environments

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Monitoring of Coastal Dunes and Lagoons: Important Ecosystems to Safeguard

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Abstract: The coast of the Province of Brindisi, located in the south of Italy, is characterised by a large network of wetlands and coastal dunes of great ecological importance. These represent important habitats for flora and fauna, serving as feeding, breeding and migration areas for many bird species. Unfortunately, the state of health of some of these species is subject to various threats that put the ecological balance and local biodiversity at risk. It is essential to conduct regular and thorough monitoring over time to fully understand the presence of impacts on these ecosystems and to quickly take all necessary corrective measures to counter their main human-made threats, such as excessive urbanisation. This work reports the methods and results of the monitoring carried out along coastal dunes and a lagoon to identify their state of health and assess the presence of threatening factors capable of negatively altering their naturalness. The results indicate a situation of degradation affecting the coastal dunes but a good quality of the water resource. The study area is not currently affected by continuous monitoring programs and, therefore, we believe it is necessary to start a process in this sense, given the high naturalistic and historical value of the area. Finally, indications are provided to implement conservation measures to protect and preserve these precious coastal habitats, ensuring their survival for future generations.

Keywords: ecosystems; water quality; anthropic impact; diffuse pollution; fragmentation

Citation: Massarelli, C.; Campanale, C.; Uricchio, V.F. Monitoring of Coastal Dunes and Lagoons: Important Ecosystems to Safeguard. *Environments* **2023**, *10*, 211. https://doi.org/10.3390/environments10120211

Academic Editors: Yiannis G. Matsinos and Chin H. Wu

Received: 3 October 2023
Revised: 2 November 2023
Accepted: 29 November 2023
Published: 3 December 2023

1. Introduction

Coastal dunes and lagoons are unique, fragile and dynamic ecosystems located between the sea and the land. They are formed as a result of the combined action of wind and waves on the sand of the beaches [1]. These areas play a vital role in the coastal environment, providing a range of ecosystem services and supporting rich biodiversity [2]. Their conservation is essential to preserve these precious habitats and to ensure their ecological functionality.

Coastal dune conservation is critical for a variety of reasons, ranging from ecological balance to storm protection; the coastal dunes, indeed, act as a first line of natural defence against storms and tides [3]. Their presence and ability to absorb wave energy help protect inhabited areas and coastal infrastructure from flooding and coastal erosion [4]. Coastal dunes have been recognised as an effective mitigation measure against the impacts of climate change [5] and sea level rise [6].

Lagoons also act as natural buffers against flooding [7] and coastal erosion, reducing the impacts of storms [8].

The coastal dunes and lagoons form a unique habitat for a wide range of flora and fauna species. Many shorebirds nest in these areas [9], while several plants are adapted to survive in brackish and windy conditions. Many fish, migratory birds (between Europe and Africa) and other animal species depend on lagoons as a place to spawn, feed and rest during migrations [10]. The coastal dunes act as important ecological corridors between the sea and the hinterland, allowing for the movement of animal and plant species and

contributing to the biological diversity of the coastal regions; the lagoons, on the other hand, act above all as nurseries for many living organisms, providing safety for the early life stages of several species.

These important habitats also act as natural filters for rainwater and inland drainage water [11]. Dune sands retain and filter sediment and freshwater contaminants while lagoon plants absorb and remove nutrients, such as nitrogen and phosphorus, and by retaining the sediment, help maintain water quality in coastal areas [12].

The dunes and lagoons attract tourists for their unique natural features and recreation opportunities, providing spaces for relaxation, bird watching and other activities [13]. Their conservation is essential to ensure sustainable tourism [14] and the responsible use of these protected areas [15].

The Habitats Directive (92/43/CEE) [16] requires a careful analysis of the state of conservation of protected habitats and species through a constant evaluation of trends and a verification of the threat factors that influence the state of the environment. The Water Framework Directive (WFD) 2000/60/EC also indicates that it is necessary to monitor the state of the waters of the river basins to avoid the deterioration of surface waters and protect and improve the state of groundwater while preserving protected areas. These assessments, therefore, envisage a capillary and standardised collection of environmental data and complex analysis activities that represent significant technical aspects.

A known problem in the territory of the Puglia region is the presence of various activities that create "strong pressure" on environmental matrices, such as mining, landfills, careless management of the waste, fertilisers and pesticides that cause the presence of potentially polluted and contaminated areas [17], nitrate-vulnerable zones [18], plant protection products vulnerable zones [19], areas subject to the risk of desertification and areas with strong tourist pressure. These activities are capable of negatively affecting the conservation status of habitats and the functionality of the related ecosystem services [20].

The monitoring methods in Italy, precisely to assess the conservation status of these habitats, are defined by various manuals [21–23]. Monitoring, i.e., the periodic and systematic detection of certain parameters, is an essential tool for the study of environmental systems, to which three main functions can be attributed: provide information on deviations from the optimal state of an ecosystem, measure the success of management and conservation actions and detect the effects of perturbations and disturbances [24]. To ensure that the data collected during a monitoring program can be sufficiently useful, it is necessary to pay particular attention to the construction of a planned scheme, keeping in mind the purposes and implementing an adequate balance between the sampling effort (data collection generally represents the most onerous part of monitoring plans, in terms of time and costs) and the type of information obtained. Indeed, it should be considered that the increase in information obtained from a monitoring project does not always translate directly into benefits for conservation purposes [25].

The problems relating to habitat-monitoring techniques are quite complex as their nature requires the consideration of different components, such as vegetation, type of substrate, geographical area of distribution and climate [26]. The complex structure of these areas means that current conservation strategies consider the protection of habitats as a necessary condition for the success of any land management action; therefore, the need emerges for the preparation of survey protocols aimed at the systematic collection of information useful for defining the ecological needs of the habitats.

This work reports the methodologies used to implement low-cost monitoring of coastal dunes and lagoons. The information collected will be useful for identifying the state of health of endangered ecosystems. The methodological approach used aims to understand whether (i) the diversity and abundance of plant species in coastal dunes can provide useful information to understand the health status of these fragile environments or if it is necessary to introduce other evaluation parameters; (ii) the presence of pioneer plant species in the coastal dunes, which play a fundamental role in stabilising the dunes, can counteract the erosion created by anthropic and natural factors.

Finally, it is hoped that these first monitoring data can be used as a useful reference for the implementation and interpretation of the results of future monitoring. Only in this way will it be possible to evaluate the effectiveness of policies and actions in contrasting environmental threats to safeguard biodiversity through the conservation of these habitats.

2. Materials and Methods

2.1. Study Area

The site is located about 10 km south of the town of Torre Canne in the province of Brindisi. It consists of a characteristic pond behind the dunes, delimited near the coast by a very thin dune cordon of several kilometres (Figure 1). The surface area is approximately 25 hectares. The dunes, formed during the Holocene [27], have allowed for the stagnation of water and the rising of the coastal water table, creating the conditions for a coastal pond and a salt marsh, with Salicornia to form behind them; today, it is partly buried, cultivated and damaged by the construction of the highway. The lagoon is also called "Lido Morelli" due to its proximity to a bathing beach with the same name. In the area, it is possible to observe the presence of the typical vegetation of the sandy coasts with the presence of some specimens of juniper trees of great naturalistic value. The back of the dunes is characterised by the presence of Mediterranean maquis, in which *Pistacia lentiscus* L. and *Myrtus communis* L. are predominant. In the area, there are also several halophilous herbaceous plants, such as glasswort and different species of rush and statice, including *Limonium apulum* Brullo, an endemic species of the Puglia coasts. The wetland is also a favourable habitat for numerous species of sedentary and migratory birds, such as *Ardea cinerea* L. and *Himantopus himantopus* L. In the past, it was used as an aquaculture facility, and indeed, there are various masonry works to delimit and convey the water and lock mechanisms to regulate water levels. In recent years, the area behind the dunes and, in general, the wetlands in the vicinity have been greatly altered following the construction of facilities for tourism [28].

(**a**)

(**b**)

Figure 1. *Cont.*

(**c**)

Figure 1. Study area: (**a**) geographical position; (**b**) "Lido Morelli" lagoon; (**c**) coastal dunes with junipers.

2.2. Floristic and Vegetation Analysis

Plant taxa were determined through the application of the taxonomic keys for classification reported in various guides [29,30], assigning the nomenclature according to the updated checklist of the vascular flora native to Italy [31–34]. For each identified species, it was identified through the Acta plantarum dataset [35], while the family and the biological form according to the Raunkiær system [36,37] and the chorological type according to Ref. [38]. The biological form represents a simple and clear system to highlight the relationships between climate and flora, while the chorological type is a useful way to define the geographical distribution of plants.

The vegetation survey was carried out using the Braun-Blanquet method [39]. This methodology is based on a qualitative evaluation of the vegetation, emphasising its structure and composition in a detailed way to provide an accurate and reproducible description of the vegetation in a given site. For this purpose, a scale of abundance–dominance of plant species is applied. This scale is subjective and requires some experience to avoid misinterpretations and be able to compare results. The ordinal values used range from 5 (coverage for more than 3/4 of the surface of the relief) to 1 (individuals are well represented, but cover less than 1/20); the symbol "+" indicates plant species with little coverage. The survey units vary from 150 to 200 m^2 from the area of land in which all the plant species present in a homogeneous vegetation sample are recorded. It varies in size depending on the purpose of the study, but it must be homogeneous from an ecological point of view. It is essential to select the survey sites representative of the area under study, identifying the survey units within each site and taking into account their ecological homogeneity. Each survey unit must contain one or more "diagnostic" species, i.e., significant botanical species that characterise that particular environment from an ecological point of view. These species are used to distinguish and identify the different types of vegetation. During the survey, information relating to the degree of coverage of the herbaceous, shrubby and tree layers is also recorded. This analysis will allow us to identify if there are aspects of vegetation degradation that can be correlated to some pressure factors. For each identified species, we also reported the presence of regulatory protection (if any).

The analysis focused on areas with dune vegetation to represent the ecological and health status of the dune cord in support of the analysis of their fragmentation.

2.3. Evaluation of Water Quality

Monitoring the water matrix of lagoons is essential for understanding the health of aquatic ecosystems and to evaluate the impact of human activities on these fragile ecosystems. One of the most advanced and widely used methodologies for collecting water quality data is the use of multiparameter probes. These instruments are designed to measure several key parameters simultaneously, providing a complete view of the water condition and its physicochemical characteristics. A Hanna Instruments® model HI 98194 probe was used for water monitoring because it can measure and memorise up to 12 different parameters for water quality. The measured parameters are pH, dissolved oxygen (% and mg/L), conductivity (ms/cm), turbidity (total suspended solids in ppt), salinity (practical

salinity unit or PSU), temperature (°C), phosphates, nitrates and ammonium (mg/L). These parameters, recorded in the spring and summer seasons, provide essential and crucial information to evaluate the balance in the lagoon ecosystem and promptly detect anomalies or pollution.

Electrical conductivity can provide an estimate of water salinity, which is a key factor in lagoons, as they can be affected by tides and freshwater inputs. The presence of nutrients in the water is essential for the assessment of algal biomass and for understanding the dynamics of algal growth, especially in the presence of algal blooms. Multiparameter probes allow one to obtain real-time data, allowing for continuous monitoring and detection of seasonal variations. This is particularly important in dynamic environments such as lagoons where conditions can change rapidly.

Using a multiparameter probe reduces monitoring costs, as it allows one to measure multiple parameters with a single instrument while at the same time allowing one to monitor different areas of the lagoon almost simultaneously.

Before using the multi-parameter probe, calibration of the sensors is required to ensure accurate measurements. This aspect involves the use of calibration solutions with known values of the parameters to be calibrated. Each acquisition had such a duration as to allow the values displayed on the data logger to stabilise, and it lasted less than 3 min. Three acquisitions were carried out at three different points in two years of monitoring for a total of 15 acquisitions; the recorded data were averaged.

2.4. Fragmentation Assessment

Habitat fragmentation is a process that occurs when a natural environment is divided into small portions separated by natural or human-made barriers, such as roads, dams, urbanisation or deforestation. This separation can prevent or limit the migration of animals and plants, creating islands of habitat that are no longer able to support all individuals of the population of each species [40].

The evaluation of the fragmentation of the dune habitats was carried out with the method used in Ref. [41], which integrates and improves the official method in Ref. [23] with the addition of some details, such as the paths created by tourists that are not contemplated in the official methods, which allow for an evaluation with a greater spatial resolution (Figure 2). The evaluation of fragmentation is based on the calculation of indices, ind1pa and ind2pa [42], based on the geometries of the areas considered concerning the lengths of the infrastructures that cut them.

Figure 2. Various human-made paths in the coastal dunes.

3. Results

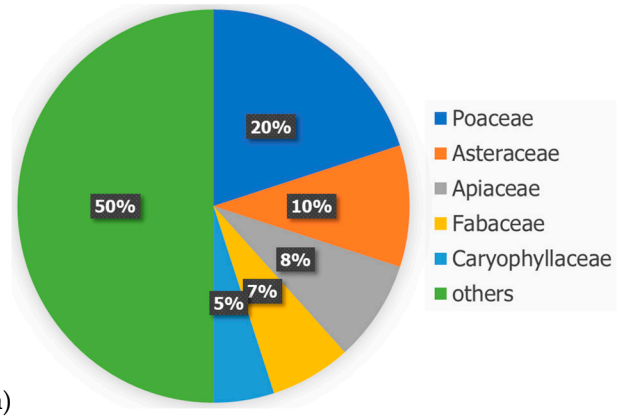
3.1. Flora and Vegetation of the Dunes

The floristic surveys carried out in the spring of 2022 made it possible to identify 60 species belonging to 29 families. An analysis of the list shows that 13 species are included in lists of protected species at the national or regional level. None of these are protected by the legislation of the study area region. The collected data with all the useful information are reported in Table S1.

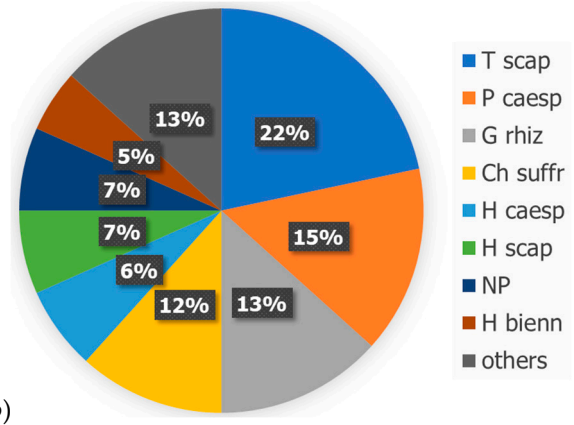
Based on the research carried out in the area under examination, the vascular flora of the dunes is mainly represented by the families Poaceae (20%), Asteraceae (10%), Apiaceae (8%) and Fabaceae (7%), which are among the most numerous (Figure 3a).

The results of the frequencies of the biological forms indicate the predominance of scapose therophytes, bushy phanerophytes, suffruticose chamaephytes and rhizomatous geophytes (Figure 3b).

From the analysis of the chorological spectrum, it can be seen that the flora of the dunes has a significant contingent of Steno and Euri–Mediterranean elements. Many widely distributed species are weeds of cultivated fields (Figure 3c).



(**a**)

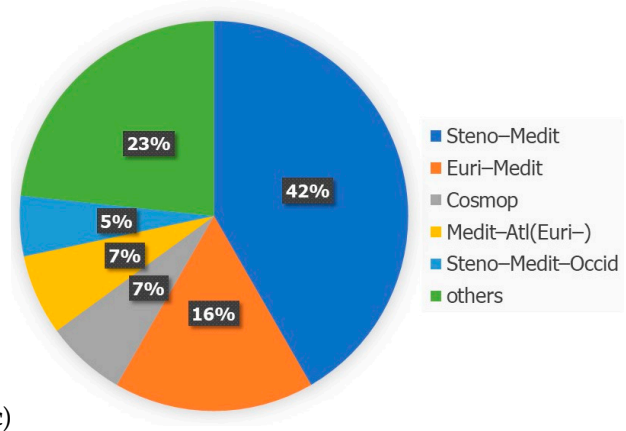


(**b**)

Legend

T scap: Scape therophytes
P caesp: Caespitose phanerophytes
G rhiz: Rhizome geophytes
Ch suffr: Suffrutex phanerophytes
H caesp: Caespitose hemicryptophytes
H scap: Scape hemicryptophytes
NP: Nano–phanerophytes
H bienn: Biennal hemicryptophytes

Figure 3. *Cont.*



(**c**)

Legend

Steno–Medit: Steno–Mediterranean
Euri–Medit: Euri–Mediterranean
Cosmop: Cosmopolitan
Medit–Atl(Euri–): Mediterranean–Atlantic(Euri–)
Steno–Medit–Occid: Western Steno–Mediterranean

Figure 3. Results of the floristic vegetation analysis: (**a**) frequency of identified species by family; (**b**) frequency of species by biological form; (**c**) frequency of species by corologic type.

3.2. Water Quality

The results of the acquisitions with the probe aimed at assessing water quality are reported in Table 1.

Table 1. Calculated values relating to the water of the lagoon.

Parameters	Mean	Dev Std
pH	7.9	0.7
Conductivity (ms/cm)	20.9	1.8
Total Dissolved Solids (PPT)	10.7	0.8
Salinity (PSU)	12.5	1.2
Temperature (°C)	20.8	3.2
Phosphates (mg/L)	0.2	0.1
Nitrates (mg/L)	<1	-
Ammonium (mg/L)	<0.02	-
DO (%)	120.5	69.4
DO (mg/L)	7.6	3.4

3.3. Fragmentation Assessment

The fragmentation assessment [41] precisely indicates the presence of a high level of fragmentation of the coastal dune habitats considering the road network and the paths created by tourists (Figure 4).

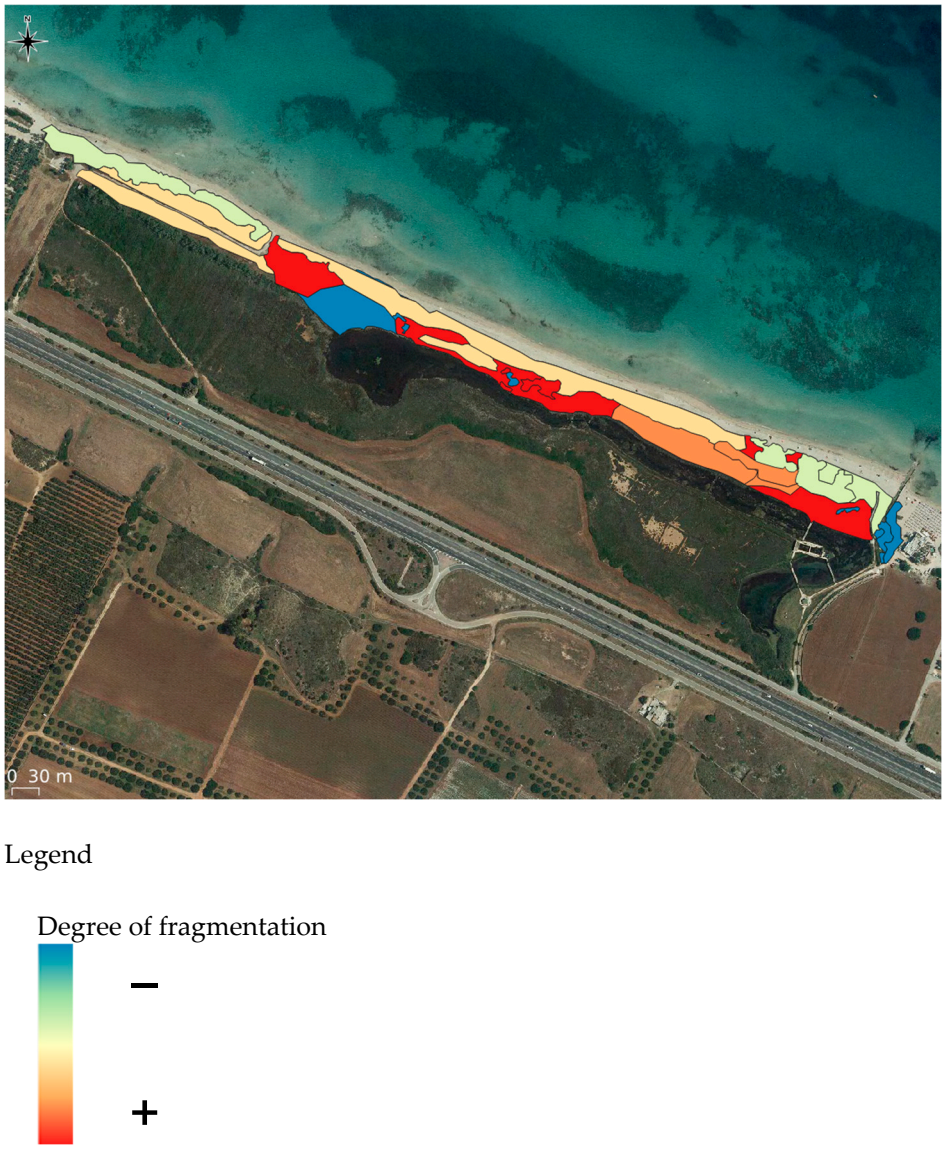


Figure 4. Degree of fragmentation of coastal dunes for homogeneous area.

4. Discussion

Coastal dune and lagoon habitats are vital for numerous species of flora and fauna, playing a crucial role in conserving biodiversity and providing essential ecosystem services for local communities. The health of some of these coastal dunes and lagoons is a matter of concern due to various environmental threats.

The coastal dune habitat in the study area is currently limited to the few coastal stretches not exploited for tourism or residential purposes. The juniper communities are fragmented and altered by urbanisation (roads and towns) and by the use of the dunes by tourists to shelter from the sun. Habitat fragmentation has serious consequences for biodiversity, as it can lead to the extinction of some species and a decrease in genetic diversity within populations [43]. To prevent or mitigate the effects of habitat fragmentation, several strategies can be adopted, such as the creation of ecological corridors connecting natural areas [44]; the conservation of remaining habitat areas; land use planning accounting for the conservation of biodiversity; and the promotion of collaboration between various stakeholders, public and private bodies for the conservation of natural habitats.

The high degree of fragmentation tells us that the coastal dune habitat is under severe pressure from tourism. The deliberate opening of paths that cross the dunes is a serious phenomenon that must be remedied quickly (Figure 2). The damage that these paths are

creating is also supported by the analyses carried out with the vegetation survey. The predominant presence of the Poaceae and Asteraceae families is indicative of the presence of numerous disturbing factors that are reflected in the vegetation of the dunes. The results of the frequencies of the biological forms indicate the presence of species typical of dune vegetation, as they have particular physiological and morphological adaptations that allow them to grow on the sands and survive in such a limiting environment. The high presence of these species indicates the presence of a climate with low rainfall and high average temperatures, compatible with the dune environment of Puglia. The presence of a considerable contingent of widely distributed species such as the cosmopolitans is linked to the species of synanthropic and ruderal environments.

The results of the floristic analysis of the dune vegetation indicate the almost total absence of lush dune vegetation and the absence of the typical schematic zoning of the vegetation of well-preserved sandy Italian coasts, and indeed, the ideal situation is represented by the sequence of annual plant communities, communities of embryonic dunes, unconsolidated dunes characterised by ammophilous species and, finally, stable dunes with juniper trees, which include woody sclerophyllous phytocoenosis up to pine forests [45]. The whole sequence is not visible in the study area [46], and the various types of vegetation are very mixed, making it sometimes difficult to identify a homogeneous vegetation cover as required by the applied method. The presence of a considerable contingent of widely distributed species such as the cosmopolitans, linked to the species of synanthropic and ruderal environments, also suggests a state of degradation. Many widely distributed species are infesting cultivated fields; in fact, near the dunes, the uncultivated fields and the ruins currently constitute a pressure factor to the protection of these environments. Even the management of the stranded parts of *Posidonia oceanica* (L.) Delile are not exactly consistent with what is prescribed by law. There are several cases in which we have found plastic waste mixed with beached *P. oceanica* leaves accumulated together and not appropriately reused for dune nourishment as required by law (Figure 5). This may cause further environmental concerns, such as microplastic diffuse pollution.

Figure 5. Example of incorrect management of accumulations of *Posidonia oceanica* (L.) Delile. Plastic fragments are evident within the accumulations of plant material.

Let us now analyse the situation of the lagoon.

The monitored lagoon "Lido Morelli" is of exceptional ecological, cultural and historical importance. As seen, there are various channels through which the water resource is managed for various purposes. In a corner of the lagoon, there is also a small underground spring whose water comes from the *Murge* plateau a few kilometres away. The monitored wetland is also a vital habitat for numerous marine and bird species [47].

The health of a lagoon is a crucial aspect of the survival of the ecosystem. In the specific case of a lagoon with recorded values (Table 1), it opens up interesting reflections on the ecological balance and its ability to support biodiversity. A pH of 7.9 favours the development of some species and hinders the establishment of others. The conductivity of water is an indicator of the presence of dissolved salts and minerals. A value of 20.9 mS/cm suggests that the water contains a significant amount of salts [48]. This high conductivity affects the ability of aquatic species to tolerate the level of salinity present. However, this value is also influenced by groundwater inputs from the spring. A suspended solids value of 10.7 ppt indicates a moderate presence of suspended solids. These solids affect the clarity of the water and the filtration capacity of the organisms that feed on it. A salinity of 12 PSU indicates a moderate concentration of dissolved salts in the water [49]. This datum is connected to conductivity and influences the composition of the marine communities present. Species that prefer more saline environments may thrive, while others may struggle to adapt. Water temperature, a key factor for marine life, can be considered moderate, but it is important to monitor seasonal variations and the effects of climate change. Temperatures that are too high or too low compared to the norm cause stress to the species present. Phosphates are essential nutrients for aquatic plants, but excessive concentrations lead to algal blooms and ecosystem imbalances. A value of 0.2 mg/L is moderate, but it is important to constantly monitor the presence of nutrients in the water. The dissolved oxygen values are optimal [50].

During the monitoring period, there were no precursory phenomena of eutrophication where the excessive supply of nutrients derived from agricultural and urban activities causes algal blooms, reducing the amount of oxygen available to marine organisms and causing excessive death of almost all organisms.

The area is the subject of long-term conservation and restoration programmes; the community that manages the protected area is very active and contributes day after day to improving the quality of the water and preserving the natural habitat for the local flora and fauna.

The characteristics of the "Lido Morelli" lagoon described offer an interesting overview of its state of health. However, it is essential to conduct regular and thorough monitoring to fully understand the impact of these conditions on the lagoon ecosystem and to take any corrective measures if necessary. Sustainable management of the environment requires constant attention to the variations and challenges that may emerge over time.

Five key measures are proposed below for the reduction of negative impacts on lagoon ecosystems:

1. Environmental monitoring over time: implementing a regular environmental monitoring system is essential to collect data on water quality, biodiversity, nutrient levels and other critical indicators, such as the presence of invasive species. This data will make it possible to promptly identify any negative changes in the ecosystem and to take preventive or corrective measures.
2. Management of pollution sources: identifying and reducing sources of pollution that can negatively affect the lagoon is an important step. This could include promoting sustainable agricultural practices to reduce nutrient inputs and proper waste management, as well as controlling industrial and domestic discharges.
3. Recovery of the coastal area: restoring the coastal area through the planting of typical species by removing human-made paths and prohibiting access to these areas by humans. This would also help stabilise the banks, improve natural water filtration and provide vital habitats for many species.

4. Creation of additional protected areas: defining areas where human activity is forbidden, restricted or controlled can help conserve the ecosystem. These areas can serve as reserves for local fauna and flora and help maintain a healthier natural environment.
5. Environmental education and community involvement: increasingly involving the local community through environmental education programs to raise awareness of the importance of the lagoon ecosystem and promote sustainable tourism practices.

These measures represent only some of the many possible strategies for reducing impacts on the ecosystems under study. The key is to adopt an integrated approach that considers the complexity of the ecosystem, involves all stakeholders and relies on solid scientific data to make informed decisions.

5. Conclusions

The floristic and vegetation analysis indicated the presence of degradation aspects of the dune vegetation, confirming itself as a valuable tool for studies on vegetation, as it allows one to obtain detailed and comparable information on the ecosystem, helping to better understand environmental changes and providing a solid foundation for the management and conservation of plant biodiversity. This analysis was supported by the assessment of habitat fragmentation, which represents a serious problem that must be addressed to preserve the biological diversity and health of these ecosystems. Tackling fragmentation requires an integrated approach and collaboration between different stakeholders to promote the conservation and restoration of natural habitats.

Monitoring lagoon water with a multiparameter probe represents a highly effective and efficient approach to obtaining detailed data on water quality and the lagoon ecosystem as a whole. This technology plays a crucial role in the management and conservation of water resources, helping to ensure sustainable management of lagoons and preserving marine biodiversity. The results indicate an excellent quality of the water resource.

The lagoons in the province of Brindisi in Puglia represent a natural heritage of great ecological and cultural value. The "Torre Guaceto" lagoon, with its conservation and protective management efforts, represents a positive example of how a lagoon can be preserved and maintained in a state of sustainable health. On the other hand, the monitored "Lido Morelli" lagoon faces several environmental challenges, implementing sustainable management measures and the active involvement of local communities crucial to preserving and protecting this precious ecosystem.

The protection of the lagoons in the province of Brindisi is essential to ensure the survival of many species of flora and fauna (acting as stepping stones for the migration of internationally protected species) and to maintain the ecological balance of these coastal habitats. It is necessary to integrate the studies with censuses of the wildlife present to understand if sensitive species frequent the study area. Only through a joint effort to protect and raise awareness can a sustainable future be guaranteed for these important natural areas of Puglia.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments10120211/s1, Table S1. Collected data with all the useful information.

Author Contributions: Conceptualisation, C.M.; methodology, C.M. and C.C.; validation, C.M. and C.C.; formal analysis, C.M.; investigation, C.M., C.C. and V.F.U.; data curation, C.M.; writing—original draft preparation, C.M. and C.C.; writing—review and editing, C.M., C.C. and V.F.U.; supervision, C.M.; project administration, C.M.; funding acquisition, C.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the project Monitoring Innovative Advanced—MIA Natura 2000 Network POR—POC Puglia 2014–2020—Axis VI Action 6.5 Sub-Action 6.5.a—Procedure for the selection of monitoring actions of the Natura 2000 Network on habitats and species of Puglia (D.G.R. n. 150/2020 and D.G.R. n. 846 of 31 May 2021).

Data Availability Statement: Data are contained within the article and Supplementary Materials.

Conflicts of Interest: The authors declare no conflict of interest.

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