Chapter 1
Navigating the Freshwaters of Patagonia… and This Book

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1 The Many Ways to Look at Patagonia

Patagonia is the southernmost geographical region outside Antarctica, which comprises the southern tip of continental South America and the surrounding archipelagos. Its main geographic feature, the Andes Mountain Range, extending in the NS direction, roughly sets the limit between the republics of Argentina and Chile, which encompass around 88% and 12% of the Patagonian land, respectively (Peri et al. 2021).

From a geological viewpoint, Patagonia constituted an independent terrane whose convergence with western Gondwana originated the Huincul High, a deformation belt running WE which represents its northern natural limit (Ramos et al. 2004; Mosquera et al. 2011) (Fig. 1.1). Its geological structure is composed of two distinct subregions: the mountainous Andean Patagonia, mainly resulting from the Tertiary folding, and the Extra-Andean plateau, resulting from the Mesozoic and Cenozoic filling of the ancient basement. Within these two large units, a number of geological provinces can be recognised (Coronato et al. 2017).

The location of Patagonia stands as the only piece of continental land south of the 40º S, and its climate is therefore signed by the Andes ridge acting as a mighty barrier against the powerful westerlies from the South Pacific anticyclone. This creates a strong rain shadow effect, with distance from the Andes accounting almost on its own for the eastward decreasing trend of the annual precipitation in mid-Patagonia (Jobággy et al. 1995). In the Tierra del Fuego Island, the Andes change their orientation towards WE, thus diminishing the rain shadow over the eastern

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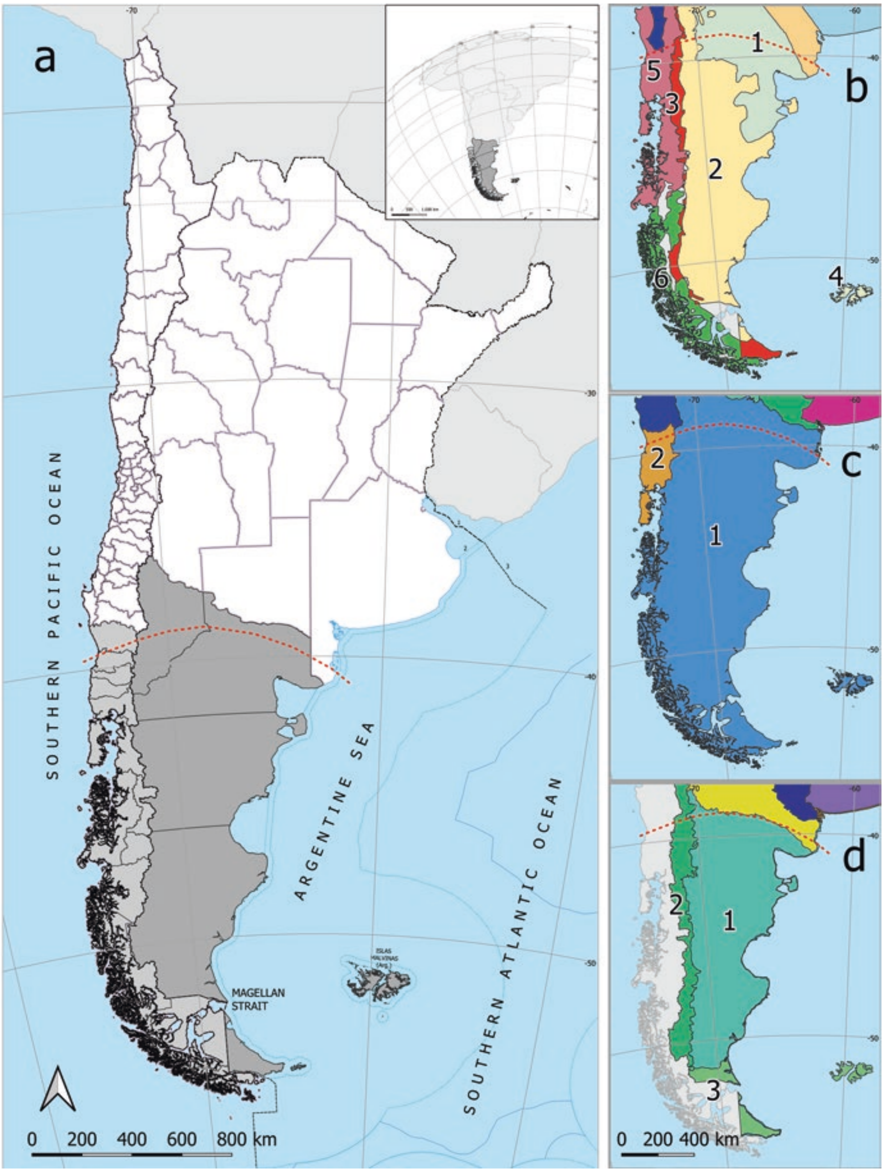

Fig. 1.1 Consistent regionalisation criteria of Patagonia. (**a**) Geographical division of Argentina and Chile, showing the provinces belonging to Patagonia (dark and light shadow, respectively). The dashed red line shows the position of the Huincul High according to Mosquera et al. (2011). (**b**) Terrestrial ecoregions of Patagonia, according to Morello et al. (2018) in Argentina and World Wildlife Fund (2022) in Chile. 1: Monte; 2: Patagonian steppe; 3: Patagonian forests; 4: Malvinas Islands; 5: Valdivian temperate rainforest; 6: Magellan subpolar forest. (**c**) Freshwater ecoregions according to Abell et al. (2008) 1: Patagonia; 2: Valdivian lakes. (**d**) Wetlands regions of Argentina according to Benzaquén et al. (2017) 1: lakes, watercourses and meadows of Patagonian Andes; 2: shallow lakes and meadows of the Extra-Andean Patagonia; 3: meadows and peat bogs of southern Patagonia and South Atlantic Islands

section of the island. The ample latitudinal range of Patagonia (ca. 20 °C) determines a strong decrease in mean annual temperatures from 12 °C in the NW to 3 °C in the S (Peri et al. 2021). Interestingly, the decreasing width of the land mass with latitude also determines a decreasing thermal range from 16 °C in the Patagonian plateau to 4 °C in the southernmost magellanic islands according to Coronato et al. (2017). These authors also give a detailed classification of the 13 identified Patagonian climatic types (Coronato et al. 2017).

Beyond geoclimatic features, Patagonia can be comprehensively regarded from an ecoregional viewpoint. To this end, Morello et al. (2018) devise an ecoregion as a geographically defined territory with a common geological and biogeographical history and a distinct regional climate based on annual mean precipitation and the presence and extent of a dry season and a cold season, characterised by homogeneous ecological responses to climate and tectonics, expressed by the vegetation, the fauna, the relief and anthropic activities such as agriculture and industry. These authors thoroughly described the whole territory of Argentina in terms of ecoregions, sub-regions and ecosystem complexes. According to them, three main ecoregions are present in Patagonia, following the formerly described geophysical and climatic patterns: from NE to SW, the *Monte* (Monte desert), *Estepa patagónica* (Patagonian steppe) and *Bosques Patagónicos* (Patagonian forests) each of them comprising different subregions. The latter include two separated N and S High Andean subregions that hold a continuity with the southern Andean Steppe Ecoregion in Chile, as defined by the World Wildlife Fund (World Wildlife Fund 2022). Beyond the Andes, the Valdivian temperate rainforest to the north and the Magellanic subpolar forest to the south spread towards the Pacific Ocean (Morrone 2001). In turn, Abell et al. (2008) also used an ecoregion-based approach for the first biogeographic regionalisation of freshwaters in order to identify global and regional conservation priorities of fish species. Amongst the 426 ecoregions so defined, they identify a Patagonia ecoregion, which roughly coincides with the one geologically delimited here, but excluding the Valdivian Lakes ecoregion, which includes the lake district of southern Chile and the island of Chiloé.

In Argentina, since the beginning of the century, a National Wetlands Inventory has progressed, with the aim of informing adequate conservation and sustainable use policies. The first spatial level of this inventory defines wetland regions and subregions strongly based on a hydrogeomorphic approach which takes into account environmental features driving the presence, spatial expression and ecological features of wetlands (Benzaquén et al. 2017). In this context, Patagonia represents a whole region, divided into three wetlands subregions: The lakes, watercourses and *mallines* (a meadow type) of Patagonian Andes; the shallow lakes and *vegas* (another meadow type) of the Extra-Andean Patagonia; and the *mallines* and *turberas* (peat bogs) of southern Patagonia and South Atlantic Islands. Unlike Argentina, Chile has not identified wetland regions and subregions. Anyway, it is recognised that most wetland areas are located in the Chilean Patagonia, particularly in the Aysén (XI) and Magallanes y la Antártica Chilena (XII) Regions (Promis 2010).

In sum, the preceding paragraphs illuminate a number of possible ways to regard the complex aspects of Patagonia through the use of complementary ecoregional approaches to terrestrial, overall freshwaters or particularly wetland ecosystems. Notwithstanding, geopolitical boundaries are most commonly used for administrative purposes. Political organisation of Chile recognises 16 regions, with those of La Araucanía, Los Ríos, Los Lagos, Aysén y Magallanes y la Antártica Chilena being included in Chilean Patagonia; while in Argentina it comprises the provinces of Neuquén, Río Negro, Chubut, Santa Cruz and Tierra del Fuego, Antártida e Islas del Atlántico Sur (AIAS). Nevertheless, as geopolitical limits of both countries encompass sovereignty claims on Antarctica suspended in accordance with the Antarctic Treaty (Secretaría del Tratado Antártico 2021), such areas are not included in the scope of this book.

2 The Many Ways to Read This Book

Due to its complex history and geographical setting, Patagonian freshwaters abound in many different forms, from small, high altitude proglacial lakes to large deep lakes of glacial origin, to shallow lakes, mountain streams and different types of wetlands in the Andean zone, to large rivers, complexes of shallow lakes and ponds and many different wetland types, particularly meadows all over the steppe and peat bogs in the southernmost Tierra del Fuego Island, and are key landscape elements on which human activities depend. Therefore, the order in which the chapters of this book are presented is not unique, and a number of different Ariadne's threads can guide the reader along thematically related chapters.

2.1 The Water, the Ecosystems and the Communities

Undoubtedly, in the last decades, for public opinion, wetlands have gone from being discarded lands to very valuable ecosystems that humanity should protect and use in a sustainable way. In any case, even today, there is much discussion about what wetlands really are. This debate has not only taken place in the media but also within the scientific community. Different viewpoints, particularly between limnologists and wetland ecologists, have given rise to hard discussions. One of the main debates regarding what a wetland is relates to its genesis since these ecosystems are neither aquatic nor terrestrial. In Chap. 2, we debate the ecological character of wetlands, comparing different definitions with constructive criticism. In addition, we describe the Brinson's hydrogeomorphic approach for wetland classification and how it was applied for the Argentinean wetland regionalisation. A general description of Patagonian wetlands is also included as well as some considerations on the wetland–society relationships and the contributions of wetlands, particularly Patagonian ones, to people. A final reflection about the Argentinean Wetland Law Project is included as an example of the difficulties in the way to get a better protection and sustainable use of these ecosystems.

The existence of different environmental (altitudinal, latitudinal, trophic) gradients in Patagonian freshwater bodies gives rise to distinct biogeographical patterns at different scales, as Schiaffino and Izaguirre extensively review in Chap. 5. These authors describe patterns of planktonic prokaryotes and eukaryotes along a gradient of Patagonian water bodies, which also includes some Antarctic lakes and highlight the role of spatial and environmental factors in controlling the bacterial community structure. They found a decrease towards higher latitudes of heterotrophic bacteria, Archaea and photosynthetic picoplankton abundances, while also remarking the importance of light conditions and trophic status of the lakes in shaping picoplankton structure. Phytoplankton diversity was also influenced at large spatial scale by geographical and environmental factors. Here, a decreasing biodiversity pattern with latitude was observed for particular taxonomic microalgal groups, as well as for the whole phytoplankton community, although local effects were stronger. In this review, the authors propose the co-existence of a 'core biosphere' containing a reduced number of dominant microeukaryote operational taxonomic units (OTUs) on which classical ecological rules apply, together with a much larger seedbank of rare OTUs driven by stochastic and reduced dispersal processes. They also present these findings as important tools for implementing land planning focused on conservation and sustainable use objectives at multiple scales.

Globally, peat bogs are much appreciated for acting as key sinks for atmospheric CO_2. In addition, these particular wetlands represent biodiversity hotspots, as they host a very distinctive acidophilic biota. In Chap. 6, Quiroga et al. take a closer look at the community structure of microalgae, ciliates and microinvertebrates in two peat bogs from Tierra del Fuego Island, which are encompassed in the largest and southernmost peatland complex in the Southern Hemisphere. The authors show that both elements of the landscape (lentic waterbodies and the surrounding *Sphagnum* moss matrix) account for the high, particular biodiversity of these systems, as they host contrasting communities building up different trophic webs. Also, taxonomic composition and community attributes are ultimately driven by interactions between environmental features sensitive to anthropogenic impacts, both direct – such as increases in nutrient concentrations, total hardness (TH) and conductivity potentially driven by housing development – and mediated by climate change, such as decreasing water table depth and increasing temperature. By means of general additive models, authors predict that changes in these parameters could have contrasting effects on the different planktonic communities. They also model their influence on the diversity and composition of microinvertebrates, covering both landscape elements at a regional scale, and pinpoint species highly indicative of environmental changes in all three communities. For instance, as easily identifiable *Bosmina chilensis* is at the same time an indicator of high microinvertebrate diversity and low TH, its decline could allow for the early detection of wastewater-mediated impacts. The synthesis of these approaches thus serves as a tool to monitor the impact of environmental changes on the fragile communities of these unique ecosystems.

Fish and fisheries distribution patterns in the Patagonian steppe are described in Chap. 13. This contribution comes to fill in a void of comprehensive information, because until now, most available knowledge on these topics pertains to the Andean sector. In this chapter, Baigún et al. describe a wide variety of the ichthyofauna characteristics, their assemblages and fisheries along the main basins of the Patagonian steppe. North Patagonia assemblages include species from the Patagonian, Andean Cuyean and Pampean ichthyological provinces with an overlapping of species from Austral and Brazilic subregions. Salmonid and anadromous species richness, on the contrary, increases from northern to southern latitudes. In addition, some endorheic basins are inhabited by species with restricted distribution ranges, including some with an extreme degree of endemism, which renders them paramount species from a conservation viewpoint. At present, several Patagonian fish species are threatened by human impacts, including climate change. In addition, historical and current management policies have permitted uncontrolled stocking of alien species due to their high fishing value, with the consequent reduction in the distribution and abundance of native fish species. The information included in this chapter thus constitutes a relevant source of information for fish and fisheries managers and decision makers.

2.2 The Many Influences of Volcanic Activity

As pointed out earlier, the Andes are a key structuring agent of the climate and the geomorphology of Patagonia, but also encompass some areas of active and even intense volcanic activity, which can have particular effects on the waterbodies subjected to it. Such is the case of the Copahue Volcano, which hosts the source of the River Agrio-Lake Caviahue system. This system was extensively studied by Temporetti et al. (Chap. 7) for two decades. Volcanic activity confers the Upper Agrio River and Lake Caviahue very distinct chemical features, such as an extremely low (<2–3) pH and very high ion concentrations, although strong eruptive episodes over the last decade have altered the ionic balance of Lake Caviahue, resulting in the deposition of ferric compounds. Interestingly, the metals are deposited in the sediments in non-toxic forms. Yet the system can be regarded as an extreme one, wherein very few algal species can survive. In turn, the Lower Agrio River is progressively neutralised by the confluence of more typical oligotrophic mountain streams, resulting in a circumneutral pH and a well-developed epilithic community. Some uses of the upper system features have been envisaged, as two acidophilic microalgae resulted in good candidates to test soil pollution by polycyclic aromatic hydrocarbons (PAHs). Also, the authors found that Fenton decontamination processes are feasible under the particular Lake Caviahue conditions and can lay the foundation for the development of a treatment plant for the wastewaters from Caviahue town in the natural conditions of the lake.

Further south along the Andean Volcanic Belt, the Puyehue–Cordón Caulle Volcanic Complex exerts a strong influence on the deep lakes within the Nahuel Huapi National Park through a strong input to the mercury biogeochemical cycle. Indeed, according to Diéguez et al. (Chap. 8), total Hg concentrations measured in the waters of the Nahuel Huapi Lake after the last eruption of this volcanic complex are amongst the highest recorded in natural systems, wherein major sources from the lithosphere are volcanic and geological activity and volatilisation, notably from extensive forest fires. Anthropogenic Hg emissions from mining, coal combustion and industry, in turn, globally exceed natural emissions and are also reflected in lake sediment archives. As pointed out by the authors, the Hg biogeochemical cycle is complex, and Hg is mobilised under different forms, some of which are toxic. Such is the case of CH_3Hg, which can be produced by microbial methylation in freshwaters. In these systems, the concentration and molecular composition of the DOM pool determine Hg fractionation, availability and biotic uptake, as well as the net Hg^{2+} methylation. Moreover, CH_3Hg can concentrate along food chains. As authors demonstrate, in large, deep lakes with extended pelagic zones, both THg and CH_3Hg concentrations in fish species vary by foraging habitat, increasing together with the proportion of benthic diet over pelagic diet. Yet, many features of the Hg cycling, such as compartment storages, fluxes, and chemical transformations, such as methylation are all climate-sensitive, and therefore the potentially profound consequences of climate change on the biogeochemical cycling of Hg are discussed.

Volcanic eruptions influence the physical and chemical properties and plankton communities of deep Andean lakes in yet other ways, as studied by Balseiro et al. (Chap. 3). Floating pumice and sestonic ashes from the last Puyehue–Cordón Caulle mega eruption have profoundly affected the light climate of ultraoligotrophic transparent lakes by decreasing the depth of the Deep Chlorophyll Maximum (DCM) wherein plankton communities find the best trade-off between avoiding excessive light radiation and P limitation. They also enhanced the food quality of phytoplankton by decreasing its C:P ratio. These effects are also generated by the presence of clay in the water column of lakes downstream from glacier or moraine-dammed lakes and can be dramatically changed by GLOFs (glacial lake outburst floods), which consist of the sudden release of such dams in the latter waterbodies due to glacial recession. Interestingly, these apparently alike events can have opposite consequences on zooplankton structure on account of their distinct nutritional requirements and feeding habits. In all, changes in DCM and the type of disturbance, including potential anthropogenic ones due to changes in land use, emerge as valuable clues to track and understand the behaviour of trophic webs in future scenarios.

2.3 Patagonian History and the Memory of Waters

First traces of human population in some reduced areas of Patagonia date back from 13,000 to 10,500 years BP. Before the European arrival, Patagonia was already occupied by different ethnic groups, mostly nomad hunter-collectors, amongst which the Mapuche were the most advanced and displaced other groups. Many Spanish (but also Portuguese, English and Dutch) expeditions and colonisation attempts failed over the sixteenth and seventeenth centuries (Matteuci 2012). During the nineteenth century and after their independence from Spain, Argentina and Chile competed over Patagonian land occupation. This was mostly aimed at sheep farming for wool trade with England and controlling the maritime transport of goods between Europe and Eastern Asia by connecting the Atlantic and Pacific oceans. In this context, both countries carried out expeditions with the objective of advancing the frontiers of Western civilisation by reducing or exterminating indigenous groups (Peri et al. 2021) under the deceitful names of *Campaña del Desierto* (desert campaign) in Argentina and *Pacificación de la Araucanía* (Araucanía pacification) in Chile. As a result of these events, most indigenous populations were annihilated, and small groups of survivors displaced to unproductive lands or absorbed as cheap labour force by large estate owners. In Argentina, five national territories were created, which later acquired their present provincial status and constituted modern Patagonia. By the end of the nineteenth century, large fractions of the so-acquired government-owned land were distributed by sale, as concessions or as payment for due services. Notably many of them were allocated to foreign companies, mostly British, and thus furthered the alienation of indigenous groups, in a process which still shapes economic activity and social relations in Patagonia: The main activities are sheep farming, oil and mineral extraction, and agriculture in the valleys along large rivers, which continue to displace local inhabitants and export most of the economic benefits (Matteucci 2012).

Presently, the National Institute of Indigenous affairs records 48 different originary people all over Argentina, amongst which the Mapuche are by far the most widespread, with a large number of communities recorded in northern Patagonia, mainly on the western side of Neuquén, Río Negro and Chubut provinces. Also relevant in Chubut and Santa Cruz are the Mapuche Tehuelche and Tehuelche communities, while only one Selk'nam and one Yagan communities remain in the Tierra del Fuego Island (Instituto Nacional de Asuntos Indígenas 2022). In a context of displacement of indigenous people to arid lands, traditional limnological knowledge is of key importance for community survival. In Chap. 16, Molares et al. apply a transdisciplinary cultural limnology approach to understand the reciprocity relationship between Mapuche people and the waterscapes they inhabit, wherein traditional water management practices allow them to perform family horticulture in a context of precarious basic services and low or no state economic or infrastructure assistance. The notion of biocultural memory about waters is key to sustain Mapuche views in the discussion of environmental policies regarding co-managed protected areas and in the claim for their right to land and water frequently lost to foreign occupation. Such a notion is one of community character, as it passes on from one generation to the next; of spatial character, as it depends on the intersubjective relationship with every specific body or source of water; and also dynamic, as it incorporates new information about perceived changes in the hydrological cycle. Yet, viewpoints rooted in traditional knowledge sometimes differ from those based on science. Here, the transdisciplinary field of cultural limnology aims at constructing a common language that is paramount for discussing inclusive, innovative ways of dealing with contemporary socio-ecological issues involving originary people.

2.4 Freshwaters and Wetlands in Present-Day Patagonia

According to the projection based on the last national census, population in Argentinean Patagonia reached 2,569,791 in 2020 (Argentina.gob.ar 2022) with a descending trend from Neuquén southwards and a minimum population density of 1.5 inhabitants km^{-2} in the vast Santa Cruz Province. Population of Chilean Patagonia was 2,440,460 inhabitants as of 2017, with an average density of 7.18 inhabitants km^{-2}, steeply decreasing from North to South in the continental section. Notably, in both countries, the population rises again around the Magellan Strait and Tierra del Fuego Island. As pointed out before, the main economic activities in both countries as of late nineteenth century have been mining, sheep farming, agriculture (mainly crops and fruit production along northern rivers valleys), and oil and gas extraction. Over the second half of the twentieth century, several large hydroelectric dams were built along many rivers, while aeolic farms are gaining importance in taking advantage of the strong Patagonian winds (Peri et al. 2021). Although the luxuriant temperate forests and vast glacial lakes that fringe the Andes make magnificent landscapes much appreciated by international tourism, areas outside protection regimes gave way to pine afforestation. All these activities interact in complex ways that affect the natural geographical distribution and cycling of water in Patagonia, as extensively reported by Urciuolo and Iturraspe in Chap. 9. All main Patagonian hydrological basins are minutely described, including information on their sizes and location. Also, flows, yearly hydrological variations and characteristics of the main rivers are given, as well as the origin and features of stagnant water systems from ancient, large glacial lakes to smaller ones formed by glacial retreat, and shallow lakes and wetlands in endorheic basins. Also, economic activities based on the physical geography of each basin are discussed. With regard to water management, both countries have developed contrasting regulatory frameworks. On the one hand, Chile is a unitary country wherein one General Water Directorate manages water resources in accordance to the 1981 Water Code all over the country. This code grants transferable ‘water rights’ to particular users, thus enabling the existence of a water market. Argentina, in turn, is a Federal Republic, wherein each province regulates and manages the use of water. Nevertheless, as many basins are shared between provinces, there is a Federal Council which oversees the many interjurisdictional basin authorities. Yet, institutional regulation does not prevent the socio-environmental conflicts around water triggered by disputes in land possession and use. Furthermore, as projected consequences of climate change foresee critical flow decreases in many key river basins over the twenty-first century, water management will be a great governance challenge in years to come.

Amongst an important number of contributions to people, wetlands are invaluable sources of freshwater, particularly in Patagonian areas where this resource is scarce. In addition, these ecosystems contribute significantly to regional biodiversity. In Chap. 10, Epele et al. describe the different Patagonian wetland types as well as their main ecological characteristics, the uses they are subjected to, and the different threats they face on account of changes in both climate and land use. In particular, the authors introduce a detailed description about the following wetland types and their contributions to people: vertientes (*springs*), lagunas (*shallow lakes* and *ponds*), vegas, mallines and turberas (*peat bogs*). They also point out the actions that should be taken in the face of present Patagonian wetlands loss and degradation. In this context, they call for the implementation of concerted actions based on adequate knowledge about these ecosystems dynamics and functioning in order to revert this negative trend. They also observe that, despite being essential for the regional economy, Patagonian wetlands are still far from meeting global conservation targets, since less than 3% of them in arid and semiarid plateau are located within protected areas. These conclusions highlight the need for advancing conservation and sustainable management policies for wetlands over the entire Patagonian region.

Introduction of alien species is presently considered one of the main environmental threats worldwide on account of its impact on both biodiversity and natural ecosystems structure and function. In Patagonia, exotic fish introduced for sport fishing are now affecting native fish populations. In Chap. 14, Porcel et al. analyse the consequences of rainbow trout (*Oncorhynchus mykiss*) introduction in many Patagonian lakes. In this context, they conducted a comparison of trout effects on community composition of fishless and stocked lakes in the southern Patagonia Plateau. By exploring changes in primary productivity and food webs in wet and dry years, the authors found that rainbow trout shaped the community of pelagic crustaceans. In addition, they observed differences in phytoplankton structure and an increase in microplanktonic cyanobacteria abundance in stocked lakes particularly during dry periods, indicating the concomitant effect of trout introduction and climate fluctuations. Changes in both food webs and habitat coupling were also observed with trout presence. These impacts give rise to major potential consequences for waterbirds, particularly for the critically endangered Hooded Grebe (*Podiceps gallardoi*), which reproduces in those aquatic systems.

Changes and intensification in land uses are deeply affecting Patagonian freshwater and wetlands in recent decades. In Chap. 11, Miserendino et al. examine the influence of the main land use practices on the ecological integrity of Patagonian aquatic and wetland environments, as well as on the organisms inhabiting them at population and community levels. Although the region exhibits a diverse array of productive activities, two of them stand out: livestock rising and agriculture. While historical mismanagement of such pursuits has deeply impacted aquatic and wetland ecosystems, more recent human activities have also had important effects: pasture conversion, forestry, pine plantations, mining, damming, oil extraction and, to a lesser extent, urbanisation and industrial development significantly impacted periphyton, macrophytes and macroinvertebrate communities. According to these authors, integrity of riparian corridors plays a crucial role in the ecological integrity of these systems. They conclude that the implementation of management and conservation actions on these ecosystems is urgently needed, and propose mitigation measures to minimise the impacts produced by the different land uses types which should be conducted through collaborative work, involving governmental agencies, scientists, landowners and local communities. Importantly, the success of these measures should be assessed by long-term programmes to monitor the evolution of the impacted ecosystems. Because of the complex nature of these problems, undertaking these measures must also consider a socio-ecological perspective for the entire region.

Chapter 4 addresses the current state and recent changes of glaciers in the Patagonian Andes between ~37 °S and 55 °S. In this context, Ruiz et al. describe the distribution and characteristics of the Patagonian glaciers together with their recent changes and hydrological implications. According to the authors, the Patagonian Andes contain the largest glaciated area in both the southern Andes and the Southern Hemisphere outside Antarctica. This region includes 24,000 ice masses which represent ca 26,100 km^2. There are also several thousand smaller ice masses which are crucial water resources to people. As in other parts of the world, Patagonian glaciers are affected by climate change. The authors point out that in the last decades most of them have experienced considerable thinning and recession, yet recent findings highlight that they have not responded in a similar way to this phenomenon. While ice dynamic processes drive mass change of larger Patagonian glaciers, increases in ice melt and snowfall depletion would be the main causes of shrinkage of the smaller ice masses. Glacier retreat is expected to continue with the consequent impact on runoff and glacier-related hazards. In particular, increase in the number and size of proglacial lakes could result in larger, more frequent glacial lake outburst floods (GLOFs) in the Patagonian Andes in the near future, with the consequent impact on people and productive activities. As this will put an additional strain on water resources in the region, this synthesis on the state and trends of the Patagonian glaciers constitutes a valuable contribution for decision-making regarding their conservation and management.

2.5 Conservation and Protection: Are We Winning?

The invasive, bloom forming diatom *Didymosphenia geminata* (Didymo) exemplifies how environmental issues challenge institutional monitoring and conservation capabilities, as exposed by Beamud et al. (Chap. 12). In 2010, the first blooms of this species in South America were detected in Chile, and only 3 months later in Argentina. As of 2012, Neuquén Province (Argentina) led a series of regional meetings and launched a provincial programme aimed at identifying and preventing the presence of this nuisance diatom in waterbodies. This was of great importance, as Didymo grows in bulky, mucous masses on the riverbed of oligotrophic Andean streams and rivers much appreciated for productive and touristic activities. Along with public informative campaigns and sanitary stations, the authors conducted a province-wide monitoring programme between 2012 and 2019. Although the measures taken did not prevent the expansion of *D. geminata*, the information collected along the monitoring programme allowed to relate the temporal invasion pattern with recreational activities and to learn that the presence and abundance of the alga is primarily driven by factors other than those described in the literature, most importantly the river order. The authors call the attention to the fact that the environmental conditions of a number of invaded sites overlap those of many un-invaded ones, thus rendering the latter susceptible to invasion by *D. geminata*. Also, the wide range of features of invaded sites suggests an ongoing expansion of its ecological spectrum. On the basis of this experience, they also discuss the role of jurisdictional issues in delaying the effective response of control measures.

The state of freshwater and wetland ecosystems worldwide has a deep impact on freshwater biodiversity. Particularly, amphibians are currently amongst the most endangered taxonomic groups on a global scale. Therefore, they are considered a target wildlife group in many international conservation programs. Waterbirds, on the other hand, have a strong dependence on freshwater habitats, and many of them exhibit a congregatory behaviour, so they are particularly sensitive to many threats. Patagonia has a remarkable diversity of both amphibians and waterbirds highly adapted to live under extreme environmental conditions. Many species are endangered by both direct and indirect anthropogenic threats including climate change. In Chap. 15, Kacoliris et al. picture the diversity, ecology and history of the Patagonian amphibian and waterbird species, describe the most relevant ones and highlight their conservation status. The authors discuss the importance of these species in supporting ecological processes that link freshwater, wetland and terrestrial ecosystems and how conservation planning should integrate them to conserve threatened species. Interestingly, they also show how some amphibians and waterbirds have served in turn as flagship species for the protection of habitats and their biodiversity. Finally, the needs for the long-term conservation of both groups in Patagonian freshwaters and wetlands are discussed, including a description of the main conservation projects in the Argentinean Patagonia. The case of the Hooded Grebe (*Podiceps gallardoi)* conservation project, which is one of the main species-framed conservation projects in Patagonia, is particularly analysed.

2.6 Water and Environmental Justice in Patagonia

As already pointed out in Sects. 2.3 and 2.4, the present configuration of human settlements, productive activities and subsequent water uses in Patagonia results from the interplay between its geography and the history of its occupation in the light of global politics, especially since the industrial revolution. As a consequence, struggles around access to water – either as a vital substance or to waterbodies – persist to this very moment. In Argentina, vast foreign-owned land properties acquired through legal loopholes can encompass whole public lakes, such as Escondido Lake, in Río Negro province, included in Hidden Lake ranch, property of the British billionaire Joseph Lewis (Iñigo Carrera 2020). Although justice granted access to the lake shore, partakers of the Sixth March for the Sovereignty of Escondido Lake were recently intercepted, harassed and illegally retained by armed Lewis employees (Página 12 2022). Such episodes are not uncommon and call for urgent, effective action at all governmental levels to democratise access to water. In

Chap. 17, Giomi et al. adopt the perspective of the Latin American Political Ecology to analyse the role of different water valuation languages underlying conflicts around water uses. The many visions of water as an economic good, a human right or a key ecosystem element conduce socio-political actors to regarding it as a public, private or common good, and hence take stands on the many conflicts derived from different uses and the environmental consequences thereof. Within this framework, authors expose the obstacles submerged in the so-called *subsoil of politics* that impeded the legislative deliberation of as much as 13 successive water bills over more than 20 years in the Tierra del Fuego, AIAS Province. Only by revealing the cultural debate amongst disparate water valuations was the construction of social legitimacy possible in order to bring the most powerful actors to negotiate the terms of a Water Law at the surface of politics level. The many conflicts due to the previous lack of regulation are described, as well as the key role of some institutions and state agencies, and the parallel processes in both levels of politics which led to the passing and regimentation of the present-day Water Law. The uncovering and analysis of such processes is particularly valuable in the face of Argentina's persistent failure to table a national law of minimum standards for the protection of wetlands.

A number of environmental justice matters have been tackled at a global level by the UN 2030 Agenda for Sustainable Development, which includes 17 Goals (SDGs) for world countries to fulfil human needs and expectations in an equitable and environmentally sustainable manner. Amongst these, SDG 6 on Clean Water and Sanitation strives to secure universal and equitable access to drinking water and sanitation, while also strongly related with SDG 3 through the importance of clean water supply to prevent and reduce illnesses; SDG 11 about risks posed by water-related disasters; SDG 12 in remarking how waste affect freshwater; and SDG 15 by highlighting the importance of protection, restoration and sustainable use of inland freshwater ecosystems and their services. Due to the abundance of freshwater and scarce population in Patagonia, the challenge of meeting SDG 6 does not relate to water availability but rather to its wise use guided by solid scientific knowledge and strong governance. As the integrated water resource management (IWRM) is recognised by the UN as a keystone policy to meet this objective, in Chap. 18 Pascual et al. critically examine the causes for the low degree of implementation of IWRM by both Argentina and Chile, which relates to the poor application of science and technology to water research and management, and water management being a top-down, bureaucratic process. Globally, the notion that human well-being depends directly on the multiple benefits that societies obtain from nature – termed 'ecosystem services' or 'Nature's contributions to people' – has fostered the application of the ecosystems services (ES) paradigm in both the academic and policy design fields. This paradigm allows to analyse the land–water–atmosphere interface in a dynamic way and to evaluate the consequences of different human interventions and remediation options for aquatic, terrestrial and wetland environments. Therefore, in the case of Patagonian freshwater and wetland ecosystems, the perspective of the ES can bridge the gaps amongst the views of water of different disciplines, thus promoting an integrated environmental perspective of water security problems and implementation of nature-based solutions as well as infrastructure-based solutions.

Furthermore, while IWRM is more paradigmatical, ES allows for normative products and applications. The authors thus propose that its assimilation can strengthen IWRM, reinforcing the environmental view on water management issues, providing technical tools to map and quantify the flow of ecosystem services, and fostering the objective evaluation of nature-based solutions as an alternative to solve such issues. This would represent a most needed change of paradigm towards reaching a more equitable water access for all.

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