., Trout and Nase have no commercial potential any longer. For several decades now, there have been no species from the genus *Acipenser* in this Lake. The catch of all the economically significant species has dropped, and that of the less significant ones has increased.

The largest number have the LC (30.5%) status, but one third of the species are in a certain category of threat (33.3%), and those are mainly those species endemic to the Adriatic watershed. Three species (5.1%) are classified as critically endangered (CR – 5.1%), and three are endangered species (EN – 5.1%), while four are vulnerable or sensitive (VU – 6.8%). The species *Salmo farioides* has also been listed in the VU group since it is a subject of sports fishing and it suffers immense fishing pressure. The data necessary for the assessment of threat status are deficient for nine species (DD – 15.2%), whereas the status of a near threatened species (NT) has been established for only two species (3.4%).

Keywords Diversity, Economic significance, Endemic fish, Lake Skadar/Shkodra, Threats

1 Introduction

There are relatively large amounts of data about the fish of the Lake Skadar/Shkodra watershed, and the number of published papers continues to increase significantly from year to year. Marić [1] in the Bibliography on Fishery-Ichthyological Research of the Fresh Waters of Montenegro cites over 300 publications presenting original data, and around 240 bibliographic units that relate to investigations of Skadar Lake fish. After this period, that is over the past 10 years, around 40 new publications on fish in the Montenegrin part of Lake Skadar have been published. Should the publications about the Albanian part of the Lake be added to this, the number of publications would exceed 300.

The first document which refers, from a scientific viewpoint, to fish from Lake Skadar, produced by the Austro-Hungarian researchers Jakob Heckel and Rudolf Kner [2], is the renowned work “Die Süsswasserfische der Östereichischen Monarchie mit Rücksicht auf der angrenzenden Länder” published in Leipzig in 1858. Almost 30 years passed before more data on Skadar Lake fish were published; they were presented by Franc Steindachner in 1882. After the works by Steindachner [3, 4], there occurs again a longer period without any information on fish or fishery in this region. The first information about fishery in Montenegro is found in the work of Andrija Jovićević [5] from 1909 in the publication “Lake Skadar and Fishing on It,” and then in Doljan [6] “Die Fisherei em Skutarisee.” Later, Karaman, in period between 1923 and 1956, see Marić [1] and Stanković [7, 8], cited data on fish and fishery related to Lake Skadar. Ndojaj [9] and Kola [10] were the first to present data on fish and fishery in the Albanian part of the lake, but there is relatively little data about this part of the lake even in the later period [11, 12].

In the field of fishery, Đorđije Drecun started the first systematic investigations (in the period between 1951 and 1989), he published more than 40 contributions, see Marić [1]; he also dealt with fundamental ichthyological research. Somewhat later (in the period between 1962 and 1983), Božina Ivanović dealt with fundamental ichthyological investigations. In the second half of the twentieth century, the ichthyofauna of Lake Skadar was studied by Draga Janković (10 papers), Tihomir Vuković (18 papers), and Vitko Šorić (18 papers), and, by the end of the century, many others had made contributions as well [1].

In recent years, with the development of techniques for DNA analysis, a number of researchers have been attracted by the endemic ichthyofauna of these waters. A significant number of species have been studied in relation to this, but there have remained some for which their status remains unresolved. That provides the opportunity to new researchers and paves the way to new discoveries.

There are only a few papers which treat this lake or this watershed in a complex way, the most recent of them being Marić and Milošević [13] and Marić [14]. In the past, comprehensive, more significant papers were published by Filipi [15], Poljakov et al. [16], Ivanović [17], and Rakaj [18]. The objective of this paper is to sum up and present in one paper the knowledge on fish and fishery as they relate to this significant water and ichthyological facility.

2 Methods

All the fish species registered in the Lake Skadar/Shkodra watershed have been cited in this paper (Table 1). This approach has been taken because it is difficult to separate what or which fish are from the lake itself (the lentic part) and which are from the tributaries (the lotic part). The River Drim/Drini has not been taken into consideration as it represents another system, although the ichthyofauna of its lower part is identical to the lake fauna and fauna of the upper (freshwater) part of the River Bojana/Buna. In the part of Lake Skadar that belongs to Albania, there are no larger tributaries so that the ichthyofauna of the small tributaries (as well as those in Montenegro) is not especially distinguished, but it still remains within the scope of the Lake Skadar watershed. The area of research does not include those waters which have no direct connection with Lake Skadar's watershed (i.e., mountainous lakes and Nikšić Field's waters), although in the watershed, besides the species which are treated here, only two introduced species were registered: *Salvelinus umbla* (Linnaeus, 1758) and *Lepomis gibbosus* Linnaeus, 1758 [19, 20]. The establishment of the number of species and their taxonomic validity was performed according to Kottelat and Freyhof [21]. For the species which Kottelat and Freyhof [21] cite as undetermined/undescribed ones, the same status has been retained, unless they have been subsequently described. Owing to their unclear–unresolved systematic status, older names have been kept for some species, as they are the most frequently cited for this watershed, for example, *Chondrostoma ohridanum*.

For the assessment of the threat to species, the categories of threat have been established pursuant to the classification of the International Union for Conservation of Nature [22]. According to these categories, for each species or population of fish populating the waters of the Lake Skadar watershed, the associated category has been cited by the respective de facto situation in this watershed. All the species have been classified into one of the nine groups, on the basis of these generally accepted criteria. Introduced species present in the past (introduced, then made extinct owing to fishing) have been designated by the symbol I^{EX}, meaning I = introduced, and ^{EX} = extinct – disappeared (extinct owing to fishing) from Lake Skadar.

The fishing (fishery) or economic significance of the ichthyofauna has been presented on the basis of officially published data (only for Montenegro's waters) which in the past have been precisely recorded (up until 1986). With the cessation of operation of the fish processing factory in Rijeka Crnojevića, there ceases the precise recording of the catch. For the reason of this imprecise recording, official data from the later period (after 1986) have not been taken into consideration, but rather personal data which are the result of field research, conducted polls, and indirect assessments.

Although the elaboration of this paper is based on data from a large number of references (around 300), in the chapter literature, only cited papers have been listed. More extensive lists of papers may be found in three sources. A complete list of papers for the lake was published by REC [11], and a short list of papers was also given by Oikonomou et al. [12], whereas the complete list of published papers (with abstracts) for Montenegro's area of the lake, from 1858 to 2008, was published by Marić [1].

3 Diversity and Distribution

So far in the watershed of Lake Skadar/Shkodra, 59 species of fishes from nine orders and 18 families have been registered (of which 17 families are native to this watershed) (Table 1). In the list, the species cited in the literature have also been included, but subsequently [13, 14] their presence has not been confirmed. Fifteen alochtonous (introduced) species have been registered, that is species which have reached these waters in any, human assisted, way. *Cyprinus carpio* which is most likely to have reached Lake Skadar during the time of the Roman Empire has not been listed among these species. In addition, it may be stated with certainty that *Rutilus prespensis* is a newcomer from Lake Prespa, but probably in a natural way. There is a probability that some other species, too, have reached this watershed from adjacent waters in natural way, for instance, *C. ohridanum*. The majority of the alochtonous species reached the waters of this watershed by direct introduction or from adjacent waters. The species from the so-called Chinese complex reached these waters by deliberate, direct introduction into Lake Skadar by Albania. This was officially confirmed at the sixth meeting of Yugoslav-Albanian Sub-Committee for Fishery, held in Tirana in 1977. It is reliably known that *Gambusia affinis*

Table 1 The presence, distribution, and conservation status of ichthyofauna in the watershed of Lake Skadar/Shkodra

Species	R. Zeta	R. Morača	Lake and R. Bojana	Conservation status
Acipenser naccarii Bonaparte, 1836	–	–	+	**EW**
Acipenser sturio Linnaeus, 1758	–	–	+	**EW**
Alosa fallax (La Cepède, 1803)	–	–	+	**VU**
Alosa sp.	+	+	+	**NT**
Anguilla anguilla (Linnaeus, 1758)	+	+	+	**EN**
Oncorhynchus mykiss (Walbaum, 1792)	+	+	+	**I**
Salmo farioides Karaman, S., 1937	+	+	+	**VU**
Salmo marmoratus Cuvier, 1829	+	+	+	**CR**
Salmo zetensis Hadžišće, 1962	+	–	–	**CR**
Salvelinus fontinalis (Mitchill, 1815)	–	–	+	**I^{ES}**
Thymallus thymallus (Linnaeus, 1758)	–	+	–	**I**
Alburnoides ohridanus (Karaman, S., 1928)	+	+	+	**LC**
Alburnus scoranza Bonaparte, 1845	+	+	+	**NT**
Barbus rebeli Koller, 1926	+	+	+	**LC**
Carassius auratus (Linnaeus, 1758)	+	+	+	**I**
Chondrostoma ohridanum Karaman, 1924	+	+	+	**VU**
Chondrostoma scodrense Elvira, 1987	–	–	+	**EX**
Ctenopharyngodon idella (Valenciennes, 1844)	–	–	+	**I^{ES}**
Cyprinus carpio Linnaeus, 1758	–	+	+	**VU**
Gobio skadarensis Karaman, S., 1936	+	+	+	**EN**
Hypophthalmichthys molitrix (Valenciennes, 1844)	–	–	+	**I^{ES}**
Hypophthalmichthys nobilis (Richardson, 1845)	–	–	+	**I^{ES}**
Megalobrama terminalis (Richardson, 1845)	–	–	+	**I^{ES}**
Mylopharyngodon piceus (Richardson, 1845)	–	–	+	**I^{ES}**
Pachychilon pictum (Heckel and Kner, 1858)	+	+	+	**LC**
Phoxinus karsticus Binco and De Bonis, 2015	+	+	+	**LC**
Pelasgus minutus (Karaman, S., 1924)	–	+	+	**CR**
Pseudorasbora parva (Schlegel, 1842)	+	+	+	**I**
Rhodeus amarus (Bloch, 1782)	+	+	+	**LC**
Rutilus albus Marić, 2010	–	–	+	**EN**
Rutilus prespensis (Karaman, S., 1924)	+	+	+	**LC**
Scardinius knezevici Bianco and Kottelat, 2005	–	+	+	**LC**

(continued)

Table 1 (continued)

Species	R. Zeta	R. Morača	Lake and R. Bojana	Conservation status
Squalius platyceps Županč̌ič, Marić, Naseka and Bogutskaya, 2010	+	+	+	**LC**
Telestes montenigrinus (Vuković, 1963)	+	+	+	**LC**
Tinca tinca (Linnaeus, 1758)	–	+	–	**I^{ES}**
Cobitis ohridana Karaman, S., 1928	+	+	–	**EN**
Barbatula zetensis (Šorić, 2001)	+	+	+	**LC**
Ameiurus nebulosus (LeSueur, 1819)	–	–	+	**I^{ES}**
Atherina boyeri (Risso, 1810)	–	–	+	**DD**
Chelon aurata (Risso, 1810)	–	–	+	**LC**
Chelon labrosus (Risso 1826)	–	–	+	**LC**
Chelon ramada (Risso, 1826)	–	–	+	**LC**
Chelon saliens (Risso, 1810)	–	–	+	**LC**
Mugil cephalus (Linnaeus, 1758)	–	–	+	**LC**
Aphanius fasciatus (Valenciennes, 1821)	–	–	+	**LC**
Gambusia holbrooki (Girard, 1859)	+	+	+	**I**
Salaria fluviatilis (Asso, 1801)	+	+	+	**LC**
Knipowitschia montenegrina Kovačić and Šanda, 2007	–	+	+	**DD**
Ninnigobius canestrinii (Ninni, 1883)	+	+	+	**DD**
Ninnigobius montenegrensis (Miller and Šanda, 2008)	–	+	+	**DD**
Pomatoschistus marmoratus (Risso, 1810)	–	–	+	**DD**
Dicentrarchus labrax (Linnaeus, 1758)	–	–	+	**LC**
Perca fluviatilis Linnaeus, 1758	–	–	+	**I**
Sander lucioperca (Linnaeus, 1758)	–	–	+	**I**
Citharus linguatula (Linnaeus, 1758)	–	–	+	**DD**
Platichthys flesus (Linnaeus, 1758)	–	+	+	**DD**
Gasterosteus gymnurus Cuvier, 1829	+	+	+	**LC**
Syngnathus abaster Risso, 1826	–	–	+	**DD**
Syngnathus acus Linnaeus, 1758	–	–	+	**DD**
Total	25	33	55	59

was introduced into Montenegrin waters for reasons of mosquito control, and *Oncorhynchus mykiss* and *Salvelinus fontinalis* for reasons of commercial culturing. In addition to deliberately introduced species, a certain number of species have reached Montenegrin waters by accident (*Pseudorasbora parva* and *Perca fluviatilis*). Additionally, *Thymallus thymallus* was translocated from the Danube watershed to the River Morača. Out of the 15 cited introduced species, eight species are not currently present (Table 1, designation I^{EX}) in Lake Skadar [13, 14]. Besides the species included in the list that follows (Table 1) some other species, too, are cited as present in Albanian waters, such as *Parabramis pekinensis* [23], but it is difficult to ascertain if this is a question of a wrong determination or if in fact the species did existed and then went extinct.

Out of the 44 autochthonous species, 15 species are marine (diadromous and euryhaline), which inhabit the brackish waters of the River Bojana/Buna or temporarily stay in freshwater rivers and lakes. Almost all lake autochthonous species enter to some degree into the river systems. So, for example, all species of fish from Lake Skadar may be found in the River Bojana/Buna, and only in its estuary we find three species from the genus *Chelon*, two species of the genus *Syngnathus*, as well as *Pomatoschistus marmoratus*, *Aphanius fasciatus*, and *Atherina boyeri* which is present in the freshwater biotope in Lake Šas only. Hybrids have also been registered in Lake Skadar: *Alburnus scoranza* × *Squalius platyceps* [14]. In this watershed alone, seven species have been registered that are endemic to the watershed: *Ninnigobius montenegrensis*, *Knipowitschia montenegrina*, *Barbatula zetensis*, *Rutilus albus*, *Gobio skadarensis*, *Salmo zetensis*, *Alosa* sp., and according to Elvira [24] *Chondrostoma scodrense* as well, which currently is not present in Lake Skadar. In terms of their systematic diversity, the majority of species – 24 (40.7%) – belong to the family of Cyprinidae, five species are from family of Mugillidae, and four are from the family of Gobiidae. There are 16 autochthonous Cyprinidae what makes up more than one third of all autochthonous species (36.3%). Cyprinidae are also the predominant group in all the individual tributaries, where they usually form at least 50% of the autochthonous ichthyofauna (for example, in the River Zeta). In the past, the largest number of species (eight) from the family of Cyprinidae was introduced in the watershed; six have recently become extinct, therefore only two of them are currently present (*Carassius auratus* and *P. parva*), but their populations are extraordinarily high. Together with *P. fluviatilis*, they probably have an abundance which is similar to the economically significant species of carp and bleak.

Observed by hydrographic entities, the lowest number of species has been registered in the Zeta River. In the upper part of this river, the ichthyofauna is predominantly formed of salmonids: *S. zetensis* – a species endemic to the Zeta River, *Salmo marmoratus*, *Salmo farioides*, and several species of cyprinids. The lower water course (and small tributaries) are mainly populated by cyprinids, and three introduced species have also been registered (Table 1). In the River Morača watershed (without the Zeta), 33 species have been registered, but there is no *S. marmoratus* in the Morača upstream of the inflow of the Zeta, and in the upper course, in addition to *S. farioides* only *Barbus rebeli*, *Telestes montenigrinus*, and *Phoxinus karsticus* are present. Cyprinidae (totaling 15 species) are predominant in the tributaries.

In Lake Skadar and in the River Bojana, most of the species (55) have been registered. Among the species present in this part are *Scardinius knezevici* which does not enter the river – lotic biotope. Species from the middle and lower course of the Morača are present in this part, but several species have not been found in the Bojana, including: *B. zetensis* (in small tributaries only), *T. montenigrinus*, *Gobio scadarensis*, *P. karsticus*, *N. montenegrensis*, *K. montenegrina*, *R. albus*, and *Alosa* sp. Additionally, several previously recorded species have not been found over the past 10 years, including eight alochtonous, two sturgeons, and *Citharus linguatula* [14]. The ichthyofauna of the River Bojana has the characteristics of lake fauna, and in the lower part the characteristics of brackish water, that is of fauna typical of an estuary. The majority of species cited for Lake Skadar were also found in Lake Šas and the River Bojana. At the mouth of this river, five species of mullet have also been registered, as well as some other species which occasionally enter fresh and brackish waters (*Anguilla anguilla* and *Dicentrarchus labrax*), including *Pelasgus minutus*, *Syngnathus abaster*, *S. acus* and *A. fasciatus*. In the Bojana and in Lake Šas, *A. boyeri* has been found as well [14].

3.1 The Economic Significance and Condition of Economically Significant Species

Fish in this watershed have significant economic potential. A large number of species are important mainly for sports–recreational fishing, whereas a lesser number are economically useful in terms of gaining profit. If we observe the lake in its entirety, it should be stated that there is little precise and reliable data on the catch of fish. On the catch of fish in the Albanian part of the lake, official statistical data are scarce, the available data are contradictory, and the assessment of the total catch varies from 200 to 500 tons, and even up to 1,000 tons. It is similar in terms of the catch of individual species, and the available data are not comparable with the Montenegrin data because of the differences in records. This especially relates to "scrap fish" in which different species are listed by one or the other side. According to this data, it is clear that in the last decade, the catch of bleak (Fig. 1) in Albanian waters has been half that of the catch of carp and some other species. All this data lacks valid references, and so, it represents mainly flat assessments and assumptions. Due to all the reasons cited, those data are merely informative and they are not analyzed further here, where only the data on the catch of Montenegrin fishermen is considered, and since 2/3 of the lake belongs to Montenegro this analysis may provide a valid picture on conditions in the entire ecosystem.

Fig. 1 Bleak (*Alburnus scoranza*). Photo by D. Marić

In the past, commercial fishing in Montenegro was organized in a significantly different way than it is currently, especially in terms of tools used, time of fishing, species, and so on [1, 25, 26]. The utilization of fish fauna in Montenegrin waters is presently regulated by the Law on Freshwater Fishery ("Official Gazette of the Republic of Montenegro," no. 11/07 of 13 December 2007). In harmony with the effective Law, sports–recreational fishing is permitted in all waters, and commercial fishing is permitted in Lakes Skadar and Šas and in the River Bojana. Commercial fishing is permitted in the part of the River Bojana which belongs to Albania. Under the Law, respectively, by the subordinate regulations, it has been stipulated which species may be utilized (fished) in commercial terms, and which ones for sports–recreational fishery, fishing times – fishing periods and closing times (prohibition), quantities and dimensions (size) of each species in separate fishing water, as well as the tools and other elements that are important for these activities. All the rules that have been established for fishing have been adopted on the basis of opinions provided by scientific institutions, presented either in the form of comprehensive studies (fishing basis) or separate opinions (as needed). These rules are significantly different for Albanian waters, and therefore it is necessary to carry out mutual harmonization of the regulations.

3.2 Commercial Fishing

On the basis of the effective laws, the following fish species may be fished for commercial purposes: Bleak (*A. scoranza*), Carp (*C. carpio*), Skadar Rudd (*S. knezevici*), Skadar Chub (*S. platyceps*), Goldfish (*C. auratus*), Ohrid Nase (*C. ohridanum*), Eel (*A. anguilla*), Spotted Roach (*P. pictum*), Yellow Roach (*R. prespensis*), White Roach (*R. albus*) (Fig. 2), mugilids (Mugilidae), species of the genus *Alosa*, Sea Bass (*D. labrax*), European Perch (*P. fluviatilis*), and Flounder (*Pleuronectes flesus*). These species are also economically significant in Albania.

Since Pike Perch (*Sander lucioperca*) is the most recent new alochtonous species [14, 23, 27] should it proliferate, it will also be a commercial-fishing species in the future. Formerly present species which used to be the subject of commercial fishing

Fig. 2 White Roach (*Rutilus albus*). Photo by D. Marić

have not been included in this survey (of economically significant species), since they have not been found during the investigations over past 10 years [14]; those are: two species from the genus sturgeon (*Acipenser*), two species from the genus *Hypophthalmichthys*, *Ctenopharyngodon idella*, *Mylopharyngodon piceus*, *Megalobrama terminalis*, *Tinca tinca*, and *C. linguatula*.

Out of three cited fishing areas in Montenegro, significant catch is only found in Lake Skadar, while in Albania the Bojana/Buna is also significant. Considerable quantities of migratory species are fished in the River Bojana. There are no official data on fish catch in the Bojana either in Albania or Montenegro, nor for Lake Šas. Regular statistical analysis of catch in Montenegro was initiated in 1947 (Figs. 3 and 4, Table 2).

Precise statistical data on catch by sports fishermen do not exist, and the data on catch in commercial fishing are unreliable and too imprecise to establishing the real possibilities of catch in this facility. All this is because systematic records have not been kept. In previous times, from 1947 to 1986, the records on catch and buying up were carried out in Montenegro by the fish processing factory, and they are reliable to a certain extent. Vujačić [28] gives data on the catch in the period 1937–1940, and for the later period data is provided by Drecun and Miranović [25], Stein et al. [29, 30], and Drecun [26, 31].

From this survey (Table 2), one can see that in some of the cited periods the catch frequently exceeded 1,000 tons per year, and the catch of bleak accounted for over 50%. In that period, records were also kept on the catch of species which nowadays are not present or are extremely scarce in the Lake, for example, trout (probably Marble trout and Trout – lake form, the so-called dentex). Until 1960, as much as

Fig. 3 Fish catch with Beach Seine in a sublacustrine spring Karuč (Montenegro) Photo by O. Vizi

Fig. 4 Fish catch with Beach Seine in Lake Skadar (Montenegro). Photo by O. Vizi

Table 2 Maximum (max) and average fish catch (in tons) of more significant species from Lake Skadar in multiannual periods (for the Montenegrin part). ? = uncertain data

Species								
Period	Bleak	Carp	Nase	Alosa	Eel	Trout	Other	Total
1937–1940	246	73	45	54	25	2.4	33	478
1947–1951	442	191	81	20	15	–	60	800
1952–1956	556	191	100	27	14	3	134	1,061
1957–1961	605	240	78	41	12	4	236	1,165
1962–1966	424	150	48	26	11	2	240	927
1967–1971	564	159	31	10	11	<1	234	1,126
1972–1976	365	86	5	1	8	1	510	1,051
1977–1981	228	99	1.6	?	?	0.5	408	730
1982–1986	97	140	0.5	?	?	0.3	350	670
1987–1991	200	100	0.5	<1	8	0	200	580
1997–2001	200	100	0	0	7	0	50	357
2002–2016	150	100	0	0	5	0	45	300
Maximum/year	811	322	227	81	26	6	600	1,311

several tons used to be caught, up to 6 tons per year [25]. According to Drecun and Miranović [25], sturgeon, which disappeared a long time ago, used to be fished in quantity to up to 3,000 kg. However, from as early as 1970, these species are absent from the records [30], and according to personal data the last ones were caught in 1982.

There are no comprehensive precise data on the catch of fish from Lake Skadar, since there are no records on the catch and sale of fish by individuals, and those quantities are significant. Catch by the private sector has not been registered, and fish used to be regularly sold at city markets in several cities in the vicinity of the lake. In addition, there are no records on smoked fish produced by the private sector and sold in the wider region. According to the published data on the catch from Lake Skadar [25, 26, 29, 30, 31], bleak was fished the most, then carp (which is also the case in Albania). Records on the catch in the earlier period over 40 years (1947–1986) are more reliable than the data recorded later. Due to the extremely imprecise records, official data from the later period (after 1986) have not been taken into consideration (culturing and fishing were jointly registered), while personal data which are the result of field research (the monitoring of the catch), conducted polls, and indirect assessments are used instead. Table 2 presents data grouped into 5-year cycles, and the graphs (Figs. 5, 6, 7, and 8) show the trends of the catch during the observed period which were demonstrated and calculated. In the period from 1937 to 1940, fish were caught using a variety of different tools and in different manner, as well as in the period until 1950, especially bleak and carp. In the subsequent periods (1950–1990), the equipment for bleak and carp fishing was improved (Gillnet – Multimesh and Trammel, Commercial Beach Seine, Trawl Nets, Fyke-Net and Longlines, or Hooks and Lines) and in that period it was fished in an identical way [25, 31]. Owing to all the cited data on the catch of bleak, carp, and nase until 1950, these have not been included in the graph surveys (Fig. 5).

Figure 5 illustrates the permanent decrease of the three cited species, but statistically the least significant decrease was recorded for carp ($R^2 = 0.5943$). A significant decrease in abundance was recorded for bleak ($R^2 = 0.7888$), and in terms of nase, we can speak of overfishing. According to the data of Drecun and Miranović [25], the largest caught quantity of nasus amounted to 227,000 kg, during 1956. As is known [32], nasus had usually been caught in sublacustrine springs

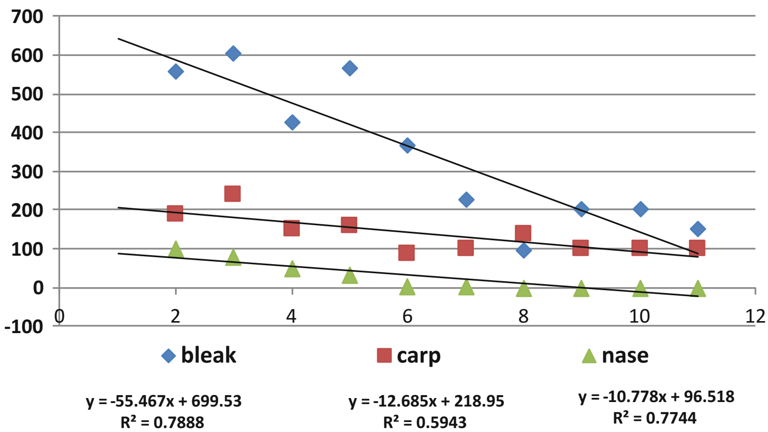

Fig. 5 Catch bleak, carp, and nase in period 1952–2016

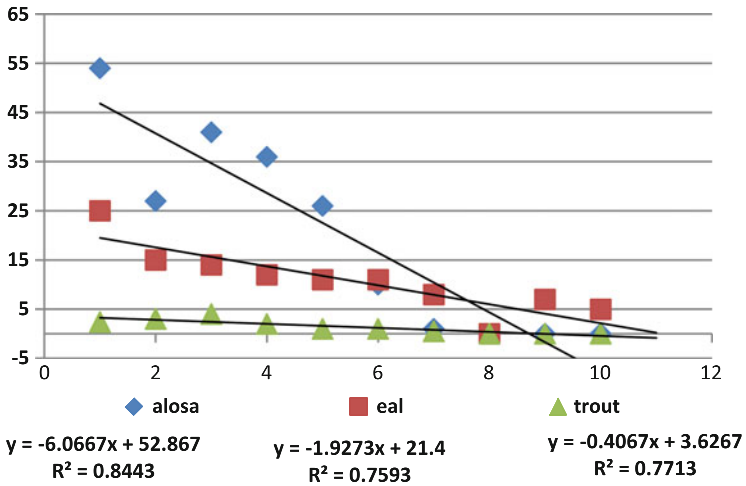

Fig. 6 Catch *Alosa*, eel, and trout in period 1937–2016

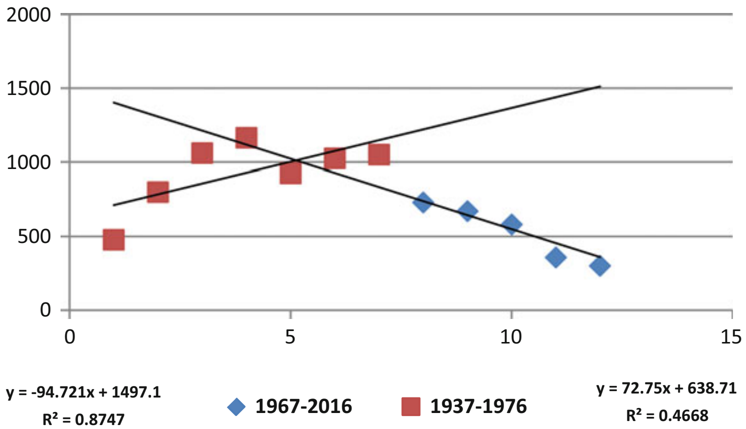

Fig. 7 Total catch of fish in Lake Skadar in two periods 1937–1976 and 1967–2016

(together with bleak) with nets designated for tiny species fishing (notably bleak), meaning that considerable quantities of juvenile specimens were caught (0^+ 1^+). That has contributed to a drastic decrease in population, thus its fishing was prohibited and the period of prohibition lasted approximately 20 years. After that, a revival was noted, but only minor quantities have been caught over recent years, so that the catch is not recorded. The catch of *Alosa*, eel, and trout has been presented for the entire period (Fig. 6), as it very illustratively demonstrates the drastic decline in the catch, and for trout practically its complete disappearance from the lake system.

In terms of trout, as with nase, there occurred overfishing for which reason the abundance of marble trout drastically declined, while the presence of areal was

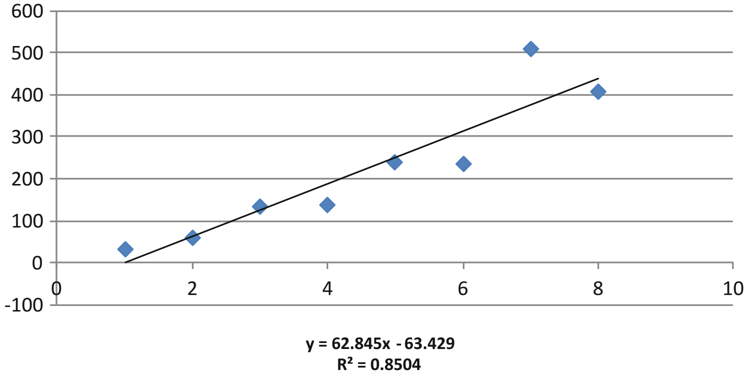

Fig. 8 Catch "Scrap fish" in Lake Skadar in period 1937–1981

practically reduced to the River Zeta only. Table 2 and Fig. 6 demonstrate that the decline in catch is statistically significant for all the species, and for *Alosa* and trout the catch was reduced to an insignificant value for a number of years (after 1972), whereas eel was constantly caught throughout the entire period. The decline in total catch is not statistically significant if the entire catch is observed ($R^2 = 0.2855$) over the entire period (80 years), but when two specific periods are observed, the first from 1937 to 1976, a trend of growth is noted, and later on (1967–2016) a significant decline (Fig. 7). A significant decline in the catch of scrap fish (economically less significant, other fish) has been evident over past two decades (Table 2 and Fig. 8), but that is the result of poor demand for these species (it was utilized for fish flour), not a real decrease in numbers as for other species.

In the period to 1981, a significant increase in scrap fish catch was stated; in addition to five autochthonous species, they also include *C. auratus* and *P. fluviatilis*. This is because, in addition to fish flour production, some species were used for canning at the Rijeka Crnojevića factory. From 1975, we find the fishing of the introduced species of "Chinese complex" in Lake Skadar; it was introduced by Albania in 1972. Goldfish (*C. auratus*) were especially numerous, reaching a maximum abundance in 1982–1983 [33] and becoming one of the more numerous species in this lake. After that period, the catch of this species in certain years exceeded the catch of carp (*C. carpio*) and totaled more than 200 tons. Several years later, the abundance of European Perch (*P. fluviatilis*) significantly increased; it was not a target for fishing but it was accidentally caught with other species (it was registered in the lake in 1978) [34]. Owing to its small dimensions, slow growth, as well as the presence of barbs on its body, the European Perch is not an economically interesting species. Despite the permanent monitoring of fish sale at the market, the sale of bigger specimens was recorded only occasionally (of approximately 0.5 kg), but considerably less than for Skadar Rudd (*S. knezevici*), Skadar Chub (*S. platyceps*), Ohrid Nase (*C. ohridanum*), and so on although its numbers were several times greater (unpublished data). There are several factors which influenced the disappearance or drastic decline in the numbers of some species; for some of them, the issue was probably overfishing, while for others it was the appearance of introduced species, but that will not be elaborated in more detail owing to the bulkiness of such analysis and the limited space available.

3.3 Sports Fishing

All the species listed for commercial fishery are also permitted for sports–recreational fishing. Besides these, the following are permitted for sports–recreational fishing: trout (Salmonidae) with the exception of Softmouth Trout (*S. zetensis*), *T. thymallus*, *B. rebeli*, and *T. montenigrinus*. The species which are not cited are not the subject of any interest from sports fishermen (or they are of small size or meager). Only the Softmouth Trout is protected by the Law and included in the list of the Red Book, other species do not have a higher level of protection other than that provided by the Law, which means that fishing of those species is not permitted.

4 The Conservation Status

On the basis of criteria/categorization according to IUCN [22], the conservation status of each fish species from the Lake Skadar (59 species – 44 autochthonous and 15 alochthonous) has been identified in this paper; that is, the conservation status of the population in this system has been determined. The first data cited for these waters were provided by Kottelat and Freyhof [21]. Subsequently, Milošević and Talevski [35] presented data on the fish of the Lake Skadar watershed, respectively, for 32 autochthonous species, but for all the species they cited an identical conservation status to that given by Kottelat and Freyhof [21].

The assessment/evaluation of the conservation status of a population in this system differs more significantly from the assessment by the previously cited authors. According to the data on the conservation status of each species (Table 1) in this watershed, only one species had the status EX – extinct (*C. scodrense*), while for two (*Acipenser* spp.) EW was assigned. Kottelat and Freyhof [21] treat these two Acipenser species as CR (extremely or critically endangered), citing that they exist in the River Po and the River Garona, respectively. Species from the genus Acipenser have not been found at all in Montenegro for more than 30 years.

According to IUCN [22] instructions, **CR** status in waters of Montenegro has been assigned to the species *S. zetensis* and *S. marmoratus*. Presently, both species subsist in a small area in Montenegro. The species *S. zetensis* is known only from the River Zeta, and *S. marmoratus*, also from the Zeta and a small portion of the Morača and the Cijevna. Data on the distribution for *S. marmoratus* in the waters of Albania are very scarce and they are not reliable. Given the fact that marble trout from

Montenegrin waters has a specific and separate haplotype [36], the assigned status of threat is clearly extremely justified. Kottelat and Freyhof [21] cite the category **EN** for the Softmouth Trout in the Adriatic watershed (all populations, whereas they do not cite Marble Trout for this area, but only for the Soča and the River Po with the status **LC**). The third species that is critically endangered in the waters of Montenegro, for the reasons of its small areal and significant anthropogenous pressure, especially in littoral tributaries, is the species *Pelasgus minutus*. In literature for this species, **DD** has been cited for the entire areal, since the data about this species have been scarce so far.

According to Kottelat and Freyhof [21], the status **CR** has also been assigned to the species *A. anguilla*, and in Montenegro, specifically in the Lake Skadar watershed, it has been assigned the status of **EN**. This is because species which are listed in the **CR** category are significantly more endangered than the eel, and therefore it was listed at a lower level of threat for this area. According to previous investigations [13, 14], one of the most endangered species is white roach – *R. albus* which is endemic to Lake Skadar. Due to the permanent and obvious decrease in its numbers, from the moment when it was registered for the first time [37, 38], it has been assigned the status *endangered* – **EN** (A and B). Out of the species which exist only in the waters of Montenegro (being endemic), two have been listed in this category: *Cobitis ohridana* and *G. scadarensis*.

On the basis of observation through relationships and percentages, and given all the cited data, three species have the status of critically endangered (CR – 5.1%), three species are endangered (EN – 5.1%), and four are vulnerable or sensitive (VU – 6.8%). The species *S. farioides*, which is the subject of sports fishing, has been listed in the category VU since it faces significant fishing pressure. Data for nine species (DD – 15.2%) are deficient for the assessment of their threat status, whereas the status of a near threatened species (NT) was assigned to only two species (3.4%). The greatest number of species has been assigned the status of LC (30.5%), but one third of species is in some category of threat (33.3%), and it is significant to point out that those are mainly those species that are endemic to the Adriatic watershed.

5 Conclusions

Each country (in this case Albania and Montenegro) needs to elaborate its own strategy for the protection of fish and their biotopes, and the first step is legislation. However, in addition to statutory solutions, the proceedings in practice, which unfortunately are conducted poorly or else virtually not at all, have to be held to a significantly higher standard. The first steps towards this goal have been made, and they are: inventorization, so that the areals of all the fish species have been established, aimed at the consideration of the general distribution of the cited fish and their communities [14]. For a minor number of species (rare and endemic ones), it is necessary to establish in more detail the zone of distribution outside this area, and then to study in detail the idioecology of each species in the scope of which the time and place of spawning is particularly relevant, as well as their habitats at each developmental stage. If the need arises, some areas should be specially protected (reserves), which has proven useful in practice [39]. In order to protect the ichthyofauna of this area in a complete and high quality (sustainable) manner, Albania and Montenegro have to cooperate much more in the future, primarily as regard the harmonization of legal documents.

All fish are very sensitive to changes in the environment (change in flow velocity, the rearrangement of rivers, the degradation of biotopes, warming up, and the intensive utilization of water), but endemic ones are especially sensitive and usually have a poor capability to adjust to changes in the outer environment. They mainly populate former glacial refuges, and thus they have specialized (evolved) within a narrow spectrum of ecological factors. This imposes the need to protect fish biotopes equally as much as individual fish species.

With the objective of the protection of all fish, in particular endemic ones, in addition to those issues already cited, it is necessary to undertake in the future a series of measures which will reduce the most significant pressures to a minimum, and eliminate some of them (for example, the entering of alochthonous species). Some of the more significant impacts on ichthyofauna are agricultural pollution, followed by industrial and urban wastewater (from Skadar, Nikšić, and Podgorica). Water pollution is a factor which endangers not only fish but the entire water biota. The pressure of these factors on ichthyofauna decreases with organic production and the construction of purification systems in urban settlements.

Commercial and sports fishing have a major impact on ichthyofauna. It has been demonstrated here that a trend in catch decrease is evident for all species, which is a consequence of their decline in numbers. Marić and Kažić [32] assume that the catch of large quantities of Nase in the past has been the main reason for the decline in its numbers. This problem can be overcome by the use of fishing tools by which juvenile species are not caught and by abiding the regulations. In commercial fishing, all the means consisting of the inadequate mesh diameter of nets should be removed (for instance, kalimera fishing traps).

According to many researchers, the introduction of alochthonous fish species is the most important factor which influences the autochthonous ichthyofauna and the entire ecosystem. In the past 50–60 years, 15 species have been introduced into Montenegrin waters. Among the first species introduced into Montenegrin waters was *G. affinis* [40]; many consider it useful in the ecosystem (for mosquito combat), whereas others believe that it endangers species of small stature (e.g., *A. fasciatus* or *P. minutus*). Several species have gone extinct over time owing to the impossibility of their natural reproduction. However, several species have remained in Lake Skadar forever, because they have adapted well. They have made a significant impact on the change of fish settlement but also on the other biota, including the dietary habits of Pelicans (Vizi, pers.com). Those are primarily *C. auratus* and *P. fluviatilis* but also some others (*P. parva* and others), and there is an immediate threat of the adaptation and expansion of *S. lucioperca* which is the most recently introduced species recorded in the Montenegrin part of the lake [14]. With the introduction of fish species, it is possible to also introduce new agents of disease or parasites. In the future, the introduction of fish should be strictly controlled, and the introduction of species which have not been sufficiently studied and species that have been identified as invasive should be banned.

References

1. Marić D (2010) Bibliografija o ribarsko-ihtiološkim istraživanjima u Crnoj Gori (150 godina istraživanja) (Bibliography on fishery-ichthyological investigations in Montenegro (150 years of research)). JU "Prirodnjački muzej Crne Gore", Posebno izdanje No 5, Podgorica, 140 pp
2. Heckel J, Kner R (1858) Die Süsswasserfische der Östereichischen Monarchie mit Rücksicht auf der angrenzenden Länder. Engelmann, Leipzig, p 388
3. Steindachner F (1882) Ichthyologische Birtage XII. Sitz-Ber Math Naturwiss Cl Acad Wiss Wien Abt 1(86):61–82
4. Steindachner F (1892) Über einige neue und seltene Fischarten aus der ichthyologischen Sammlung des K.K. Naturhistorischen Hofmuseums. Denkschr Akad Wiss Wien Math Naturwiss Cl Abt 1(59):357–383
5. Jovićević A (1909) Skadarsko jezero i ribolov na njemu (Skadar lake and its fishery). Srpski etnografski zbornik 13:157–259
6. Doljan E (1918) Die Fisherei am Skutarissee. Wien, p 36
7. Stanković S (1929) Riblji produktivitet južno-balkanskih jezera (Fish productivity in South-Balkan lakes). Glasnik geografskog društva 15:22
8. Stanković S (1939) O našem jezerskom ribarstvu (On our lake fishing). Ribarstvo Jugoslavije 2:3–12
9. Ndojaj IGJ (1941) Fauna ihtiologjike e Liqenit te Shkodres. Hylli i Drites 9–10:398–412
10. Kola GJ (1942) Gjuetia e peshkut ne Liqenit te Shkodres e lumenjte Buna, Kir e Drin. Hylli i Drites 1–2:72–78
11. REC (2001) Bibliography on Shkodar/Skadar Lake. REC, Shkodra and Podgorica, 137 pp
12. Oikonomou A, Leprieur F, Leonardos ID (2014) Electronic supplementary material – the online version for article: biogeography of freshwater fishes of the Balkan Peninsula. Hydrobiologia 738(1):205–220
13. Marić D, Milošević D (2011) Katalog slatkovodnih riba (Osteichthyes) Crne Gore (Catalogue of the freshwater fishes (Osteichthyes) of Montenegro). Crnogorska akademija nauka i umjetnosti, Katalozi 5, Knjiga 4, Podgorica, p 114
14. Marić D (2018) Fauna slatkovodnih riba Crne Gore (The fauna of freshwater fishes of Montenegro). Crnogorska akademija nauka i umjetnosti Podgorica (in press)
15. Filipi N (1953) Ihtiofauna e Liqenit te Shkodres. Buletin i Shkencave Natyrore 3:3–24
16. Poljakov G-D, Filipi N, Basho K, Hysenaj A (1958) Peshqit e Shqiperise. Universiteti Shteteror i Tiranes, Tirana. 286 pp
17. Ivanović B (1973) Ichthyofauna of Skadar Lake. Institut za biološka i medicinska istraživanja, Podgorica. 146 pp
18. Rakaj N (1995) Iktiofauna e Shqiperise (Ichthyofauna of Albania). Shtëpia Botuese "Libri Universitar", Tirana. 700 pp
19. Marić D (1991) Prilog poznavanju taksonomskih karakteristika vrsta roda Salvelinus (Richardson, 1836) (Pisces) iz Crne Gore (Contribution to the knowledge of taxonomical characteristics of species of the genus *Salvelinus* Richardson, 1836 (Pisces) from Montenegro) Ichthyos 10:18–24
20. Marić D, Rajković M (2004) Competitors and predators the cause of crayfish (*Astacus astacus* L.) numerosity decrease in the waters of Nikšić region. Natura Montenegrina 3:101–111
21. Kottelat M, Freyhof J (2007) Handbook of European freshwater fishes. Kottelat, Cornol and Freyhof, Berlin. 646 pp

22. IUCN (2001) IUCN red list categories and criteria: version 3.1. IUCN Species Survival Commission, Gland and Cambridge
23. Dhora D (2010) Regjistër i specieve të faunës së Shqipërisë (Register of species of the fauna of Albania). Camaj-Pipa, Shkodër. 208 pp
24. Elvira B (1987) Taxonomic revision of the genus *Chondrostoma* Agassiz, 1835 (Pisces, Cyprinidae). Cybium 11(2):111–140
25. Drecun D, Miranović M (1962) Ulov ribe na Skadarskom jezeru 1947–1960. godine (The fishing on Skadar Lake from 1947 to 1960). Hydrobiologia Montenegrina 1(10):1–19
26. Drecun Đ (1980) Izmjena riblje populacije u Skadarskom jezeru (Changing of fish population in the Lake Skadar). In: Radovi sa simpozijuma, CANU 9: Zbornik referata sa naučnog skupa o Skadarskom jezeru, Podgorica, 30 Oct–1 Nov 1980, pp 129–140
27. Dhora D, Hysa M (2000) Peshku *Stizostedion lucioperca* (Linne, 1785) ne liqenin e Shkodres. Bio Eko 3:19–20
28. Vujačić J (1949) Ulov ribe na Skadarskom jezeru (Fishing on the Skadar Lake). Ribarstvo Jugoslavije 4(2–4):29–30
29. Stein AR, Mecom OJ, Ivanović B (1975) Commercial exploitation of fish stocks in Skadar Lake, Yugoslavia, 1947–1973. Biol Conserv 8:1–18
30. Stein AR, Mecom OJ, Ivanović B (1981) Commercial exploitation of fish stocks in Lake Skadar, 1947–1976. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica and Belgrade, pp 343–354
31. Drecun Đ (1985) Smanjenje populacije ukljeve (*Albumus albidus alborella*) u Skadarskom jezeru (The decrease of the population of bleak (*Albumus albidus alborella*) in Lake Skadar). Agrosaznanje 2:15–28
32. Marić D, Kažić D (1990) Kvalitativno-kvantitativni sastav ihtiofaune sublakustičnih izvora Skadarskog jezera u zimskom periodu od 1976–1987 (Qualitative-quantitative composition of Ichthyofauna of Skadar Lake's sublacustrine springs in winter period from 1976 to 1987). Glas Republ Zavoda Zašt Prirode - Prirodnjačkog muzeja 23:85–96
33. Marić D (2004) Distribution and abundance of introduced german carp *Carassius auratus gibelio* (Bloch) in the Lake Skadar in period 1972–1992. Glas Republ Zavoda Zašt Prirode - Prirodnjačkog muzeja 27–28:113–126
34. Knežević B, Marić D (1979) *Perca fluviatilis* Linnaeus, 1958. (Percidae, Pisces) nova vrsta za jugoslovenski dio Skadarskog jezera (*Perca fluviatilis* Linnaeus, 1758. (Percidae, Pisces) new species for the Yugoslav part of Lake Skadar). Glas Republ Zavoda Zašt Prirode - Prirodnjačkog muzeja 12:177–180
35. Milošević D, Talevski T (2015) Conservation status of native species in natural lakes of Drim system (Prespa, Ohrid and Skadar Lake) and dangers of commercial fishing. Bulg Agric Sci 21(Suppl 1):61–67
36. Pustovrh G, Snoj A, Sušnik Bajec S (2014) Molecular phylogeny of *Salmo* of the western Balkans, based upon multiple nuclear loci. Genet Sel Evol 46:1–7
37. Marić D (1989) The species revision of genus *Rutilus* Rafinesque, 1820 (Pisces) from western part of Balkan Peninsula. Glas Republ Zavoda Zašt Prirode - Prirodnjačkog muzeja 21:55–79
38. Marić D (2010) *Rutilus albus* sp. n. (Cyprinidae) from Skadar Lake. Period Biol 112 (2):153–158
39. Suski CD, Cooke SJ (2007) Conservation of aquatic resources through the use of freshwater protected areas: opportunities and challenges. Biodivers Conserv 16:2015–2029
40. Drecun Đ (1957) Ihtiofauna Skadarskog jezera (Ichthyofauna of Skadar Lake). Naša poljoprivreda 3(3):33–39

Diversity and Conservation Status of Batrachofauna and Herpetofauna in the Lake Skadar Region

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 383–414, DOI 10.1007/698_2018_252,

© Springer International Publishing AG 2018, Published online: 1 June 2018

Abstract The basin of Lake Skadar with its drainage area represents one of the Balkan Peninsula's hotspots regarding amphibian and reptile fauna. The value of the batracho- and herpetofauna of the Lake Skadar region is reflected in a rich and diverse composition of species. This is undoubtedly the result of the basin's specific geographic position and complex geological history. Recent studies revealed that Lake Skadar's watershed is inhabited by 15 amphibian and 36 reptile species. Among these, one amphibian (*Pelophylax shqipericus* – EN) and two reptile species (*Dinarolacerta mosorensis* and *Vipera ursinii*, both VU) are considered to be globally threatened according to IUCN criteria. An additional three reptile species (*Emys orbicularis*, *Testudo hermanni*, and *Elaphe quatuorlineata*) could become threatened in the future. As an attractive tourist area, a significant part of the Lake Skadar region could be impacted by fast and intense anthropogenic changes. Therefore, preserving the network of suitable habitats, maintaining continuous monitoring, and investing in additional research are essential for maintaining this rich local amphibian and reptile diversity.

Keywords Albania, Amphibians, Biodiversity hotspot, Montenegro, Reptiles, The Lake Skadar region

1 Introduction

The Balkan Peninsula is designated as one of the biodiversity hotspots in Europe [1] and one of the three southern refugia of European biodiversity [2, 3]. This applies equally to batrachofauna (amphibians, e.g., salamanders, newts, toads, and frogs) and herpetofauna (tortoises, terrapins, lizards, and snakes) of this area [4].

The basin of Lake Skadar together with its drainage area represents one of the hotspots for amphibian and reptile fauna on the Balkan Peninsula [4–7]. Local amphibian or reptile species diversity refers to the trans-boundary water ecosystem between two countries – Montenegro and Albania [8], also named as the Lake Skadar region [5] (Fig. 1). The entire area could be described as a big pot consisting of a natural depression maintaining a large, shallow lake and the surrounding lowlands bound by the slopes of Dinaric Alp mountain belt.

In Montenegro (stretching in the clockwise direction from the Bojana/Buna river to the northeast), these mountains include Taraboš, Rumija, Sutorman, Sozina, Lovćen, Stavor, Garač, Prekornica, Žijevo, and through Grbaja and Plav valleys into the Prokletije massif to Bogićevica [5]. Unique elements of Lake Skadar's natural treasure are two groups of small lacustric islands: the first group of permanent and temporary islands is located in the area of "Fučko blato" in the shallower, northwestern part of the lake and includes Velja Čakovica, Mala Čakovica, Kamenik, Liponjak, Kosmač, Prevlaka,

Fig. 1 Lake Skadar region

Odrinska gora, Kom, and Žabljak islands. The second group, situated in the area of "Veliko blato," includes Vranjina and Lesendro plus a group more than 30 small karstic islands named "southwestern archipelago" [7] (Figs. 2 and 3).

The Albanian part of the Lake Skadar region could be defined as the lowland area of the Shkodra district plus the surrounding mountain slopes of Prokletije massif exposed to the Adriatic Sea (Fig. 4). The eastern and southern parts of the lake are composed of lowlands and wetlands, due to the presence of the Bojana, Drini, and Kiri rivers. The southwestern part of the lake is limited by the Taraboshi mountain with a lesser presence of the water. Moving north from Bojana Bridge to the Montenegrin part of the lake, the coastline is rocky and amphibians are less predominant. Amphibians having higher ecological valence, such as *P. kurtmuelleri*, are mainly found there. This area (26.535 km^2) is a "Managed Nature Reserve" (Category IV as per IUCN). Since 2005 the area between the Albanian part of the Lake Skadar, Delta, and the island of Franz Josef, all along the Buna rivers, Domni wetland, Viluni lagoon, and surrounding areas, has been designated a "Protected Landscape" (Category V as per IUCN).

The value of the batracho- and herpetofauna of the Lake Skadar region is reflected in a composition of species occurring and coexisting within a relatively small area. This is undoubtedly the result of its geographic position plus complex geological history, where

Fig. 2 Southwestern Lake Skadar Archipelago. View from Rumija Mountain (Photo: J. Crnobrnja-Isailović)

Fig. 3 Bisag island. Southwestern Lake Skadar Archipelago (Photo: Natural History Museum Podgorica Photo Archive)

Fig. 4 Surroundings of Koplik, Shkodër District (Photo: J. Crnobrnja-Isailović)

orography and the climate have shaped the composition of vegetation [9], resulting in Mediterranean, oro-Mediterranean, Mediterranean-middle-European, boreal, arcto-alpine, and steppic elements [5]. Local herpetofauna is predominantly Mediterranean, with typical elements comprising the most common species, not only on the islands and coastal area of the lake but in the entire lowland, spreading toward the north of the Lake Skadar region via the canyons and gorges of the Rijeka Crnojevića, Zeta, Morača, Cijevna, and Drin/Drini rivers [7]. Elements of pontic herpetofauna are more common in the lowlands of northwestern Albania in the Drin/Drini river valley [7]. The representatives of Middle-European batracho- and herpetofauna are distributed throughout the region, depending on their ecological requirements, while species typical for the boreal and arcto-Alpine fauna of amphibians and reptiles inhabit higher elevations and mountain peaks, mostly on the eastern part of the mountain ridges that surround the Lake Skadar depression [7].

According to [10], the Lake Skadar region harbors representatives of three out of nine (33.3%) and seven out of thirteen (54%) distribution types, identified as class Amphibia and Reptilia, respectively. Although the results of this analysis are somewhat inflated by the quality of donated input data (and therefore must be interpreted with caution), general distribution patterns obtained could help to highlight conservation priorities.

The amphibians in the Lake Skadar region mostly belong to western European (CA2: five species or 33% of total number of amphibian species within the area) or a widespread European (CA3: five species or 33%) distribution type, plus one representative of Alpine and Dinaric distribution types (CA9: one species or 7%). This could mean that 73% of amphibians of the Lake Skadar region are neither specifically endemic to the area of the Lake Skadar and the Balkan Peninsula nor to Southeastern Europe. For various reasons, four amphibian species (*Triturus macedonicus*, *P. kurtmuelleri*, *P. shqipericus*, and *Rana graeca*), or 27% of the total number of amphibian species in the area, were not incorporated into that classification, despite all of them being endemic to the entire or southeastern part of the Balkan Peninsula (Fig. 5).

As expected, the highest number of reptile species in the Lake Skadar region belongs to the Balkan Peninsula and Southeastern Europe distribution type (CR4: 11 species or 31% of total number of reptile species occurring in the area), while the group belonging to widespread European distribution type is the second highest in number (CR6: seven species or 19%). Additionally, 50% of the reptile species in the area fit into the following three groups: the Italian/Balkan Peninsulas and Southeastern Europe distribution type (CR1: six species or 17%), Western-Central European distribution type (CR7: five species or 14%), or eastern Adriatic coast distribution type (CR5: five species or 14%). The remaining 5% of the total number of reptile species in the Lake Skadar region belong to western-southern Mediterranean distribution type (CR2: one species or 2.5%) or Southeastern Europe distribution type (CR11: one species or 2.5%). In summary and by distribution type, 64.5% of total number of reptile species recorded within the Lake Skadar region belongs to an entire or specific part of Southeastern Europe. Therefore, the reptile fauna of the region is much more diverse and specific than local amphibian fauna. This could be explained by the higher diversity of local habitats and ecosystems utilized by reptiles. Shaped by complex orography, climate, and history, those habitats and ecosystems provide suitable conditions for relatively similar numbers of reptile species belonging to different distribution types (Fig. 6).

2 Species Richness

2.1 Amphibians

The first comprehensive list of batrachofauna of the Lake Skadar region contained 15 amphibian species: *Salamandra atra*, *S. salamandra*, *T. alpestris* (now *Ichthyosaura alpestris*), *T. vulgaris* (now *Lissotriton vulgaris*), *T. carnifex* (now *T. macedonicus*), *Bombina variegata*, *Bufo bufo*, *B. viridis* (now *Bufotes viridis*), *Hyla arborea*, *R. balcanica* (now *P. kurtmuelleri*), *R. dalmatina*, *R. graeca*, *R. ridibunda* (now *P. ridibundus*), *R. shqiperica* (now *P. shqipericus*), and *R. temporaria*) [5, 11]. *Pelophylax kurtmuelleri* was recorded only on the Albanian part of the Lake Skadar region [11]. In addition to the two green frog species (*P. kurtmuelleri* and *P. shqipericus*), in this area their hybrid is found. Taxonomic and bioacoustics' studies conducted in the area [12, 13]

Species Distribution type*	English Common Name	Albanian Common Name	Montenegrin Common Name	Presence in Albanian part	Presence in Montenegrin part
Urodela					
Salamandridae					
Salamandra atra CA9	Alpine salamander	Salamandra e zezë	Crni daždevnjak	+	+
Salamandra salamandra CA2	Fire salamander	E bukura e dheut, Picrrak, Pisrenge, Picnok	Šareni daždevnjak	+	+
Ichthyosaura alpestris CA2	Alpine newt	Tritoni i alpeve	Planinski mrmoljak	+	+
Lissotriton vulgaris CA3	Smooth newt	Triton i zakonshëm	Mali mrmoljak	+	+
Triturus macedonicus **	Macedonian crested newt	Tritoni me kreshtë	Makedonski mrmoljak	+	+
Anura					
Bombinatoridae					
Bombina variegata CA2	Yellow-bellied toad	Bretkosa barkverdhë	Žutotrbi muk-ač	+	+
Bufonidae					
Bufo bufo CA3	Common toad	Thithlopa, Shapulicë	Krastača, Smeđa krasta-va žaba, Velika krastača	+	+
Bufotes viridis CA3	Green toad	Thithlopa e gjelbër	Zelena krastača, Zelena krastava žaba	+	+
Hylidae					
Hyla arborea CA2	Common tree frog	Verore, Bretku, Gargaliq, Bretkosa e drurëve	Gatalinka	+	+
Ranidae					
Pelophylax kurtmuelleri **	Balkan water frog	Bretkosa e gjelbër e zakonshme,	Balkanska zelena žaba	+	

Fig. 5 Amphibian species occurring in the Lake Skadar region. For abbreviations see Introduction. Cell in *black* color: species presence not confirmed in respective country. *According to [10]. **Not classified there. ***The bioacoustic studies conducted by Prof. Haxhiu and Prof.

		Zhaba			
Pelophylax ridibundus CA3	Marsh frog		Zelena žaba, Velika zelena žaba		+
Pelophylax shqipericus **, ***	Albanian water frog	Bretkosa e Shqipërisë, Bretkosa e leshterikut	Skadarska žaba, Skadarska zelena žaba	+	+
Rana dalmatina CA2	Agile frog	Bretkosa kër-cimtare	Šumska smeđa žaba, Šumska žaba	+	+
Rana graeca **	Greek stream frog	Bretkosa e përrenjeve	Grčka žaba	+	+
Rana temporaria CA3	Grass frog	Bretkosa e malit, Bretkosa e kuqërremtë e pyllit	Travnjača, Žaba travnjača, Livadska smeđa žaba	+	+

Fig. 5 (continued)

confirmed the presence of this hybrid (about 2%) in the areas with a high presence of vegetation.

Recent studies also suggest that the Lake Skadar watershed is inhabited by 15 amphibian species ([14], Fig. 5). However, Haxhiu [15] listed 13 amphibian species in the Shkodra district of Albania, excluding *R. graeca* and commenting that in some contemporary fauna studies on the batrachofauna of Albania, the authors synonymized *P. kurtmuelleri* with *P. ridibundus*. The newest list [16] confirms the presence of *R. graeca* in a wider area of the Albanian part of the region. They did not refer in details to the presence of particular *Pelophylax* species, summarizing records as "*Pelophylax* sp." In the Montenegrin part, the number of amphibian species reaches 13 (Fig. 5). However, a relatively recent analysis of the Montenegrin part of the Lake Skadar (northeastern part and vicinity of Vranjina) suggested the occurrence of *P. kurtmuelleri* and *P. shqipericus* [17], which highlights the importance of additionally clarifying water frog species richness in this area.

Fig. 5 (continued) Schneider have shown the sonograms and oscillograms of the frog found at Lake Skadar to be the same as those recorded in the Central EU. In their opinion the frog named *P. shqipericus* is indeed *P. lessonae*. However, as this chapter follows Frost as amphibian taxonomic authority, we kept the name *P. shqipericus*. Taxonomy followed [68]. English common names followed [10]. Albanian names followed Red List of Wild Flora and Fauna of Albania (Ministerial Order No. 1280 of 20.11.2013) and [69]. Montenegrin common names are given according to resolution on placing certain plant and animal species under protection (Official Gazette of the Republic of Montenegro, No. 76/06) [70] and author's modifications of common names according to the work in progress

Species Distribution type*	English Common Name	Albanian Common Name	Montenegrin Common Name	Presence in Albanian part	Presence in Montenegrin part
Chelonia					
Emydidae					
Emys orbicularis CR6	European pond terrapin	Breshkujza	Barska kornjača	+	+
Geoemydidae					
Mauremys rivulata CR4	Balkan terrapin	Breshkujza	Riečna kornjača	+	+
Testudinidae					
Testudo hermanni CR7	Hermann's tortoise	Breshka tokës, Breshka e zakonshme, Breshka e ugareve	Kopnena kornjača, Šumska kornjača	+	+
Sauria					
Anguidae					
Anguis fragilis/graeca CR6	Slow worm	Kakzogëza	Sljepić	+	+
Pseudopus apodus CR4	Glass lizard	Bullari	Blavor	+	+
Gekkonidae					
Hemydactilus turcicus CR2	Turkish gecko	Hardhuca me venduza e mureve	Kućni macaklin, Kućna gubavica	+	+
Mediodactylus kotchyi CR4	Kotchy's gecko	Hardhuca me kthetra e mureve		+	

Fig. 6 Reptile species in the Lake Skadar region. For abbreviations see Sect. 1. Cell in *black* color: species presence not confirmed in respective country. *According to [10]. Taxonomy followed [71]. English common names followed [10]. Albanian names followed Red List of Wild Flora and Fauna of Albania (Ministerial Order No. 1280 of 20.11.2013) and [72]. Montenegrin common names followed resolution on placing certain plant and animal species under protection (Official Gazette of the Republic of Montenegro, No. 76/06) for protected species. For other species the Montenegrin common names followed authors' work in progress and particular references on national herpetofauna (for *H. turcicus* [6], for *D. montenegrina* [27], for three viper species [73]). For unprotected species that do not have common names in literature on Montenegrin herpetofauna (*P. tauricus*, *A. kitaibelii*, and *D. caspius*), the authors followed Serbian regulation on the designation and protection of the strictly protected and protected wild species of plants, animals, and fungi (Official Gazette of the Republic of Serbia, No. 5/2010), as linguistically the most similar

Lacertidae					
Algyroides nigropunctatus CR5	Dalmatian Algyroides	Hardhuca me luspa të më mëdha	Mediteranski gušter, Mrki gušter, Ljuskavi gušter	+	+
Dalmatolacerta oxycephala CR5	Sharp-snouted rock lizard	/	Oštroglavi gušter, Plavi gušter	+	+
Dinarolacerta montenegrina CR5	Prokletije rock lizard	/	Prokletijski gušter, Crnogorski gušter	+	+
Dinarolacerta mosorensis CR5	Mosor rock lizard		Mosorski gušter		+
Lacerta agilis CR6	Sand lizard	Zhapiu i ngathët	Sivi gušter, Livadski gušter	+	+
Lacerta trilineata CR4	Balkan green lizard	Zhapiu me tre vija	Veliki zelembać	+	+
Lacerta viridis complex CR1	Eastern green lizard	Zhapiu i gjelbër	Zelembać	+	+
Podarcis erhardii CR4	Erhard's wall lizard	Hardhuce e vogel muri		+	
Podarcis muralis CR7	Common wall lizard	Hardhuca e mureve	Zidni gušter	+	+
Podarcis melisellensis CR5	Dalmatian wall lizard	Hardhuca bishtgjatë	Kraški gušter	+	+
Podarcis siculus CR7	Italian wall lizard	Hardhuca Italiane e mureve	Primorski gušter	+	-
Podarcis tauricus CR1	Balkan wall lizard	Hardhuca e barit	Stepski gušter	+	+
Zootoca vivipara CR6	Viviparous lizard	Zhapiu që lind këlysh	Planinski gušter	+	+

Fig. 6 (continued)

2.2 Reptiles

According to the distribution data available in 1997 [11], the Lake Skadar region harbored 33 reptile species: *Emys orbicularis*, *Mauremys caspica* (now *M. rivulata*), *Testudo hermanni*, *Anguis fragilis*, *Ophisaurus apodus* (now *Pseudopus apodus*),

Scincidae					
Ablepharus kitaibelii CR1	Snake-eyed skink	Zhapi këmbëvogël	Kratkonogi gušter	+	–
Ophidia					
Typhlophidae					
Xerotyphlops vermicularis CR4	Worm snake	Gjarpri i verbër	Slijepa zmija	–	+
Colubridae					
Coronella austriaca CR6	Smooth snake	Gjarpri i zi	Smukulja	+	+
Dolichophis caspius CR1	Caspian whip snake	Shigjeta e gjatë	Stepski smuk	+	+
Elaphe quatuorlineata CR7	(Western) Four-lined snake	Bolla me katër vija, Rrëshaja	Prugasti smuk	+	+
Hierophis gemonensis CR4	Balkan whip snake	Shigjeta e shkurtër	Primorski smuk	+	+
Malpolon insignitus CR4	Eastern Montpellier snake	Biroja	Mrki smuk	+	+
Natrix natrix CR6	Grass snake	Gjarpri i madh i ujit	Barska bjelouška	+	+
Natrix tessellata CR1	Dice snake	Gjarpri i vogel i ujit	Riječna bjelouška	+	+
Platyceps najadum CR4	Dahl's whip snake	Shigjeta e hollë	Zmija šilac	+	+
Telescopus fallax CR4	Cat snake	Gjarpri me lara	Mačja zmija	+	+
Zamenis longissimus CR7	Aesculapian snake	Bolla e shtëpisë	Obični smuk	+	+
Zamenis situla CR4	Leopard snake	Bolla laramane	Šareni smuk	+	+

Fig. 6 (continued)

Cyrtodactylus kotschyi (now *Mediodactylus kotschyi*), *Hemidactylus turcicus*, *Algyroides nigropunctatus*, *Lacerta agilis*, *L. mosorensis* (now *Dinarolacerta mosorensis*), *L. oxycephala* (now *Dalmatolacerta oxycephala*), *L. trilineata*, *L. viridis*, *L. vivipara* (now *Zootoca vivipara*), *Podarcis melisellensis*, *P. muralis*, *P. taurica* (now *P. tauricus*), *Ablepharus kitaibelii*, *Coluber caspius* (now

Viperidae					
Vipera ammodytes CR1	Nose-horned viper	Nëpërka, Gjarpri me bri, Gjarpri i bokës, Gjarpër shullani, Gjarpri me nuska (hajmali), Gjarpri me xhepa, Bishtcung, Gjarpri me hundë, Gjarpri me kycylyt	Poskok	+	+
Vipera berus CR6	Adder	Nëpërka me lara e malit, Nëpërka e malit me lara të ndërprera	Šarka	+	+
Vipera ursinii CR11	Meadow viper	Nëpërka e vogel e malit	Krški šargan	+	+

Fig. 6 (continued)

Dolichophis caspius), *C. gemonensis* (now *Hierophis gemonensis*), *C. najadum* (now *Platyceps najadum*), *Coronella austriaca*, *Elaphe longissima* (now *Zamenis longissimus*), *E. quatuorlineata*, *E. situla* (now *Z. situla*), *Malpolon monspessulanus* (now *M. insignitus*), *Natrix natrix*, *N. tessellata*, *Telescopus fallax*, *Typhlops vermicularis* (now *Xerotyphlops vermicularis*), *Vipera ammodytes*, *V. berus*, and *V. ursinii*. The most recent list includes 36 species (Fig. 6), where *M. kotschyi*, *P. erhardii*, *P. siculus*, and *A. kitaibelii* are recorded only in the southwesternmost part of the region (Albanian part), while *D. mosorensis* and *X. vermicularis* are recorded only in the Montenegrin part of the region [18, 19].

A study published in 1995 showed that 28 species were recorded in the Montenegrin part of the area (*M. rivulata*, *D. montenegrina*, *P. tauricus*, *A. kitaibelii*, and *D. caspius* were not registered) [5]. Recently, the list has been significantly updated, resulting in 32 species on the Montenegrin side, including *M. rivulata*, *D. montenegrina*, *P. tauricus*, and *D. caspius* [18]. For comparison, in 1997, 29 species were recorded on the Albanian side of the region [11, 20]. Later, 30 species were reported [14], but the recent fauna study suggests that the total number of species could increase to 34, if *P. erhardii* is added to the list [19].

3 Species Conservation Status

3.1 IUCN Global

The International Union for the Conservation of Nature (IUCN) is the oldest and largest global environmental organization, with a central mission to conserve biodiversity worldwide [21]. IUCN regularly updates Red Lists of threatened species and produces publications relating to the status of endangered species (for European amphibians and reptiles; see [22, 23]).

Only one amphibian species in the Lake Skadar region is globally threatened (*P. shqipericus*) (Fig. 7). It is categorized as Endangered (EN) because its distribution area is less than 5,000 km^2 and severely fragmented, with a reported continuous decline in the extent and the quality of its habitat [24]. *Triturus macedonicus* has still not been evaluated for Red List, but there are indications that it could be threatened.

Two reptile species in the region are globally threatened (*D. mosorensis* [25] and *V. ursinii* [26]) (Fig. 7). Both are Vulnerable (VU), having an overall area less than 2,000 km^2, severely fragmented, and they require specific habitats, discontinuously distributed throughout the range [25, 26]. *Dinarolacerta montenegrina* [27] was proclaimed to be of Least Concern (LC) in the absence of evidence of threats [28].

Emys orbicularis, *T. hermanni*, and *E. quatuorlineata* could be threatened in the future (Fig. 7). Those Near Threaten (NT) species should be carefully monitored as the size of their overall distribution range and/or the quality of their habitats are already recognized as impacted by threatening factors. Continuation or intensification of those threats could easily shift the species into one of the threatened IUCN categories [29–31].

3.2 CITES

The Convention on International Trade in Endangered Species of Wild Fauna and Flora establishes and regulates conditions that govern the transfer of wild species or their parts or derivatives across the countries' administrative borders [21].

Two of the reptile species listed here are covered by CITES annexes – *T. hermanni* and *V. ursinii* (Fig. 7). The level of their international transport control differs: the transport of Hermann's tortoise across borders requires an export permit from the country of origin, issued by the governmental authority, while for the meadow viper, both export and import permits (issued by the relevant government authority of the country of import) must be provided.

Species	IUCN[1]	CITES[2]	BERN[3]	HABITATS[4]	Albania[5]	Montenegro[6]
Amphibia						
Urodela						
Salamandra atra	LC	–	**II**	**II, IV**	+ (LRnt)	+
Salamandra salamandra	LC	–	**III**	–	+ (DD)	+
Ichthyosaura alpestris	LC	–	**III**	–	+ (DD)	+
Lissotriton vulgaris	LC	–	**III**	–	+ (LRlc)	+
*Triturus macedonicus**	NE	–	**II**	**IV**	+ (LRlc)	+
Anura						
Bombina variegata	LC	–	**II**	**II, IV**	+ (LRcd)	–
Bufo bufo	LC	–	**III**	–	+ (LRnt)	+
Bufotes viridis	LC	–	**II**	**IV**	+ (LRnt)	+
Hyla arborea	LC	–	**II**	**IV**	+ (LRlc)	+
Pelophylax kurtmuelleri	LC	–	**III**	–	+ (VU)	
Pelophylax ridibundus	LC	–	**III**	**V**		+
Pelophylax shqipericus	**EN**	–	**III**	–	+ (VU)	+
Rana dalmatina	LC	–	**II**	**IV**	+ (LRlc)	–
Rana graeca	LC	–	**III**	**IV**	+ (LRnt)	+
Rana temporaria	LC	–	**III**	**V**	+ (LRcd)	–

Fig. 7 Global conservation status and international/national levels of legal protection of amphibians and reptiles that inhabit ecosystems of the Lake Skadar region and their degree of legal protection on the international and local level. Cell in *black* color: species presence not confirmed in respective country. [1]IUCN (*International Union for Conservation of Nature*) – Listed categories of threat according to IUCN categorization: LC, species is not threatened (*Least Concern*); NT, species is almost threatened (*Near Threatened*); VU, species is considered to be facing a high risk of extinction in the wild (*Vulnerable*). [2]CITES (*Convention on International Trade of Endangered Species*) – (Appendix I, species that face extinction; Appendix II, species that should be under the control of trade to avoid the threat of extinction; Appendix III, species that are protected on the territory of at least one country. [3]BERN (*Bern Convention on the Conservation of European Wildlife and Natural Habitats*) – (II, strictly protected animal species; III, protected animal species). [4] HABITATS (*European directive on conservation of natural habitats and of wild fauna and flora*) – (Annex II, Vulnerable/sensitive species which could become endangered in the near future if the factors of threat continue to act, and * means priority species; Annex IV, species that require strict protection;

Reptilia						
Chelonia						
Emys orbicularis	**NT**	–	**II**	**II, IV**	+ (LRnt)	+
Mauremys rivulata	LC	–	**II**	**II, IV**	+ (VU)	+
Testudo hermanni	**NT**	**+(II)**	**II**	**II, IV**	+ (LRnt)	+
Sauria						
Anguis fragilis/graeca	LC	–	**III**	–	+(NE)	+
Pseudopus apodus	LC	–	**II**	**IV**	+ (LRnt)	+
Hemydactilus turcicus	LC	–	**III**	–	+ (LRcd)	–
Mediodactylus kotschyi	LC	–	**II**	**IV**	+ (LRcd)	
Algyroides nigropunctatus	LC	–	**II**	**IV**	+ (LRcd)	+
Dalmatolacerta oxycephala	LC	–	**III**	**IV**	–	+
Dinarolacerta montenegrina	LC	–	**III**	–	–	–
Dinarolacerta mosorensis	**VU**	–	**III**	**II, IV**		+
Lacerta agilis	LC	–	**II**	**IV**	+ (LRnt)	+
Lacerta trilineata	LC	–	**II**	**IV**	+ (LRcd)	+
Lacerta viridis	LC	–	**II**	**IV**	+ (LRcd)	+
Podarcis erhardii	LC	–	**II**	**IV**	+ (LRcd)	
Podarcis melisellensis	LC	–	**II**	**IV**	+ (LRcd)	+
Podarcis muralis	LC	–	**II**	**IV**	+ (NE)	+

Fig. 7 (continued)

Fig. 7 (continued) Annex V, species which breeding in the wild and exploitation could be a matter of management). [5]Red List of Wild Flora and Fauna of Albania (approved by Ministerial Order No. 1280, 20.11.2013). [6]Resolution on placing certain plant and animal species under protection (Official Gazette of the Republic of Montenegro, No. 76/06). *Named as *T. carnifex* in [6]. **Named as *M. monspessulana* in [6]

Podarcis siculus	LC	–	**II**	**IV**	–	+
Podarcis tauricus	LC	–	**II**	**IV**	+ (LRnt)	–
Zootoca vivipara	LC	–	**III**	–	+ (LRnt)	+
Ablepharus kitaibelii	LC	–	**II**	**IV**	+ (LRnt)	–
Serpentes						
Xerotyphlops vermicularis	LC	–	**III**	–	+ (CR)	–
Coronella austriaca	LC	–	**II**	**IV**	+ (LRnt)	+
Dolichophis caspius	LC	–	**II**	**IV**	+ (LRlc)	–
Elaphe quatuorlineata	**NT**	–	**II**	**II, IV**	+ (CR)	+
Hierophis gemonensis	LC	–	**II**	**IV**	+ (CR)	+
*Malpolon insignitus***	LC	–	**III**	–	+ (LRlc)	+
Natrix natrix	LC	–	**III**	–	+ (NE)	+
Natrix tessellata	LC	–	**II**	**IV**	+ (NE)	+
Platyceps najadum	LC	–	**II**	**IV**	+ (LRcd)	+
Telescopus fallax	LC	–	**II**	**IV**	+ (LRlc)	–
Zamenis longissimus	LC	–	**II**	**IV**	+ (EN)	+
Zamenis situla	LC	–	**II**	**II, IV**	+ (CR)	+
Vipera ammodytes	LC	–	**II**	**IV**	+ (LRnt)	–
Vipera berus	LC	–	**III**	–	+ (LRnt)	–
Vipera ursinii	**VU**	**+ (I)**	**II**	***II, IV**	+ (LRnt)	–

Fig. 7 (continued)

3.3 BERN Convention

The main goal of the Bern Convention on the Conservation of European Wildlife and Natural Habitats is to conserve wild flora and fauna and their natural habitats and to promote European cooperation in this field [21]. Species and habitats of conservation concern are listed under several appendices. However, it is obvious that some species have not been properly evaluated, despite having a very restricted distribution range. These are occurring exclusively in the Balkans and/or in Eastern Europe.

All European amphibian and reptile species, and therefore also those occurring in the Lake Skadar region, are included in the annexes of the Bern Convention (Fig. 7). Regarding scientific names of species in the annexes, it is obvious that there is a certain time lag in adopting recent taxonomic changes, so we took the liberty of adding the same status to new species that have appeared by splitting species already listed in the Convention or to those whose species status is still being debated.

3.4 Habitats Directive

Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora, known as the Habitats Directive, combines the idea of maintaining a network of protected sites with a strict system of species protection on a European level [21].

Six out of fifteen amphibian species from our study (or 40%) are not listed in annexes of the Habitats Directive (*S. salamandra*, *I. alpestris*, *L. vulgaris*, *B. bufo*, *P. kurtmuelleri*, *P. shqipericus*) (Fig. 7). Although they inhabit European countries outside EU, the last two species could hardly be considered to be widespread throughout member states of the European Union (EU), so they have not been taken into consideration for the annexes of the Habitats Directive yet. In fact, 8 out of 36 reptile species occurring in the Lake Skadar region (or 22%) are not included in the annexes (*A. fragilis/graeca*, *H. turcicus*, *D. montenegrina*, *Z. vivipara*, *X. vermicularis*, *M. insignitus*, *N. natrix*, *V. berus*) (Fig. 7). Some of these species do belong to the category of "widely widespread" throughout EU, while some others are probably considered as stable. The reasons above could also explain the absence of *D. montenegrina* [27] in the annexes.

3.5 National Legislatives

3.5.1 Albania

Fifteen amphibian and 37 reptile species are listed under the Red List of Wild Flora and Fauna in Albania. Two out of three amphibians listed as Vulnerable are found in the Lake Skadar region. Meanwhile, one EN, three CR, and one VU reptile species found in this region were reported in the last evaluation adopted in 2013 by the Law on Biodiversity Protection (Order No. 1280, dated 20.11.2013 on the Approval of the Red List of Wild Flora and Fauna). The collection of amphibians and reptiles is regulated by the Law on Transboundary Lakes (Law No. 9103, dated 10.7.2003), while these species are not included in the list of wild species subject to hunting (Decision No. 546, dated 07.07.2010). It is necessary during the next evaluation to update the recent status of some species, as well as the nomenclature used.

3.5.2 Montenegro

Thirteen amphibian and 26 reptile species are protected by law in Montenegro (Law on Nature Protection – Official Gazette of the Republic of Montenegro, No. 54/16) according to the latest resolution on placing certain plant and animal species under protection (Official Gazette of the Republic of Montenegro, No 76/06, 12 December, 2006). Of that number, 11 species of amphibians and 23 species of reptiles that inhabit the Montenegrin part of the Lake Skadar region are protected, which represents approximately 79 and 72% of the total number of amphibian and reptile species recorded in this area (Fig. 7).

The list of protected species was adopted in 2006 and needs revision for consistency with current nomenclature, eventual inclusion of newly established species for Montenegro (*D. montenegrina*, *A. kitaibelii*), and correction of some initial shortcomings. For example, the list includes species not officially confirmed on the territory of Montenegro (*Proteus anguinus*, *Pelobates fuscus*) yet excludes complete families (e.g., Viperidae). Such errors and discrepancies clearly need to be amended in accordance with international conventions (e.g., status of *V. ursinii*), which is one step included in the harmonization of Montenegrin legislation with the EU legislation and standards in the environmental sector in the process of EU accession.

4 Main Threats

The main drivers of contemporary extinction of wildlife are often briefly described as "evil quartet" [32]. They refer to the negative human impact on biodiversity and include habitat fragmentation and degradation, overexploitation of the species, successful colonization of allochthonous species ("invasive species"), and the chain effects of species extinctions. Human persecution, road kills, and pathogens are sometimes considered as separate threat factors. Climate change has also had visible impact on biodiversity: the majority of models in simulation studies suggest alarming consequences for life at all scales [33].

Although most of the Lake Skadar region is legally protected, negative anthropogenic impacts have not been excluded: demographic movements have intensified since 1990, leading to increased exploitation of local natural resources [8]. Intensification of industry and agriculture in the lowland parts of the region has resulted in deforestation, drainage of wetlands beside Lake Skadar, and chemical pollution [5]. Economic improvement in the mountainous part of the region has been made through the development of ski-tourism and tourism in general (involving transformation of Vulnerable local amphibian breeding sites into fisheries), as well as deforestation and change of landscape, all of which have a negative impact on local batracho- and herpetofauna.

4.1 Amphibians

Amphibians are currently the most threatened group of vertebrates [34]. They are declining in numbers rapidly due to intensive habitat fragmentation, degradation, alteration, or entire loss of their breeding sites [35]. The apparent sensitivity of amphibians to environmental and/or anthropogenic changes is a consequence of their complex life history, where both aquatic and terrestrial environments are required for the successful completion of their life cycle.

Ćirović [36] listed several global threats that also disturb amphibians in Montenegro. Habitat fragmentation and degradation in Montenegro and therefore in the Lake Skadar region as well could be a particularly sensitive issue for newts: their breeding sites show decreasing trends due to demographic changes in the area [37]. In the karst, most suitable spawning sites for newts are actually of anthropogenic origin, made and maintained for water collection. When abandoned (due to mass migration of local people to the cities), those aquatic habitats undergo degradation and became unsuitable for newts and other amphibians.

A variety of anthropogenic influences have affected the populations of amphibians in Albania: reduction of lowland aquatic habitats; construction of large drainage channels to gain land for agriculture; pollution by sewage, detergents, and other chemicals, especially over the last 25 years; usage of the riverbeds for construction materials [15, 38]; etc.

Over exploitation (i.e., collection and harvesting) of water frogs on the territory of Montenegro has certainly occurred recently [39], although it is not easy to evaluate its consequences in the absence of the quantitative population data before overexploitation. In Albania, exploitation of *P. epeiroticus* (water frog species not present in the Lake Skadar region) was so big that regulations and laws were needed to prohibit collection [15]. Over-collection for commercial purposes is specifically mentioned as a threat for *P. kurtmuelleri* [40].

Allochthonous species that can jeopardize local amphibians are mainly fish species accidentally or intentionally introduced by people to fishless, stagnant waters where they usually cause lower breeding success, decline, or even extinction of local amphibians [41]. In the Montenegrin karstic environment particularly, newts prefer aquatic environment without fish [42]. Moreover, the deliberate introduction of allochthonous water frogs (e.g., for economic reasons) could negatively impact at least endemic and globally threatened Albanian water frogs [39]. Additionally, new invasive pathogens such as chytrid fungus (*Batrachochytrium dendrobatidis*) are specifically alarming [43]. This was first detected in the western part of Europe, while the Balkan Peninsula was only recently checked for the presence of chytrid fungus. A study conducted in the

Montenegrin part of the Lake Skadar region detected *B. dendrobatidis* mostly in samples of water frogs (*Pelophylax* sp.), but there were sporadic cases of infested yellow-bellied toads (*B. variegata*), tree frogs (*H. arborea*), and even smooth newts (*L. vulgaris*) and Macedonian crested newts (*T. macedonicus*) [44].

4.2 Reptiles

Reptiles have been recently recognized as a vertebrate group of conservation concern, being prone primarily to anthropogenic threats [45]. Mediterranean and sub-Mediterranean areas of Montenegro provide apparently high diversity of suitable habitats for a number of reptile species, but this richness could be severely decreased by intensive habitat degradation, fragmentation, and destruction due to aggressive development of tourism and consequent urbanization in the area. Species utilizing specific habitats whose natural history may not be well known could be especially affected (e.g., *X. vermicularis*, *A. nigropunctatus*, *D. montenegrina*, *V. ursinii*). Wildfires strongly affect local herpetofauna, particularly slow-moving species such as tortoises [46], and that issue is increasing in the study area [47].

Overexploitation (overharvesting) particularly impacted *T. hermanni* in former Yugoslavia. In a recent review study [48], Lake Skadar region was indicated as a possibly Vulnerable area. The illegal trade in tortoises could still be a current issue there despite CITES initiatives and the recent efforts of local ecologically oriented NGOs. Moreover, the flagrant illegal export of 800 *T. hermanni* to Italy by Albanians was reported two decades ago. Overkilling by vehicles produces an outcome similar to that of overexploitation, and Hermann's tortoises are again among the most targeted reptiles in the area [47]. *Vipera ammodytes* is another reptile species that could be locally devastated, traditionally collected for venom supplies [49], and harvested in this area [50].

Transition, intensification of communications, tourism, and the increasing influence of general trends in western society inevitably brings new threats to local wildlife. One of them is keeping allochthonous species as pets followed by their deliberate release into local ecosystems, as happened with the spectacled caiman near the town of Budva on the nearby Adriatic coast [51]. Another attractive allochthonous pet species, the common slider (*Trachemys scripta*), poses a great threat to autochthonous terrapins: neglected common sliders are being released into the local aquatic ecosystems, where they can easily establish viable populations [52]. This species has already been recorded in the freshwater ecosystem near the Adriatic coast of Montenegro [53] and may form part of the local aquatic fauna in the Lake Skadar region. The small Indian mongoose (*Herpestes auropunctatus*) is an allochthonous predator that already has a reputation for exterminating reptile fauna in Southern Europe. It has been detected along the entire Montenegrin coastal zone but could also spread to the Lake Skadar region by the valley of Bojana/Buna river [54].

5 Species of Special Conservation Concern

5.1 Amphibians

Although all amphibian species in Albania and most in Montenegro are protected [15, 36], the threats listed above warn us of the necessity to continuously monitor local amphibian populations. The high species richness in Lake Skadar region almost reflects the total amphibian diversity in those two countries. However, some species are rather specific to Lake Skadar, such as *P. shqipericus* [24] (Fig. 8). *Salamandra atra* (Fig. 9) has a very restricted distribution in this area and apparently contributes to its conservation value. Although not threatened by IUCN criteria, these southernmost populations could be quite fragile and susceptible to the negative effects of recent climate change, particularly if combined with intensive human alterations of species habitats [55].

Fig. 8 *Pelophylax shqipericus* (Photo: B. Prakljačić)

Fig. 9 *Salamandra atra* (Photo: Natural History Museum Podgorica Photo Archive)

Ichthyosaura alpestris (Fig. 10) has a broader ecological niche than the Alpine salamander, but it has become generally exposed to a threat of local extinction by the introduction of fish to the primarily fishless mountainous lakes and the destruction of breeding sites due to the establishment of ski resorts [56]. There is still a possibility to maintain viable local populations of Alpine newts in the region if nature conservation authorities actively participate in the projects of sustainable development. *Triturus macedonicus* (Fig. 11) is the only crested newt species in Montenegro and

Fig. 10 *Ichthyosaura alpestris* (Photo: N. Čađenović)

Fig. 11 *Triturus macedonicus* (Photo: J. Crnobrnja-Isailović)

Albania [57] and, according to evidence, has become quite Vulnerable throughout Montenegro with regard to breeding site stability (see in [36, 37, 41]).

5.2 Reptiles

The reptile species of special conservation concern in the Lake Skadar region were chosen applying the same criteria as for amphibians: global conservation status by IUCN, local rareness, and/or fragility of local populations.

Globally threatened reptile species by the IUCN criteria are *D. mosorensis* [25] (Fig. 12) and *V. ursinii* [26] (Fig. 13). Both species have rather specific habitat requirements [58, 59] and therefore restricted distribution within the region [59, 60]. Also, local meadow viper populations belong to *macrops* subclade, as do those from Bosnia and Herzegovina [61]. Three species with Near Threatened (NT) global status – *T. hermanni* (Fig. 14), *E. orbicularis* (Fig. 15), and *E. quatuorlineata* (Fig. 16) – must also be included in the list of local reptile conservation priorities, for reasons already presented in Sect. 4. The apparent intentional killing of a four-lined snake in the Montenegrin part of the Lake Skadar coastal area has been the consequence of local human attitude, probably because of the size and robustness of this snake (Crnobrnja-Isailović, pers. obs.), while the specific coloration of juveniles resembles that of vipers (Ljubisavljević, pers. obs.). Therefore, this species should be checked for population size and abundance. Further education and awareness-raising activities would also be welcomed.

Mauremys rivulata (Fig. 17) should be a conservation priority because of its suspected vulnerability to the invasive common slider and to destruction and alteration of its habitats along the Montenegrin coast due to excessive urbanization [62]. Additionally, *D. montenegrina* (Fig. 18) must be a conservation priority in the region because of its endemic status and information on likely occurring

Fig. 12 *Dinarolacerta mosorensis* (Photo: L. Polović)

Fig. 13 *Vipera ursinii macrops* (Photo: J. Crnobrnja-Isailović)

Fig. 14 *Testudo hermanni* (Photo: L. Polović)

threats [63]. There are additional two lizard species, of which special care should be taken, due to its very restricted area of occupancy in the region or Vulnerable habitats: *P. erhardii* has so far been detected in a very small part of the

Fig. 15 *Emys orbicularis* (Photo: L. Polović)

Fig. 16 *Elaphe quatuorlineata* (Photo: Natural History Museum Podgorica Photo Archive)

northeasternmost Lake Skadar region (Albanian part) [19], while *Z. vivipara* occurs here at the southern edge of the species range and occupies specific boreal and Alpine meadow habitats which could be degraded by climate change (generally explained in [64]) and ski-tourism.

Fig. 17 *Mauremys rivulata* (Photo: L. Polović)

Fig. 18 *Dinarolacerta montenegrina* (Photo: K. Ljubisavljević)

Vipera ammodytes (Fig. 19) and *V. berus* (Fig. 20) should be carefully monitored within the region as recent publications indicate some global contemporary issues relating to snakes [65] and particularly vipers [66]. The nose-horned viper is

Fig. 19 *Vipera ammodytes* (Photo: J. Crnobrnja-Isailović)

Fig. 20 *Vipera berus* (Photo: O. Isailović)

specifically threatened, being a quite visible snake that often inhabits sites in close vicinity to human settlements, where local people have a strong negative attitude toward vipers [49]. Therefore, permanent education of inhabitants about the importance of vipers and the ecosystem services they provide should follow. Moreover, populations of nose-horned viper from Montenegro and adjacent parts of Albania form a separate genetic clade and are therefore additionally valuable for conservation as a specific evolutionary significant unit [67].

Acknowledgments The authors are grateful to Z. Dedej of the Albanian National Agency of Protected Areas; to A. Martini, A. Dardha, and T. Macaj from the Regional Administration of Protected Areas, Shkodër; as well as to Dr. M. Paunović and Dr. P. Reynolds for the help in certain aspects of this study. Proofreading was done by Mrs. Esther Helajzen, English translator from Belgrade, Serbia. JCI is indebted to Lj. Orlandić and S. Marinković for their generous hospitality during a detailed survey of the southeastern coastal area of Lake Skadar. JCI was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 173025).

References

1. Krystufek B, Reed JM (2004) Pattern and process in Balkan biodiversity. In: Griffiths KI, Reed JM, Krystufek B (eds) Balkan biodiversity: pattern and process in the European HotSpot. Kluwer, Amsterdam, pp 203–2017
2. Crnobrnja-Isailović J (2007) Cross – section of a refugium: genetic diversity of amphibian and reptile populations in the Balkans. In: Weiss S, Ferrand N (eds) Phylogeography of Southern European Refugia. Springer, Berlin, pp 327–337
3. Radović I, Radović D, Jakšić P, Džukić G, Stevanović V, Bulić Z, Bušković V (2008) Skadar Lake region and “target species” of European conservation concern. Nat Montenegrina 7:31–44
4. Kalezić ML, Džukić G (2004) The biodiversity of amphibians and reptiles on the Balkan Peninsula. In: Griffiths KI, Reed JM, Krystufek B (eds) Balkan biodiversity: pattern and process in the European HotSpot. Kluwer, Amsterdam, pp 167–192
5. Crnobrnja-Isailović J, Džukić G (1995) First report about conservation status of herpetofauna in the Lake Skadar Region (Montenegro): current situation and perspectives. In: Llorente G, Montori A, Santos X, Carretero MA (eds) Scientia Herpetologica. Association Herpetologica Espanola, Barcelona, pp 373–380
6. Džukić G (1995) Diversity of amphibians (Amphibia) and reptiles (Reptilia) of Yugoslavia, with overview of internationally important species. In: Stevanović V, Vasić V (eds) Biodiversity of Yugoslavia with an overview of internationally important species. Faculty of Biology and Ecolibri, Belgrade, pp 449–469
7. Crnobrnja-Isailović J (1997) Biogeographic, genetic and morphological features of Lacertid lizards (Lacertilia) from Lake Skadar region. Dissertation, University of Belgrade, (In Serbian with English summary)
8. Bejko D (2011) Promoting environmental protection through the management of shared natural resources between Albania and Montenegro: the Shkodra Lake Watershed. In: Montini M, Bogdanovic S (eds) Environmental security in South-Eastern Europe, NATO science for peace and security series C: environmental security. Springer Science + Business Media B.V, pp 197–212
9. Sadori L, Giardini M, Gliozzi E, Mazzini I, Sulpizio R, van Welden A, Zanchetta G (2015) Vegetation, climate and environmental history of the last 4500 years at lake Shkodra (Albania/Montenegro). The Holocene 25:435–444
10. Sillero N, Campos J, Bonardi A, Corti C, Creemers R, Crochet P-A, Crnobrnja-Isailović J, Denoël M, Ficetola GF, Gonçalves J, Kuzmin S, Lymberakis P, de Pous P, Rodríguez A, Sindaco R, Speybroeck J, Toxopeus B, Vieites DR, Vences M (2014) Updated distribution and biogeography of amphibians and reptiles of Europe. Amphibia-Reptilia 35:1–31

11. Gasc JP, Cabela A, Crnobrnja-Isailović J, Dolmen D, Grossenbacher K, Haffner P, Lescure J, Martens H, Martínez-Rica JP, Maurin H, Oliveira ME, Sofianidou TS, Veith M, Zuiderwijk A (eds) (1997) Atlas of amphibians and reptiles in Europe. Societas Europaea Herpetologica & Museum Nationall d' Histoire Naturelle (IEGB/SPN), Paris, 496 p
12. Haxhiu I (1994) The herpetofauna of Albania: Amphibia: species composition, distribution, habitats. Zool Jahrb Syst 121:109–115
13. Schneider H, Haxhiu I (1994) Mating call and taxonomy of water frogs (Ranidae, Anura) in Albania. Zool Jahrb Syst 121:248–262
14. Dhora Dh, Sokoli F (2000) Liqeni i Skhodrës – Biodiversiteti. ShRMMNSh, UNDP, GEF/SGP. Shkodër 10–13, 14–23, 58–4
15. Haxhiu I (2015) Amphibians of Albania. In: Heathvole H, Wilkinson J (eds) Amphibian biology vol 11. Part 4. Status of conservation and decline of amphibians: eastern hemisphere: southern Europe and Turkey. Pelagic Publishing, Exeter, UK, pp 74–79
16. Szabolcs M, Mizsei E, Jablonski D, Vági B, Mester B, Végvári Z, Lengyel S (2017) Distribution and diversity of amphibians in Albania: new data and foundations of a comprehensive database. Amphibia-Reptilia 38:435–448
17. Vucić M (2015) Determination of species and hybrids of water frogs (genus *Phelophylax*) from Skadar Lake, Montenegro using molecular markers. Graduation Thesis, Faculty of Science University of Zagreb, 54 p. (In Croatian with English summary)
18. Polović L, Ljubisavljević K (2010) Herpetofaunal richness of the Skadar Lake region, Montenegro: a review and update. Scripta Scientiarum Naturalium 1:113–121
19. Mizsei E, Jablonski D, Végvári Z, Lengyel S, Szabolcs M (2017) Distribution and diversity of reptiles in Albania: a novel database form a Mediterranean hotspot. Amphibia-Reptilia 38:157–173
20. Haxhiu I (1998) The reptiles of Albania: species composition, distribution, habitats. Bonn Zool Jahrb Syst 121:321–334
21. Crnobrnja Isailović J, Adrović A, Ćafuta M, Ćosić N, Jelić D, Kotrošan D, Lisičić D, Marinković S, Poboljšaj K, Presetnik P, Sekulić G (2015) Fauna of the riparian ecosystems – amphibians, reptiles, birds and mammals. In: Milačič R, Ščančar J, Paunović M (eds) The handbook of environmental chemistry. The Sava River, vol 31. Springer-Verlag GmbH, Heidelberg, Germany, pp 401–436
22. Anthony B, Arntzen JW, Baha El Din S, Böhme W, Cogalniceanu D, Crnobrnja-Isailović J, Crochet P-A, Corti C, Griffiths R, Kaneko Y, Kuzmin S, Wai Neng Lau M, Li P, Lymberakis P, Marquez R, Papenfuss T, Pleguezuelos JM, Rastegar N, Schmidt B, Slimani T, Sparreboom M, Ugurtas I, Werner Y, Xie F (2006) Amphibians of the Palaearctic realm. In: Stuart SN, Hoffmann M, Chanson JS, Cox NA, Berridge RJ, Ramani P, Young BE (eds) Threatened amphibians of the World Lynx Edicions, with IUCN – The World Conservation Union, Conservation International and NatureServe, Barcelona, pp 106–113
23. Cox NA, Temple HJ (2009) European red list of reptiles. Office for Official Publications of the European Communities, Luxembourg
24. Uzzel T, Crnobrnja-Isailović J (2009) *Pelophylax shqipericus*. The IUCN Red List of Threatened Species. e.T58715A11829016. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T58715A11829016.en
25. Crnobrnja-Isailović J, Ajtić R, Vogrin M (2009) *Dinarolacerta mosorensis*. The IUCN Red List of Threatened Species. e.T61526A12504486. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T61526A12504486.en
26. Joger U, Crnobrnja Isailovic J, Vogrin M, Corti C, Sterijovski B, Westerström A, Krecsák L, Pérez Mellado V, Sá-Sousa P, Cheylan M, Pleguezuelos JM, Sindaco R (2009) *Vipera ursinii*. The IUCN Red List of Threatened Species. e.T22997A9406628. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T22997A9406628.en
27. Ljubisavljević K, Arribas O, Džukić G, Carranza S (2009) Genetic and morphological differentiation of Mosor rock lizards, *Dinarolacerta mosorensis* (Kolombatović, 1886) with the description of a new species from Prokletije Mountain Massif (Montenegro)(Squamata: Lacertidae). Zootaxa 1613:1–22

28. Crnobrnja-Isailović J, Bowles P (2011) *Dinarolacerta montenegrina*. The IUCN Red List of Threatened Species. e.T196001A8989716. https://doi.org/10.2305/IUCN.UK.2011-2.RLTS.T196001A8989716.en
29. Tortoise & Freshwater Turtle Specialist Group (1996) *Emys orbicularis* (errata version published in 2016).The IUCN Red List of Threatened Species. e.T7717A97292665. https://doi.org/10.2305/IUCN.UK.1996.RLTS.T7717A12844431.en.
30. van Dijk PP, Corti C, Mellado VP, Cheylan M (2004) *Testudo hermanni*. The IUCN Red List of Threatened Species. e.T21648A9306057. https://doi.org/10.2305/IUCN.UK.2004.RLTS.T21648A9306057.en
31. Crnobrnja Isailović J, Ajtić R, Vogrin M, Corti C, Pérez Mellado V, Sá-Sousa P, Cheylan M, Pleguezuelos JM, Lymberakis P, Sindaco R, Romano A, Jelić D (2009) *Elaphe quatuorlineata*. The IUCN Red List of Threatened Species. e.T157264A5065135. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T157264A5065135.en
32. Diamond JM (1989) Overview of recent extinctions. In: Western D, Pearl MC (eds) Conservation of the twenty-first century. Oxford University Press, Oxford, pp 37–41
33. Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F (2012) Impact of climate change on the future of biodiversity. Ecol Lett 15:365–377
34. Stuart SN, Chanson JS, Cox NA, Young BE, Rodrigues ASL, Fischman DL, Waller RW (2004) Status and trends of amphibian declines and extinctions worldwide. Science 306:1783–1786
35. Cushman SA (2006) Effects of habitat loss and fragmentation on amphibians: a review and prospectus. Biol Conserv 128:231–240
36. Ćirović R (2015) Amphibian declines and conservation in Montenegro. In: Heathvole H, Wilkinson J (eds) Amphibian biology vol 11. Part 4. Status of conservation and decline of amphibians: eastern hemisphere: Southern Europe and Turkey. Pelagic Publishing, Exeter, UK, pp 56–61
37. Ćirović R, Radović D, Vukov T (2008) Breeding site traits of European newts (*Triturus macedonicus*, *Lissotriton vulgaris* and *Mesotriton alpestris*: Salamandridae) in the Montenegrin Carst region. Arch Biol Sci 60:459–468
38. Haxhiu I (1995) Results of studies on the Chelonians of Albania and current data on the Chelonians of Albania. J IUCN/SSC 1(4)
39. Džukić G, Kalezić ML, Ljubisavljević KM (2003) Protection and conservation of green frogs in Serbia and Montenegro. Federal Secretariat for Labor, Health and Social Care, Belgrade. (in Serbian)
40. Uzzell T, Andreone F, Lymberakis P, Vogrin M, Haxhiu I, Crnobrnja-Isailović J, Sindaco R, Romano A (2009) *Pelophylax kurtmuelleri*. The IUCN Red List of Threatened Species. e. T58637A11817029. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T58637A11817029.en
41. Pilliod DS, Peterson CR (2001) Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. Ecosystems 4:322–333
42. Ćirović R, Vukov TD, Radović D, Ml K, Džukić G (2008) Distribution patterns and environmental determinants of European newts in the Montenegrin karst area. Biologia 63:745–752
43. Rödder D, Kielgast J, Bielby J, Schmidtlein S, Bosch J, Garner TWJ, Veith M, Walker SF, Fisher MC, Lötters S (2009) Global amphibian extinction risk assessment for the Panzootic Chytrid fungus. Diversity 1:52–66
44. Vojar J, Havlikova B, Solsky M, Jablonski D, Iković V, Balaž V (2017) Distribution, prevalence and amphibian hosts of *Batrachochytrium dendrobatidis* in the Balkans. Salamandra 53:44–49
45. Böhm M, Collen B, Baillie JEM et al (2013) The conservation status of the world's reptiles. Biol Conserv 157:372–385
46. Esque T, Schwalbe C, DeFalco L, Duncan R, Hughes T (2003) Effects of desert wildfires on desert tortoises *Gopherus agassizii* and other small vertebrate. Southwest Nat 48:103–111
47. Vujović A, Iković V, Golubović A, Đorđević S, Pešić V, Tomović LJ (2015) Effects of fires and Roadkills on the isolated population of *Testudo hermanni* Gmelin, 1789 (Reptilia: Testudinidae) in Central Montenegro. Acta Zool Bulgar 67:75–84

48. Ljubisavljević K, Džukić G, Kalezić M (2011) The commercial export of the land tortoises (*Testudo* spp.) from the territory of the former Yugoslavia: a historical review and the impact of overharvesting on wild populations. North-Western. J Zool 7:250–260
49. Jelić D, Ajtić R, Sterijovski B, Crnobrnja-Isailović J, Lelo S, Tomović LJ (2013) Legal status and assessment of conservation threats to vipers (Reptilia: Squamata: Viperidae) of the western and Central Balkans. Herpetol Conserv Bio 8:764–770
50. Ajtić R (2008) Nose-horned viper (*Vipera ammodytes*) – conservation problems in Serbia. Zaštita Prirode 60:319–326. (In Serbian with summary in English)
51. Gvozdenović S, Iković V (2014) The capture of a spectacled caiman *Caiman crocodilius* Linnaeus, 1758 (Crocodylia, Alligatoridae) in Montenegro. Hyla 2014:30–32
52. Scalera R (2006) *Trachemys scripta*. DAISIE Database. http://www.europe-aliens.org/pdf/Trachemys_scripta.pdf
53. Žagar A, Ćafuta V, Drašler K, Jagar T, Krofel M, Lužnik M, Ostanek M, Petkovska V, Planinc G, Sopotnik M, Vamberger M (2013) A review of eleven short-term reptile surveys in the western Balkans. Hyla 2013:3–21
54. Ćirović D, Raković M, Milenković M, Paunović M (2011) Small Indian Moongoose *Herpestes auropunctatus* (Herpestidae, Carnivora): an invasive species in Montenegro. Biol Invasions 13:393–399
55. Andreone F, Denoël M, Miaud C, Schmidt B, Edgar P, Vogrin M, Crnobrnja-Isailović J, Ajtić R, Corti C, Haxhiu I (2009) *Salamandra atra*. The IUCN Red List of Threatened Species. e.T19843A9023725. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T19843A9023725.en
56. Arntzen JW, Denoël M, Kuzmin S, Ishchenko V, Beja P, Andreone F, Jehle R, Nyström P, Miaud C, Anthony B, Schmidt B, Ogrodowczyk A, Ogielska M, Bosch J, Vogrin M, Tejedo M (2009) *Ichthyosaura alpestris*. The IUCN Red List of Threatened Species. e.T59472A11946568. https://doi.org/10.2305/IUCN.UK.2009.RLTS.T59472A11946568.en
57. Wielstra B, Crnobrnja-Isailović J, Litvinchuk SN, Reijnen BT, Skidmore AK, Sotiropoulos K, Toxopeus AG, Tzankov N, Vukov T, Arntzen JW (2013) Tracing glacial refugia of *Triturus* newts based on mitochondrial DNA phylogeography and species distribution modeling. Front Zool 10:13
58. Crnobrnja-Isailović J, Džukić G (1997) Lacerta mosorensis. In: Gasc J-P et al (eds) Atlas of amphibians and reptiles in EuropeSocietas Europaea Herpetologica & Museum Nationall d' Histoire Naturelle, Paris, France, pp 250–251
59. Jelić D, Ajtić R, Sterijovski B, Crnobrnja-Isailović J, Lelo S, Tomović LJ (2012) Distribution of the genus *Vipera* in the western and central Balkans. Herpetozoa 25:109–132
60. Ljubisavljević K, Polović L, Iković V, Vuksanović S, Zagora V, Urošević A, Tomović L (2016) New records and updated distribution of the endemic Balkan rock lizards *Dinarolacerta* spp. in Montenegro. Ecol Montenegrina 9:46–50
61. Ferchaud A-L, Ursenbacher S, Cheylan M, Luiselli L, Jelić D, Halpern B, Major A, Kotenko T, Crnobrnja-Isailović J, Tomović LJ, Ghira J, Ioannidis Y, Arnal V, Montgelard C (2012) From south to north: mitochondrial markers reveal an unexpected colonization route for vipers of the *Vipera ursinii* complex in the Palaearctic region. J Biogeogr 39:1836–1847
62. Gvozdenović S, Iković V (2016) Distribution and vulnerability of Balkan Terrapin (*Mauremys rivulata*) in Montenegro. In: Jelić D, Ćurić A (eds) "Nature knows no boundaries" Rufford small grants conference in Bosnia and Herzegovina, 21st-22nd March, 2016. Abstract Book, Banja Luka, Bosnia and Herzegovina, pp 47–48
63. Ljubisavljević K, Polović L, Vuksanović S, Iković V (2014) A new record of the Prokletije rock lizard, *Dinarolacerta montenegrina* (Squamata: Lacertidae) in Montenegro. Ecol Montenegrina 1:201–203
64. Crnobrnja-Isailović J, Dinov J, Isailović O, Ranđelović V (2015) Westernmost record of *Zootoca vivipara* (Lichtenstein, 1823), in the Rhodope Massif, Serbia. Herpetozoa 27:162–165
65. Reading CJ, Luiselli LM, Akani GC, Bonnet X, Amori G, Ballouard JM, Filippi E, Naulleau G, Pearson D, Rugiero L (2010) Are snake populations in widespread decline? Biol Lett 6:777–780

66. Maritz B, Penner J, Martins M, Crnobrnja-Isailović J, Spear S, Alencar LRV, Sigala Rodriguez J, Messenger K, Clark RW, Soorae P, Luiselli L, Jenkins C, Greene HW (2016) Identifying global priorities for the conservation of vipers. Biol Conserv 204:94–102
67. Ursenbacher S, Schweiger S, Tomović LJ, Crnobrnja-Isailović J, Fumagalli L, Mayer W (2008) Molecular phylogeography of the nose-horned viper (*Vipera ammodytes*, (Linnaeus, 1758)): evidence for high genetic diversity and multiple refugia in the Balkan Peninsula. Mol Phylogenet Evol 46:1116–1128
68. Frost DR (2017) Amphibian species of the world: an online reference. Version 6.0 (November 23, 2017). Electronic Database. American Museum of Natural History, New York, USA. http://research.amnh.org/herpetology/amphibia/index.html
69. Haxhiu I, Alimehilli G (1987) Emertime te amfibeve ne shqipen popullore. Buletini i Shkencave Filologjike Tirane 1:185–189
70. Čađenović N (2014) Katalog faune Amphibia Crne Gore, katalozi 10, knjiga 9. Crnogorska akademija nauka i umjetnosti, Odjeljenje prirodnih nauka, Podgorica, 62 pp
71. Uetz P (ed) (2017) The Reptile Database. http://www.reptile-database.org. Accessed 23 Nov 2017
72. Haxhiu I (1981) Emertime popullore te zvarranikeve. Buletini i Shkencave Filologjike 4:209–217
73. Džukić G (1991) Amphibians and reptiles (Amphibia-Reptilia), material for the fauna of amphibians and reptiles of Durmitor. In: Nonveiller G (ed) The Fauna of Durmitor, part 4, special editions vol 24, Section of natural sciences, 15. Crnogorska akademija nauka i umjetnosti, Titograd, Yugoslavia, pp 9–78 (in Serbian with an abstract in English)

Ornithological Features of Skadar Lake

Ondrej Vizi

Contents

Abstract This paper presents the variety of habitats on Skadar Lake, one of the best known ornithological sites in the Mediterranean. It is characterised by marshy areas and their zonal distribution. Colonies of swamp birds, their distribution on the lake as well as their dynamics have been described. The problems regarding pollution, disturbance and poaching have also been tackled.

The list of fauna of Skadar Lake, observed within the borders of the National Park, amounts to 260 species. Their essential ecological properties, status of protection and current status in scope of the National Park have been given.

Keywords Diversity, Ornithofauna, Protection, Skadar Lake

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 415–446, DOI 10.1007/698_2018_263,
© Springer International Publishing AG 2018, Published online: 27 April 2018

1 Introduction

Bird's life plays a major role in every ecosystem, and especially in a dynamic, marshy environment like Skadar Lake. Occupying a high place in the trophic pyramid, birds are the best indicators of the entire metabolism of the ecosystem, its vitality and sanity. That is why the investigations and monitoring of ornithofauna have a great importance for monitoring the condition of the environment and all the changes emerging there. The pronounced mobility of birds in any space and their dynamics in all time segments make birds an excellent indicator for studying all the developments in dynamics of biotopes and of complete ecosystems. With its varied, abundant and dynamic ornithofauna, Skadar Lake represents a good example of the complexity of an ecosystem and a location entirely favourable for studying the processes in it.

Skadar Lake is the only freshwater basin of large size in this part of the Mediterranean and it is an important locality for breeding, wintering and migration of the birds. It has been maintained in a relatively well-preserved state.

The ornithological complex of Skadar Lake is not linked exclusively to water ecosystems. Birds, as very mobile organisms, travel over a wide area. For that reason, it is difficult to set the borders of an ornithological site. A common approach of earlier ornithological research was that the ornithological expanse of the lake included the entire complex of Ćemovsko Field with canyon of the Cijevna River on its northern shore as well as the slopes of coastal mountains on the south and southwest. It used to also encompass the Šas Lake with the Bojana River and saline in Ulcinj. This has its justification, since many birds breeding in the swampy part of the lake sometimes fly to the adjacent agricultural zones, and also get into the arid, semi-desert areas of Ćemovsko Field, and in post-nesting wondering they move to a much wider area. The distribution of some species and populations is completely disrupted in the time of migrations.

For elaborating the list of birds of Skadar Lake and for ecological analyses, we decided to restrict ourselves to the narrower area of Skadar Lake. The criterion used for defining the study area is the border of the National Park Skadar Lake, embracing a total area of circa 40,000 ha. This way, the over-mixing of "terrestrial" ornithofauna with the aquatic one has been avoided, and at the same time, all registered types of biotopes at Skadar Lake have been included.

When elaborating the list of birds, data from the literature were used as well as unpublished data from a number of monitoring programmes on Skadar Lake, and unpublished data from my personal data basis. Data on biotopes, bird colonies and recorded changes have been extracted primarily from personal notes made during the long-standing investigations and monitoring of the lake. The enclosed photographs are the originals taken by the author.

2 Brief History of the Ornithological Research of Lake Skadar

The first, rudimentary recognition about the abundance of ornithofauna on Skadar Lake originates from the second half of the nineteenth century, when the first naturalists came to Montenegro, at that time a largely mystic and unknown part of Europe; during the investigations in their fields of interest, they cite some species of birds [1–3]. Such a situation existed until the end of the nineteenth century, when the most eminent investigator of ornithofauna of Montenegro, Ludwig von Führer[1] [4–7] arrived on the scene. From 1893 to 1932, Führer collected and published a series of data on the birds of Montenegro and he collected a number of demonstrative samples for several natural history museums. On the basis of his work, the best known ornithologist of the Balkan countries, the curator from Sarajevo, Dr. Othmar Reiser [8], published the fourth volume of his series on birds of the Balkan Peninsula, until now an unequivocal work for Montenegrin ornithology.

In the turbulent years of Montenegrin history, only individual and sporadic investigations were carried out. The sporadic and occasional character of the investigations was maintained until 1965, when the Biological Institute Titograd was established. That is when the regular investigations of bird's fauna of Skadar Lake as well as of entire Montenegro commenced. The first list of birds of Skadar Lake was published by Matvejev [9], Matvejev and Vasić [10], Vasić [11], Vasić [12] and Stojković and Vasić [13]. The investigations obtained greater impetus in 1972. That year Ondrej Vizi started working on the lake and that work lasts until today. He has particularly studied the ecology of the Dalmatian Pelican Vizi [14–19].

At the beginning of the third millennium, the situation in Montenegrin ornithology changed considerably. Faunistic and idioecological investigations have given way to investigations of the type of monitoring, primarily from the aspect of the protection of birds and the protection of biotopes. The forerunner of those projects is the IWC (International Waterfowl Census) programme which has lasted at the lake for almost 30 years and it is currently implemented by the ornithologist of the Natural History Museum, National Parks, and Centre for Protection and Research of Birds, assisted by volunteers.

3 Ornithofauna of Skadar Lake

3.1 Ornithological Biotopes of Skadar Lake

The geomorphologic and climate properties of the lake have conditioned the development of a series of specific biotopes, very different from each other. The diversity

[1]In the literature his name is also spelled as Ljudevit Firer and Ludwig Fuehrer.

of biotopes is one of the essential features of the lake and it is, to a large extent, the cause of its biological diversity and abundance. The development of a specific type of biotope is primarily defined by the presence of water. In places where water is constantly or periodically present, an adequate type of substrate develops, thus an adequate type of vegetation and respectively of fauna. The survey of biotopes is given in the form of a table (Table 1).

Although presented in the shortest form, the distribution of biotopes on Skadar Lake clearly reflects its essential feature – its zonality, primarily defined by the depth of water. That by all leads to colonies of ornithofauna which is also zonally distributed, as established for the spring period by Stojković and Vasić [13]. Zonality also exists in the winter period [20].

3.2 Bird Colonies

Breeding in colonies is very distinctive for water birds. This feature is also to be found on Skadar Lake.

3.2.1 Colony of Pelicans

The Dalmatian Pelican (*Pelecanus crispus*) is the best known breeding species of Skadar Lake and a mascot of the National Park. It is a rather small population of an, until recently, endangered bird. The colony on Skadar Lake is the most western nesting area of this species.

The breeding of the Dalmatian Pelican on Skadar Lake was originally reported by Führer [4] who found a colony of 29 nests in the peaty zone of Pančeva oka in 1894. The colony existed in approximately the same size until the beginning of the 1970s, when 24 nests were found in 1973 [14].

Subsequently, variations were found in the number of nests, and Vizi [14] deems the main cause of this to be the lack of peat islets for breeding. Namely, due to the gradual eutrophication of the lake in the zone of inundated willows as well as due to changes in the climate and the hydrology of the lake, the number of newly created islets has decreased, and the old ones have become overgrown by reeds and willows, thus becoming unsuitable for the colony of Pelican (Fig. 1) [21]. That resulted in an attempt to form a new colony at a stony islet at Grmožur in 1991 [22]. The gradual decline in the number of Pelican nests continued in the following years so that by the end of the 1990s the Pelicans had disappeared from the lake as a breeding species.

At the beginning of the third millennium, the Pelicans gradually returned to the lake. The colony was small (less than 20 pairs), their breeding frequently unsuccessful [23]. In those years, when the physical protection on the lake was at a low level, there emerged another significant factor in the reduction in the number of pelicans – disturbing. This is the period in which this problem culminated, although Vizi [24] was previously drawing attention to it.

Table 1 Survey of Skadar Lake biotopes

Type of biotope	Substrate properties	Characteristic plants	Characteristic birds (breeding, wintering and feeding)
Stony shore and islands	Typical karstic biotopes with limestone substrate and scarce soil in fissures of rocks	*Asphodelus microcarpus*, *Asphodeline lutea*, *Salvia officinalis*, *Paliurus spina-christi*, *Punica granatum. Phillyrea media*, *Fraxinus ornus*	*Alectoris graeca*, *Ardea cinerea*, *Emberiza melanocephala*, *Monticola solitarius*, *Oenanthe hispanica*, *Prunella modularis*, *Sitta neumayer*, *Sylvia cantillans*, *Troglodytes troglodytes*, *Turdus merula*
Main lake	Open water of the lake, with submerged vegetation	*Vallisneria spiralis*, *Potamogeton* sp.	*Pelecanus crispus*, *Phalacrocorax carbo*, *Phalacrocorax*, *pygmaeus*, *Podiceps cristatus*, *Fulica atra*, *Anas platyrhynchos*, *Anas penelope*, *Anas strepera*, *Aythya ferina*, *Aythya fuligula*, *Podiceps nigricollis*
Biotopes with floating vegetation	Zone between the main lake and vegetation. There are large surface areas of floating vegetation of a mosaic character present	*Nymphaea alba*, *Nuphar luteum*, *Trapa natans*	*Chlidonias hybrida*, *Chlidonias niger*, *Fulica atra*, *Podiceps cristatus*, *Tachybaptus ruficollis*, *Sterna hirundo*, *Larus ridibundus*
Biotopes with emerged vegetation	They extend from the zone of floating vegetation towards the northern shore. Mosaic type of distribution is also present	*Phragmites communis*, *Scirpus lacustris*, *Polygonum aquaticum*, *Bolboschoenus maritimus*	*Acrocephalus arundinaceus*, *Ardea purpurea*, *Circus aeruginosus*, *Podiceps cristatus*, *Tachybaptus ruficollis*, *Ixobrychus minutus*
Inundated willow shrubberies	Dense willow shrubberies, with reeds and sedge. They are marked by "canals" with open water, or floating vegetation. Substrate is peaty. The zone is inundated during the majority of the year	*Salix cinerea*, *Salix alba*, *Salix fragilis*, *Typha latifolia*, *Typha angustifolia*, *Fraxinus oxycarpa*	*Pelecanus crispus*, *Microcarbo pygmaeus*, *Ardeola ralloides*, *Egretta garzetta*, *Nycticorax nycticorax*, *Plegadis falcinellus*, *Bubulcus ibis*, *Ardea cinerea*, *Phalacrocorax carbo*, *Corvus cornix*, *Anas platyrhynchos*, *Aythya nyroca*, *Gallinula chloropus*

(continued)

Table 1 (continued)

Type of biotope	Substrate properties	Characteristic plants	Characteristic birds (breeding, wintering and feeding)
Flooded forests and flooded meadows	This biotope is inundated when the water level is high, without water during the summer. Alleys, groves and shrubs and hygrophilic meadows are mosaically distributed	*Populus alba*, *Populus nigra*, *Fraxinus oxycarpa*, *Alnus incana*, *Quercus robur squtariensis*	*Corvus cornix*, *Streptopelia turtur*, *Parus major*, *Oriolus oriolus*, *Remiz pendulinus*, *Alcedo atthis*, *Motacilla flava*
Agricultural zone	Only a part of agricultural zone of Ćemovsko Field belongs to the zone of interest. Agriculture is of extensive type with divided plots frequently bordered by hedge and bushes	*Rosa canina*, *Punica granatum*, *Paliurus spina-christi*, *Celtis australis*, *Morus alba*	*Pica pica*, *Lanius collurio*, *Emberiza calandra*, *Carduelis carduelis*, *Passer montanus*, *Sylvia communis*, *Merops apiaster*, *Streptopelia decaocto*
Arid biotopes	Formerly, they covered the entire area of Ćemovsko Field and Kotrabudansko Field. That is a plain with pronouncedly skeletal soil (pebbly substrate) and minimal layer of humus. In the observed zone, there are only some smaller parts in area bordering the NP	*Asphodelus microcarpus*, *Asphodeline lutea*, *Satureja montana*	*Alauda arvensis*, *Galerida cristata*, *Anthus campestris*

The idea on placing rafts for the breeding of pelicans is not new [25] and it emerged by the development of a method, at that time already utilised, of constructing fixed platforms for pelicans breeding. Platforms are not suitable due to the unstable peaty substrate of Skadar Lake, severe spring storms and the great changes in water level. The rafts can resist these problems, but they require constant attention and oversight, as shown in 2001 when the first rafts, placed by the Centre for the Protection and Research of Birds, quickly disappeared due to the lack of control.

A new attempt was made in 2010 by the National Parks when several rafts were placed at Pančeva oka. Some of them were immediately settled by the Common Tern (*Sterna hirundo*), but in 2011 Pelicans started breeding on two of them. Unfortunately, this colony on the rafts was later destroyed by a severe storm.

In 2013, the project "Conservation of Dalmatian Pelicans, a key biodiversity species from Skadar Lake" was started. It is implemented by the Natural History

Fig. 1 An example of a breeding Pelican on a miniature peaty islet in 1977. Photo by O. Vizi

Museum of Montenegro, EuroNatur, Noé Conservation, NP Skadar Lake and the Centre for the Protection and Research of Birds. The project has envisaged the placing of new rafts in the same place selected from the earlier investigations. By the end of 2013, the first four rafts were successfully placed.

Breeding in the next year, 2014, was successful, with, until then, record number of the young. It has started on two natural peat islets but, at the final of breeding, several pairs of pelicans have also settled the new rafts on which they have successfully bred the young.

In winter 2015, another raft was added, and an additional two in 2016. During all these years, the Pelicans have bred exclusively on the rafts (Fig. 2). The number of breeding couples has stabilised to around 35, and the number of successfully raised young has exceeded the number of 50. This way, the critical period for the survival of the Dalmatian Pelican on Skadar Lake was successfully overcome.

The project: "Support to the conservation of Dalmatian Pelicans, a key biodiversity species from Skadar Lake National Park in Montenegro" continues. The objective for further work is to replace the rafts made of wood, which have a limited duration, with permanent metal or plastic ones, and to increase their total surface area, which would be able to accommodate 50–60 Pelican nests. We consider this size of population optimal, both from the aspect of the survival of Pelicans, and in respect of the general production capacities of Skadar Lake, primarily in terms of fish biomass production.

Fig. 2 Successful breeding of Pelican on the rafts, March 2015. Photo by O. Vizi

3.2.2 Mixed Colonies

A mixed colony of swamp birds is rightfully called an "ornithopolis". Such colonies are found in every larger marshy biotope and they gather similar birds' species.

The monitoring of mixed swamp bird colonies was initiated only at the beginning of the 1990s when it was based at the locality of Crni žar [26]. The colony numbered around 1,500 nests. The Pigmy Cormorant (*Microcarbo pygmaeus*) was predominant, then the Squacco Egrett (*Ardeola ralloides*), Little Egrett (*Egretta garzetta*), Night Heron (*Nycticorax nycticorax*), Grey Heron (*Ardea cinerea*), and Cormorant (*Phalacrocorax carbo*). With the exception of the last two species, practically the entire populations of these species bred there.

In later years, some new breeding birds appeared on Skadar Lake, like the Glossy Ibis (*Plegadis falcinellus*) [27] and the Cattle Egret (*Bubulcus ibis*) [28]. Each year, the number of nests of all species gradually increased to finally stabilise at around 2,200 (Fig. 3).

The mixed colony of swamp birds is not always at the same place. Actually, the colony moves some 100–200 m every year. This phenomenon has also been recorded at other locations, for example, at Obedska Marsh in Serbia [29]. It is explained by the fact that water ichthyophagous birds through their aggressive excrement destroy the branches of trees and bushes on which they make their nests; the branches dry out and die. In the following year, the birds chose "fresh" trees.

Fig. 3 Mixed colony of birds in 2006 (Photo O. Vizi)

However, on Skadar Lake, in addition to these microchanges, there also occur real migrations of mixed colonies, up to distances of several kilometres away. The colony has moved several times from Crni žar–Pančeva oka, and in 2013 it was located in willow trees at Pjavnik (Fig. 4).

3.2.3 Colonies of Cormorant

The colony of Cormorants (*Phalacrocorax carbo*) has also experienced an interesting development on Skadar Lake. A permanent colony did not exist in the 1970s of the last century. An exception was a short-term colony at Manastirska tapija, where the Cormorants bred together with Grey Herons [31].

An unsuccessful attempt of breeding was recorded at the locality of Crni žar in 1978 [26]. The colony which formed then has "wandered" indeed (Manastirska tapija, islet Grmožur), until it has finally stabilised at the locality of Pančeva oka (Fig. 5).

From that colony, there have emerged a few secondary ones – Manastirska tapija, Zetica and Ckla [32]. The main colony (Pančeva oka) and the colony at Ckla are stable nowadays. The total number of breeding pairs of Cormorant currently ranges from 800 to 1,500.

Fig. 4 Distribution of bird colonies on Skadar Lake in 2009 [30]

Fig. 5 Cormorants in colony "Pančeva oka" in 2007 (Photo O. Vizi)

3.2.4 Colonies of Whiskered Tern

The Whiskered Tern (*Chlidonias hybrida*) is a relatively new breeding bird of Skadar Lake. As late as in 1974, the first colony consisting of 15 pairs was discovered at the locality of Crni Žar [33]. The number of breeding pairs then rapidly grew to reach a record of 1,322 nests (the Albanian part of the lake is included) in 2008 [23]. The colonies of Whiskered Tern are situated on floating patches of water lily and breeding starts relatively late, because the floating layer of water lilies has to reach the necessary density (Fig. 6). Since eggs losses are great. Disturbing leads to destruction of eggs owing to high isolation and predators (Hooded Crow – Corvus cornix, Four Lined Snake – Elaphe quatorlineata). For this reason secondary nests are common, thus the breeding continues until mid-summer.

There are several colonies among which Virpazar, Pijesci and Crni žar are the permanent, whereas the others move depending on the prevailing water level (Fig. 7).

3.2.5 Colonies of Grey Heron (*Ardea cinerea*)

A large colony of Grey Heron was recorded behind the island of Vranjina by Führer [4]. It must have been the colony the remains of which were found at the beginning of the 1970s of the last century in the reserve “Manastirska tapija” [29]. That colony no longer exists.

Fig. 6 A colony of Whiskered Tern in 2004

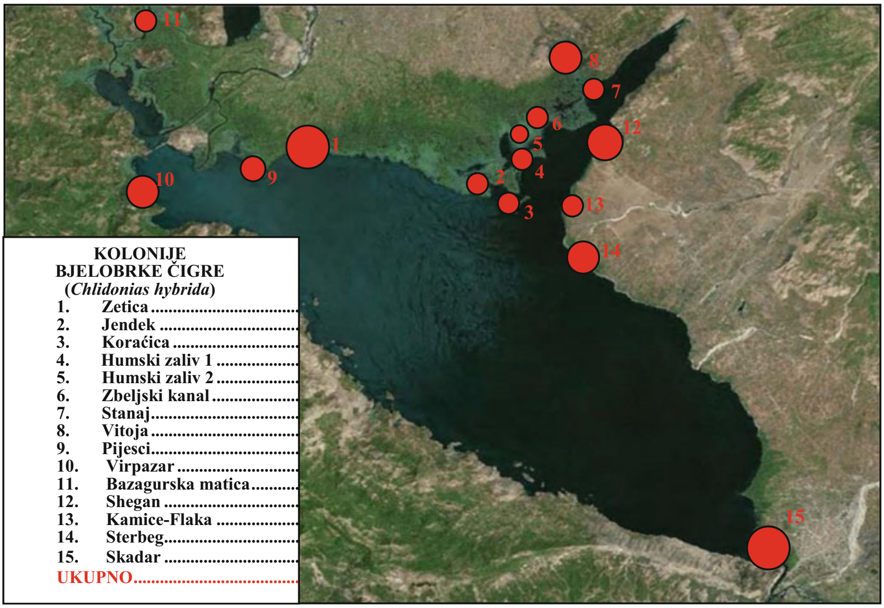

Fig. 7 Colonies of Whiskered Tern on Skadar Lake with the number of nests in 2008 [30]

A new colony was revealed by Vasić [34], on the small islet of "Omerova gorica" along the south shore of the lake. The Herons breed here on laurel trees (*Laurus nobilis*), what is the only known such case (Fig. 8). The colony, amounting to 40–50 pairs, remains active nowadays.

In addition, a minor number of Grey Heron pairs also breed in a mixed colony of swamp birds and in colonies of Cormorant.

3.3 Wintering

Its geographic situation, large surface of fresh water, spacious macrovegetation zone, warm climate and abundance of nutrients have all led to Skadar Lake being a very important place for migratory birds. This fact has been long known, but more detailed monitoring only began in 1991 when a winter census of water birds started through an IWC programme. The results of the census from 1991 to 1996 and the relationship between the wintering populations and the most significant swamp birds according to regional populations were given by Vasić et al. [35].

The IWC programme has continued with short interruptions until today, so that we have a comparative record available of the numbers and size of wintering populations. The dynamics of migrations has been investigated in the scope of a project by the National Park of Montenegro: "Monthly monitoring of Skadar Lake ornithofauna – autumn migration, wintering and spring migration".

Fig. 8 Colony of Grey Heron on laurel trees at islet Omerova gorica in 2008. Photo by O. Vizi

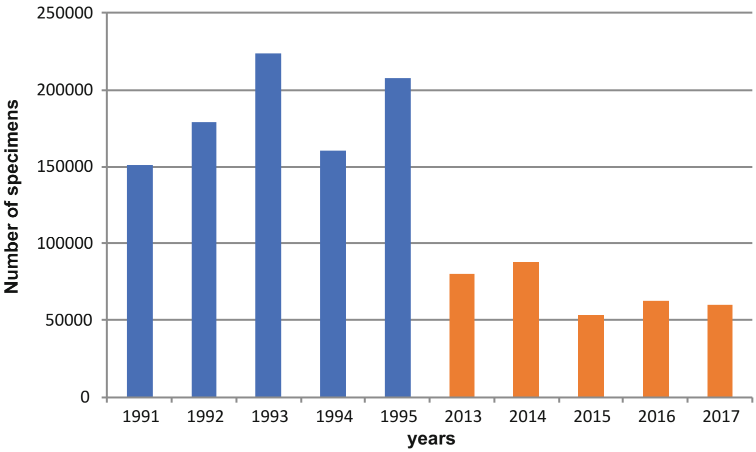

Fig. 9 Total number of wintering birds on Skadar Lake in years 1991–1995 and 2013–2017. Wetlands International (2017) IWC Online database. http://iwc.wetlands.org. Data extracted on: 14 October 2017 by Andrej Vizi

The results have indicated that massive swamp birds' migrations via Skadar Lake starts in October, and it lasts until April the following year. The winter census has indicated a drastic decrease in the number of wintering species as related to the beginning of the 1990s. Comparative results for the total number of wintering birds on Skadar Lake in the period 1991–1996, and until today, are presented in the Fig. 9.

Extensive investigation of the exact causes of the decrease in the number of wintering birds has not yet been conducted. It is assumed that, in addition to disturbances in the larger area, the increased presence of humans, especially the number of cutters, have contributed to this decrease.

4 Protection of Birds on Skadar Lake

Birds, as a group of organisms, occupy the top of the trophic pyramid and yet they are sensitive to all the disturbances on the lower "floors". The factors which endanger ornithofauna are either natural (primarily changes in climate), as they have the strongest impact on birds exactly through the trophic pyramid, or anthropogenic, which may be very dangerous.

In the observed period, we have not recorded any major changes in climate, hydrology, pedology and similar factors, the intensity of which would be sufficient to lead to a destructive impact on the bird fauna on Skadar Lake. On the other hand, anthropogenic influences are both present and significant. In addition, the general circulation of birds in the wider area, in the region, Europe, and even wider should be taken into consideration. Organised investigations which could cast light on that impact have not yet been conducted on Skadar Lake; nevertheless, some local impacts have been recorded:

4.1 Pollution

Skadar Lake is exposed to minor cross-border pollution which comes from the rivers and the circulation of air in the atmosphere. On the other hand, internal pollution is much more marked. The most important forms are:

Industrial pollution. The main polluters of this type are the Aluminium Plant in Podgorica and the steelworks in Nikšić. More recently, the level of pollution has decreased since these facilities operate with decreased capacities, and their protection systems are better. The earlier well-developed metal and wood processing industry is mainly idle at present.

Urban pollution. Three big Montenegrin cities (Podgorica, Nikšić and Cetinje) discharge their waste waters into Skadar Lake. The improving Montenegrin economy is slowly helping to resolve this problem. The situation is increasingly better, because all these cities are now constructing facilities for the purification of waste waters which will significantly alleviate this problem.

On Skadar Lake shore, there are a number of urban settlements which do not have purification systems. The exception is the small town of Virpazar which has a functional facility. A series of basic catering outlets and accommodation facilities, which have been hastily constructed on the lake shore, are a special danger. Here, too, there is a positive example. That is a new restaurant at Plavnica which has built a functional purification system.

Agricultural pollution. Agriculture is developed on the north shore of Skadar Lake. Individual households are mainly involved in the production of vegetables on small plots, but, large plantations of vines and fruit, which apply modern agro techniques, have been set up on a great portion of the former semi-desert of Ćemovsko Field. That inevitably produces a “surplus” of mineral fertilisers and pesticides which reach the lake by underground water channels. The full impact of these components, especially pesticides, on the lake ecosystem remains largely unknown.

Fortunately, there is a great self-purification power to Skadar Lake’s ecosystem, especially of its vast macrophyte zone. The distribution of precipitation also contributes to a relatively favourable situation, because in periods of intensive precipitation (from autumn to spring) the entire water volume of the lake is replenished some two to three times.

4.2 Disturbing

Disturbing is an ecological factor to which birds are particularly sensitive. The number of species which have become accustomed to human presence and which live alongside people is small. Birds are especially sensitive in the time of breeding.

Disturbing is certainly present on Skadar Lake and it is increasingly intensified. There are several types of disturbing:

Disturbing by fishermen. The lake has always been an important site for fishing and for the economy of Montenegro; nowadays, too, it is of great importance. Nevertheless, traditional fishing by gill-net and Bleak fishing by beach seine nets are of no decisive significance. Traditionally, fishing used to be performed by small, locally designed wooden boats with oars; subsequently, small four horse-power outboard engines were used. The time of when they could be lowered into the water and the time of their removal was each prescribed. There also existed an annual fishing season close to the time of spawning, which only partially overlapped with the birds breeding season.

The fact is that the main nesting sites of birds (bird colonies, with the exception of the Pelican colony) are situated in barely accessible parts of the vegetation zone and as a result, they are naturally protected.

More recently, the growing problem is the increasing use of high-speed boats with powerful outboard motors by fishermen. Any use of these boats on the lake represents a destructive factor.

Sports fishing, which is also very developed, does not constitute a problem for birds since it is mainly conducted from the shore, and the fishermen barely move. The NP decision to have sports fishing prohibited on the islands where the birds breed has also contributed to protection.

Disturbing by tourism is becoming an increasingly significant factor. A number of small craft with a capacity of 50–100 visitors cruise the lake during the tourist season. Nevertheless, we do not deem this situation serious since those sailings are performed in a period when significant numbers of birds have already completed their breeding, and the tourist waterways are situated away from the main nesting sites of birds. Here, too, nature is the best “protector” since larger vessels may not approach the nesting sites owing to the shallow water and dense vegetation. The exception is the islands along the south shore, where the NP ranger service needs to strengthen the level of protection. There is an opinion that Pelicans deserted the colony on the islet of Grmožur after 1991 exactly because of the frequent presence of tourist craft [22].

A significant and growing trend is disturbing by curious persons and “admirers of nature”. It is undisputed that even qualified investigators, trained for field work can disturb birds, although they approach colonies with a high level of care. Amateur bird watchers frequently approach bird colonies without such care in order to take photographs, an event which in conditions of great insolation may have fatal consequences for eggs in the nests. Pelicans, Whiskered and Common Terns are particularly endangered. Whereas the protection of the Pelican colony is nowadays well organised (there is video surveillance), Tern colonies remain exposed. Additional pressure is then created by predators which attack any temporarily deserted nests.

4.3 Hunting and Poaching

Intensive hunting, especially when poorly controlled, has disastrous consequences on birds’ fauna, especially in wetland ecosystems, where all birds are potential targets. Skadar Lake has always been a hunting ground, but the pressure has significantly increased after the Second Word War. In the period of Führer [4], he mentions that Montenegrins rarely hunt birds, as they deem bird hunting a futile waste of time. At that time, hunting guns were quite rare. Nevertheless, Führer himself [22] in probably his first paper, in which he calls for protection of the birds on Skadar Lake, showed images of poaching, as one can see on the photograph he published then (Fig. 10 and Table 2).

Hunting was intensified during the 1970s and 1980s of the last century, when Italian hunters were very frequent guests on Skadar Lake.

This hunting activity did not cease immediately after the establishment of the National Park Skadar Lake in 1986. Hunting was officially prohibited only in 2000 and since then it has not been performed. Poaching is still present. A special problem are the modern poachers who use very fast boats from which they chase flocks of wintering water birds, especially Mallards and Ducks of the genus, *Aythya* and Coots.

Another group of poachers uses the many uncontrolled accesses to the lake on the north shore and hunts in the barely accessible zone of vegetation.

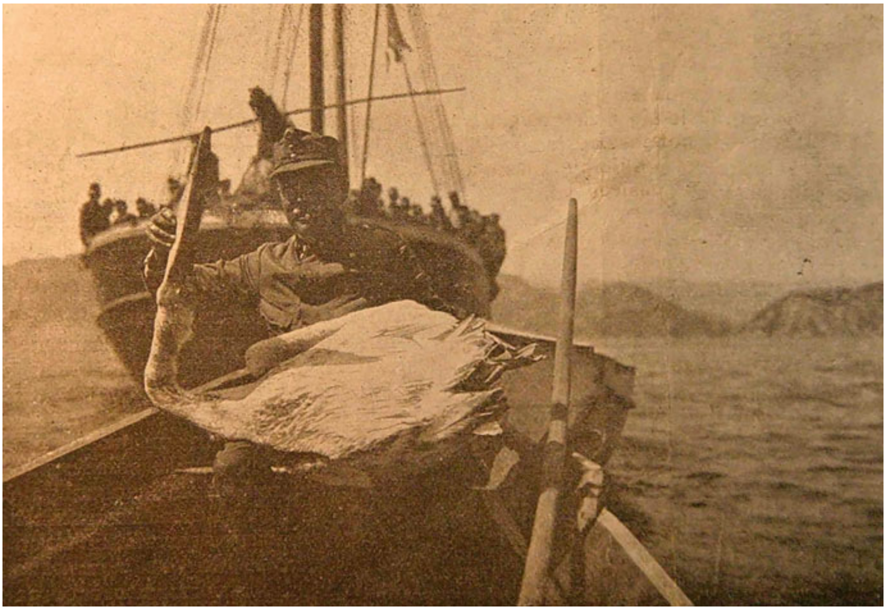

Fig. 10 Hunting of Pelicans on Skadar Lake in 1917. Photo by Führer [36]

5 Conclusion

Skadar Lake has been recognised as one of the most significant ornithological sites in the Mediterranean, which is still relatively well preserved. It enjoys the status of a national park (for the Montenegrin part), which stretches on an area of 40,000 ha.

Favourable geological, pedological and climatic conditions have provided for the development of a large number of freshwater habitats with abundant plant and animal life.

In the distribution of habitats, irrespective of the unavoidable, partial mosaicism, certain zones are clearly distinguished, defined by the depth of water, that is the development of vegetation: rocky shores, an open lake, floating vegetation, submerged vegetation, inundated willow shrubberies, flooded forests and meadows as well as agricultural and arid surface areas.

Ornithofauna is also zonally distributed and follows the distribution of habitats very strictly in the time of breeding, but it is also notable in the winter period.

The most important swamp birds breed in colonies. There are established colonies of Dalmatian Pelicans, Cormorants, mixed colonies of swamp birds mainly Pigmy Cormorant, several species of Heron, and the Black Ibis, a colony of Grey Heron and a large number of Whiskered Tern colonies.

The lake is an important wintering place for birds. In the past 20 years, the total number of wintering birds has halved, what is not the case with breeding birds which (with exception of rare and sensitive species, particularly predators) have maintained their numbers, some have increased and new breeding birds have appeared.

Table 2 List of birds of Skadar Lake with basic ecologic indicators and status of international protection[a]

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
1.	*Acanthis cannabina*	–	–	+	–	–		
2.	*Accipiter brevipes*	–	+	–	–	–		I
3.	*Accipiter gentilis*	–	–	+	–	–		I*
4.	*Accipiter nisus*	–	–	+	+	–		I*
5.	*Acrocephalus arundinaceus*	–	+	–	–	–		
6.	*Acrocephalus melanopogon*	–	–	+	–	–		
7.	*Acrocephalus palustris*	–	–	+	–	–		
8.	*Acrocephalus schoenobaenus*	–	+	–	+	–		
9.	*Acrocephalus scirpaceus*	–	–	+	+	–		
10.	*Aegithalos caudatus*	–	–	+	–	–		
11.	*Alauda arvensis*	–	+	–	–	–		II/2
12.	*Alcedo atthis*	+	–	–	–	–		I
13.	*Alectoris graeca*	+	–	–	–	–		I*, II/1**
14.	*Anas acuta*	–	–	–	+	–		II/1, III/2
15.	*Anas angustirostris*	–	–	–	–	+	+	
16.	*Anas crecca*	–	–	–	+	–		II/1, III/2
17.	*Anas platyrhynchos*	+	–	–	–	–		II/1, III/2
18.	*Anas querquedula*	–	–	+	+	–		II/1
19.	*Anser albifrons*	–	–	+	–	–		I*, II/2, III/2*
20.	*Anser anser*	–	–	+	+	–		II/1, II/2
21.	*Anser erythropus*	–	–	–	–	+	+	I

22.	*Anser fabalis*	–	–	+	+	–		II/1
23.	*Anthus campestris*	–	+	–	–	–		II/1, III/2
24.	*Anthus pratensis*	–	–	–	+	–		
25.	*Anthus richardii*	–	–	–	–	+	+	
26.	*Anthus spinoletta*	–	–	+	+	–		
27.	*Anthus trivialis*	–	–	–	+	–		
28.	*Apus apus*	–	–	+	–	–		
29.	*Apus melba*	–	–	+	–	–		
30.	*Aquila chrysaetos*	–	–	+	–	–		I
31.	*Aquila clanga*	–	–	+	–	–	+	I
32.	*Aquila fasciatus*	–	–	+	–	–	+	I
33.	*Aquila heliaca*	–	–	–	+	–	+	I
34.	*Aquila pomarina*	–	–	+	+	–		I
35.	*Ardea alba*	–	–	+	+	–		I
36.	*Ardea cinerea*	+	–	–	–	–		
37.	*Ardea purpurea*	–	+	–	–	–		I
38.	*Ardeola ralloides*	–	+	–	–	–		I
39.	*Asio flammeus*	–	+	–	–	–		I
40.	*Asio otus*	–	+	–	–	–		I
41.	*Athene noctua*	+	–	–	–	–		
42.	*Aythya ferina*	–	–	+	+	–		II/1, III/2
43.	*Aythya fuligula*	–	–	+	+	–		II/1, III/2
44.	*Aythya marila*	–	–	–	+	–		II/1, III/2
45.	*Aythya nyroca*	+	–	–	+	–		I
46.	*Botaurus stellaris*	+	–	–	–	–		I
47.	*Bubo bubo*	+	–	–	–	–		I
48.	*Bubulcus ibis*	–	+	–	–	–		

(continued)

Table 2 (continued)

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
49.	*Bucephala clangula*	–	–	–	+	–		II/2
50.	*Buteo buteo*	–	–	+	+	–		
51.	*Calandrella brachydactyla*	–	+	–	+	–		I
52.	*Calidris alpina*	–	–	+	–	–		I*
53.	*Calidris ferruginea*	–	–	–	–	+	+	
54.	*Calidris minuta*	–	–	+	–	–		
55.	*Calidris pugnax*	–	–	+	+	–		I, II/2
56.	*Caprimulgus europaeus*	–	+	–	–	–		I
57.	*Carduelis carduelis*	+	–	–	–	–		
58.	*Carduelis spinus*	–	–	+	–	–		I
59.	*Cettia cetti*	+	–	–	–	–		
60.	*Charadrius alexandrinus*	+	–	–	–	–		I
61.	*Charadrius dubius*	–	+	–	–	–		
62.	*Charadrius hiaticula*	–	–	–	–	+	+	
63.	*Chlidonias hybrida*	–	+	–	+	–		I
64.	*Chlidonias leucopterus*	–	–	–	+	–		
65.	*Chlidonias niger*	–	+	–	+	–		I
66.	*Chloris chloris*	–	+	–	–	–		
67.	*Ciconia ciconia*	–	–	–	+	–		I
68.	*Ciconia nigra*	–	+	+	–	–	+	I
69.	*Cinclus cinclus*	+	–	–	–	–		

70.	*Circaetus gallicus*	–	+	–	–	–		I
71.	*Circus aeruginosus*	+	–	–	–	–		I
72.	*Circus cyaneus*	–	–	+	–	–		I
73.	*Circus macrourus*	–	–	–	–	+		I
74.	*Circus pygargus*	–	+	–	–	–		I
75.	*Clamator glandarius*	–	+	–	–	–		I
76.	*Clangula hyemalis*	–	–	+	–	–		I
77.	*Coccothraustes*	–	–	+	–	–		I
78.	*Coloeus monedula*	+	–	–	–	–		I
79.	*Columba livia*	+	–	–	–	–		II/1
80.	*Columba oenas*	–	–	+	–	–		I/2
81.	*Columba palumbus*	–	–	+	–	–		I*, II/1**, III/1
82.	*Coracias garrulus*	–	+	–	–	–		II/1
83.	*Corvus corax*	+	–	–	–	–		I/2
84.	*Corvus cornix*	+	–	–	–	–		II/2
85.	*Corvus frugilegus*	–	–	–	–	+	+	II/2
86.	*Coturnix coturnix*	–	–	–	+	–		II/2
87.	*Crex crex*	–	–	–	–	+	+	I
88.	*Cuculus canorus*	–	+	–	–	–		
89.	*Cygnus cygnus*	–	–	+	–	–		I
90.	*Cygnus olor*	–	–	+	–	–		II/2
91.	*Delichon urbica*	–	+	–	–	–		
92.	*Dendrocopos major*	+	–	–	–	–		I*
93.	*Dendrocopos medius*	–	–	+	–	–		I
94.	*Dendrocopos minor*	–	–	–	–	+	+	
95.	*Dendrocopos syriacus*	+	–	–	–	–		I

(continued)

Table 2 (continued)

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
96.	*Dryocopus martius*	+	–	–	–	–		I
97.	*Egretta garzetta*	–	+	–	+	–		I
98.	*Egretta gularis*	–	–	+	–	–	+	
99.	*Emberiza calandra*	–	+	–	–	–		
100.	*Emberiza cia*	–	–	+	–	–		
101.	*Emberiza cirlus*	–	+	–	–	–		
102.	*Emberiza citrinella*	–	–	+	–	–		
103.	*Emberiza hortulana*	–	–	+	–	–		I
104.	*Emberiza melanocephala*	–	+	–	–	–		
105.	*Emberiza schoeniclus*	+	–	–	–	–		
106.	*Erithacus rubecula*	+	–	–	–	–		
107.	*Falco biarmicus*	–	+	–	–	–		I
108.	*Falco cherrug*	–	–	–	–	+	+	I
109.	*Falco columbarius*	–	–	–	–	+	+	
110.	*Falco naumanni*	–	–	+	–	–	+	I
111.	*Falco peregrinus*	–	–	+	–	–		I
112.	*Falco subbuteo*	–	–	+	–	–		
113.	*Falco tinnunculus*	–	–	+	–	–		
114.	*Falco vespertinus*	–	–	+	+	–		I
115.	*Ficedula albicollis*	–	–	+	–	–		I
116.	*Ficedula hypoleuca*	–	–	+	–	–		I
117.	*Fringilla coelebs*	+	–	–	–	–		I*

118.	*Fringilla montifringilla*	–	–	+	–	–		
119.	*Fulica atra*	+	–	–	+	–		II/1, III/2
120.	*Galerida cristata*	+	–	–	–	–		
121.	*Gallinago gallinago*	–	–	+	+	–		II/1, III/2
122.	*Gallinago media*	–	–	+	+	–		I
123.	*Gallinula chloropus*	+	–	–	–	–		II/2
124.	*Garrulus glandarius*	+	–	–	–	–		II/2
125.	*Gavia arctica*	–	–	+	–	–		
126.	*Gavia immer*	–	–	+	–	–	+	I
127.	*Gavia stellata*	–	–	+	–	–		I
128.	*Gelochelidon nilotica*	–	–	–	+	–	+	I
129.	*Glareola pratincola*	–	–	+	–	–		I
130.	*Grus grus*	–	–	–	+	–		I
131.	*Gyps fulvus*	–	+	–	–	–		I
132.	*Haematopus ostralegus*	–	+	–	–	–		II/2
133.	*Haliaeetus albicilla*	–	–	+	–	–		I
134.	*Himantopus himantopus*	–	–	+	–	–		I
135.	*Hippolais olivetorum*	–	+	–	–	–	+	I
136.	*Hippolais pallida*	–	+	–	–	–		
137.	*Hirundo daurica*	–	+	–	–	–		
138.	*Hirundo rustica*	–	+	–	–	–		
139.	*Hydroprogne tschegrava*	–	–	–	+	–		I
140.	*Ixobrychus minutus*	–	+	–	–	–		I
141.	*Jynx torquilla*	–	–	–	+	–		

(continued)

Table 2 (continued)

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
142.	*Lanius collurio*	–	+	–	–	–		I
143.	*Lanius excubitor*	–	–	–	+	–		
144.	*Lanius minor*	–	+	–	–	–		I
145.	*Lanius senator*	–	+	–	–	–		I
146.	*Larus canus*	–	–	+	–	–		II/2
147.	*Larus michahellis*	+	–	–	–	–		II/2
148.	*Larus minutus*	–	–	+	–	–		I
149.	*Larus ridibundus*	+	–	+	–	–		II/2
150.	*Limosa limosa*	–	–	+	+	–		II/2
151.	*Lullula arborea*	–	–	–	+	–		I
152.	*Luscinia megarhynchos*	–	+	–	–	–		
153.	*Lymnocryptes minimus*	–	–	+	–	–		II/1, III/2
154.	*Mareca penelope*	–	–	+	+	–		II/1, III/2
155.	*Mareca strepera*	–	–	+	+	–		II/1, III/2
156.	*Melanitta fusca*	–	–	+	–	–	+	II/1, III/2
157.	*Melanitta nigra*	–	–	+	–	–	+	II/2, III/2
158.	*Melanocorypha calandra*	–	+	–	–	–		I
159.	*Mergellus albellus*	–	–	–	+	–		I
160.	*Mergus merganser*	–	–	–	+	–		II/2
161.	*Mergus serrator*	–	–	–	+	–		II/2
162.	*Merops apiaster*	–	+	–	–	–		
163.	*Microcarbo pygmaeus*	+	–	–	+	–		I

164.	*Milvus migrans*	–	–	+	–	–		I
165.	*Milvus milvus*	–	–	+	–	–		
166.	*Monticola saxatilis*	–	–	–	+	–		
167.	*Monticola solitarius*	–	+	–	–	–		
168.	*Motacilla alba*	+	–	–	–	–		
169.	*Motacilla cinerea*	–	–	+	–	–		
170.	*Motacilla flava*	–	+	–	–	–		
171.	*Muscicapa striata*	–	–	–	+	–		
172.	*Neophron percnopterus*	+	–	–	–	–	+	I
173.	*Netta rufina*	–	–	–	+	–		II/1
174.	*Numenius arquata*	–	–	+	–	–		II/2
175.	*Nycticorax nycticorax*	–	+	–	+	–		I
176.	*Oenanthe hispanica*	–	+	–	–	–		
177.	*Oenanthe oenanthe*	–	–	–	+	–		
178.	*Oriolus oriolus*	–	+	–	+	–		
179.	*Otus scops*	–	+	–	–	–		I
180.	*Oxyura leucocephala*	–	–	+	–	–	+	I
181.	*Pandion haliaetus*	–	–	–	+	–		
182.	*Parus ater*	–	–	+	–	–		I*
183.	*Parus caeruleus*	+	–	–	–	–		
184.	*Parus lugubris*	–	–	+	–	–		I*
185.	*Parus major*	+	–	–	–	–		
186.	*Passer domesticus*	+	–	–	–	–		
187.	*Passer hispaniolensis*	+	–	–	–	–		
188.	*Passer montanus*	+	–	–	–	–		
189.	*Pelecanus crispus*	+	–	–	–	–		I

(continued)

Table 2 (continued)

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
190.	*Pelecanus onocrotalus*	–	–	+	–	–		I
191.	*Pernis apivorus*	–	–	+	–	–		I
192.	*Phalacrocorax aristotelis*	–	–	+	–	+		
193.	*Phalacrocorax carbo*	+	–	–	+	–		
194.	*Phoenicurus ochruros*	–	–	+	–	–		I
195.	*Phoenicurus phoenicurus*	–	–	–	–	+	+	I
196.	*Phylloscopus collybita*	–	–	–	+	–		I*, II/1**, III/1
197.	*Phylloscopus sibilatris*	–	–	–	+	–		I
198.	*Phylloscopus trochilus*	–	–	–	+	–		
199.	*Pica pica*	+	–	–	–	–		II/2
200.	*Picus canus*	+	–	–	–	–		I
201.	*Picus viridis*	+	–	–	–	–		
202.	*Platalea leucorodia*	–	–	+	–	–		I
203.	*Plegadis falcinellus*	–	+	–	–	–		I
204.	*Pluvialis apricaria*	–	–	+	–	–		
205.	*Pluvialis squatarola*	–	–	+	–	–		
206.	*Podiceps cristatus*	+	–	–	+	–		
207.	*Podiceps nigricollis*	–	–	+	+	–		
208.	*Porzana parva*	–	+	–	–	–		I

209.	*Porzana porzana*	–	+	–	–	–		I
210.	*Prunella modularis*	–	–	+	+	–		
211.	*Ptyonoprogne rupestris*	–	–	–	–	+	+	
212.	*Pyrrhocorax graculus*	–	–	+	–	–		
213.	*Pyrrhula pyrrhula*	–	–	+	–	–		
214.	*Rallus aquaticus*	–	+	–	–	–		II/2
215.	*Recurvirostra avosetta*	–	+	–	+	–		
216.	*Regulus ignicapillus*	–	–	+	–	–		
217.	*Regulus regulus*	–	–	+	–	–		
218.	*Remiz pendulinus*	–	+	–	–	–		
219.	*Riparia riparia*	–	+	–	–	–		
220.	*Saxicola rubetra*	–	–	+	–	–		
221.	*Saxicola torquata*	–	–	+	–	–		
222.	*Scolopax rusticola*	–	–	+	+	–		II/1, III/2
223.	*Serinus serinus*	–	–	+	–	–		
224.	*Sitta neumayer*	–	+	–	–	–		II/2
225.	*Spatula clypeata*	–	–	+	+	–		II/1, III/2
226.	*Sternula albifrons*	–	+	–	–	–		
227.	*Sterna hirundo*	–	+	–	+	–		I
228.	*Streptopelia decaocto*	+	–	–	–	–		II/2
229.	*Streptopelia turtur*	–	+	–	–	–		II/2
230.	*Strix uralensis*	–	+	–	–	–		II/1, III/2
231.	*Sturnus vulgaris*	+	–	–	+	–		II/2
232.	*Sylvia atricapilla*	–	+	–	+			
233.	*Sylvia borin*	–	–	+	–	–		

(continued)

Table 2 (continued)

	Scientific name	Resident	Breeding visitor	Non-breeding visitor	Passage migrant	Season unknown	No data more recent than 10 years	EU Directives Annexes on birds
234.	*Sylvia cantillans*	–	+	–	–	–		
235.	*Sylvia communis*	–	+	–	–	–		
236.	*Sylvia curruca*	–	–	+	+	–		
237.	*Sylvia hortensis*	–	+	–	–	–		
238.	*Sylvia melanocephala*	–	+	–	–	–		
239.	*Sylvia nisoria*	–	+	–	–	–		I
240.	*Tachybaptus ruficollis*	+	–	+	–	–		
241.	*Tadorna tadorna*	+	–	–	–	–		
242.	*Tichodroma muraria*	–	–	+	–	–		
243.	*Tringa erythropus*	–	–	+	–	–		II/2
244.	*Tringa glareola*	–	–	+	–	–		I
245.	*Tringa hypoleucos*	+	–	–	–	–		
246.	*Tringa nebularia*	–	–	+	–	–		II/2
247.	*Tringa ochropus*	–	–	+	–	–		
248.	*Tringa stagnatilis*	–	–	+	–	–		
249.	*Tringa totanus*	–	–	+	–	–		II/2
250.	*Troglodytes troglodytes*	–	–	+	–	–		I*
251.	*Turdus iliacus*	–	–	+	–	–		II/2
252.	*Turdus merula*	+	–	–	–	–		II/2
253.	*Turdus philomelos*	–	–	+	–	–		II/2
254.	*Turdus pilaris*	–	–	+	–	–		II/2
255.	*Turdus torquatus*	–	–	+	–	–		II/2
256.	*Turdus viscivorus*	–	–	+	–	–		II/2

257.	*Tyto alba*	+	–	–	–	–		
258.	*Upupa epops*	–	+	–	–	–		
259.	*Vanellus vanellus*	–	–	+	+	–		II/2
260.	*Zapornia pusilla*	+	–	–	–	–	+	I

[a]At the national level, all birds on Skadar Lake are protected since it is a matter of the National Park
Asterisks (* and **) designate bird species in which only some subspecies have been protected [37]

On the territory included in the NP Skadar Lake, 260 bird species have been reported.

Several negative factors, which have an increasing impact on the ornithofauna, have been recorded on Skadar Lake. Those primarily are the pollution of the lake, disturbing and poaching.

References

1. Küster HC (1843) Reisebericht aus Dalmatien und Montenegro. Okens Isis 9:654–666
2. Fritsch A (1858) Einige ornithologische Notizen, gesammelt auf einer Reise durch Croatien, Dalmatien und Montenegro. J Ornit 6(35):411–415
3. Powys ThL (1860) Notes on birds observed in the Jonian Islands, the province of Albania proper Epirus, Acarnania and Montenegro. Ibis 5:1–10, 133–140, 228–239, 338–357
4. Firer L (1894) Jedna godina ornitološkog izučavanja u Crnoj Gori. Glasnik Zemaljskog muzeja u Bosni i Hercegovini Sarajevo 6:543–608
5. Firer L (1895) Produžena posmatranja na ornitološkom polju u Crnoj Gori godine 1895. Glasnik Zemaljskog muzeja u Bosni i Hercegovini Sarajevo 7:241–258
6. Führer L (1900–1901) Beiträge zur Ornis Montenegro's und der angrenzenden Gebietes von Nordalbanien. Ornithol Jahrb 11(4–5):169–189, 12(1):1–20, (2–3):41–79
7. Fuehrer L (1934) A Supplement to the Ornis of Montenegro and Albania. Ibis 4(Ser 13):172
8. Reiser O, Führer L (1896) Materialien zu einer Ornis Balcanica IV, Montenegro
9. Matvejev SD (1976) Pregled faune ptica Balkanskog poluostrva, prvi deo: *Piciformes* et *Passeriformes*. Srpska akademija nauka i umetnosti 491
10. Matvejev S, Vasić V (1973) Catalogus faunae Jugoslaviae IV/3 Aves. Academia Scientiarumet Artium Slovenica, Ljubljana, pp 1–118
11. Vasić V (1975) Gnežđenje obične čigre, *Sterna hirundo hirundo* L., u Južnoj Crnoj Gori. Arhiv biol nauka 27(1–2):47–60
12. Vasić V (1980) List of birds of Skadar Lake. Larus 31–32:185–208
13. Stojković Z, Vasić V (1968) Zonalnost u ornitofauni sjeverne obale Skadarskog jezera. Poljoprivreda i šumarstvo 14(3):59–74
14. Vizi O (1975) O gnežđenju pelikana kudravog (*Pelecanus crispus* Bruch 1832), na Skadarskom jezeru i problem njegove zaštite. Glasn Republ Zavoda zašt Prirode - Prirodnjačkog muzeja Titograd 8:5–13
15. Vizi O (1979) New data on breeding of Dalmatian pelican *Pelecanus crispus* Bruch, 1832 on Lake Skadar. Glasn Republ Zavoda zašt Prirode - Prirodnjačkog muzeja Titograd 12:125–139
16. Vizi O (1979) Ishrana pelikana kudravog *Pelecanus crispus* Bruch, 1832 na Skadarskom jezeru i njegov značaj za ribarstvo. Poljoprivreda i šumarstvo 25:45–57
17. Vizi O (1981) The Dalmatian pelican of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 419–424
18. Vizi O (1981) Srebrnasti galeb, *Larus argentatus michahellis Naumann 1840*, nova gnezdarica Skadarskog jezera. Glasnik Repub Zavoda zašt Prirode - Prirodnjačkog muzeja, Titograd 14:57–64
19. Vizi O (1981) Ornithology of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Podgorica, Belgrade, pp 391–413
20. Vizi O, Šoti J (1978) Zimski aspekt zonalne distribucije ornitofaune Skadarskog jezera. Glasn Republ zavoda zašt Prirode - Prirodnjačkog muzeja, Titograd 11:47–63

21. Vizi O (1997) Neki efekti eutrofizacije Skadarskog jezera na primjeru makrofitske vegetacije. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera. CANU, Naučni skupovi, vol 44, pp 298–308
22. Vizi O (1991) Ornitološke odlike ostrvceta Grmožur na Skadarskom jezeru. Glasn Republ Zavoda zašt prirode - Prirodnjačkog muzeja Podgorica 24:13–28
23. Dubak N, Vizi O, Vizi A (2008) JPNP: Izvještaj o rezultatima monitoringa vodenih ptica-gnjezdarica u NP „Skadarsko jezero u 2008. godini, Podgorica, 38 pp
24. Vizi O (1997) Uticaj povećanog uznemiravanja na neke ugrožene vrste ptica na Skadarskom jezeru. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera. CANU, Naučni skupovi, vol 44, pp 323–330
25. Crivelli A, Vizi O (1981) The Dalmatian pelican, *Pelecanus crispus* Bruch, 1832, a recently world endangered bird species. Biol Conserv 30:297–310
26. Vizi O (1997) Crni žar – nova kolonija močvarnih ptica na Skadarskom jezeru. In: Mijušković M (ed) Prirodne vrijednosti i zaštita Skadarskog jezera, vol 44. CANU, Naučni skupovi, Titograd, pp 309–320
27. Vizi O, Vizi A (2006) Glossy ibis (*Plegadis falcinellus* (L.1766)) nesting on Skadar Lake. Natura Montenegrina 5:169–170
28. Vizi O, Vizi A (2007) Affirmed discovery of cattle egret (Bubulcus ibis (L.1758)) on Skadar Lake (Montenegro). Natura Montenegrina 5:171
29. Szlivka L (1961) Prilog ornitofauni Obedske bare i bliže okoline (Prilog poznavanju ornitofaune Vojvodine). Larus 15:100–126
30. Dubak N, Vizi O, Vizi A (2008) JPNP: Izvještaj o rezultatima monitoringa vodenih ptica-gnjezdarica u NP „Skadarsko jezero" u 2009. godini, Podgorica, 30 pp
31. Vizi O (1979) Gnežđenje sive čaplje (*Ardea cinerea*) na Skadarskom jezeru u periodu 1972-1975 i 1977-1978. godine. Drugi kongres ekologa Jugoslavije, Zadar-Plitvice, pp 1705–1716
32. Vizi A (2013) Status of the breeding population of Great Cormorants in Montenegro in 2012. In: Bregnballe T, Lynch J, Parz-Gollner R, Marion L, Volponi S, Paquet J-Y, van Eerden MR (eds) National reports from the 2012 breeding census of Great Cormorants Phalacrocorax carbo in parts of the Western Palearctic. IUCN-Wetlands International Cormorant Research Group Report. Technical Report from DCE – Danish Centre for Environment and Energy, Aarhus University No. 22, pp 72–74
33. Vizi O (1979) Čigra bjelobrada (*Chlidonias hybrida hybrida* Pall., 1811), gnezdi na Skadarskom jezeru. Glasn Republ zavoda zašt Prirode - Prirodnjačkog muzeja Titograd 12:117–123
34. Vasić FV (1976) Gnežđenje sivih čaplji, *Ardea cinerea cinerea* L., na lovorikama (*Laurus nobilis* L.,), na Skadarskom jezeru. Glasn Republ Zavoda zašt Prirode-Prirodnjačkog muzeja, Titograd 9:31–38
35. Vasić V, Puzović S, Vizi O (1992) Capacities of Skadar Lake in relation to European regional populations of water birds. Glasn Republ zavoda zašt prirode - Prirodnjačkog Muzeja, Podgorica 25:53–62
36. Führer L (1917) Život ptica na Skadarskom jezeru. Cetinjske novine, II/73
37. BirdLife International (2004) Birds in Europe: population estimates, trends and conservation status. BirdLife International, Cambridge (BirdLife Conservation, Series No. 12)

Integrated Lake Basin Management for Lake Skadar/Shkodra

Aleksandar Vujović, Zdravko Krivokapić, Miladin Stefanović, Vladimir Pešić, and Jelena Jovanović

Contents

Abstract The natural and cultural heritage of the Lake Skadar/Shkodra basin require the implementation of an efficient management system at the level of the whole lake for the purpose of its continuous protection and the valorization of this unique ecosystem. In this study, we have suggested that there is no difference between the Lake Shkoder Basin Management Strategy (LSBMS) and the Integrated Lake Basin Management (ILBM) which is widely accepted today as a guideline for the achieving of the sustainable management of lake basins. In this chapter, we have

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 447–458, DOI 10.1007/698_2018_264,

© Springer International Publishing AG 2018, Published online: 8 June 2018

reviewed the relevant national and international documents about Lake Skadar such as the Strategic Action Plan (SAP) for Lake Skadar/Shkodra to analyze the current management plans of the lake and basin according to the six governance pillars of ILBM (institutions, policies, participation, technology, information, and finance).

Keywords Integrated Lake Basin Management (ILBM), Lake Shkodra Basin Management Strategy, Lake Skadar/Shkodra, The Skadar Lake National Park

1 Introduction

At the global level, there are 117 million lakes >0.002 km^2 covering 3.7% of the Earth's nonglaciated land area [1] and which contain approximately 90% of the liquid freshwater on the surface of the earth [2]. Lakes provide many ecosystem services necessary for human survival and economic development. At the same time, they are among the most vulnerable ecosystems, being susceptible to climate change and any increased demand for water. Lake Skadar is the largest lake in the Balkan Peninsula [3] and one of the richest basins of freshwater in the world [4].

The ecological importance of Lake Skadar has been recognized by establishing a National Park on the Montenegrin side, and a "Managed Natural Reserve" covering the Albanian part of the lake, while at the international level it is recognized as a Ramsar site and as one of the Key Biodiversity Areas across the Mediterranean biodiversity hotspot [5]. Lake Skadar offers various ecosystem services that include outstanding biodiversity richness and fisheries, but also regulating (the control of flooding, the purification of water, and climate regulation) and cultural services that should be taken into consideration when developing management plans.

Bearing in mind the natural and cultural heritage of the Lake Skadar basin, and its historical significance, it seems necessary to implement an efficient management system for the purpose of its continuous protection and the valorization of this unique ecosystem. This requires a detailed analysis of the opportunities offered by the international standards of management systems, and testing their applicability to the Lake Skadar basin. The significance of establishing an integrated management system for a valuable freshwater resource such as Lake Skadar is in line with the obligation that Montenegro has to comply with the relevant European regulations in the field of protection and the sustainable use of water resources. Despite the efforts that have been made over the last decade in creating the Lake Skadar/Shkodra Basin Management Strategy [6], Lake Skadar is still not managed as a whole system.

For the purposes of the development of lake management systems, it is necessary to emphasize the *Integrated Lake Basin Management* (ILMB) approach, as a model that primarily ensures the protection of ecosystems, efficient water resources management, and better living conditions in the lake area [7]. This system was adopted by the International Lake Environment Committee (ILEC) in 2007 and is based on six governance pillars: (1) institutions, (2) policies, (3) participation, (4) technology, (5) information, and (6) finance – that form the basis for the sustainable management of lake basins [8]. The approach relies on the Integrated Water Resources Management (IWRM) process recommended by the 1992 International Conference on Water and the Environment. The latter approach emphasized three characteristics of lakes and their implementation in further management plans: (1) their integrating nature based on treating the lake as one unit, regardless of any existing boundaries, (2) their retention time which in the case of Lake Skadar compared with other lakes is not long (a water residence time of about 100 days), which can have advantages when pollution is in situ, and (3) their complex response dynamics which requires the inclusion of scientific data in the current management strategies of Lake Skadar [9].

Many studies have demonstrated that introducing the ILBM approach might result in both human and ecosystem benefits, as well as solutions moving toward the sustainable development of the whole lake system [10–12]. The ILBM approach has particular significance for the development of ecotourism, especially in providing livelihood support for the local community [11]. Moreover, the ILBM model has produced excellent results in terms of establishing a multi-lakes management strategy, especially in terms of better communication and the coordination of activities between the local community and the government [12]. The importance and necessity of establishing an ILMB system are connected with the promotion of public awareness through different activities such as establishing educational centers, and better communication between the administration at the local and state level [13]. An integrated quality management system, followed by an integrated biomonitoring program, both contribute to the better control of water pollution, the reduction of costs, and the efficiency of water resource use [14]. In addition to monitoring and analyzing water quality, integrated management systems must take into consideration all the processes related to cost management and risk analysis, as well as to the use of modern information and communication technology for efficient resource management [15]. For example, using a computerized decision support system for Lake Trasimeno in central Italy, it was possible to monitor the quality of water flowing into the lake, but also the use of water resources, depending on the needs of different stakeholders and in that sense to achieve optimization through an integrated management system [16]. The ILBM model has been successfully used both for national lakes such as Lake Rawa Pening in Indonesia [8] and Lake Biwa in Japan [17] but also for transboundary lakes such as Lake Malawi in Africa [18] and Lake Baikal in Russia [19].

The examples presented and the emphasizing of the ILBM approach to the management of lake basins all indicate the need to define an efficient approach to the integrated resource management of Lake Skadar. The information and data in this chapter comes mostly from the published literature and interviews and is built upon the ILBM approach discussed above. In this study, we have reviewed the relevant national and international documents about Lake Skadar to analyze the current management plans of the lake and basin according to the six pillars of ILBM.

2 The Lake Shkoder Basin Management Strategy and Integrated Lake Basin Management

A comprehensive analysis of the Lake Skadar Basin was conducted in 2006 within the framework of the project “Lake Shkoder Transboundary Diagnostics Analysis” [6] and resulted in creating the first setup of the Lake Shkoder Basin Management Strategy (LSBMS). This strategy formed the skeleton of the Strategic Action Plan (SAP) for Lake Skadar/Shkodra, which was adopted in 2007 [20]. The LSBMS was based on recommendations derived from River Basin Management Plans (RBMP) for each river basin. The LSBMS defined the main objectives and components of the strategy, the current status, the pressures and threats, the approaches for improvement, and the policies that are needed to support the Strategy [6]. There are four main goals in the LSBMS: (1) a healthy ecosystem (flora, fauna, and habitat) in the lake and its basin, (2) the sustainable use of natural resources, (3) access to all the lakes without endangering the ecosystem, and (4) collaboration and exchange in the field of ecosystem and water management at the national, bilateral (Montenegro and Albania), and international level [6]. For the implementation of the LSBMS objectives, the following approaches were proposed [6]:

- Institutional development and coordination
- Nature development
- Pollution reduction
- Legal framework
- Education and awareness raising
- Information and knowledge development
- An environmental impact evaluation
- Livelihood support
- Investment support

These proposed approaches in the LSBMS were actually in line with the six pillars in ILBM (Fig. 1). The pillar of institution in ILBM is in line with Institutional development and coordination in LSBMS. The approach to technology is in line with the Pollution reduction and Environmental impact evaluation approaches of LSBMS while the information pillar of ILBM is in line with the LSBMS Information and knowledge development area. Policies in ILBM are in line with the Legal framework and Nature development areas in the LSBMS. Participation in ILBM is in line with the Education and awareness and Livelihood support approaches, whereas the finance of ILBM is in line with Investment support in the LSBMS.

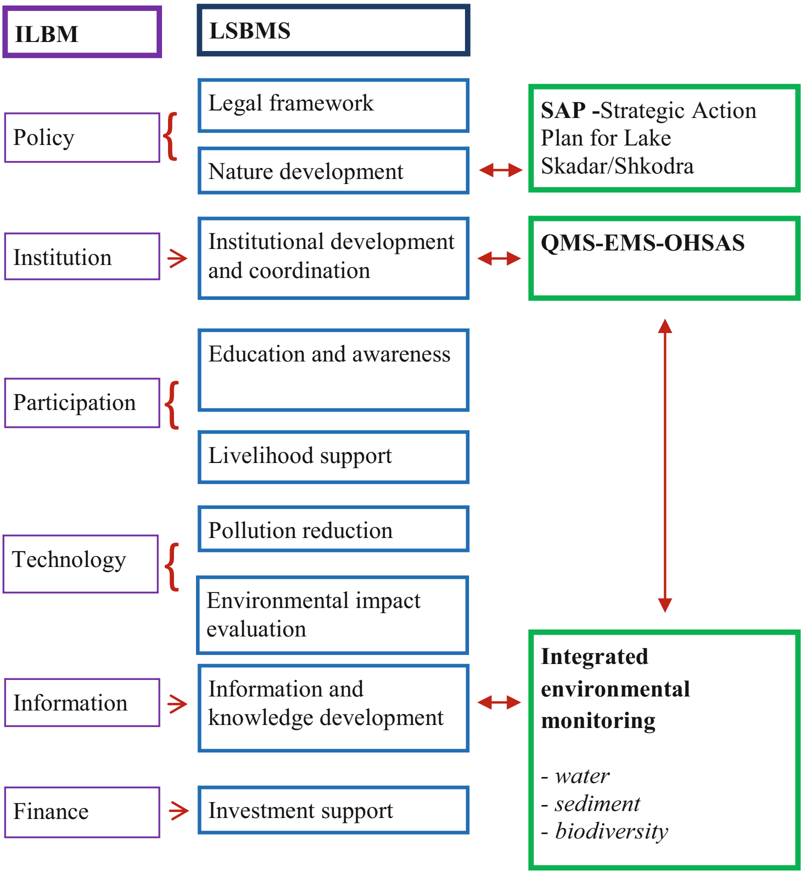

Fig. 1 The comparative and analytical framework for the Lake Skadar integrated management

3 Recent Advances in the Current Management Plans for Lake Skadar, with Implementation According to the Six Pillars of ILBM

3.1 Policies

As already pointed by Keukelaar et al. [6], the policies that relate to Lake Skadar basin management are in place at the national level. On the transborder issues, some activities have been taken in the past such as the signing of the Memorandum of Understanding (MoU) for the Protection and Sustainable Development of Lake Skadar between the Montenegrin and Albanian governments in 2003 [6].

3.2 Institutions

There is no specific institution which is responsible for managing the lake as a whole. At the transborder level, cooperation is established and exists between various governmental and nongovernmental institutes and organizations from both countries. The institutional framework and stakeholders both in Montenegro and Albania are thoroughly discussed in the SAP for Skadar/Shkodra Lake [20]. Most of these institutions and stakeholders are hampered by unstable funding and often by having inadequate resources to fulfill their activities.

Regardless of the SAP for Lake Skadar [20] and the LSBMS approaches [6] that suggest a number of measures to promote transborder cooperation, over the last decade poor progress has been evident in establishing more intensive collaboration. The SAP for Lake Skadar suggests establishing "*a joint Lake Planning and Management on the level of the entire Lake Basin*" [20]. The lack of unified planning at the level of a whole lake makes the decision-making process about the processes and challenges that Lake Skadar face at the level of the whole ecosystem difficult. This is especially important in the case of those environmental challenges that Lake Skadar will continue to face in the future, such as increasing eutrophication, the impact of invasive species, and the non-sustainable use of the natural resources of Lake Skadar. An ILBM approach could significantly assist in defining joint effective trans-boundary management as well as in the decision-making process at the level of the entire lake related to the abovementioned challenges.

The Lake Skadar National Park (LSNP) management authority is recognized as one of the main institutions that is directly involved in the protection and management of the lake [6]. It is important to emphasize the benefits of using integrated management systems for specific organizations that have a particularly important role in decision-making, like the LSNP authorities. The integration of different models of management systems, e.g., quality management systems (QMS), environmental management systems (EMS), and occupational health and safety assessment standards (OHSAS), in an institution like LSNP must be carried out on the basis of best practices which emphasize the requirement for quality and standards in relation to environmental protection. It is worth mentioning that the implementation of ISO norms in national parks in neighboring countries is still under development: for example, in 2017 only the ISO 9001 certificate was awarded to Paklenica National Park, the first one to be awarded in Croatia [21].

The standards of the ISO 14000 series provide basic guidelines for the systematic improvement of an organization's behavior toward the environment. They define a system of environmental management by applying environmental objectives set by regulations and laws [22]. The new edition of ISO 14001: 2015 is designed to represent the basis for strategic environmental management by creating a system that aims to constantly improve environmental performance. The emphasis of both standards is on defining the concept of organization, a stronger role for top management, leadership, risk assessment, and performance evaluation, which significantly increases the seriousness of approaches to this issue. Based on a "Risk-Based

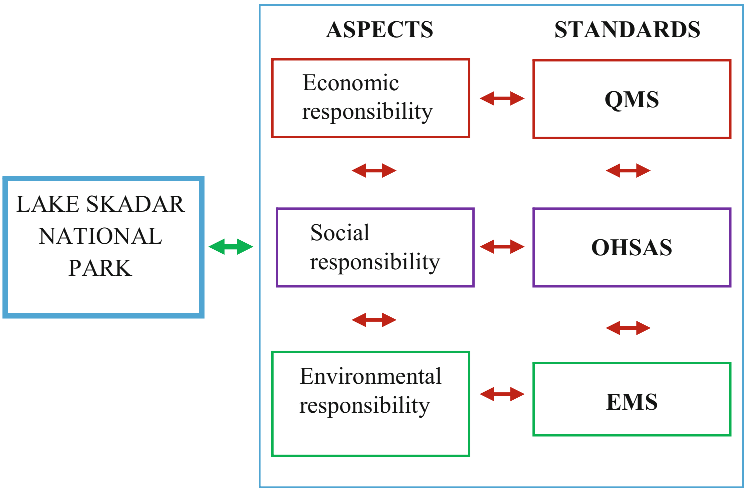

Fig. 2 Corporate social responsibility for NP Lake Skadar using an integrated management system

Thinking" approach, with additional explicit requests for "Performance Evaluation" and "Enhancement," they are a key tool that can provide success in the field of improving environmental performance [23]. In summary, the implementation of an integrated management system based on the three abovementioned standards is recommended for LSNP (Fig. 2):

- Economic responsibility, which implies approaches of continuous improvement to those issues of a financial nature (QMS)
- Social responsibility, which indicates how employers and communities establish their interaction with the goal of protecting employees and caring for health and safety (OHSAS)
- Health and safety responsibility in terms of environmental impact assessments and the elimination of negative circumstances as a result of organizational activities (EMS)

3.3 *Information and Science*

Obtaining and including scientific information is a substantial step toward sustainable and science-based ecosystem management [9]. The SAP for Lake Skadar/Shkodra provided for a set of different activities dedicated to the improvement of ecological and socioeconomic monitoring, aimed at "*establishing a permanent joint monitoring system covering all elements of the eco-system, following the EU Water Framework Directive and the Ramsar Convention*" [20]. The LSBMS emphasizes the importance of the Centre for Ecotoxicological Research (CETI) in Montenegro and the University of Shkodra and the Maize and Rice Institute in Albania in establishing a permanent joint monitoring system [6]. However, a single joint monitoring system at the level of the whole Lake Skadar still does not exist. This is due to a variety of issues, most notably in defining the components which should be included in this type of single integrated monitoring as well as in defining and selecting “reference sites” (see the discussion in the last chapter of this book [9]).

On the other hand, a program to monitor the components of the Lake Skadar environment on the Montenegrin side of Lake Skadar has been run every year by the Environmental Protection Agency of Montenegro. The water quality monitoring program each year was proposed by the Ministry of Agriculture and Rural Development, in accordance with the Law of Waters [24] and implemented by the Institute for Hydrometeorology and Seismology of Montenegro. The monitoring of the water quality of Lake Skadar is carried out at nine locations and analyzes both chemical and microbiological water quality parameters [25]. Furthermore, the “Vranjina” automatic station monitors water quality across six parameters: temperature, pH, electrical conductivity, oxygen content, oxygen saturation, and chlorophyll a, as well as the height of the water column [25]. By contrast, the monitoring program related to Lake Skadar biodiversity is carried out by an expert team from the Environmental Protection Agency of Montenegro, which is the main user of the data obtained by this monitoring [25]. The current biodiversity monitoring program of Lake Skadar does not include some of the main components of lake biodiversity such as plankton and benthos [25].

Based on the number of conservation programs that have been implemented over the last decade to protect the threatened species of Lake Skadar, it can be concluded that a minimal effort has been made in the protection of biodiversity, and especially of endangered and endemic species. This has resulted in a lack of restoration activities aimed at improving the protection of species that are subject to the risk of local extinction. Several studies have stressed that eutrophication, overexploitation, and the impact of invasive species are the main threats to Lake Skadar biodiversity [9]. The current monitoring of Lake Skadar does not include the monitoring of endangered and endemic species. Furthermore, there is a lack of monitoring of noninvasive species and their impact on autochthonous species.

3.4 Participation

Participation includes active public and stakeholder involvement aimed at raising public support for the sustainable development of Lake Skadar and a better understanding of the environmental issues that face the lake basin among the wider public. Over the last decade, the greatest progress has been achieved in environmental awareness thanks to activities undertaken by NGOs which have built public support for the protection and sustainable development of the lake. However, despite the intensive effort made by NGOs it seems that tourism development, most especially the construction of significant tourist infrastructure, has occurred without taking into account the ecological considerations. In the last decade, the development of tourism has become an increasingly important form of economic activity, and therefore the sustainable planning of the tourist use of the lake is becoming more and more important. The number of visitors to the National Park increased from 7,000 in 2004 to 74,649 in 2013, of which over 75% were foreign tourists [26]. Sustainable planning is especially important in the case of the development of excursion tourism – most notably boat rides on the lake which can be a disturbing factor for some ecosystem components (notably birds). About two-thirds of the people who visited the lake say that they visited the lake because of its scenic beauty, but at the same time about 65% of them stated that they would be less likely to continue to visit the lake if the quality of water decreased [27]. One of the key preconditions for successful tourism development is to provide the right conditions for the environmental safety and security of the destination from various standpoints [28], which is certainly possible and must be achieved by the adequate application of relevant international standards.

3.5 Technology

Technology includes aspects related to pollution control and waste management and plays an important role in the management of the resources of Lake Skadar. "*Reduction and prevention of pollution of Lake waters and sediments, and establishing a basin pollution control system*" is emphasized as one of the strategic goals in the SAP of Lake Skadar [20]. In this topic, one substantial area of progress is evident. Recent research has shown that chemical and water quality parameters have not changed significantly over the last few decades, suggesting that the water and sediment quality is satisfactory and the current level of pollution of Lake Skadar is low [29].

3.6 Finances

The experience of the main stakeholders that need to be involved in the realization of the activities in the research, protection, and management of Lake Skadar has revealed that the government is the main bottleneck because of the insufficient financial support it provides. This is especially true in the case of financial support for projects aimed at biodiversity protection, where, for example, protection is not recognized as one of the operational objectives in achieving the Strategic Goal of the 'Realization of urgent environmental investments' suggested by SAP for Lake Skadar [20]. All the operational objectives within this strategic goal were devoted to the prevention of pollution, ignoring other environmental issue such as increasing eutrophication, the impact of non-native species and the increased risk to endangered and endemic species, all of which requires urgent environmental investment.

4 Conclusion

Over recent decades, the protection and sustainable development of Lake Skadar and its basin has been the subject of a number of transboundary initiatives including the "Lake Shkoder Transboundary Diagnostics Analysis" project financed by the World Bank. In this chapter, we have demonstrated that the LSBMS which was created by the mentioned project is in line with ILBM. Moreover, we have analyzed the current management plans of the lake and basin according to the six pillars of ILBM and highlighted several topics that need improvement. An integrated management strategy for Lake Skadar includes, on the one hand, improving the social and corporate responsibility of the main institutions (such as LSNP) involved in the activities aimed at the sustainable development of Lake Skadar by the implementation of an integrated management system based on QMS, EMS, and OHSAS standards. On the other hand, there is a need to develop an indicator framework based on the ILBM approach which will help to defining any successful strategy toward sustainable and science-based ecosystem management.

References

1. Verpoorter C, Kutser T, Seekell DA, Tranvik LJ (2014) A global inventory of lakes based on high-resolution satellite imagery. Geophys Res Lett 41:6396–6402
2. ILEC (2005) Managing Lakes and their basins for sustainable use: a report for lake basin managers and stakeholders. International Lake Environment Committee Foundation, Kusatsu
3. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Berlin, Heidelberg
4. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82
5. Darwall W, Carrizo S, Numa C, Barrios V, Freyhof J, Smith K (2014) Freshwater key biodiversity areas in the Mediterranean Basin hotspot: informing species conservation and development planning in freshwater ecosystems. IUCN, Cambridge
6. Keukelaar F, De Goffau A, Pradhan T, Sutmuller G, Mišurović A, Ivanović S, Uskokovic B, Hetoja A, Haxhimihali E, Prifti A, Kapidani E, Kashta L, Gulan A (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515. Royal Haskoning, Podgorica, 111 pp
7. Lintner SF (2007) Opportunities and challenges in integrated lake basin management. World Bank, Washington
8. Soeprobowati TR (2015) Integrated lake basin management for save Indonesian lake movement. Procedia Environ Sci 23:368–374
9. Pešić V, Karaman GS, Kostianoy AG, Vukašinović-Pešić V (2018) Conclusions: recent advances and the future prospects of the Lake Skadar/Shkodra environment. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Berlin, Heidelberg
10. Juarez-Aguilar A (2010) Lake Chapala, Mexico: integrating sub-basins as an integrated lake basin management (ILBM) strategy. In: Annual review meeting of the ILBM-Governance Project for FY2009

11. Sharip Z, Jusoh J (2010) Integrated lake basin management and its importance for Lake Chini and other lakes in Malaysia. Lakes Reserv Res Manag 15:41–51
12. Shailendra O, Masahisa N (2011) Integrated lake basin management (ILBM) for sustainable conservation of Himalayan lakes of Nepal. Sci Environ Sustain Soc 8(1):13–24
13. Saragih B, Sunito S (2001) Lake Toba: need for an integrated management system. Lakes Reserv Res Manag 6:247–251
14. Zheng JF, Jiao JD, Zhang S, Sun LP (2017) An optimization model for water quantity and quality integrated management of an urban lake in a water deficient city. Urban Water J 14(9):922–929
15. Arabatzis S, Manos B (2005) An integrated system for water resources monitoring, economic evaluation and management. Oper Res J 5(1):1–10
16. Casadei S, Pierleoni A, Bellezza M (2016) Integrated water resources management in a lake system: a case study in Central Italy. Water 8:570
17. Uchimura M (2008) Approach toward better lake water environment: case of Lake Biwa. In: Proceedings of Taal 2007: the 12th world lake conference, pp 1414–1416
18. Chidammodzi CL, Muhandiki VS (2015) Development of indicators for assessment of Lake Malawi Basin in an integrated lake basin management (ILBM) framework. Int J Commons 9(1):209–236
19. Lomonosov (2014) Integrated natural resource management in the Baikal Basin transboundary ecosystem. Helmholtz Centre for Environmental Research (UFZ), Moscow State University
20. APAWA and CETI (2007) The strategic action plan (SAP) for Skadar/Shkodra Lake Albania & Montenegro. GEF, World Bank, LSIEMP Shkodra-Tirana-Podgorica, Washington, 72 pp
21. Svijet Kvalitete (2017) http://www.svijet-kvalitete.com/index.php/okolis/3751-nacionalnom-parku-paklenica-dodijeljen-certifikat-iso-9001-2016. Accessed 25 Dec 2017
22. Jovanović J (2009) Model unapredjenja sistema upravljanja zaštitom životne sredine primjenom multisoftvera. Dissertation, University of Montenegro
23. Jovanović J, Krivokapić Z, Vujović A (2015) Sistem menadžmenta zaštitom životne sredine u duhu standarda iso 14001:2015. Kvalitet i izvrsnost 9(10):71–78
24. Law of Water (2007) Official Gazette of Montenegro, No. 27/07
25. EPA (2016) Informacija o stanju životne sredine za 2016. godinu. http://www.epa.org.me/images/izvjestaji/Informacija-o-stanju-zivotne-sredine-za-2016.pdf. Accessed 26 Dec 2017
26. Denda S, Stojanović J (2015) Protection of the "Lake Skadar" national park in the function of sustainable development of tourism. In: 8th international scientific conference "science and higher education in function of sustainable development", Užice
27. Skarbøvik E, Perović A, Shumka S, Nagothu US (2014) Nutrient inputs, trophic status and water management challenges in the transboundary lake Skadar/Shkodra, western Balkans. Arch Biol Sci 66(2):667–681
28. Krivokapic Z, Jovanovic J, Vujovic A, Pekovic S (2016) Kvalitet u turizmu. University of Montenegro, Podgorica
29. Kastratović V (2018) The water and sediment chemistry of Lake Skadar. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra Lake environment. Springer, Berlin, Heidelberg

Cultural-Historic Heritage of the Lake Skadar Basin

Adnan Prekić

Contents

Abstract The Lake Skadar basin harbours a rich cultural and historical heritage of different epochs and forms. Traces of the first human communities appeared way back in the Palaeolithic period, while archaeological founds from a cave on the Lake Skadar coast imply on the first traces of spiritual life from the Neolithic period. The monumental heritage of the Middle Ages is the most preserved, architectonically the most important and stylistically the most authentic. Under the influence of different political and social circumstances, the area of the Lake Skadar becomes the place of interference of stylistic and architectonical headings. Profane building characterizes construction of different fortification objects and a smaller urban settlements. Wider area of the Lake Skadar presents one of the most significant regions in civilizational developments of Montenegro, and it will be the area in which appeared the first forms of spirituality, literacy and cultural development. In seven subchapters of this text, we will explain historical context in which those processes were developed and look back to cultural contents, profane and sacral buildings of civilizations, that formed wealth and diversity of cultural layers of the Lake Skadar.

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 459–480, DOI 10.1007/698_2018_304,
© Springer International Publishing AG, part of Springer Nature 2018,
Published online: 29 April 2018

Keywords Doclea, Fortress, Illyrians, Lake Skadar, Montenegro, Slovenes, Temples, Zeta

1 Historical Context

Optimal climate conditions, favourable geographical position and richness of plants and animal species influenced so that the wider area of the Lake Skadar was inhabited way back in prehistory. Thus far known results of the archaeological testing showed that, near the lake, in the valley of Morača River, were established archaeological findings that imply on the existence of human settlement in Palaeolithic age [1]. It is certain that the communities of the wider area were oriented to the shores and hinterland of the Lake Skadar because these areas were ideal for hunting and fishing (Fig. 1), the basic production branch of Palaeolithic communities. It is confirmed by findings from the cave at the locality Dučić, in the mountain hinterland of the lake where are discovered the archaeological findings, implying that this cave was a temporary settlement in the Neolithic period [2]. In the Early Iron Age (800–400 BC) occurred the consolidation of the first ancestral communities into the first tribal communities. Those communities had different ethnic composition and origin, but all of them, after long processes of ethno genesis, became recognizable by one unique name – Illyrians [3].

The Lake Skadar (*Lacus Labeatis*), and its hinterland was the living area of three Illyrian tribes: *Labeati*, *Enchelei* and *Albani*, while nearby lived also tribes *Docleatae*, *Plearaei* and *Pirusta*. The Illyrian tribe, *Labeati* (*Labeates*), is named right after the Lake Skadar whose coasts it settled. In the East, the Labeati had the common border with *Scirtones* and in the north with Docleatae (*Docleates*). East

Fig. 1 Lake Skadar. Photo by J. Jovićević

from the Lake Skadar, near the Drin River, originally lived the Illyrian tribe Pirusti (*Pirustai*) that, over the time, migrated into different regions. In the near close of the Labeati, also in the Southeast brim of the Lake Skadar, lived a small Illyrian tribe *Albani* (*Albanoi*) after whom todays Albanians got their national name [3]. Interrelationships Illyrian tribes are going to become more closer that will lead to the establishment of the Illyrian state that will continuously function in the period between 490 and 164 BC [4]. The fall of this state is connected to the battle in the Lake Skadar surrounding, when the Roman army, led by *Lucije Anicije Galo* with about 30,000 legionnaires, attacked todays Skadar/Shkoder – fortified capital of Illyrian state. The last Illyrian king – *Genci* – couldn't manage to hold the Roman army, and he withdrew to the mountain hinterland of Lake Skadar [5]. After the Roman conquest, the wider area of the Lake Skadar becomes a part of the *Prevalis* province, and after the division of the Roman Empire in 395, this area entered into the structure of Byzantine Empire. Since the sixth century, this area was under plundering intrusions of Avarian and Slovenian tribes, and at the beginning of the seventh century, the Slavic tribes started to settle in these areas. The permanent settling of Slavic tribes marked the end of one historical phase and beginning of another one in which the Byzantine Empire will try to include these tribal groups into its social and political context. At the end of the tenth century, one of the hereditary Slavic dukes of this region – Vladimir – denied Byzantine governance and formed the first mediaeval state – *Doclea* (Duklja). The area of the Lake Skadar will take the central place of this mediaeval state, and according to the Chronicle of the Priest of Dioclea (Gesta Regnum Sclavorum) [6], among nine parishes of Doclea, there was parish Podlugiae around the Skadar Lake. This parish is known under the name of Gornja and Donja Zeta and spreads to the banks of the Morača River, that flows into the lake, and mountain hinterland of the lake on the East [2]. The strategic position of the Lake Skadar basin in the Doclea state will determine the stage of two of the biggest mediaeval battles in the history of Montenegro. First, in 1040, the duke of Doclea Vojislav, in Crmnica, immediate hinterland of the Lake Skadar, defeated the military expedition of the Byzantine emperor Mihailo IV and 2 years later, also in the hinterland of the Lake Skadar, achieved the most significant victory against Byzantine. In the glorious victory at the mountain hinterland, on the locality Tudjemili, Doclean army achieved the victory, and by that the independence of Doclea from Byzantine government was confirmed. Only few decades after the victory over the Byzantine army, the mediaeval Doclea will be disturbed by internal problems, and for that reason it will be conquered in the twelfth century by the Serbian ruler Stefan Nemanja and will be joined to Serbia. Since that time, the mediaeval name of Doclea state is gradually vanishing, and more often the name Zeta is being used for this area.

After the death of Serbian Emperor Dušan in 1355, local feudalists throughout his country became more independent, and one of them was Balša I who has already, in 1360, established his power in the area of Donja Zeta. The family Balšić expanded their power very fast onto neighbour areas, but the central place of their state occupied the part around the Lake Skadar. In that period, near the hinterland of the Lake Skadar, one more Montenegrin mediaeval family – Crnojević – become stronger and they will, instead of Balšići, until the second half of the fifteenth century, rule Montenegro. In the alliance with the Republic of Venice, Crnojevići will, very soon, expand their influence, but this short-term rise will be stopped by Ottoman conquests. With the great military expedition by which the Ottoman army tried to conquer Skadar, fell the most significant fortress of Crnojević family on the Lake Skadar – Žabljak fortified town.

The conquering of Žabljak Crnojevića in 1478 and Skadar, a year later, will indicate the start of the four-century domination of the Ottomans over the wider area of the Lake Skadar. Montenegro also fell under the Ottoman control (1469), and domination of the Empire will be disturbed only few centuries later when the formation of the liberation movement, led by orthodox metropolitans from Cetinje, started. The liberation movement will get strong support from orthodox inhabitants in the region of the Lake Skadar, and very soon there will be established contacts in relation to activities between the local inhabitants and authorities in Cetinje. The best testimony on the significance of the Lake Skadar basin for Montenegrin liberation movement is the political programme of the Metropolitan Vasilije (1744–1766) from Cetinje. The Metropolitan Vasilije, in the programme of creating independent Montenegro, clearly stated that the central place in that country should have the Lake Skadar (Fig. 2) and town of Skadar/Shkodra itself. This programme will be the foundation of further political and military engagement of Montenegro, because fertile Zeta plain and the lake guaranteed fertile ground, excellent conditions for cattle rising and fish as an important trade good. This meant solving the most important problem for Montenegrin population – alleviation of hunger and poverty. Already, during the rule of the Metropolitan Peter II (1830–1851), the inhabitants that lived around the Lake Skadar massively participated in military actions of the authorities from Cetinje, so that final association of these areas occurred after the war between Montenegro and the Ottoman Empire (1876–1878). After this war,

Fig. 2 The Northwest part of the Skadar Lake. Photo by: J. Jovićević

happened the international recognition of Montenegro at the Berlin Congress 1878. The demarcation between Montenegro and the Ottoman Empire is performed through the Congress' decisions, and a part of the border passed exactly through the Lake Skadar basin that, with the exception of the part from the spring of the Bojana River to Plavnica, was assigned to Montenegro.

After its incorporation in Montenegro, this area of the Lake Skadar becomes the most significant economical region of Montenegro, the region with the most intensive migration of inhabitants from neighbouring mountain areas. Agriculture, cattle rising and fishery stayed the most important sources of income, but over time, there started more and more intensive production of vine and tobacco. One of the biggest infrastructure projects of the Principality of Montenegro is planed exactly on the area of the Lake Skadar. King Nikola Petrović had an idea to regulate water level of the Lake Skadar by which huge agricultural surfaces would be acquired [7]. There was no effect from this plan, and with the similar idea, the political life after 1945 started the Communist Party of Montenegro. Within big infrastructural works during 5-year plans, socialist authorities planned a regulation of the Bojana River, and with that there would be formed conditions for creating huge surfaces of agricultural ground.

2 Cultural Heritage of the Prehistory and Old Century

In the Iron Age, human communities that lived in the area around the Lake Skadar abandoned the natural shelters and started to create the first settlement and habitations in the open air. On the shores of the Lake Skadar and different high grounds of Zeta Plain are formed many prehistoric settlements like these, out of which the most significant were Oblun-locality Malo Blato, Planinica in the area of Tuzi and Đuteza in the area of Dinoša. Similar settlements are formed on the other shore of the Lake Skadar, the area that nowadays belongs to Albania. In the near area of Skadar, at the beginning of Older Iron Age, at about 800 BC, one of dominant high grounds was formed fortress Gajtan [8]. Meteon or Medun (Fig. 3) is situated in mountain hinterland of the Lake Skadar, and for the first time, it is mentioned by *Titus Livius*, in the first years of Anno Domini, as a settlement near the Labeates and place where Romans captivated the last Illyrian King *Genci* in 168 AD. This settlement was exceptionally fortified with stone walls whose remains are kept up to nowadays. Fortification objects are built of cut rubble stone in multi-stone rows. The Illyrian settlement Samobor was situated at an outstanding strategic position, just near the current Montenegrin-Albanian border on the Lake Skadar. The settlement is formed on the steeply and inaccessible hill, on one kind of a peninsula, enclosed with fortification objects built of irregular stone. According to finds discovered on this place (coins), it is assumed that this settlement functioned in the period 225–110 BC [2]. The finds of ceramics discovered in this fortress are from the same period. There are serious claims that on the location of Samobor could be found antique settlement *Birziminium* that is situated on the famous Peutinger Table of Roman communications [9]. On the other side of the Lake Skadar, on the elevation above Skadar, is

Fig. 3 Medun fortifications. Photo by S. Kajošević

formed Illyrian settlement Kratuli that is protected with thick ellipsoid walls that are built of huge stone blocks [8].

The prehistoric colonies on the coasts of the Lake Skadar will lose its function after the Roman conquest. Instead on preservation of the existing settlements, Romans directed their attention on tracing the new roads and construction of objects that served for those communications. On the strategic positions are built smaller towers and observation posts for the protection of a road, trade caravans and public order. There are also formed smaller colonies or stations along the main communications with special objects that provided shelter for the night, food or similar kind of help to the travellers. These localities presented important traffic hub for Romans because on the shores of the lake is traced one of the most important communications – the road from *Narona* (near current Metkovići in Herzegovina) to Skadar/Shkodra. On the Peutinger Table of Roman communications, that deals with stations situated on the route of this road through inland, states several stations near the Lake Skadar. The road led from the direction of Bjelopavlići Plain towards the Lake Skadar and on the trace to Skadar/Shkodra several Roman stations (settlements): Halata-Bersumno-Cina-Scodra were situated [5]. From Alata, the route of Roman road went into direction of the current settlement Tuzi where, on the location Vuksanlekići, the remains of Roman milepost were found.

The first traces of the culture and spiritual life in the region of the Lake Skadar can be followed since prehistory, to be more precise Eneolit or Copper Age (3000–2000 BC) [5]. In the graves from this period were found a material traces that confirmed nurturing different cults. Several huge necropolis of the Illyrian tribe

Fig. 4 Gold jewellery (3–2 ct. BC) from the Gostilj village. Photo by M. Ilić

Labaeti were found in the wider area of the Lake Skadar. Besides the traces of ceramics, there was found a great number of different shapes of jewellery and money. The most significant necropolis discovered on the shores of the Lake Skadar is Gostilj (Fig. 4) and Velje Ledine, where are found different types of jewellery: fibulas, bracelets and necklaces. There are also discovered coins of the last Illyrian King *Genci*, different shapes of weapons and numerous relief displays of mythological motifs, leaves, women and soldiers [2]. The existence of different cults of prehistorically communities will remain the only trace of spirituality until the appearance of Christianity.

3 Prophane Constructions of the Middle Ages

The modest fortresses that had control function of the communications on the shores and hinterland of the Lake Skadar present the most significant construction activities in the Middle Ages, too. On the east shores of the Lake Skadar, at the place that local inhabitants call Malo Blato, on the remains of the settlement from the Illyrian-Greek period, is formed Oblun. Situated on the dominant elevation of this part of the Lake, the fortress had clear control function over a part of the Lake Skadar basin and

Ćemovsko polje. Several similar fortresses, with the similar function, are situated on the dominant positions. Above the villages Vranj and Mataguži is situated fortress that is, among the local inhabitants, known as the fortress on Kranjska Gora. The fortress of Balša is situated above the village Ponari, and the remains of its protecting walls are preserved. The inhabitants connected the fortress with the Balšić dynasty, but archaeological exploration discovered traces of prehistorically and antique ceramics so that the settlement itself could be significantly older [2]. At the end of the fifteenth century, another fortress is built on the shores of the Lake Skadar. On the elevation above the current Rijeka Crnojevića, at the end of the fifteenth century, Ivan Crnojević built the fortress Obod that will be later known under the name Riječki grad. Inside the fortress, except the protecting walls, is built a church, too. Due to specific political circumstances, the fortress already lost its function at the beguiling of the sixteenth century, and in the seventeenth century, only the ruins remained at this place.

The most significant mediaeval settlement on the Montenegrin shores of the Lake Skadar was *Žabljak Crnojevića*, settled on the hill just near the River Morača and a part of the Lake Skadar that the local inhabitants call Gornje or Malo Blato (Fig. 5). In addition to different interpretations on the existence of fortresses even in the tenth century, the first written data on Žabljak originate from Venetian sources in 1453 that registered the presence of Djurdj Crnojević's army. Specific geographic position enabled ideal conditions for defence, and during spring and in the period of high

Fig. 5 Žabljak Crnojevića. Photo by D. Dajković

water levels, the hill, on which the fortress is situated, turns into an island. Protecting walls are permanently strengthened, and the whole complex is built of ashlar that is tied with lime plaster. As the main settlement and seat of the feudal family Crnojevići, Žabljak experienced its greatest rise in the middle of the fifteenth century. It is primary conditioned by the position on the crossroad of the lake and land roads and enabled strong economic and trade development of the settlement. It is assumed that, during mediaeval ages, there were about 300 houses in the settlement. Strategic position on the crossroad of water and land roads is one of the reasons why Žabljak Crnojevića was one of the most significant military targets of the Ottoman Empire that in the second part of the fifteenth century started a strong military campaign in this region. Within military actions by which they tried to take Skadar from the Republic of Venice, the Ottomans took Žabljak Crnojevića in the action from 1478. Being aware of strategic significance of the fortress, the Ottomans additionally fortified protecting town walls, organized military detachment and in the following, almost 4 years, they governed this fortress [10].

Also, a line of smaller fortification objects is built on the shores of the Lake Skadar. The oldest object of that type is military tower – *Tophala* – situated on the namesake island on the southwest shore of the Lake Skadar. The tower itself had a quite simple construction, square shape, with four strong pilasters on the angles and four more on the walls between. It is built of huge pieces of broken and ashlar stone in plaster. The walls are about 2 m thick. Just near the tower, the remains of a church from the twelfth century are found. Much complex fortification objects are built after the fifteenth century. Also, on the other coastline of the Lake Skadar, several fortresses are formed with the function of protection and control of the neighbouring areas. The oldest fortress of this type on Albanian side of the shore is formed between the seventh and eighth century. The fortress *Shurdhahu-Srada* is situated near Skadar/Shkodra city, on the rocks above the River Drin. During the Byzantine authority, this was an important fortress, and additional fortification of protecting walls, during the tenth century, testifies to that. In documents from the twelfth century, Shurdhahu-Srada is mentioned as the canter of diocese, and later archaeological explorations will discover the existence of 11 (eleven) Christian temples from different periods [8]. Without a doubt, the biggest and the most significant fortress on the shores of the Lake Skadar is situated on the rock above the river-mouth of the River Drin into the River Bojana – the fortress *Rozafa* (*Kalaja e Rozafës*), near Skadar/Shkodra. Due to exceptional position, the fortress is formed way back in the time of the Illyrians, and it was the residence of the Illyrian King *Agron* and his wife, later Queen *Teuta*. The fortress Rozafa is the place of the decisive conflict between Illyrians and Romans that, after the conquest of the fortress in 167 BC, established their authority in this region [11]. Later, the fortress Rozafa was the base of military resistance during the attempts of Venetians, Ottomans and later Montenegro to conquest Skadar/Shkodra. This town, above which the fortress is situated, will be the most important settlement of the entire Lake Skadar basin. The market in Skadar/Shkoder was the most important trade canter of the wider region, where was traded with wheat, livestock products, ores and other craftsman and luxury products. Connected, by different roads, with Montenegro, Albania, Serbia and Bosnia on one side, and the River Bojana and littoral on the other side, Skadar/Shkodra was the crossroad of all trade roads in this region [12].

4 Church Architecture of the Middle Ages

Based on the material evidences, the first traces of the Christianity in the wider area of the Lake Skadar can be followed since the fifth century, but it is certain that some shapes of Christian spirituality also existed in the fourth century, when Christianity became the official religion of the Roman Empire. The known historical sources confirm the establishment of diocese in antique settlement *Doclea* that is found in the sixth century, and this is supported by written documents from 599 [5]. The diocese seat in antique settlement is destroyed during the seventh century by attacks of Slavs and Avars, and afterwards it was abolished. The new church seat in this area is not formed until the ninth century, when the diocese seat is established in Bar, and at the beginning it was under the jurisdiction of Drac and since the eleventh century Archdiocese of Dubrovnik. At the end of the eleventh century, a new centre of Christian spirituality was formed. In 1089, the ruler of Doclea, Bodin Voislavljević, by using conflicts in Roman curia, got, from the Pope Clement III, the confirmation on establishing Archdiocese of Doclea and Bar.

The traces of material culture in the region of the Lake Skadar that imply on presence of Christian tradition date from the fifth century. In the necropolis of antique *Doclea* are discovered traces of material culture with Christian motives, ceramic items: Podgorička čaša (Podgorica cup) and Podgorički tanjir (plate from Podgorica). On those items are found the motives and iconography of early Christianity, where are combined texts of the old and new Bible [1]. The first Christian temples near the Lake Skadar are located in the antique *Doclea*, where, since the second half of the fourth century, have already appeared the first early Christianity temples. After the Christianity become the official religion of the Roman Empire, a whole part of the antique *Doclea* started to be built in accordance with the spiritual principles of the new religion. In the east part of Doclea is formed a new Christian core of the town with diocesan complex. There are no accurate data when the seat of the diocese is established in *Doclea*, and the first document that confirms the existence of this type of Christian centre dates from 599 [12]. The influence of Christianity is stronger, and antique temples in *Doclea*, situated in the west part of the town, started to be abandoned. Thus far, in the region of antique *Doclea* are discovered remains of four early Christian churches. The first, until now known, Christian temples on the shores of the Lake Skadar, which appear after the ninth century, are characteristic for very simple architecture and absence of decorative elements. These temples of simple construction are built of ashlar, slightly processed stones, with flat facades, shallow lesena (pilaster strip) and blind arcades. There are mislaid elements of fine processing with expressed artistic details and precise construction. Strong mark on the construction heritage of the Lake Skadar gave local craftsman that, with their experience and impressions, also left a specific mark on this heritage [13]. It is hard to classify Christian temples on the Lake Skadar; however, in accordance with the period of its occurrence and styles of construction, two categories can be pointed out. The first group includes temples built under the strong influence of Romanesque and Gothic period and in the second group are included temples from the fourteenth and fifteenth century, built under the influence of artistic styles from Byzantium.

Probably, the oldest familiar temple in the region of the Lake Skadar is the church of Saints Sergius and Bacchus (svetog Srđa i Vaha) on the left shore of the Bojana River. Primarily, the temple is founded as a modest benedict abbey, and over the time, on this location is built big three-nave church. The Benedictine abbey had the function of a smaller settlement because around it there is a developed landing place with a customhouse and square. The temple, in whose architecture can be recognized numerous elements of Gothic style, is rectangular in its shape, while the main space is divided in one central and two lateral naves. The church walls are built of stone with two rows of constructed pillars, and the holes between the stone blocks are filled with bricks. The temple walls are on the outside and inner side strengthened with shallow pillars – plasters that were connected with arches. On the west wall were classical Gothic broken arches, while the semi-circular windows were decorated with framed ornaments. There are indications that in the monastery complex of Saints Sergius and Bacchus (svetog Srđa i Vaha) are situated graves of the Voislavljević dynasty and that within the Benedictine abbey existed a separate chapel for burial [14].

The two temples, dating from this period, are situated in the mediaeval fortress Svač: Cathedral sv. Jovana and church of sv. Marije (Katedrala sv. Jovana i crkva sv. Marije). Those are single nave temples with simple construction, built of rough stone blocks. The St. John's Cathedral (Katedrala sv. Jovana) is dedicated to the Doclean duke Jovan Vladimir, and in the stone block, near the entrance, is a Latin inscription certifying that the temple is built in 1300. The shape of the cathedral is quite simple, long rectangular base finishes on the east side with one semi-circular apse. More modest dimensions had the church of St. Mary in Svač that is, according to tradition, built by Serbian King Uroš I for catholic inhabitants that lived in this region and for Franciscan (Order of Saint Francis) that used this temple. This temple is in its base one nave church with square apse, wooden roof and apse that is broken with semi-spherical arch. Windows on the object have all elements of Gothic period [14]. One of the oldest Christian constructions on the shores of the Lake Skadar is situated in the fortress Rozafa by Skadar/Shkodra city, and today it is in semi-ruined condition. St. Stephen's Basilica was primarily built as modest little church with small altar, but subsequently there are added naos and porch. After the Ottoman conquest of Skadar/Shkodra city, in the second half of the fifteenth century, the church is turned into a mosque, and at that time minaret is added to the primary object [8].

The most significant temple from the period of *Doclea* state is monastery *Prečista Krajina* in the west part of the Lake Skadar basin (Fig. 6). The whole complex that surrounds the monastery is believed to be, in a certain period, the mediaeval capital of Doclean state. The monastery complex with the church of Holy Mother of God is

Fig. 6 Prečista Krajina. Photo by M. Ilic

built in the tenth century as endowment of Doclean Duke Vladimir. The mediaeval temple is nowadays mostly ruined, and there are only preserved the remains of the tower that is subsequently renewed. With length of 14.5 m and width of 7 m, this was the most monumental temple on the Lake Skadar [15]. In its foundation, the temple has triconchal base over which were cupola and arcade. The temple was a central object of the whole complex, onto which, on the west side, leaned narthex of irregular shape. In the northwest part of the temple is added the tower with church – bell of five floors that have all elements of Gothic constructing.

Changes in aesthetic of sacral constructing on the Lake Skadar appeared in the fourteenth century, at the time of existence of the independent Montenegrin state Zeta, that is led by the Balšić dynasty. The temples from this period, by the rule, were built on the so-called triconchal base (inscribed cross – the shape of the trefoil) with one or three altar apse, lateral apse or choir offices, narthex and simple, unfinished cupola. Temples with triconchal base appeared again in this region four to five centuries later, when similar churches, with elements of Romanesque, are built on Montenegrin coast. The temples that are built in this period on the Lake Skadar had completely new constructional and architectonical solutions. This was the consequence of strong influence of the aesthetic of Mount Athos or a number of monks that arrived from Greece to the Lake Skadar. Nevertheless architectonic elements of temples on the Lake Skadar do not present a copy of traditional temples of Mount Athos because the specific construction work was performed by craftsman from the coast. As a result of that, the architectonic elements of the temples built in the fourteenth and fifteenth century on the Lake Skadar can be considered the mixture of eastern styles that were coming from the Mount Athos and western aesthetic that was arriving with craftsman from the coast [16].

The oldest temple of this type is the church dedicated to the Mother of God, situated within the monastery complex on the island *Starčeva Gorica*. Except the temple, monastery complex also consists of the remains of residences, great stone gate and small pier on the Lake shore. According to the legend, the church is built by old man Makarije between 1376 and 1378, after whom the whole complex was named Old Man's Mountain (Starčeva Gorica). The base of the modest temple (6.5×3.5 m) makes triconchal base, and on its ends are situated one central and two lateral apse. The cupola, that directly rises from the roof, stands on the circular foundement that bands on simple tambour on which are with stone blocks framed four little windows. The construction and manner of layering stones in this temple are characteristic for western craftsman, and it can be assumed that the temple is built on the tradition of the churches of Mount Athos and that the specific, masonry work was performed by the craftsman from the coast [4].

Almost identical architecture has the monastery complex on the island *Beška* that includes two churches: St. George's and Holy Mother of God's (crkve sv. Đorđa i sv. Bogorodice). The St. George's temple (hram sv. Đorđa) was built by Djuradj II Stracimirović Balšić and the Holy Mother of God's church (Bogorodičina crkva) by his wife Jelena, who built the temple as her crypt (Fig. 7). The St. George's temple (crkva sv. Đorđa) is a bigger building with one nave situated on triconchal base over which rises the cupola, while the narthex is made in classical Gothic style, on which bends wall with a bell tower above the entrance. The temple is built of curb rubble stone and church proportions, steep roof and construction give impression of strong Gothic influence and imply that the constructor was one of the craftsmen from the coast. The smaller church is built in 1440, and it testifies the inscription over the

Fig. 7 The Island Beška is home of the two churches: St. George's and Holly Mother of God's. Photo by D. Dajković

entrance door. This church had very modest dimensions with expressed elements of Gothic style that reflect in broken arches on the temple roof [5].

The smallest temple of Mother of God (Hram svete Bogorodice) is situated on the island Moračnik that, as well as the other churches from this period, has triconchal base with one central and two lateral apse. The cupola on the church leans on pilasters over which are shaped arches. This temple is just one of objects that constitutes bigger monastery complex within which are, besides the temple, situated protecting the tower, narthex, lateral chapel and two other objects, while the whole complex was protected with defensive walls. Because of the island strategic position, it is believed that the first object built on this island was the protecting tower built at the same time when the tower on island Tophala was built. Unlike the temples dedicated to the Mother of God (Hram svete Bogorodice), monastery Kom on the island Odrinska gora, near Žabljak Crnojevića, possesses completely different characteristics. The temple was built by Radič Crnojević sons, Djuradj and Lješ Crnojević, between 1415 and 1427. Modest one nave building (8 m × 4.5 m) poses only one apse onto which a window is situated. The church is built of pieces of tufa-soft, meuble sandy mas that are lined in horizontal rows. Only frames for windows and doors are built of hard stone. In the central space of the temple, four gravestones of the rulers from Crnojević dynasty are situated.

5 Profane Heritage of the Modern Age

Profane heritage of the wider area of the Lake Skadar is defined by the appearance of Ottoman Empire in this region that they had controlled since the end of the fifteenth century. For that reason different profiles of military fortresses present the only trace of profane heritage of this region. Until the occurrence of liberation movement in Montenegro, the Ottomans didn't need to construct fortresses on the shores of the Lake Skadar. The first objects of this type started to be built in the eighteenth century. In the aim of taking under control northwest shores of the Lake, the Ottomans raised modest fortress on the island Lesendro that was taken over and additionally fortified by Montenegrin ruler Petar II Petrović – Njegoš (Fig. 8). On the basis of the testimony of an English travel writer from the nineteenth century, the fortress was divided into two parts [17]. In one part was situated big round tower with cannons and in another part of the island was square construction with fortress in one angle. This description does not mention high walls that surround the fortress, and it can be assumed that the primary protective walls were significantly lower, but later were added parts that exist nowadays. On the north part of the island, under ramparts, is a small breakwater with pier. In 1843, the Ottomans took control over the fortress Lesendro, and 4 years later they built a new fortress on the Gromožur Island. The protecting walls of this fortress follow the terrain configuration prate, and in the base they have irregular shape of rectangle in which dominates the square shape tower on the west side of island. It is interesting that after the Berlin Congress in 1878, this fortress was changed into prison where the most dangerous prisoners

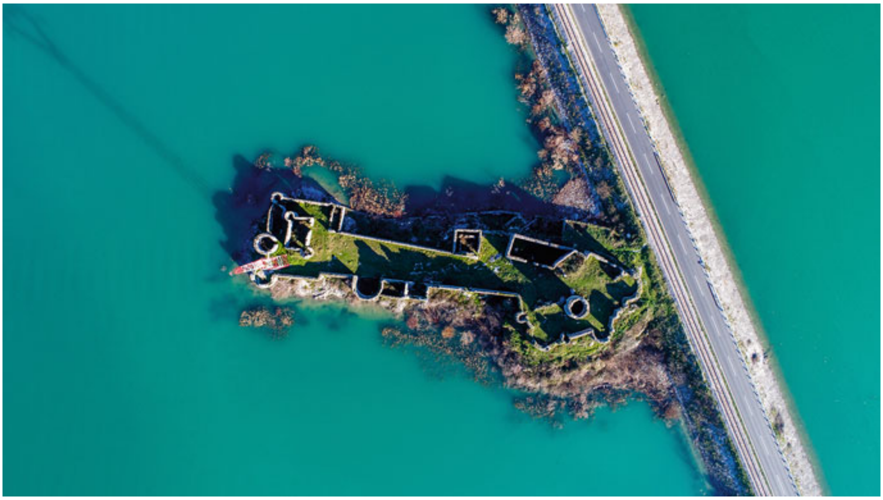

Fig. 8 Lesendro fortress. Photo by J. Jovićević

served sentences [16]. As a response to the fortress on the Gromožur Island, Petar II, on Montenegrin territory, above the market place Vir (current Virpazar), built fortress Besac. Situated on one plateau over the Lake, it follows the natural configuration of the terrain, and in its base has shape of irregular triangle. Protecting walls are built of curb rubble stone that is in regular rows tied with lime plaster. Two towers, one against another, with observation posts, dominate the fortress. Several objects are situated within the fortress, and they are connected with stone paths. By the entrance door was situated the biggest stone object that served as army barrack [15].

Advantageous natural conditions for developing agriculture and cattle-breeding and strong trade links with coastal towns through the River Bojana influenced on creating several mediaeval settlements on the shores of the Lake Skadar or its immediate vicinity. There were mostly smaller fortresses that were built on the strategic positions or smaller piers in which developed market places or markets for exchange and sale of local products, and those were settlements with clear trade and handcraft functions. The most significant settlement of this type was the fortress Svač, one of the oldest settlements in Montenegro. The settlement is situated onto very important strategic position – hill that is over the delta of the River Bojana, on the north part of the Lake Skadar. The settlement is formed in prehistory as one of the local centres of the Illyrian tribe *Labeati*. It is assumed that it existed until the seventh century when it was destroyed in the invasion of Avar tribes. A new phase in development of settlements started in the Middle Ages when near the settlements passed important communication road from Ulcinj to Skadar. In that period, according to some sources, Svač was the seat of the Archdiocese. Archaeological research also indicated these allegations because they were found in the remains of eight temples. In its campaigns the Prince of Serbia (Raška) Stefan Nemanja conquered Svač and in 1241; the settlement was devastated by

Mongols. The mediaeval town Svač on the south side was protected by steep cliffs that directly sloped towards the Lake. On that side are situated remains of the gate for which is assumed that led to the Lake pier, while, on other sides, the settlement was fortified with walls and stone towers.

During the nineteenth century, in immediate vicinity of the mediaeval fortress *Obod*, will be formed a new settlement Rijeka Crnojevića that will be the most important trade centre of Montenegro in this century. One of the first objects built in this settlement was the house of Montenegrin Metropolitan Petar I, raised between 1810 and 1815. This construction was the base for further formation of urban part of the settlement. On Rijeka Crnojevića was situated one of the most significant public objects in the nineteenth century in Montenegro – the bridge on Rijeka Crnojevića or Danilo's Bridge (Fig. 9). On the place where once existed a wooden bridge, in 1853/55, the Prince Danilo built a new, stone bridge that served as connection between that part of Montenegro and old road to Virpazar and further to Skadar. The bridge with the house leaning on it makes a unique architectonic complex that the local inhabitants even nowadays call by unique name *Mostina*. The bridge was built of stone blocks that were tide with lime plaster, it is 43 m long and has two arcade openings, one of which leans on the reef that is in the water, and for that reason the object has asymmetric construction. Near this bridge, in 1881, the King of Montenegro, Nikola, built a new bridge that was part of a new road in Cetinje – Rijeka Crnojevića. Near this road, on the locality Karuč, is situated one of the most original objects of the profane constructing, so-called – Bishop's Tower (Vladičina kula). The big stone building was built in 1808 as winter resting place of Montenegrin Metropolitan Petar I, and now it is in ruinous condition. This object is interesting as a place of strong resistance of Montenegrin army during the military campaign of Ottoman Vizier from Shkodra in 1862 and later as the building in which is organized one of the first schools in this region [15].

Fig. 9 The old bridge called "Mostina" in Rijeka Crnojevića. Photo by D. Dajković

6 Religious Objects in the Modern Age

A significant number of temples on the Lake Skadar was built later during the nineteenth and twentieth century. According to some data, on the wider area of the Lake Skadar, today there are about 30 orthodox temples built on a very similar constructional base. Those are modest one naval temple with semi-circular apse on the east and entrance door and bell tower on the west side. Almost each of these churches was built of stone with two watershed roofs without cupola [2]. During the Ottoman rule, the area of the Lake Skadar was, in a wide range, settled also with Muslim inhabitants, and in this period several mosques were built. In that period, on the area of nowadays, Golubovci lived a big Muslim community gathered around the mosque that was destroyed later. In this part of the Lake Skadar hinterland existed also the mosque in Goricani, and nowadays only walls remained of it, while the location of the third mosque in Berislavci is still unknown. Much more are preserved mosques along the northwest shore of the lake in places Krajina and Ostros where, according to some data, existed 11 mosques. The most significant mosques from this area are the mosque in Gornji Murići (1602), Ćurjan (1602), Kostajnica (-1673), Bobovište (1673), Veliki Ostros (1680), Ftjan (1756), Arbanes (1768), Ckla (1816), Mali Ostros (1844), Runj (1862) and the mosque in Donji Murići (1864). Also, in the wider area of the Lake Skadar were built mosques in Sukobin (1820), Sas (1880) and Tuđemili (1931). Every mentioned mosque was built by local craftsmen without any special decorative elements. Those are, by the rule, simple constructions with square stone base, with four watershed roofs and with modest minaret [18].

7 The Area of Cultural Continuity

Due to its geographical and strategic position, the region around the Lake Skadar, since the ancient times until the twentieth century, presents central place of many cultural processes. With the exception of the areas by shores of the Adriatic Sea, the region of the Lake Skadar is one of the rare territories on which the traces of literacy, literature and culture can be followed in continuity. Literacy and literal creation arrived on the shores of the Lake Skadar Christian missionaries that since the fifth century promoted new religion – Christianity. The most significant missionary order in this region was the Order of Saint Benedict, to which are linked the first traces of literacy in Latin language forms *Carolingian minuscule* [19]. Within their temples, Benedictines formed the so-called scriptoria in which different books were rewritten. The Benedictines rewrote texts from Latin language but also texts written in Slavic languages that were translated into Latin – the official letter of all catholic church monk orders.

Rewriting traditions of the monasteries on the Lake Skadar were continued in the following period when, after the appearance of Slavic letters, will occur the necessity for liturgical books in native language – Slavic language. Over the time, under the influence of these processes, there will be created the first literary works speaking about lives of saints, tsars, heroes as well as the texts on different native legends [16]. Literary works created in this period support Byzantine concept of rewriting literal work, showing at the same time increasing interest for historical contents that are later developed in religious and monarchical tone. The area around the Lake Skadar, on which are formed several rewriting centres, presents one of the most important regions of mediaeval literacy and spirituality with all the South Slavs. In scriptoriums of the monasteries on the Lake Skadar are created a number of liturgical books that are rewritten in order to be used in everyday services: *Four gospels*, *Apostol*, *Liturgical repertory*, *Menaion*, *Psalter*, *Octoechos* and *Triodion*. Rewriting activity of monasteries in the Lake Skadar basin will affect the creation of the so-called Žabljak school. The basic characteristic of this school and the specific style of rewriting church books is a strong influence of the so-called hesychasm. In brief, hesychasm presents the manner of understanding reality characteristic for monarch orders on Mount Athos. This includes religious life, penitence as the first step towards the redemption and at the end everyday prayer that finally should lead to "experiencing light of God". This practice of spiritual life, brought to Montenegro with monks that arrived from Greece and Mount Athos, is also transferred into literature. *The most significant works of this school are Gorički zbornik* (Gorica Miscellany), *Vlastar's Syntagma*, *Koporin Chronicle*, *Vranjina's Four Gospels*, *Prologue* and *Hexameron Šestodnev* [19].

The most significant rewriting text of the Žabljak school is *Gorica Miscellany*, written on the island of Beska (Fig. 10). Except the specific rewriting style, this book presents the original testimony on the cultural circumstances of that period in Montenegro. A manuscript was created between 1441 and 1442 and presents correspondence among Jelena Balšić – daughter of the Serbian Prince Lazar – and her spiritual father, monk Nikon of Jerusalem. The text is preserved on 273 leaves of paper, with dimensions 21 × 14 cm, written in Old Church Slavonic with certain Greek phrases and that will later leave space for suspicion of some authors that Nikon of Jerusalem was of Greek ancestry. Jelena Balšić, after death of her husband Djuradj II Stracimirovic Balšić, remarried for a feudalist Sandalj Hranic Kosaca, but after death of her second husband in 1435, she got back to Montenegro and in 1440 raised a church of Holy Mother of God on the island Gorica in the Lake Skadar. Jelena lived her last years dedicated to the religion and conversations with spiritual father, monk Nikon of Jerusalem, who wrote down those conversations and on the basis of which was created Gorica Miscellany. Jelena wrote to her spiritual father three epistles to which Nikon responded and in his writings offered to Jelena church standings on different theological issues onto which she pointed out in her epistles. In the second part of the text, Nikon describes some historical events through genealogy of Jelena's family, while the last part of the text consists of liturgical texts drafted on Jelena's order and that were used in everyday ceremonies in the endowment of Jelena Balšić. The *Gorica Miscellany* is kept in the Archive of the Serbian Academy of Science and Art.

In the middle of the fifteenth century in the monastery Koporinja, whose precise location was not established, was drafted another significant work of this

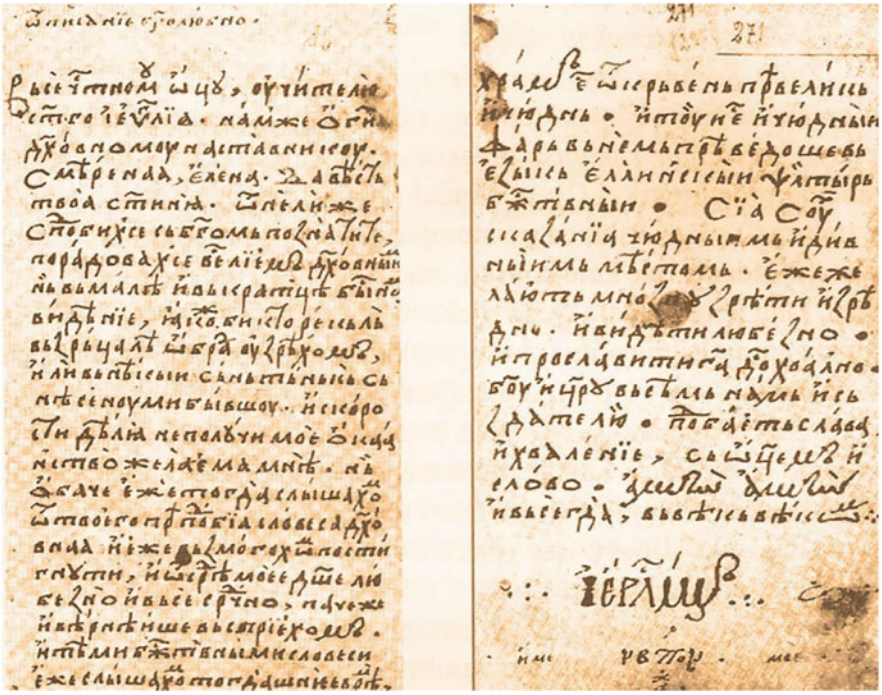

Fig. 10 The fragment of the Book "Gorica Miscellany" (Gorički Zbornik). Photo by M. Ilić

school – *Vlastar's Syntagma* – that is nowadays kept in the Museum of Serbian Orthodox Church in Belgrade. This book presents rewriting of Byzantine legal miscellany which deacon Damjan, upon the request of Stefan Crnojević and metropolitan and Metropolitan of Zeta – Joseph, rewrote in 1453. This miscellany on 342 pages brings an overview of the most significant legal and church norms of Byzantine Empire. The manner of rewriting text, its redaction and shape of letters confirms strong influence of Byzantine spirituality. Very significant segment of rewriting activity on the Lake Skadar presents mediaeval charters drafted in scriptoriums of these temples. Those charters testify first-hand on specific political and religious circumstances of this region, and as such they are primary historical source. The most significant of them is the collection of charters from the monastery Vranjina that are in scientific literature known under the unique name – *Charters of Vranjina* – where during a certain period was the seat of Metropolis of Zeta are written *Vranjina's Four Gospels*, whose author was local hieromonk Mina. Also, a significant rewriting canter presents monasteries on the island Starceva Gorica, whose scriptoriums was written *Prologue* that is kept in state library in Berlin, as well as the scriptorium on the island Beška in which is created *Hexameron*, that is nowadays kept in the monastery Savina near Herceg Novi [19].

8 Conclusions

The Lake Skadar is one of the most important locations in the development of culture and civilization in Montenegro. A favourable natural environment has created the preconditions for forming the first human community on the shores of the lake in prehistoric times. The lake will be a place wherein Illyrian tribes established their state. Later, in the Middle Ages, it will be the centre of military resistance to the Byzantine Empire and the basis for establishment of the first mediaeval state of Southern Slavs – Duklja. Until the twentieth century, this will be the place of dynamic political processes and civilizational conflicts that will decisively influence the formation of cultural and historical heritage. On the lake shores and in its immediate hinterland are preserved cultural traces of material civilization: Illyrians, Romans, Avars, Venetians, Ottomans and Slavs. Unfortunately only fragments of rich heritage and material culture are preserved. Also, incomplete and inadequate archaeological researches contributed to the fact that a significant part of this heritage has not yet been fully revealed, and there are only fragmentary testimonies about it. The largest part of the previous researches took place during the 1960s and 1970s of the twentieth century, and no modern methods for locating traces of material culture were used. Another problem is inadequate protection of the existing cultural heritage of the Lake Skadar, and this was also stated in an official document of the Montenegrin government in 2004. Therefore, dedicated protection of the existing heritage and efforts in further research on the cultural and historical heritage of the Lake Skadar are the biggest challenges in the upcoming period. Only a comprehensive and dedicated approach to the protection and improvement of this cultural and historical heritage can guarantee preservation of this unique civilization areas.

References

1. Marković Č (2006) Arheologija Crne Gore. CID, Podgorica
2. Andrijašević Ž (ed) (2017) Zeta. Opština Golubovci, Podgorica
3. Stipčević A (1989) Iliri. Školska knjiga, Zagreb
4. Mijović P (1970) Tragom drevnih kultura Crne Gore. Graficki zavod, Titograd
5. Grupa autora (1967) Istorija Crne Gore, vol 1. Redakcija za istoriju Crne Gore, Titograd
6. Peričić E (1998) Sclavorum Regnum grgura Barskog. Conteco, Bar
7. Marović B (2006) Ekonomska istorija Crne Gore. CID, Podgorica
8. Daberdaku R (2014) Some monuments and old church in Shkodra. Anglisticum J 3(6):46–54
9. Mijović P, Kovačević M (1975) Gradovi i utvrđenja u Crnoj Gori. Arheološki institut, Beograd
10. Marković Č (2010) Graditeljska baština Crnojevića. Matica 2010:587–612
11. Evans A (2006) Ancient Illyria. I.B. Tauris, New York
12. Andrijašević Ž, Rastoder Š (2006) Istorija Crne Gore. Centar za iseljenike, Podgorica
13. Zagarčanin M (2012) O nekim pitanjima ranohrišćanskog i srednjovjekovnog graditeljstva u Dokleji i Baru, sa posebnim osvrtom prema paganskim kultnim predstavama. Zbornik radova Nova antička Duklja 3:41–71
14. Korać V (1961) Sv. Sergije (Srđ) i Vakh na Bojani. Starinar 12:74–97
15. Gagović Z (2013) Stanje kulturne baštine u basenu Skadarskog jezera. Samizdat, Podgorica

16. Grupa autora (1970) Istorija Crne Gore, vol 2. Redakcija za istoriju Crne Gore, Titograd
17. Wilkinson J (1848) Dalmatia and Montenegro. J. Murray, London
18. Agović B (2001) Džamije u Crnoj Gori. Almanah, Podgorica
19. Sindik D, Tomović G (eds) (1996) Književnost Crne Gore od XII do XIX vijeka-pisci srednjovjekovnog latiniteta. Obod, Cetinje

Conclusions: Recent Advances and the Future Prospects of the Lake Skadar/Shkodra Environment

Vladimir Pešić, Gordan S. Karaman, Andrey G. Kostianoy, and Vesna Vukašinović-Pešić

Contents

Abstract The 23 chapters in this book synthesize the information on the Lake Skadar/Shkodra environment. This book has shown that several significant steps have been made over the past four decades in improving the gaps in our knowledge of the Lake Skadar/Shkodra ecosystem. This last chapter identifies seven themes related to the ecology and management of Lake Skadar/Shkodra. These themes emphasize the current knowledge

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*,
Hdb Env Chem (2018) 80: 481–500, DOI 10.1007/698_2018_274,
© Springer International Publishing AG 2018, Published online: 15 July 2018

gaps, recent advances, and future prospects of the Lake Skadar/Shkodra ecosystem providing some ideas as to how to incorporate scientific research into the current management of the lake basin. The key to a better understanding of the Lake Skadar/Shkodra environment remains transboundary cooperation. This is particularly important given the global challenges that Lake Skadar/Shkodra can be expected to face as climatic change and increasing demands for water increasingly impact the lake ecosystem.

Keywords Albania, Ecology, Ecosystem, Environment, Lake Skadar/Shkodra, Montenegro, Sustainable development

In the preparation of and work on this book, we kept in mind some of the goals that were discussed in the Introduction [1]. The first goal was to review the scientific literature about the Lake Skadar/Shkodra basin, while the second goal was to determine how the existing management of Lake Skadar/Shkodra benefits from that scientific data. For this purpose, we invited experts to collaborate in writing chapters ranging across different disciplines, from hydrology, biodiversity, and ecology to the management of Lake Skadar/Shkodra itself. This last chapter, based on the results that are thoroughly discussed in the previous chapters, identifies seven themes about the ecology and management of Lake Skadar/Shkodra (Fig. 1).

1 Theme 1

Changes to the hydrological regime which generate extreme spatial and temporal variability in the flow regime and hydrological connectivity cause spatiotemporal variability in both the water physicochemistry and in the level of autotrophic production in Lake Skadar/Shkodra.

Fig. 1 Lake Skadar/Shkodra. Photo by M. Jovićević

The changes to the hydrological regime of Lake Skadar/Shkodra are the result of several related processes. First of all, the seasonality of the discharge is conditioned by climatic factors, with low water levels in summer and high floods during winter months (November–April) leading to the flooding of the flatland and the formation of one large inundated area along the northwestern shoreline. As a result of the flooding, the lake surface area may vary from 353 to 500 km^2 [1]. The flooding area provides active processes, such as nutrients exchange and natural erosion control (preventing further flood damage), habitat for lake organisms, and feeding/breeding grounds for both waterfowl and fish [2]. Therefore a comprehensive program of floodplain management which will include the preservation and restoration of the natural function of the floodplain is necessary. In this sense, the use of remote sensing technology (Fig. 2) can be especially helpful, most notably in the estimation of the extent of the floodplains and flood-prone areas.

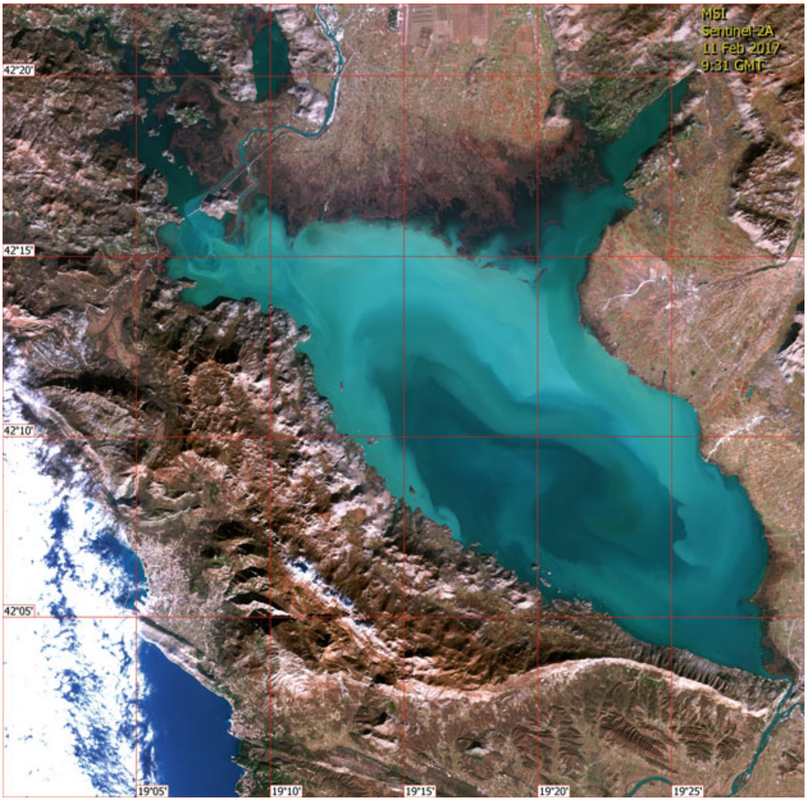

Fig. 2 Using new technology, such as satellite remote sensing in different spectral bands, is greatly enhancing our understanding of some of the hydrophysical and ecological processes of Lake Skadar/Shkodra. The figure shows suspended matter distribution in Lake Skadar/Shkodra derived from MSI Sentinel-2A on 11 February 2017 (09:31 GMT) [3]

There is a correlation between the water level of the River Morača and the flooded areas of Lake Skadar/Shkodra. The River Morača provides more than 60% of the lake's water, affecting the lake water level [4]. Recent studies have shown that the water levels of Lake Skadar/Shkodra in the period 2002–2004 were considerably lower than those in 1960s [5]. This was caused by the construction of hydropower dams (at the end of the 1960s and in the early 1970s) upstream on the River Drin [5]. As a result of the water released from the hydropower dams, the high water level of the River Drin blocks the discharge by the River Bojana/Buna which leads to a significant increase in the water level in the lake [5]. This occurs mostly in the period from December to February. The result of impediment to lake discharge is sediment deposition in the channels of the River Bojana/Buna, followed consequently by interrupted water flow, most noticeably in the summer months.

Knežević and Todorović [6] emphasized the need for the sustainable development of the lake floodplain zone by regulation and flood protection. According to these authors, the constant flooding zone of Lake Skadar/Shkodra (10,268 ha) should be maintained in order to guarantee the biodiversity and the sustainability of water level regulation in the lake. On the other hand, in the remaining part of the flooded zone exposed to periodic flooding (2,042 ha), it is recommended that there be regulation by the construction of dams and accumulation lakes on the River Morača [6].

Changes in the flooding zone of Lake Skadar/Shkodra should be taken into account when analyzing the possible impact of the planned construction of hydropower dams on the River Morača. Their construction would undoubtedly have an impact on the variation of the water level in the lake and on the extent of the floodplain zone. A similar effect would be caused by the construction of a hydropower plant on the River Drin near Bushati in Albania [5]. The preparations for the Bushati hydropower project, which included the River Drin, started in 2002, were accompanied by a desire on the Montenegrin side to dredge the River Buna/Bojana, something that would lower the lake level and make more land available, especially on the Montenegrin side of the lake [5]. Both projects will have a harmful environmental impact on the biodiversity of Lake Skadar/Shkodra. At the moment, these projects have been stopped, but the threat that their realization would have on the biodiversity and ecological processes in Lake Skadar/Shkodra and its flooding zone remains.

2 Theme 2

Water and sediment physicochemistry, biotic diversity, and its composition and abundance in Lake Skadar/Shkodra are strongly influenced by river inflows.

The River Morača and the inflowing rivers have a great influence on almost every component of the water physicochemistry (transparency, water temperature, electrical conductivity, pH, dissolved oxygen, and nutrient concentration) of Lake Skadar/Shkodra [7, 8]. Several studies have shown that microbial and planktonic diversity and their composition in Lake Skadar/Shkodra are influenced by river inflows. For example, Kostanjšek et al. [9] observed lower bacterial diversity at the mouth of both the Morača and the Plavnica. The part of the lake affected by the water of the River Morača exhibited the lowest densities of rotifer and crustacean plankton [10]. This lower zooplankton diversity is the result of the selective pressure of low water temperatures and higher turbidity on the growth and reproduction of rotifers and crustacean plankton near river mouths and outflows [10].

The River Morača is the main way that nutrients but also the pollutants reach the lake as the lake tributaries are common places of disposal for both poorly treated waste and waste water [5]. Skarbøvik et al. [11] calculated the annual inputs from the tributaries to the lake approximately to 176 tons of total phosphorus (TP) and 3,200 tons of total nitrogen (TN), with annual area specific loads of 50–70 kg/km^2 of TP and 950–1,100 kg/km^2 of TN. On the other hand, it seems that Lake Skadar/Shkodra receives good-quality water from an intergranular aquifer [12]. The highest concentration of heavy metals in the water, sediment, and macrophytes was identified within the area directly influenced by river inflows [5, 13]. Moreover, the concentrations of polycyclic aromatic hydrocarbons (PAH) and polychlorinated biphenyls (PCB) were highest at the mouth of the River Morača [14]. It is worth mentioning that the effect of river inflow is modified by factors such as the substrate type and especially the vegetation [15].

The spatial arrangement of the lake inflows influences community composition; for example, Chlorococcales, which depend on water mixing, are the dominant greens around the mouths of the Morača and the Plavnica [16]. On the other hand, bacterial and zoobenthos diversity is probably influenced to a greater degree by the substrate availability and the type of sediment [9, 17]. An analysis of sediment-dwelling oligochaete assemblages showed that the oligochaete index of lake bioindication (IOBL) is lowest in the lake part that is directly influenced by the Morača inflow [17]. Moreover, the studies on oligochaetes revealed shifts toward resistant species in the community structures at those sites contaminated by river inflow [17].

The reduced bacterial and Oligochaeta diversity in the above-mentioned studies was generally explained as an effect of anthropogenic pollution on the lake ecosystem caused by the inflowing waters [9, 17]. This finds confirmation in the results of some bioassay tests [18, 19]. Other bioassay tests conducted to assess the sediment quality of Lake Skadar/Shkodra [20] also revealed high toxicity at sites not directly affected by river inflows contamination: the sediment contact tests performed on plants (*Myriophyllum*), zebrafish embryos (*Danio rerio*), and bacteria (*Arthrobacter globiformis*) revealed significant toxicity in the sediment samples from Raduš and Kamenik, whereas the aquatic *Lemna* test showed inhibition effects for the samples from Sterbeq, Plavnica, and Kamice [20]. Therefore, the correlation between the impact of the river inflows and sediment toxicity needs more research, aimed at understanding the effects of river inflows on the lake assemblages and the ecological processes in the lake. Also, satellite remote sensing of Lake Skadar/Shkodra showed that cyclonic or anticyclonic gyres (Fig. 2) play a very important role in the redistribution of physical, chemical, and biological characteristics of lake waters [3]. It was found that these gyres have a size of the lake, thus they are responsible for transboundary transfer of water and pollution which was not taken into account before. Moreover, it seems likely that this will require the modification of water quality assessment methods and guidelines for the monitoring programs, as well as a closer coordination of monitoring programs between Montenegro and Albania. It became evident that a special permanent satellite monitoring program of Lake Skadar/Shkodra is required [3].

3 Theme 3

Lake Skadar/Shkodra governs the provision of nutrients required by algae and vascular plants for autotrophic production, which has resulted in an increase in the trophic level over recent decades.

Lake Skadar/Shkodra supports a variety of primary producers such as cyanobacteria, algae, aquatic macrophytes, and riparian plants (Fig. 3). Their

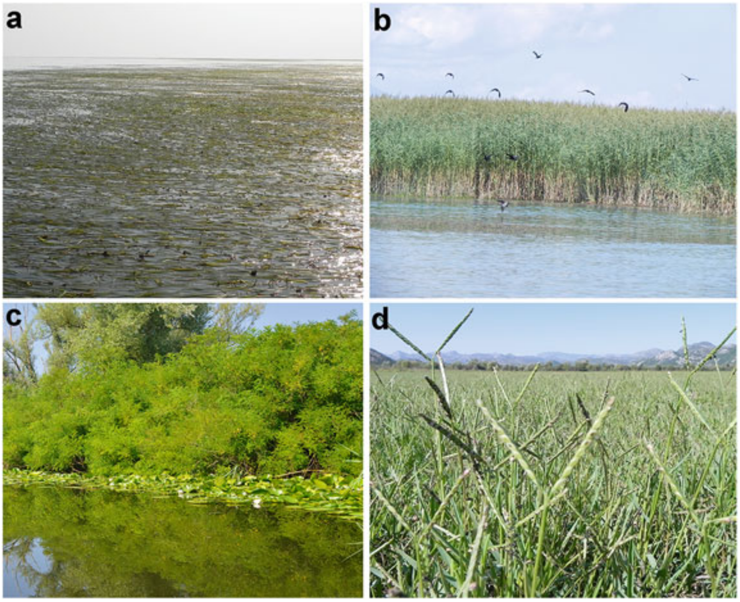

Fig. 3 (**a**) Eelgrass (*Vallisneria spiralis*) occupies the largest area of the aquatic submerged vegetation of Lake Skadar/Shkodra; (**b**) *Phragmites australis* (the common reed) dominates in the vegetation of the shorelines and swamps of Lake Skadar/Shkodra; (**c**) *Amorpha fruticosa* (bagremac) is among the most harmful invasive species; if not deep, this species can be found in other wetland communities in Lake Skadar/Shkodra, for example, with the common reed. The chemical constituents of this shrub have therapeutic potential; (**d**) the typical habitats of *Paspalum paspaloides* (knotgrass – "troskot") are muddy flooded areas. Despite its invasive potential, this species and its communities are listed as a Natura 2000 habitat type occurring in Lake Skadar/Shkodra (S. Hadžiablahović pers. communication) Photos by S. Hadžiablahović

abundance depends on a number of factors (discussed in [16]) and correlates with the trophic level of the lake. Based on the mean annual chlorophyll *a* concentration, Lake Skadar/Shkodra can be classified as mesotrophic [16]. In the summer, when the greatest phytoplankton abundance and biomass occurs, the trophic level of the lake increases to eutrophy [16]. Changes in the trophic level of Lake Skadar/Shkodra have been confirmed in recent research conducted on macrophytes on both the Albanian and Montenegrin sides of Lake Skadar/Shkodra [21]. This study revealed that the values of the lake macrophyte trophic index [22] in Lake Skadar/Shkodra correspond to eutrophic to hypertrophic conditions [21]. The overall degree of eutrophication was greater in Montenegro than in Albania [21]. The oligochaete trophic condition index indicates mesotrophic to eutrophic conditions, depending on the season, the sampling site, and the variable ecological conditions [17]. In summary, all these studies indicate that over the last 40 years, the trophic level of Lake Skadar/Shkodra has increased in comparison with the 1970s, when Lake Skadar/Shkodra was considered oligotrophic [23].

Changes in the trophic level of Lake Skadar/Shkodra lead to changes in the community structure of the phytoplankton, also influencing zooplankton and zoobenthos. The shift from diatoms to greens and blue greens in Lake Skadar/Shkodra may be connected with the increase in the TN/TP ratio over the last 30 years [16]. There is also an evident increase in the trophic state from the southeast toward the northwest of the lake [16]. Applying new methods such as remote sensing using aerial or satellite photography may be significant in the characterization of spatial patterns of eutrophication [3].

4 Theme 4

The diverse types of habitat in Lake Skadar/Shkodra and its catchment area promote high diversity in many biotic groups.

Despite the fact that Lake Skadar/Shkodra does not show vertical stratification, the diversity in most of the biotic groups that inhabit the lake is heterogeneously distributed, and at a larger scale the two zones, the nearshore and the open lake zone, can be distinguished [24]. At a smaller scale, the type of the available habitats mainly affects the species richness within each zone. The highest diversity in the benthic community was found in the nearshore environment where the habitat complexity is the greatest, but this is also due to the presence of a large number of sublacustrine springs which significantly contribute to the overall biodiversity of the lake [24]. For example, recent studies on gastropods show that the sublacustrine spring at Karuč harbors has more than 30% of the endemic gastropods of the Lake Skadar/Shkodra basin including two point endemics [25] and represents a hot spot of Lake Skadar/Shkodra biodiversity. Nevertheless, the Montenegrin government had plans to use the Karuč spring for the regional water supply of the Montenegrin coastal area [4]. For a long time, sublacustrine springs have been considered as environments that do not have endemic species [26]. Recent studies have stressed the importance of sublacustrine springs in maintaining the endemic diversity of Lake Skadar/Shkodra, including point endemics that require the specific environment associated with this type of habitat [27]. Bearing in mind the significance of sublacustrine springs and the human impacts they are exposed, additional efforts are needed in order to establish adequate protection measures for them [11].

A survey of the aquatic flora and epigean aquatic fauna of Lake Skadar/Shkodra confirms that the lake itself harbors a moderately endemic biodiversity. Endemism in Lake Skadar/Shkodra occurs in different groups such as diatoms, molluscs, oligochaetes, ostracods, and fish [24, 28]. At the Lake Skadar/Shkodra level, only one genus is endemic: the monotypic gastropod genus *Karucia* that is restricted to the sublacustrine environment [27]. Despite the poor knowledge of some biotic groups (Fig. 4), approximately 1,900 native species are known from Lake Skadar/Shkodra,

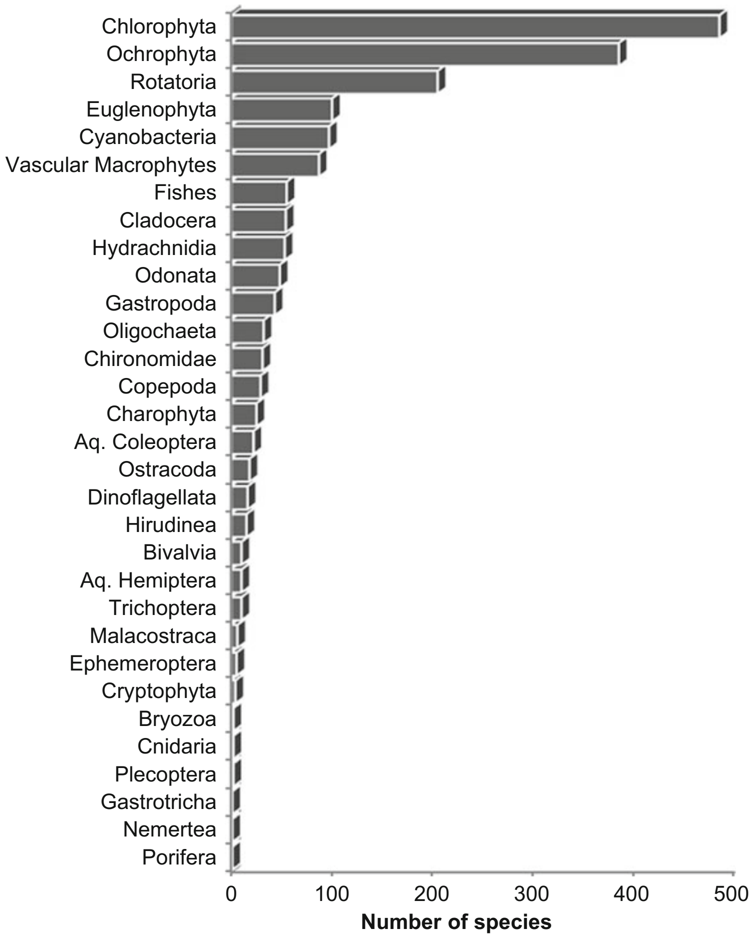

Fig. 4 Number of epigean species of selected aquatic groups from Lake Skadar/Shkodra

including 754 animals, of which 22 species (2 diatom, *Cyclotella scadariensis* and *Cymbella scutariana* [29], and 20 animal species) are endemic. The adjusted rate of endemicity is estimated at 1.8% for all taxa and 2.7% for animalia. In terms of the total number of species, Lake Skadar/Shkodra is richer than Lake Ohrid (approximately 1,200 species), but the adjusted rate of endemicity for the latter lake is estimated at 36% for all taxa and 34% for animalia [30]. The greatest number of endemics occurs for gastropods (Fig. 5b) with 12 species (subterranean species are excluded) being endemic for Lake Skadar/Shkodra and Lake Šasko [25].

Pešić and Glöer [27] defined eutrophication and use as a water supply as the main threats to the endemic fauna. However, the impact of these factors on endemic fauna is unstudied. Interestingly, an increased number of gastropod endemic species was observed in the areas of the greatest anthropogenic pressure (Vranjina, Virpazar and Karuč) [27].

The diverse mosaic of different habitats at the catchment area scale promotes high diversity in many biotic groups. Within the catchment area, the rate of endemicity is

Fig. 5 (**a**) *Utricularia vulgaris* is the common bladderwort in Lake Skadar/Shkodra; (**b**) *Viviparus mamillatus* is the largest freshwater gastropod in the lake catchment area and the first animal endemics described from Lake Skadar/Shkodra – recent studies have shown that this species can be a good indicator of heavy metal pollution in Lake Skadar/Shkodra. Photos by S. Hadžiabalhović (**a**) and V. Pešić (**b**)

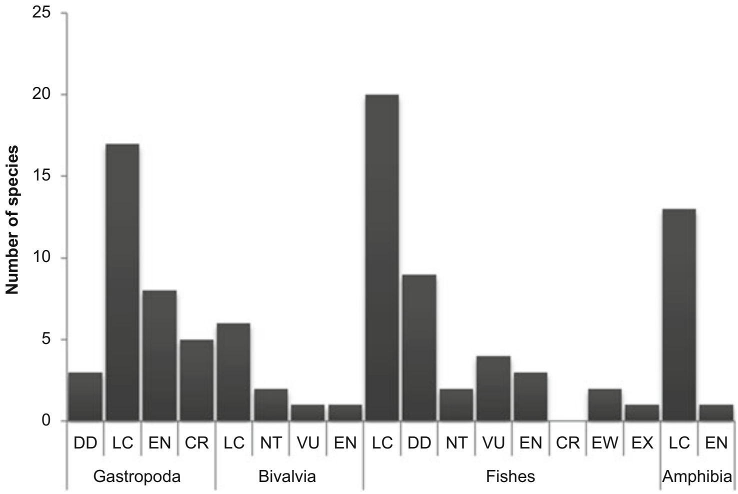

Fig. 6 The number of species of some selected biotic groups inhabiting Lake Skadar/Shkodra in comprehensively assessed groups on the IUCN Red List of Threatened Species. *EX* extinct, *EW* extinct in the wild, *CR* critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened, *LC* least concern, *DD* data deficient

generally higher than at the lake level. For example, the adjusted rate of endemicity of fish at the catchment level is estimated at 13.6 and 3.6% at the level of Lake Skadar/Shkodra. The highest endemicity is observed within the hydrobiid gastropods: around 82% of the species that inhabit the Lake Skadar/Shkodra catchment area are known only from the type localities [24].

Many species, especially the endemic ones, that inhabit Lake Skadar/Shkodra are considered regionally or globally threatened. The greatest number of threatened species occurs among molluscs (Fig. 6). Thus 15 (28%) are considered as threatened, with a high proportion of critically endangered species [25]. Threatened species were also found within the other groups that inhabit Lake Skadar/Shkodra like vascular plants (Fig. 5a), fish (Fig. 6), malacostracans, amphibians (Fig. 6), reptiles, and birds. At least one species, *Chondrostoma scodrense* (Cyprinidae), is assumed to be extinct [31].

5 Theme 5

Pollution, overfishing, and other types of anthropogenic pressure affect community composition in the lake and can promote the presence and spreading of invasive species, resulting in a decrease in or the extinction of rare and endangered species.

Lake Skadar/Shkodra have been degraded by various human activities such as pollution, shoreline modification, gravel mining (especially in the lower part of the Morača, Fig. 7), and overfishing. A recent study has shown that most parameters of water physicochemistry have not significantly changed over the last four decades [14]. The higher values of some parameters (temperature, oxygen saturation, ammonia, nitrites, TOC, and detergents) are related to the impact of the river inflows [14]. The pollution load index (PLI) revealed that only baseline levels of pollutants are present [14], indicating low-level pollution activities in and around Lake Skadar/Shkodra. The values of the enrichment factor (EF) indicate the anthropogenic source of zinc, nickel, chromium, cadmium, and lead in the lake sediment [32]. In summary, based on the assessment test of sediment contamination, the potential risks offered by the metal load for Lake Skadar/Shkodra ranges from "no risk" to "low risk" [32]. However, regardless of any satisfaction with the current situation, it is necessary to monitor further changes in the water and the sediment quality of Lake Skadar/Shkodra. In addition, there is also a need for a detailed understanding of the physical and chemical processes in the Lake Skadar/Shkodra environment by selecting reliable indicator parameters and suitable reference sites, so that proper monitoring can be successfully achieved.

Overfishing and the impact of invasive species are recognized as one of the main problems affecting fish abundance and composition in Lake Skadar/Shkodra [28]. Recent data has shown that some species like *Alosa* sp., trout, and nase (*Chondrostoma ohridanum*), the latter as a result of overfishing, no longer offer any commercial potential [28]. The decline in the fish stock is followed by a significant decrease in the number of wintering bird species, evident from the

Fig. 7 Lake Skadar is exposed to different direct human impact, such as sand and gravel extraction in the lower part of the River Morača, which led to river channel instability and bank erosion. Photo by M. Jovićević

beginning of the 1980s [33]. Still, 15 fish species (forming 25.4% of the ichthyofauna of the Lake Skadar catchment area) have been introduced into Montenegrin waters over the past 50–60 years [28]. Some invaders such as mosquito fish (*Gambusia affinis*) and the topmouth gudgeon (*Pseudorasbora parva*) are present in fairly large quantities in the phytolittoral and astatic zones of Lake Skadar and may potentially have an impact on macroinvertebrate assemblages [34]. The impact of invasive species on the native assemblages in Lake Skadar/Shkodra is mainly unstudied. Marić and Rajković [35] discussed that the main causes of the decrease in crayfish (*Astacus astacus*) in the artificial reservoirs (Lake Slano, Lake Krupac, and Lake Liverovići) in Nikšićko polje field were the introduction and spreading of American catfish (*Ictalurus nebulosus*) and the common chub (*Squalius cephalus*) which intensively feeds on crayfish. Interestingly, the loss of the crayfish population in the above-mentioned reservoirs coincided with an increase in the population of the mussel *Dreissena carinata* (unpublished data). It is known that crayfish predation can decrease the population of invasive zebra mussels (*Dreissena polymorpha*) indicating that those lakes containing crayfish populations may experience slower colonization and lower overall densities of *Dreissena* mussels than systems lacking crayfish [36]. The invasive zebra mussel (*Dreissena polymorpha*) is present only in Lake Šasko [37] and the River Bojana/Buna (unpublished data). The latter species does not show any spread to other habitats inhabited by the native *D. carinata* [25]. Molecular analysis showed that Lake Ohrid is the source of the population of the latter species which started its spatial expansion into Lake Skadar/Shkodra about 320,000–300,000 years ago [37].

Special concern is required when introducing invasive pathogens. The presence of chytrid fungus (*Batrachochytrium dendrobatidis*) in Lake Skadar/Shkodra is particularly alarming [38] as it could negatively impact the endemic Albanian water frog (*Pelophylax shqipericus*) (an endangered species according to the IUCN Red List of Threatened Species).

Potentially, other invasive species of aquatic invertebrates might also cause dramatic ecological effects. Grabowski et al. [39] emphasized the risk of the introduction of the foreign killer shrimp (*Dikerogammarus villosus*) into Lake Skadar/Shkodra and the potential negative impact on the population of the endemic *Laurogammarus scutariensis*.

6 Theme 6

The ecological status assessment of Lake Skadar/Shkodra requires a definition of "reference conditions" leading to the establishment of protocols for use in biomonitoring programs. The application of newly developed methods may help overcome the limitations of existing monitoring.

Almost every chapter in this book proposes a long-term interdisciplinary approach. One frequent constraint of this approach is the limited opportunity for inexpensive monitoring, something that would involve different aspects of the Lake

Skadar/Shkodra ecosystem. The second constraint relates to what type of monitoring might be introduced, taking into account the presence of different habitats in the lake basin. The Water Framework Directive 2000/60/EC requires the achievement of a minimum of a “good” ecological status or “good ecological potential” in all surface waters [40]. Assessing that ecological status requires the definition of “reference sites” and their communities. The identification of reference sites is based on a number of different attributes, often related to the absence of any form of anthropogenic pressure. The identification of this type of undisturbed site is, in practice, often rather complicated due to the long-term human impact on Lake Skadar/Shkodra including pollution, land use change, and other ecosystem changes. One of the options for the selection of “reference sites” is to select those sites that are located along the “international border,” where anthropogenic pressure is not expected. In the case of a transborder lake, such as Lake Skadar/Shkodra, this approach would have the advantage of motivating international cross-border cooperation.

The most common problem that occurs in the characterization of reference conditions at the selected sites is their spatial heterogeneity, which prevents the adequate characterization of the communities at these sites. In addition to the spatial issue, the temporal resolution of the sample collection, which includes seasonal variation, is significant, and it is therefore necessary to characterize the seasonal variability within each reference site. Last, but not least, it should be remembered that one such community that might describe an unimpacted site may be exposed to this unpredictable variation in assemblage composition, which may in turn have an impact on the assessment of the environmental status.

The current monitoring system is based on the use of a taxonomic approach to characterize communities. This approach implies different species responses to environmental variation and includes the use of the appropriate taxonomy-based indices of environmental degradation (especially in groups such as macrophytes, macroinvertebrates, and fish). The main constraint of this approach is that it ignores metacommunity dynamics, which in practice leads to erroneous conclusions about the ecological status of a particular site or community. Understanding metacommunity dynamics is particularly important for some habitats such as intermittent rivers and ephemeral streams [41] and the riparian springs whose communities depend on the taxon-specific dispersal abilities of their inhabitants and, consequently, on the mode of recolonization of these habitats. There are many springs that lie along the margins of the lake, and during high water periods, they fall below the water level of the lake [42] (Fig. 8a). The assemblage composition of these springs is strongly influenced by local flooding events which result in a decrease in the number of crenobiontic species [43]. Moreover, many crenobionts are vulnerable to threats by habitat degradation such as the use of a site for drinking water purposes [44]. A recent survey showed that 38% of the 119 surveyed springs in the Lake Skadar/Shkodra catchment area were under some type of anthropogenic influence, while almost 18% were intermittent springs which dry up in one part of the year, mainly in the summer [45]. The largest number of springs that were exposed to anthropogenic and/or natural stressors was of a rheocrenic type and was situated at lower altitudes. The development of new status assessment methods

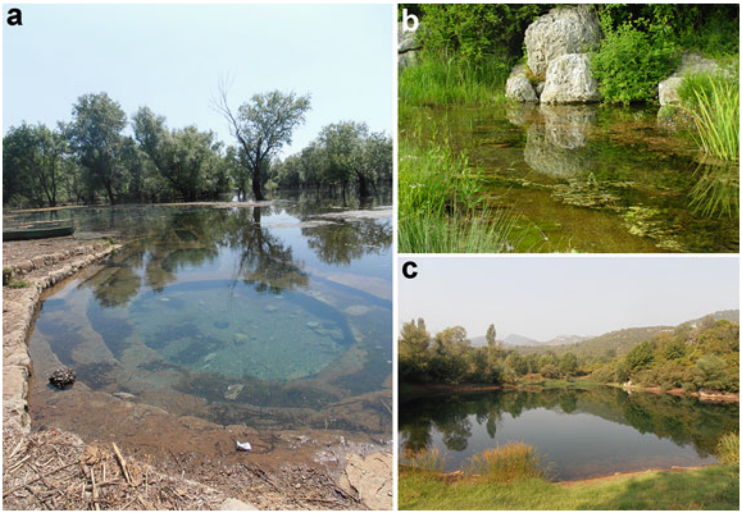

Fig. 8 (**a**) The spring at Vitoja located on the northwestern shore of Lake Skadar/Shkodra flooded in the winter months; (**b**) the Mareza Springs are the source of much of Podgorica's drinking water, and only a small part (limnocrene) is non-captured, but recently this part has been built around with an artificial canal that drains water from the spring source: here is the *locus typicus* of several endemic and endangered species (*Candonopsis mareza*, *Leptocythere pseudoproboscidea*, and *Hygrobates marezaensis*); (**c**) the sublacustrine spring ("eye") Kaluđerovo Oko located on the southwestern rim of Lake Skadar/Shkodra is planned to be tapped as the drinking water source. Photo by V. Pešić

and protocols that would help to better delimitate those sites that are under the influence of natural and anthropogenic environmental stressors is required.

Recently the attention of ecologists and regulatory agencies has been attracted by the possibility of the molecular characterization of the communities by using genetic methods [46]. This method has advantages over a standard taxonomy-based monitoring system which is often constrained by the taxonomic limitations of those who have been monitored, which often result in a too coarse taxa identification. For example, the list of chironomid species from Lake Skadar and its associated springs obtained through molecular identification is 31–34% larger than that provided by the traditional analysis based on morphological characters [24]. Applying molecular analysis has the potential to improve the quality of ecological assessment by detecting cryptic species [44]. *Hygrobates fluviatilis* was considered the water mite species that was most tolerant to pollution, which inhabit diverse running water habitats, but a recent molecular study has shown that its spring water dwelling population represent molecularly distinct species which is restricted to the large karstic springs in the Lake Skadar catchment area [44].

Regardless of the benefits of applying molecular methods, their limitation should be highlighted with regard to the discovery of rare species which are often the target of conservation [47]. Including multiple methods at the same time can help overcome the above-mentioned limitations. Some other methods, like satellite remote sensing or aerial photography, might help in investigating processes such as eutrophication and/or managing the aquatic vegetation. The application of new methods requires their testing and validation, followed by the development and implementation of standardized protocols by regulatory agencies. New approaches can include citizen science programs that have been shown to be a useful tool, for example, in tracking the spread of invasive plants or animals, in ornithology for collecting bird migration data, and also in hydrology in providing valuable data on the river levels and the flood risk [48].

7 Theme 7

The lack of environmental and ecological data, especially as a result of poor transborder cooperation, remains the main gap in our knowledge of the Lake Skadar/Shkodra environment.

The lack of data obtained through regular monitoring, especially through an integrated monitoring system for hydrological, biogeochemical, and ecological parameters, influences the current management plans and the use of fragmented scientific data as a surrogate. Moreover, the lack of data or their poor quality negatively affects both the suggestion and verification of the success of the restoration activities that are undertaken.

The current state of knowledge in many disciplines is incomplete, leaving vast gaps and preventing either conclusions or synthesis. The unequal distribution and depth of knowledge can affect the management and protection of Lake Skadar/Shkodra. However, it is worth mentioning that there are some significant steps that were taken to remedy the geographical and disciplinary gaps in our knowledge of the Lake Skadar/Shkodra environment. The project "Promotion of Networks and Exchanges in the South-Eastern Countries" resulted in a comprehensive bibliography on the Lake Shkodra/Skadar environment [49]. This project has shown a significant difference in the amount of data in the levels of discipline-specific knowledge (Fig. 9). For example, the largest number of publications on the lake was related to chemistry and ichthyology. There is also a significant difference in the amount of discipline-specific knowledge between Montenegro and Albania. The imbalance also applied to the number of annual reports and other documents of the regulatory agencies and governmental institutions in Montenegro and Albania relating to Lake Skadar/Shkodra. For example, the recognition of both management plans and related studies is more advanced in Montenegro.

The above-mentioned imbalance in the depth of knowledge significantly influences the perception of the importance of certain processes and phenomena at the level of the entire lake, especially given the often different priorities in the aims of the research and protection of Lake Skadar/Shkodra in Montenegro and in Albania. In this context, the question arises as to whether the data in some specific disciplines are valid, so we can extrapolate conclusions at the level of the whole lake and of how to interpret the sometimes contradictory data. Therefore, it is difficult to propose a

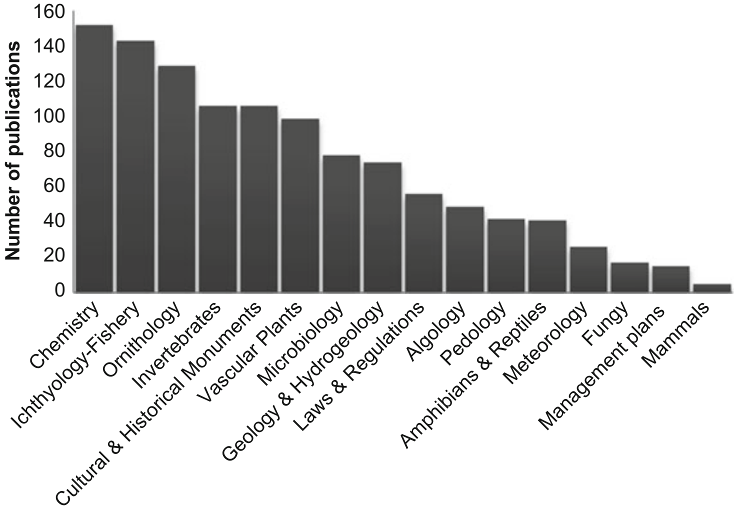

Fig. 9 The number of publications on Lake Skadar/Shkodra for specific disciplines. Data taken from [49]

reliable generalization, and thus the conclusions in some chapters on certain processes at the level of the entire lake should be taken as tentative.

The second substantial step was created by defining a Lake Skadar/Shkodra Basin Management Strategy by Keukelaar et al. [5] within the framework of the project "Lake Shkoder Transboundary Diagnostics Analysis" which resulted in the Strategic Action Plan (SAP) for Lake Skadar/Shkodra in 2007 [50]. By describing the key stakeholders in lake basin management and the main pillars (institutions, supporting policies, information – current situation and future-expected pressures, and finances), the basis for one sustainable management system of the Lake Skadar/Shkodra basin is given, which is essentially no different to the Integrated Lake Basin Management (ILBM) which is today widely accepted as a guideline for the achievement of the sustainable management of lakes basins [51]. Improving lake management is especially important in the face of global challenges such as climate change and the increasing demands for water that Lake Skadar/Shkodra expects to face in the future. The average specific yield of the lake amounts to as much as 54 l/s/km^2, meaning that the Lake Skadar/Shkodra basin represents one of the richest basins of freshwater in the world [52].

Scientific institutions (especially the universities in Podgorica and Shkodra) and non-governmental organizations have an important role in improving the knowledge and public environmental education on the Lake Skadar/Shkodra ecosystem. In the period from 2011 to 2016, 5 PhD dissertations and more than 20 master's and undergraduate theses dealing with the environmental issues of Lake Skadar/Shkodra and its catchment were defended at the Department of Biology of the University of Montenegro. In the last decade, NGOs have played a major role in stimulating public dialogue in interaction with government organizations and local communities and in creating awareness of the environmental issues facing Lake Skadar/Shkodra [53]. The partnership between NGOs and scientific institutions should be emphasized especially in organizing workshops and training schools about specific environmental issues but also in organizing scientific meetings like The International Symposium of Ecologists of Montenegro (ISEMs, from 2004 organized every second year) which, in addition to their scientific significance, also have an important role in spreading the message concerning education and public awareness for the sustainability of the Lake Skadar/Shkodra ecosystem.

The ecological importance of Lake Skadar/Shkodra was recognized by the establishment of a National Park covering the Montenegrin side in 1983, and its inclusion on the list of Ramsar Areas (in 1995) and the list of freshwater Key Biodiversity Areas (KBAs) across the Mediterranean hot spot region [54]. Moreover, Lake Skadar/Shkodra supports 24 KBA trigger species which qualify Lake Skadar KBA (which includes the lake itself and its catchment) as one of the Alliance for Zero Extinction (AZE) sites [55] where urgent immediate conservation actions are required [54].

The key to the better understanding of the Lake Skadar/Shkodra environment remains transborder collaboration. Collaboration between scientific institutions and scientific teams in Montenegro and Albania aims at the better understanding of the ecological processes in Lake Skadar/Shkodra and proposing protection measures; it is for non-governmental organizations and the scientific community to raise awareness about the protection and significance of the ecosystem services provided by the Lake Skadar/Shkodra ecosystem; between the scientific communities and the regulatory agencies, we should develop effective status assessment methods which can be used in monitoring; between local community and government, the aim is to promote the interests of the local community and the sustainable use of natural resources; in short, it is for the two countries to develop a legislative and institutional framework for the long-term protection of the Lake Skadar/Shkodra environment.

Acknowledgments We also thank all the authors of the 23 chapters for their enthusiasm, commitment, and insights that have resulted in this book. We thank the many people who discussed ideas for this book and Sead Hadžiablahović and Mihailo Jovićević for the permission to use their photos. A.G. Kostianoy was partially supported in the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2018-0003).

References

1. Pešić V, Karaman GS, Kostianoy AG (2018) Introduction. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
2. Beeton AM (1981) Physical conditions of Lake Skadar and its Basin. General introduction. In: Karaman GS, Beeton AM (ed) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 15–17
3. Kostianoy AG, Soloviev DM, Kostianaia EA, Sirota AM (2018) Satellite remote sensing of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg

4. Radulović V (1997) The waters of the Lake Skadar and its neighbouring aquifers as a water supplying sources. In: Mijušković M (ed) Natural values and protection of Lake Skadar, vol 44. CANU, Scientific Meeting, pp 39–65
5. Keukelaar F, De Goffau A, Pradhan T, Sutmuller G, Mišurović A, Ivanović S, Uskokovic B, Hetoja A, Haxhimihali E, Prifti A, Kapidani E, Kashta L, Gulan A (2006) Lake Shkoder transboundary diagnostics analysis Albania & Montenegro. Project number 9P6515, Podgorica, Royal Haskoning, Nijmegen, 111 p
6. Knežević M, Todorovic M (2004) Sustainability aspects of the Skadar Lake water level regulation, BALWOIS, Ohrid, Macedonia
7. Beeton AM (1981) Water masses, thermal conditions and transparency of Lake Skadar. In: Karaman GS, Beeton AM (Ed) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 38–55
8. Petrović G (1981) Chemical investigations of water and sediment of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 68–96
9. Kostanjsek R, Lapanje A, Drobne D, Perovic S, Perovic A, Zidar P, Strus J, Hollert H, Karaman G (2005) Bacterial community structure analyses to assess pollution of water and sediments in the Lake Shkodra/Skadar, Balkan Peninsula. Environ Sci Pollut Res 12:361–368
10. Gannon J, Stemberger R (1981) Impact of influent rivers in the distribution of zooplankton in Skdar lake. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 199–216
11. Skarbøvik E, Perović A, Shumka S, Nagothu US (2014) Nutrient inputs, trophic status and water management challenges in the trasboundary lake Skadar/Shkodra, Western Balkans. Arch Biol Sci 66(2):667–681
12. Radulović MM (2018) Hydrogeology of the Skadar Lake basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
13. Vukašinović-Pešić V, Blagojević N (2018) Metal pollution: evidences from plants, aquatic invertebrates and fishes from the Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
14. Kastratović V (2018) The water and sediment chemistry of Lake Skadar. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
15. Beeton AM (1981) Relationships of aquatic macrophytes to the chemistry of Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 109–113
16. Rakočević J (2018) The phytoplankton and trophic state of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
17. Šundić D, Radujković B (2012) Study on freshwater Oligochaeta of Montenegro and their use as indicators in water quality assessment. Nat Montenegr 11:117–383
18. Perovic A, Bushati N, Nikcevic S, Pesic V, Karaman G, Seiler TB, Maric D, Rastall A, Erdinger L, Hollert H (2004) Integrative assessment of sediments of the Lake Skadar/Shkodra using a Triad approach. Proceedings annual meeting of SETAC Europe in Prague
19. Perović S, Rakočević J, Perović A (2011) In vitro bioassays as diagnostic tools for toxicological effects assessment of polluted environment and triad approach. Nat Montenegrina 10 (4):497–505
20. Stesevic D, Feiler U, Sundic D, Erdinger L, Seiler TB, Heininger P, Hollert H (2005) Application of a new sediment contact test with *Myriophyllum aquaticum* and of the aquatic *Lemna* test to assess the sediment quality of Lake Skadar. J Soil Sediment 7(5):342–349
21. Peveling R, Brämick U, Densky H, Parr B, Pietrock M (eds) (2017) Initial characterisation of Lakes Prespa, Ohrid and Shkodra/Skadar (Implementing the EU Water Framework Directive in South-Eastern Europe). Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH

22. Melzer A (1999) Aquatic macrophytes as tools for lake management. Hydrobiologia 395–396:181–190
23. Petković S (1971) Prilog poznavanju fitoplanktona Skadarskog jezera sa posebnim osvrtom na dinamiku brojnosti i ritam razvića *Ceratium hirundinella* (O.F. Müll) Schrank. Poljoprivreda i šumarstvo 21(2):33–56
24. Pešić V, Gadawski P, Gligorović B, Glöer P, Grabowski M, Kovács T, Murányi D, Płóciennik M (2018) The diversity of the Zoobenthos communities of the Lake Skadar/Shkodra basin. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
25. Pešić V, Glöer P (2018) The diversity and conservation status of the Molluscs of Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
26. Jacobi GZ (1981) Zoobenthos from Sublacustrine Springs in Lake Skadar. In: Karaman GS, Beeton AM (eds) The biota and limnology of Lake Skadar. University Veljko Vlahović, Institute of Biological and Medicine Research Titograd, Smithsonian institution, Washington, DC, USA, pp 251–263
27. Pešić V, Glöer P (2013) A new freshwater snail genus (Hydrobiidae, Gastropoda) from Montenegro, with a discussion on gastropod diversity and endemism in Skadar Lake. ZooKeys 281:69–90
28. Marić D (2018) The Ichtyofauna of Lake Skadar/Shkodra: diversity, economic significance, condition and coservation status. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
29. Krammer K (2002) *Cymbella*. In: Lange-Bertalot H (ed) Diatoms of Europe: diatoms of European inland waters and comparable habitats, vol 3. Gantner Verlag, Ruggell, pp 1–584
30. Albrecht C, Wilke T (2008) Ancient Lake Ohrid: biodiversity and evolution. Hydrobiologia 615:103–140
31. Crivelli AJ (2006) *Chondrostoma scodrense*. The IUCN Red List of Threatened Species 2006: e.T61345A12465545. https://doi.org/10.2305/IUCN.UK.2006.RLTS.T61345A12465545.en. Accessed 28 Dec 2017
32. Kastratović V, Jaćimović Ž, Bigović M, Đurović D, Krivokapić S (2016) Environmental Status and geochemical assessment sediments of Lake Skadar, Montenegro. Environ Monit Assess 188:449
33. Vizi O (2018) Ornithological features of Skadar Lake. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
34. Zawal A, Pešić V (2018) The diversity of water mite assemblages (Acari: Parasitengona: Hydrachnidia) of Lake Skadar/Shkodra and its catchment area. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
35. Marić D, Rajković M (2004) Competitors and predators the cause of crayfish (*Astacus astacus* L.) numerosity decrease in the waters of Nikšić region. Nat Montenegrina 3:101–111
36. Perry WL, Lodge DM, Lamberti GA (1997) Impact of crayfish predation on exotic zebra mussels and native invertebrates in a lake-outlet stream. Can J Fish Aquat Sci 54:120–125
37. Wilke T, Schultheiß R, Albrecht C, Bornmann N, Trajanovski S, Kevrekidis T (2010) Native *Dreissena* freshwater mussels in the Balkans: in and out of ancient lakes. Biogeosciences 7:3051–3061
38. Vojar J, Havlikova B, Solsky M, Jablonski D, Iković V, Balaž V (2017) Distribution, prevalence and amphibian hosts of *Batrachochytrium dendrobatidis*in the Balkans. Salamandra 53:44–49
39. Grabowski M, Bącela-Spychalska K, Pešić V (2014) Reproductive traits and conservation needs of the endemic gammarid *Laurogammarus scutarensis* (Schäferna, 1922) from the Skadar Lake system, Balkan Peninsula. Limnologica 47:44–51
40. EC (European Commission) (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC): Guidance Document No. 11: Planning Processes. Office for

Official Publications of the European Communities, Luxembourg. http://ec.europa.eu/environment/water/water-framework/facts_figures/guidance_docs_en.htm. Accessed 5 Dec 2017
41. Stubbington R, Chadd R, Cid N, Csabai Z, Miliša M, Morais M, Munné A, Pařil P, Pešić V, Tziortzis I, Verdonschot RCM, Datry T (2018) Biomonitoring of intermittent rivers and ephemeral streams in Europe: current practice and priorities to enhance ecological status. Sci Total Environ 618:1096–1113
42. Šundić M, Pešić V (2007) Seasonal changes in the abundance of benthic assemblages in the spring on Vranjina island (Skadar Lake National Park). Glas Republ Zavoda Zašt Prirode – Prirodnjačkog muzeja 29–30:125–130
43. von Fumetti S, Dmitrović D, Pešić V (2017) The influence of flooding and river connectivity on macroinvertebrate assemblages in rheocrene springs along a third-order river. Fund Appl Limnol 190(3):251–263. https://doi.org/10.1127/fal/2017/0992
44. Pešić V, Asadi M, Cimpean M, Dabert M, Esen Y, Gerecke R, Martin P, Savic A, Smit H, Stur E (2017) Six species in one: evidence of cryptic speciation in the *Hygrobates fluviatilis* complex (Acariformes, Hydrachnidia, Hygrobatidae). Syst Appl Acarol 22(9):1327–1377
45. Gligorović B (2018) Faunistic and ecological research on the springs of Lake Skadar catchment with a special reference of fauna of Odonata and Hemiptera. Dissertation, Faculty of Sciences, University of Montenegro
46. Leese F, Altermatt F, Bouchez A, Ekrem T, Hering D, Meissner K, Mergen P, Pawlowski J, Piggott JJ, Rimet F et al. (2016) DNAqua-Net: developing new genetic tools for bioassessment and monitoring of aquatic ecosystems in Europe. Research Ideas and Outcomes. e11321. doi: https://doi.org/10.3897/rio.2.e11321
47. Hajibabaei M, Shokralla S, Zhou X, Singer GAC, Baird DJ (2011) Environmental barcoding: a next-generation sequencing approach for biomonitoring applications using river benthos. PLoS One 6:e17497. https://doi.org/10.1371/journal.pone.0017497
48. Starkey E, Parkin G, Birkinshaw S, Large A, Quinn P, Gibson C (2017) Demonstrating the value of community-based ("citizen science") observations for catchment modelling and characterisation. J Hydrol 548:801–817
49. Kashta L, Dhora D, Sokoli F, Rakaj M, Hoti M, Beka I, Bekteshi A, Ziu T, Pulević, V, Hadžiablahović S, Kasom G, Rakočević-Nedović J, Nikčević, S, Pešić V, Ražnatović A, Ćirović R, Saveljić D, Bušković V, Micev B, Filipović S, Fuštić B, Radulović M, Žižić-Velimirović O (2001) Bibliography on Shkodra/Skadar Lake. Checklist of species. The Regional Environmental Center for Central and Eastern Europe, Activity 1.2.1
50. APAWA and CETI (2007) The strategic action plan (SAP) for Skadar/Shkodra Lake. GEF, World Bank, LSIEMP Shkodra-Tirana-Podgorica, Albania and Montenegro, 72 p
51. Vujović A, Krivokapić T, Stefanović M, Pešić V, Jovanović J (2018) Integrated Lake Basin Management (ILBM) for Lake Skadar/Shkodra. In: Pešić V, Karaman GS, Kostianoy AG (eds) The Skadar/Shkodra lake environment. Springer, Berlin, Heidelberg
52. Radulović MM, Radulović M, Stevanović Z, Sekulić G, Radulović V, Burić M, Novaković D, Vako E, Blagojević M, Dević N, Radojević D (2015) Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. Environ Earth Sci 74:71–82
53. Green Home (2013) Environmental management action plan, Assessment of the threatening factors on biodiversity of the lake, especially aquatic and forest vegetation and Draft actions that guarantees their protection – until 2016. Montenegro – Albania, Shkoder, Podgorica. http://www.greenhome.co.me/fajlovi/greenhome/attach_fajlovi/eng/main-pages/2014/01/pdf/Assessment_of_the_threatening_factors_on_biodiversity_of_the_Skadar_Lake.pdf. Accessed 10 Dec 2017
54. Darwall W, Carrizo S, Numa C, Barrios V, Freyhof J, Smith K (2014) Freshwater key biodiversity areas in the Mediterranean basin hotspot: informing species conservation and development planning in freshwater ecosystems. IUCN, Cambridge, UK and Malaga, Spain
55. Ricketts TH, Dinerstein E, Boucher T et al (2005) Pinpointing and preventing imminent extinctions. Proc Natl Acad Sci U S A 102:18497–18501

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V. Pešić et al. (eds.), *The Skadar/Shkodra Lake Environment*, Hdb Env Chem (2018) 80: 501–508, https://doi.org/10.1007/978-3-319-99250-1,
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