Burden of the Coastal Area with Solid Waste in Kornati National Park (Croatia)

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Abstract The problem of waste disposal in the Kornati archipelago is clearly an issue of hidden geography since it is often neglected in the scientific literature and media alike. This paper summarises a realised joint preparation of the methodology for the inventory of solid waste in the coastal zone. The methodology was used and tested for the inventory of solid waste in Kornati National Park which encompasses a large part of the Kornati archipelago located in the central part of the Croatian Adriatic coast. Inventory of solid waste is the first and crucial step in the management of this often-overlooked issue. Approximately two-thirds of the land and the waters of the Kornati archipelago (217 km^2) in Central Dalmatia were proclaimed as a national park in 1980. It is a place of exceptional natural values, cultural heritage and occasional population, which is at the same time very attractive for visitors. The purpose of the National Park's management plan for the area was to maintain high aesthetics of the landscape and the extremely rich marine ecosystem. The observed natural conditions (winds and currents) and socio-economic features (environmental pressures during the peak tourist season) are causing specific problems within the park in terms of waste pollution. Human activities and their influence seem to be concentrated in the coastal zone: (a) areas with (occasional) settlements and infrastructure intended for the predominant nautical tourism, and (b) uninhabited areas mostly with bays and coves accessible only from the sea. Data show different origins of the waste according to the country of their production: Croatia, Turkey, Albania, Poland, Italy, Bosnia and Herzegovina, Montenegro, Germany, France, Greece, Hungary and North

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Macedonia with prevailing household plastic waste and solid wood waste. Evidently, waste has not stopped accumulating there.

Keywords Marine pollution · Coastal area · Solid waste · Cluster analysis · Kornati National Park · Croatia

1 Introduction

Marine waste is a complex cultural and multi-sectoral problem that imposes tremendous ecological, economic and social effects, and costs to communities around the world. One of the substantial barriers to addressing marine waste is the absence of adequate scientific research, assessment and monitoring. There is a gap in the information necessary to evaluate the impact of marine debris on coastal and marine species, habitats, economic development, human health and safety and social values. More information is also needed to understand the status and trends in amount, distribution and types of marine debris. There is also a gap in capacity in the form of new technologies and methods to detect and remove accumulations of marine debris (United Nations 2016).

The case of the environmental (waste) burden of the oceans was recognised pretty much as a disparity. The key findings determined already in the 1990s are five global ocean gyres where plastic gathers due to the current circulation. Only about 20% of the ocean plastic comes from marine sources, such as discarded fishing equipment or cargo ship mishaps. About 80% of it washes out to the sea from the beach litter or is carried downstream in rivers (Parker 2014). As for most of the beaches, the major debris is plastic. The spatial distribution of plastic debris is affected by multiple factors, including land uses, human population, fishing activity and oceanic current systems (Ribic et al. 2010).

The interaction between humans and the environment has caused intense landscape transformations which often led to landscape degradation. Working together, scientific and professional knowledge are able to keep the natural and cultural environment in sustainable, self-regenerating conditions. Self-sustainability is a necessity also in the field of waste treatment.

The issue of sea waste pollution represents an even greater threat when its long-term impact is considered. Since the sea waste does not care for the borders, the sea waste management, on the opposite side, should. The spatial distribution of sea waste led by natural arrangements (prevailing winds, dominant sea currents) is undoubtedly a matter of hidden geography.

The Kornati archipelago in the central part of the Adriatic Sea recognised as a landscape of natural values is threatened by the sea waste pollution. The islands are promoted as a preserved and pristine natural environment, which is therefore attracting a growing number of visitors each year. However, mostly hidden from the public eye lies the problem of an increased burden of the sea waste along the shores of the Kornati. This issue is mostly omitted in both scientific literature and media coverage, which often focus on more positive topics (e.g. natural and cultural heritage, positive impacts of tourism, and nature protection) since emphasising the waste management issues in the archipelago could possibly divert visitors from the islands. Besides the sea waste along the coast, there is also a problem of inland waste disposal. In most cases, these sites are hard to detect as the locally produced waste is intentionally illegally disposed of in more secluded locations, and the local population is sometimes reluctant to discuss this topic. On the other hand, sea waste washed ashore can easily be spotted even from the distance, but most of this waste is not locally produced and its origin can only be determined by the detailed analysis which is the main topic of this paper.

Here, the first analysis of the solid waste accumulation in the Adriatic coastal area is presented. Based on the social–environmental approach, no economic indicators had been included so far. Since our life and economies strongly depend on the oceans (50% of oxygen is produced in the ocean), we explored one view of that global issue at the regional level of Kornati National Park. A real impact of (plastic) waste introduction to the marine ecosystem (e.g. in biota and sea-floor sediments) is far from being globally controlled thus presenting a very unpredictable issue and in the case of the Kornati archipelago, as long as no organised international action is taken in the Adriatic Sea, the sea waste will remain a hidden geography topic.

Visible anthropogenic influences in the form of various types of waste distributed along the island' coasts should have already been studied. However, we have not found evidence of any long-term study regarding the surveyed topic of different waste types and materials.

2 Study Area and Environmental Settings

The Kornati archipelago is situated in the Croatian part of the Middle Adriatic (Fig. 1) covering an area of ca. 320 km^2, and includes ca. 150 karstified land entities (either permanently or occasionally above the sea level) arranged in four island chains in NW–SE direction. Kornati National Park, where the research was conducted, encompasses 68% of the Kornati archipelago (217 km^2), i.e. 89 islands (Fig. 1). In geological terms, they are part of >8,000 m thick carbonate succession deposited in several episodes from Upper Palaeozoic to Palaeogene (Vlahović et al. 2005) reworked by intensive tectonics mostly related to Alpine orogeny. Subsequent karstification and Late Pleistocene–Holocene transgression finally shaped the archipelago.

Presently, environmental features and processes strongly depend on the regional oceanographic and local climatic settings. Namely, Adriatic is a semi-enclosed sea connected to the Mediterranean Sea through the relatively narrow Otranto Straight, and is deeply indented into the European continent. Its surface circulation is generally cyclonic (Zore 1956), characterised by the northwest current along the eastern Adriatic coast, and southeast West Adriatic Current (WAC) along the western Adriatic coast (Fig. 2). Along with cyclonic circulation, a short-term phenomenon manifested as transitional currents occurs on the scale from days to weeks. These currents

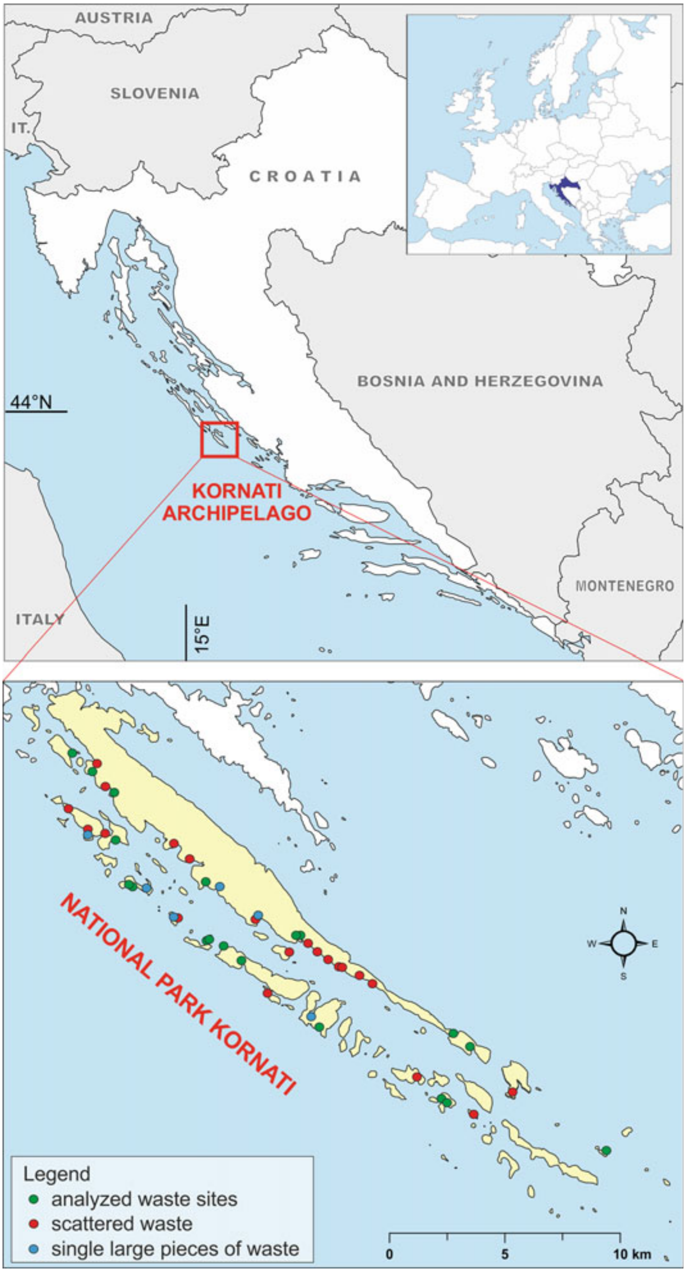

Fig. 1 Location of Kornati National Park and study sites within

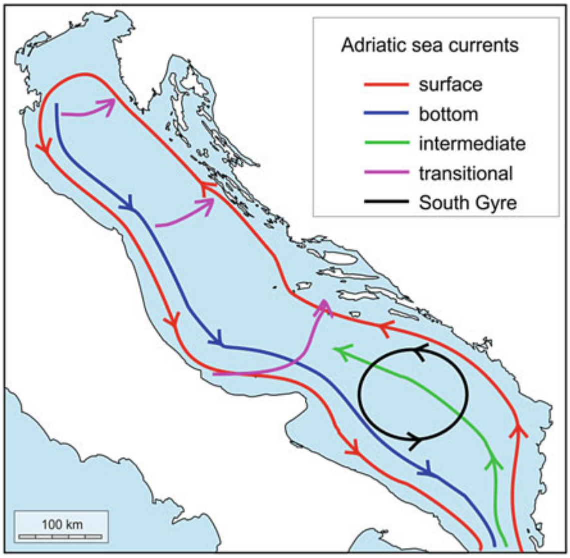

Fig. 2 Generalised Adriatic Sea circulations (after Morović et al. 2018)

are caused by a strong synoptic disturbance when strong bora and sirocco winds force WAC shift towards the Croatian coast, particularly at the Palagruža Sill and off Ancona (Vilibić et al. 2009; Morović et al. 2018). Astronomical tides have an average range of 25–30 cm, but occasionally meteorological influences, such as storm surges and tsunami-like sea-level oscillations induced by air pressure oscillations (Šepić and Vilibić 2011), can enhance the common range.

The climate of the study area is Mediterranean with hot and dry summers (Csa according to Köppen classification). Prevailing weather types are determined by the contact of the continental air masses from Central and Eastern Europe, and maritime air masses originating from the Atlantic Ocean and the Mediterranean Sea (Surić et al. 2018). During the summer, there is a dominant influence of the Azores High which supports stable, dry and warm weather with minimal, mostly local air circulation. During the autumn the high-pressure zone weakens, allowing the inflow of the Atlantic air masses within the low-pressure systems which are frequently moving across the Adriatic Sea bringing wet and windy weather throughout the autumn and early winter. During the winter, the weather often stabilises under the influence of the Siberian High, which induces incursions of the cold air over the Adriatic. These incursions, combined with the transition of low-pressure systems over the Mediterranean and the Adriatic Sea, induce the occurrence of the NE *bora* wind, the most frequent wind in the Kornati Islands (Fig. 3), which often reaches gale force. The second most frequent wind is the sirocco, SE wind, which is formed on the front side of the low-pressure systems and is typical for the autumn (CHMS 2020). Although it is not as strong as the bora wind, it produces the highest waves in the Adriatic Sea due to a larger fetch and a more constant speed. In November 2019, during a particularly strong sirocco episode, a record-breaking wave was recorded off

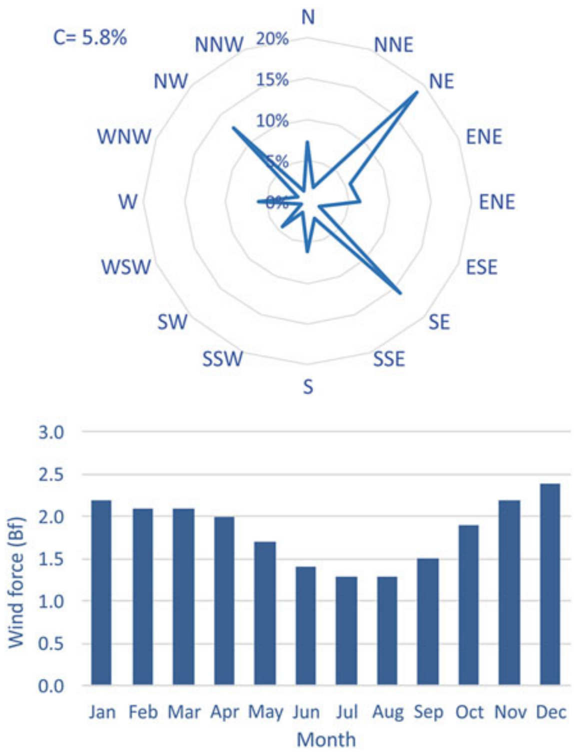

Fig. 3 Wind frequency and wind force recorded in Vela Sestrica meteorological station (NW part of the archipelago) for the 1990–2018 period

Dubrovnik, measuring 10.87 m (Hydrographic Institute of the Republic of Croatia 2019).

3 Historical Socio-economic and Landscape Changes

Although the Kornati Islands form an archipelago of around 150 islands, none of those are permanently inhabited. Scientists still debate the reasons for the absence of permanent settlements without reaching any consensus. The most probable cause is a combination of narrow-shaped islands which can only support small patches of arable land with sparse water sources and the distance from both the mainland and the settlements on the neighbouring islands. Additionally, these islands lack natural harbours, so only smaller vessels could anchor in few sheltered coves (Skračić 2013). Throughout history, the islands were inhabited only seasonally as the two cornerstones of the local economy—fishery and livestock breeding—were also seasonal. The settlers originated from the adjacent Dugi otok Island and from the late 1800s from the more distant Murter Island. The number of seasonally present population was always relatively small, usually between 200 and 300 inhabitants. Official census data cover the period from the mid-1850s onward. The first two censuses (in 1857 and 1869) showed no population on the Kornati Islands, while the 1880 census revealed 37 people living on the islands, and 23 of them on Kornat Island, the largest in the archipelago. Population peak of 313 inhabitants was recorded in the 1931 census, after which population rapidly declined, particularly after the end of the Second World War, so the 1953 census found no people living on the islands. During the last two decades, a small rebound of the population has occurred with 21 inhabitants recorded in the 2011 census (Magaš 2013). It is worth noticing that the census methodology has been changing, which prevents reliable comparison of the population numbers. Some censuses only recorded permanently inhabited population, while others recorded population which was present on the islands at the time of the census.

In their traditional economy, fishing prevailed as the main source of income. The target species were sardines, mackerels and bonitos with an occasional catch of tuna. Fishermen rarely ventured offshore and the school of fish was typically trapped with the net in bays and coves. Livestock breeding (mostly sheep) was extensive so animals were often left to fend for themselves and were occasionally gathered for milking or wool shearing. Other activities included olive growing, small-scale salt extraction and lime production which was—together with livestock grazing—responsible for the destruction of the islands' forests (Fig. 4).

The shift in the local economy came during the second half of the twentieth century. The 1960s saw the onset of mass tourism along the Croatian coast and a growing number of tourists visited the Kornati Islands. Tourism, although also seasonal and limited only to summer months, offered a far better perspective for the local population. Many people migrated to the mainland in order to work in tourism,

Fig. 4 Patches of arable land protected from livestock in the past on an otherwise barren island

while some of the old homes and storages on the islands were refurbished and offered to tourists. Along with the restoration of old houses the new ones were built, and at such rate that the number of newly built homes in the late twentieth and early twenty-first century surpassed the number of houses built in the entire history of these islands. For example, at the beginning of the 1800s, there were only around 20 houses in the whole of the archipelago. By the 1960s, this number increased to over 270, and today the number of houses there stands at over 800 houses (Magaš 2013). Furthermore, the islands have become very popular as a destination for nautical tourism which prompted the opening of two marinas and other tourism infrastructure (Fig. 5) in the archipelago. One of the marinas is located within the borders of the national park. The number of tourists was constantly rising until the early 1990s when tourism was halted by the outbreak of the Croatian War for Independence. The revival of their tourism began shortly after the end of the war in 1995, and today the national park is annually visited by more than 100,000 people. The real number is probably significantly greater because official statistics do not include visitors who do not enter the park. However, alongside evident economic benefits, tourism also carries numerous threats: increased traffic congestion, air and water contamination, increased quantities of waste, increased noise, a possible loss of the local identity and non-reinvestment of revenues achieved in the protected areas.

Such pressure on the environment necessitated some level of legal protection. The first initiatives appeared during the 1960s when it became apparent that the number of visitors was on the rise and the landscape began to suffer. The final result of the

Fig. 5 Restaurant and mooring area on Smokvica island

environment protection initiatives came in 1980 when a large part of the archipelago became a national park—the second highest level of protected areas in the Croatian legal system.

4 Environmental Starting Point

On the global level, the factors contributing most to the environmental risks are the fishing industry, chemical pollution and eutrophication, physical changes of the ecosystem (invasions of allochthones species) and global climate changes (National Research Council 1995). Kornati NP is usually considered an unpolluted reference area in environmental and ecological studies, but with growing tourism and increasing exposure to anthropogenic inputs. Some parts of the national park are still well preserved and mostly intact. On the other hand, there are some areas where human activity has already made an evident impact and has consequently contributed to the changes in environmentent. The pilot study showed that areas closer to marinas and seasonally inhabited villages (Fig. 6) are more likely to be affected by anthropogenic pollution. Yet, more distant areas remain anthropogenically unaltered (Ilenič et al. 2018).

5 Methodology and Fieldwork

The vessel-based pre-research of Kornati National Park directed to the systematic survey of the sea waste in the islands' area has been conducted as early as 2002. We recognised the exploration as reasoned and quite sensible, although we speak of the

Fig. 6 Seasonal settlement Vrulje, the largest on the islands, located in the cove sheltered from the dominant winds and near a favourable agricultural zone. The name of the settlement indicates the presence of freshwater (*vrulje* = submarine springs)

protected area of many natural and cultural values. In addition, Kornati has had the reputation of the tourist (nautical) attraction since the 1960s. Additionally, we used Sustainable Tourism Development Strategy for the Broader Kornati National Park Area (2015), which was produced following the Kornati National Park Management Plan (2014–2023). The mentioned documents have been confirmed also to keep the Kornati archipelago ecosystems' goods and services as a natural, self-regeneration environment.

The fieldwork was carried out in May 2018 as a cooperation of the Environmental Protection College Velenje and the Department of Geography, University of Zadar. To assess the protection regime in Kornati National Park area, we altered the method of indicators as the main methodological approach. For the purpose of fieldwork, we also adapted the questionnaire of landfill indicators. Sea kayak was used as the means of transport, since we had to directly approach the waste locations to create the database of ashore waste.

Firstly, in order to introduce principles of solid waste accumulation ashore in the archipelago of Kornati islands, we made a model based on evidence of 11 indicators. It helped to evaluate the waste locations: (1) geomorphological (2) coast characteristics, orientation, (3) openness of the bay/cove to the sea, (4) vegetation conditions, (5) distance of waste from the sea, (6) waste distribution, (7) landscape exposure of the waste area, (8) the amount of waste (in m^3), (9) origin of waste (information obtained from the packaging), (10) type and percentage of the waste type, and (11) share of plastic waste (in %).

5.1 Cluster Analysis

We applied the method of hierarchical agglomerative clustering to define statistically important characteristics for the waste deposited ashore. Cluster analysis itself can be understood as a method or a task to group a set of units in such a way that units inside the same group (also called a cluster) are as similar as possible and as different as possible compared to units from other groups. As a technique, cluster analysis was already introduced in the first half of the previous century by different authors (Driver 1932; Tryon 1939; Cattell 1943). There are several clustering algorithms, one of the most popular being connectivity-based clustering also called hierarchical clustering. Based on distances calculated between units, we can produce a dendrogram when applying hierarchical clustering. It provides a hierarchy of clusters that merge with each other at different distances. Based on the dendrogram, the number of clusters can be determined.

For the purpose of this research, we applied the method of hierarchical agglomerative clustering with the Ward method and squared Euclidian distance (Everitt et al. 2011) to define statistically important characteristics for the ashore waste accumulation. Six indicators (out of 11) were normalised and included in the clustering analysis. Based on the dendrogram in Fig. 13, the location's (19) features were joined into four clusters.

6 Results

The research encompassed the most indented west coast of Kornati NP islands in order to include as many locations as possible. The collected fieldwork data enabled the following categorisation of waste sites: (A) 19 locations were recorded, where the list of indicators could be completely filled in and statistically analysed (Cluster) (*analysed waste sites* in Fig. 1), (B) 21 locations were redefined as the waste spread along the shore area (category *scattered waste* in Fig. 1) and (C) 6 locations characterised with the large individual waste pieces, e.g. abandoned fishing vessel (category *single large pieces of waste* in Fig. 1).

6.1 Evaluation of the Natural Settings

Wind conditions are discussed in relation to the waste locations in bays' and coves' exposition to the prevailing wind directions (Fig. 7). Coasts with south and northwest exposure of the bays/coves proved to be the most affected by the waste was accumulation and coasts with southeast and southwest exposure followed. No waste has been recorded in the bays/coves with the northeast exposure.

Although the absence of waste in the bays/coves exposed to the predominant bora wind (NE) would imply that the wind is not the main contributor of the sea waste, detailed analysis of the prevailing winds and the origin of the waste suggests otherwise. Namely, most of the sea waste can be tracked down to the illegal landfills along the Albanian coast (Tudor and Janeković 2011) which is then washed into the sea, particularly during the autumn when gale-force SE wind (*scirocco*) often occurs. During such events, huge amounts of this sea waste can be found along the coast of the mainland and the islands in southern Croatia. When gale-force winds occur over longer periods of time, the sea waste can be carried further towards the central and

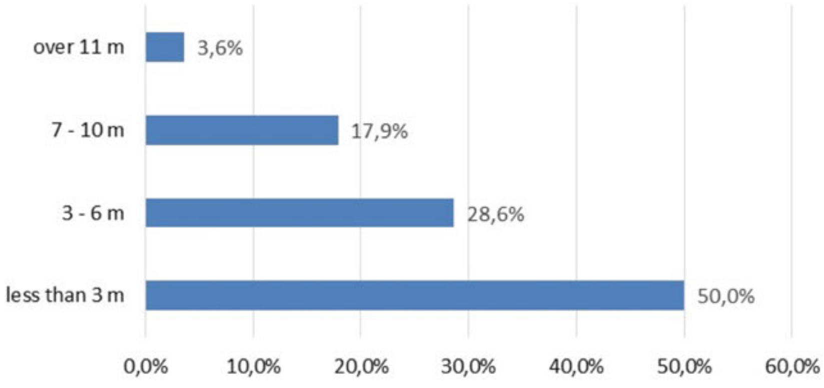

Fig. 7 Exposure of the bays and coves to the prevailing winds

even northern part of the Adriatic Sea. The effect of the scirocco wind on the spatial distribution of the sea waste is amplified by the fact that it coincides in direction with the dominant sea current in the Adriatic Sea. In the case of the Kornati Islands, since the scirocco is the second most frequent wind, it can be assumed that the wind in combination with the prevailing sea currents is the main contributor of the sea waste which is supported by the fact that the coasts exposed towards SE are usually the most affected by sea waste pollution (Fig. 7).

The paper also presents data about the origin of the waste (Fig. 8) which is mostly determined from the "made in" labels (e.g. on the food packages). Such determination is not reliable because the country of origin written on a package does not tell us in which country this item has been disposed of. For example, Italian-made automobile tyre can be washed to sea from the illegal waste site on Albanian shore, so the origin of that tyre is Albania and not Italy. Based on the "made in" labels, we determined that in most cases waste had a domestic origin (16 cases), followed by the waste originating from Italy (9 cases), Turkey (9) and Greece (8).

The prevailing orientation of the coast with waste sites was northwest–southeast (Fig. 9). This is in accordance with the prevailing NW–SE orientation of the eastern Adriatic coast.

According to the distance of the accumulated waste from the sea, the most frequent category of the waste distribution was the closest to the sea; in 50% of the locations, waste was deposited less than 3 m from the sea. The distance from the waste density was decreasing (Fig. 10).

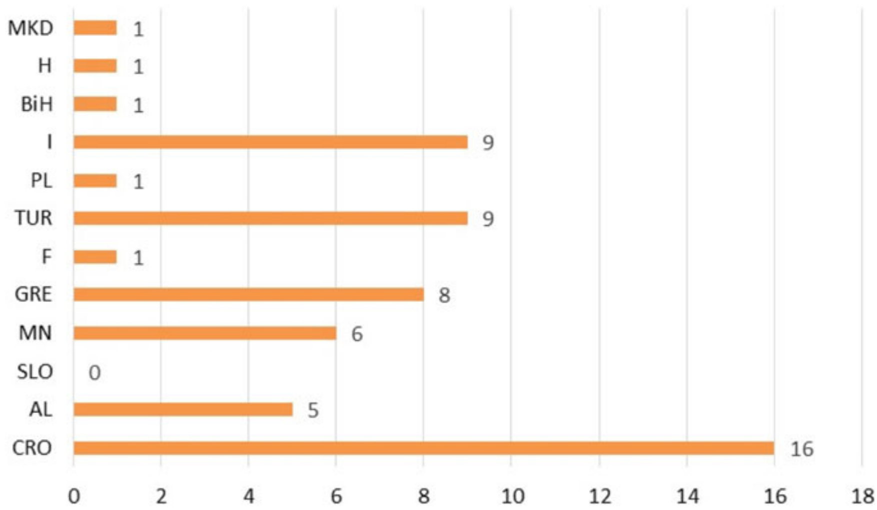

Fig. 8 Origin of the waste. Key: MKD—North Macedonia, H—Hungary, BIH—Bosnia and Herzegovina, I—Italy, PL—Poland, TUR—Turkey, F—France, GRE—Greece, MN—Montenegro, SLO—Slovenia, AL—Albania, CRO—Croatia

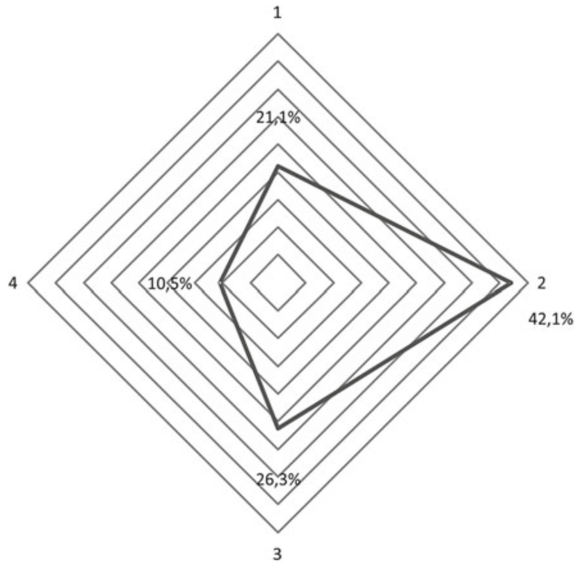

Fig. 9 Coast orientation. Key: 1 (N-S); 2 (NW–SE); 3 (NE-SW); 4 (E-W)

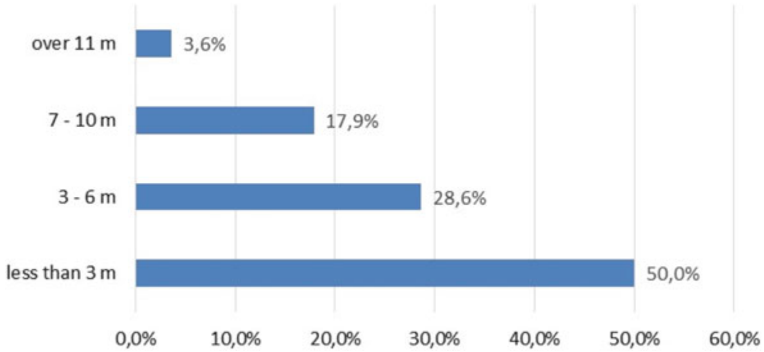

Fig. 10 Distance of the waste from the sea

6.2 Social Features of the Waste Locations

The following data on the anthropogenic settings were considered: (1) the access to the location and (2) the type and the share of the waste. The share of waste type indicator was favourable to the human impact (the maximum share represented household waste, which accounted for 32.1%; Fig. 12). All the waste locations were accessible by the sea (100%) and some also by (worse) path (26.3%)—Fig. 11. We reasoned the result from the occasional, tourism (nautical) activities causing overpopulation of the researched aquatory from May to October.

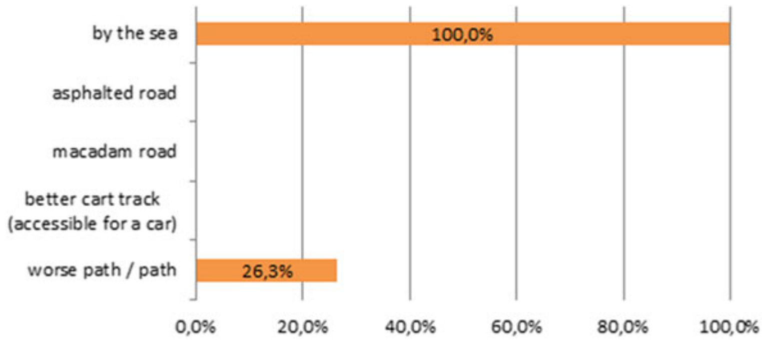

Fig. 11 Access to the waste location

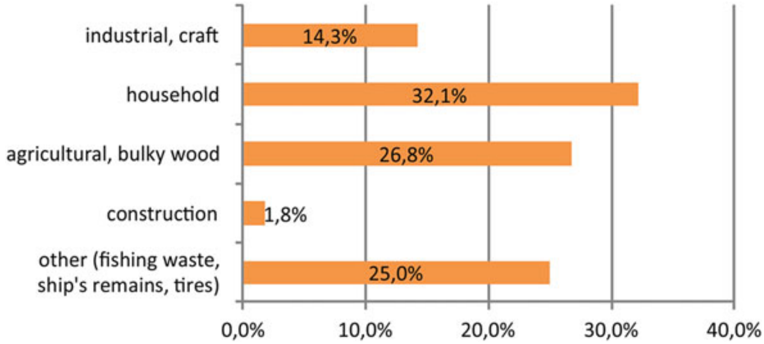

Fig. 12 The type and the share of the waste

6.3 Cluster Analysis

Following the method of hierarchical agglomerative clustering to define statistically important characteristics for waste accumulation ashore, the following six indicators (out of 11) were normalised and included in the clustering analysis: (1) the amount of waste, (2) the type and the share (in %) of waste accumulated, (3) the share of plastic waste, (4) the distance of waste from the sea, (5) the distance from a settlement area and (6) the origin of waste production. Based on the dendrogram in Fig. 13, locations' characteristics (19) were joined into four clusters (groups).

Four groups and their descriptions were formed taking also the rest of the five indicators surveyed into account:

1. Group 1: The highest amount of waste, biomass prevailing, SE openness of the bays/coves to the sea (Fig. 14);
2. Group 2: West openness of the bays/coves to the sea, mixed waste structure, the lowest amount of waste;
3. Group 3: The most frequent plastic, household waste;

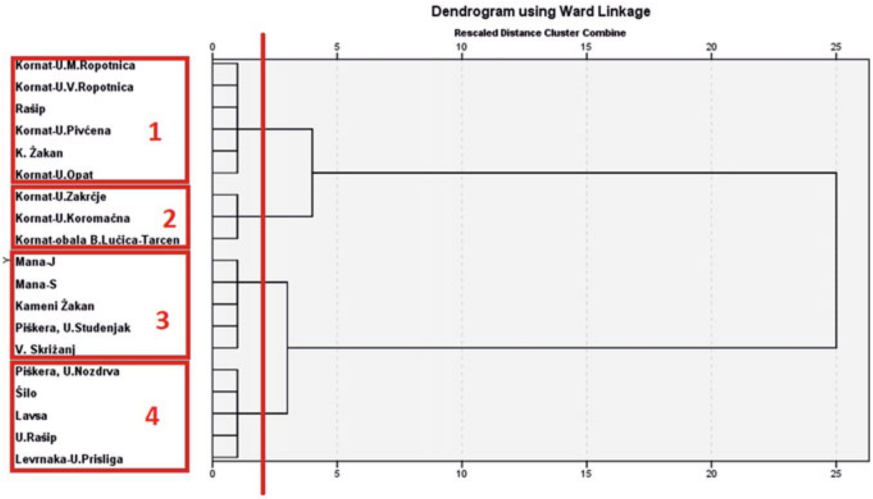

Fig. 13 Dendrogram of agglomerative hierarchical clustering of 19 waste locations in Kornati region

Fig. 14 The deposit of sea waste ashore, biomass prevailed (cluster group 1)

4. Group 4: Miscellaneous.

7 Conclusions

The introduced indicators'' approach represents an initial step in understanding the key characteristics of the littoral burden with waste accumulated in the Adriatic Sea. However, the field inventory followed the model, the quality of which will be proven after (a) repetition of the fieldwork at the same area and (b) a study of another island(s) in other parts of the Adriatic coast.

If we look back, Kornati National Park used to have the image of an area with minimal anthropogenic and natural disturbance. The collected data showed that the coastal waste composition and accumulation were determined by various impacts, both environmental and human. In the researched area we listed (A) 19 locations where it was possible to fill in the questionnaires completely; the waste material lay ashore in various condensed forms (e.g. Cluster Group 1, Fig. 14), (B) category were locations (21 cases) with the dispersed of waste ashore and (C) individual pieces of the waste (6 locations).

Apparently, the observed environment of Kornati NP should be discussed as an intertwined identity of (A) their applicable value based on the (B) well preserved natural values.

Following the essential pollution aspect of the research, we numbered the following findings of the inquiry:

(1) Considering the diversity of the sea waste type, we estimated 26.8% out of 52.8 m^3 of total waste (biomass; agricultural, bulky wood) as not risky for the environment. The rest should be treated as a potential for reuse or recycle.
(2) Waste in this area was distributed in layers (0.3 m average thickness) in 47.7% cases, and 8.4% in piles. In 47.9% of cases, we found waste scattered.
(3) In 73.3% of cases, waste locations presented the distance from the nearby village over 1000 m and an individual house was over 1000 m away in 57.9% of cases.
(4) In 78.9% of cases, the waste sites were assessed as exposed.
(5) The average amount of waste per location summed 2.8 m^3 (of a total of 52.8 m^3).
(6) In 84.2% of cases, the sites exhibited a state of occasionally washed ashore waste.
(7) The average share of plastic waste accounted for 65.4% of total waste.

To upgrade the above-concluded results, we composed some recommendations:

1. Regarding the waste structure, three types of potential sanitation measures are recommended: (a) disposal of waste to a municipal landfill for further waste management, (b) composting and (c) waste incineration.
2. Considering the human–nature relationship, a coordinated environmental action and engagement of the public should perform (a) a coordination of the private

sector and within it and (b) a multidisciplinary approach of land-based and sea-based activities including (human, material) sources to establish the actual and potential effects of (sea waste) plastics.

3. To cope with protected natural values of national importance and their use, some of the issues (conflicts) would be prevented if we gave top priority to public education about the sea and the sea waste issue and the awareness of its importance prior to the legislation and short-term economic gains.

The obtained results can be considered as an initial step in the waste management in the archipelago or as a signal to the public and the authorities that there is an issue of the sea waste pollution and that there is a need for organised action to deal with this issue on the local, national and international (Adriatic region) level. This research can also help to move the problem of the sea waste in the Kornati Islands from "hidden" to "visible" geography.

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