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The Po Delta Biosphere Reserve: Management challenges and priorities deriving from anthropogenic pressure and sea level rise

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Abstract

The Po Delta Biosphere Reserve is located in Northern Italy and has attained recognition by UNESCO in 2015 due to its unique natural and cultural value. The reserve covers an area of approximately 140 000 hectares, supporting a human population of 118 000, as well as a complex mosaic of ecosystems, which are found in this transitional waters landscape.

Administratively the area is highly fragmented and this renders its management challenging. Besides administrative fragmentation between two Park Authorities and a number of local and provincial authorities, organizational challenges within the Authorities themselves make it increasingly difficult to ensure continuity in the maintenance, review and update of conservation priorities.

The present study is intended to establish a comparative analysis of conservation priorities within the Po Delta Biosphere Reserve, in order to support relevant Authorities and conservation managers in ensuring the preservation of high value areas. The study was articulated according to five objectives, which were fulfilled by making use of publicly available data. Data was analysed by performing a weighted overlay analysis to address the research questions that were relevant to each objective.

The first objective of the study was to determine parameters that could be used to characterize conservation value. In this context, the Conservation Value Index (CVI) was implemented, which enabled the localization of areas of value within the study area. The CVI was based on land cover characteristics, the presence of designated protected areas and the presence of protected species included in the International Union for Nature Conservation (IUCN) Red List. According to the CVI characterization, approximately 50% of the Biosphere Reserve area was defined as having high or very high conservation value, with a further 31% having medium conservation value.

Upon determining the location of high conservation value areas, the effect of two different types of environmental pressure was assessed, both individually and in combination, by linking the effect of pressure to the distribution of conservation value within the Biosphere Reserve. This assessment was the

subject of the subsequent three objectives of the study (objectives 2-4), whereby risk to water quality, risk deriving by sea level rising due to climate change and the combination of these risks were assessed.

The first type of pressure, examined under the second objective of the study, was associated with the potential risk that human activities place on water quality. For this purpose, the distribution of agricultural and farming activities was assessed, as well as the distribution of tourism. It was considered that both these activities could potentially adversely affect water quality by contributing to the accumulation of organic nutrients, which could create imbalance in the most valuable areas for conservation.

In this study, approximately 28% of the total Biosphere Reserve area was associated with high risk to water quality and 55% with medium risk, based on the types of activities supported. Upon linking risk to water quality to the distribution of areas of high and very high conservation value, it was determined that approximately 18% and 23% of the total high and medium risk areas were composed of high and very high value areas.

The second type of pressure was examined under the third objective of this study and was associated with the risk of flooding deriving by climate-induced sea level rise. For this purpose, elevation information was taken into consideration, together with sea level rise estimates from the Intergovernmental Panel on Climate Change (IPCC). Overall, 75% of the Biosphere Reserve area was observed to be located below sea level. Under the worst-case scenario, corresponding to an increase in sea level of 0.82 m by 2100, the total area located below see level was estimated to increase to almost 90% of the total. Under these conditions, approximately 44% of the total flooded area would be made up of high and very high conservation areas, with a further 28% corresponding to areas of medium conservation value.

The fourth objective of the study examined how the combination of risk factors relating to water quality and climate change-induced sea level rise would impact the distribution of conservation value within the Po Delta Biosphere Reserve. Overall, only 0.38% of the total area was free of from risk, whilst 12.5% would only be impacted by one type of risk. The remaining 87% of the

Biosphere Reserve area is expected to be susceptible to combined risk factors, albeit with different intensity. Under the worst sea level rise predictions, high and very high conservation areas extended to over 37% of the combined medium and high risk areas for water quality.

In the last part of the study, the fifth objective was addressed, which related to comparing current prioritization for conservation, which is based on three different conservation management types, with the prioritization in this study based on the combination of water quality and flooding risks. Results indicated that under the current practices, 50% of the area is identified as medium or high priority. However, under the newly proposed prioritization methodology, this area would increase to 60% of the total area. Furthermore, under the newly proposed prioritization, some 36% of the area would experience a positive change towards a higher priority status, whilst 13% would experience a negative change towards decreased priority.

The most notable differences related to the extent of high priority areas in the Northern and Southern part of the Biosphere Reserve, which would increase in their extension. Similarly, medium priority areas would also increase their extension in the Southern part of the Biosphere Reserve, but would decrease in the central part of the Biosphere Reserve under the newly proposed prioritization regime.

Overall, the study objectives were achieved and a new prioritization method for the management of areas within the Po Delta Biosphere Reserve is proposed. The proposed methodology sets the basis for advocating the inclusion of risk factors in the definition of conservation priorities.

Contents

Figures

Tables

Abbreviations

BSL	Below Sea Level
CIESIN	Centre for International Earth Science Information Network
CORINE	Coordination of Information on the Environment
CVI	Conservation Value Index
DPSIR	Driving Forces, Pressures, States, Impacts, Responses
DSS	Decision Support System
EC	European Community
EU	European Union
EEA	European Environment Agency
EIONET	European Environment Information and Observation Network
FAO	Food and Agriculture Organisation
ha	Hectare
HNV	High Nature Value
HWR	High Water Risk
ICZM	Integrated Coastal Zone Management
IPCC	Intergovernmental Panel on Climate Change
ISTAT	Istituto Italiano di Statistica / Italian National Institute of Statistics
IUCN	International Union for the Conservation of Nature
LSU	Livestock Load Units
LWR	Low Water Risk
MWR	Medium Water Risk
N	Nitrogen
NCR	No Combined Risk
P	Phosphorus
RCP	Representative Concentration Pathway
SRES	Special Report on Emission Scenarios
TWC	Transition Water Contaminants
UAA	Utilized Agricultural Area
WDPA	World Database of Protected Areas
WFD	Water Framework Directive

1. INTRODUCTION

The Po River is the main watercourse in Italy, which extends over a distance of approximately 650 km from the Western Alps to the Adriatic Sea. Its basin, known as the Po Valley, is Italy's most populated area and the Country's main industrial and agriculture hub. Hence the geographic position of the river reflects its economic importance for the area (ISTAT, 2017). The Po River forms the only delta in Italy, as it enters the Adriatic Sea. This factor alone contributes to making the area unique. However, it is the mosaic of diverse landscapes supporting rich biodiversity (UNESCO, 2015), which really renders the area exceptional. In recognition of its uniqueness, the Po River delta was designated as a UNESCO Biosphere Reserve in 2015 (Delta-Po, 2017; UNESCO, 2015).

The Po River delta, covering an area of approximately 1400 km^2 is one of the largest deltas in the Mediterranean and has been the subject of continuous variation and evolution deriving from geological, climatic and human influences throughout the millennia. The impact of human activities and settlement on the area have been instrumental in modifying sedimentation and water flow, also through the development of economic activities and settlement, which contributed to the creation of an ecological landscape typical of today's delta (Cencini, 1998). The characteristics of the area contribute to making it an important tourism attraction, whilst ensuring its role at the heart of economic activities supporting the local communities, which depend largely on agriculture and fish farming (UNESCO, 2015).

Nevertheless, the context in which the area is located makes its ecosystems vulnerable to degradation. Areas such as the Po Delta are characterized by low water exchange, which can be a cause of reduced water quality (Elliott et al., 2014; Elliott and Whitfield, 2011). This is amplified by the extent of economic activities taking place upstream of the area, which contribute to the release of substantial amounts of nutrients and contaminants into the river waters. In addition to this, local farming activities may further exacerbate the problem, whilst on a global scale, climate-induced sea level rise is expected to cause extensive flooding and affect the distribution of ecosystems, economic activities and pollutants (Elliott et al., 2015; Elliott et al., 2014). This complex scenario provides multiple challenges to environmental managers responsible for maintaining the biodiversity and environmental integrity of the area. The following sections present an analysis of the *status quo* in relation to some of the factors outlined above.

1.1. Problem statement

The Po Delta Biosphere Reserve is a transitional water system and, as such, it is characterized by low water exchange (McLusky and Elliott, 2007). This fact induces the occurrence of multiple simultaneous pressures deriving from a number of anthropogenic activities occurring upstream of the conservation area and within it, which may impact the overall ecosystem quality. Whilst a rich body of research is available on the effect of single anthropogenic stressors on freshwater (riverine) ecosystems, as reviewed in the work of Chiogna et al. (2016), other factors come into play when assessing the effect of stressors on the ecosystem and when carrying out impact assessments. First and foremost, there is a need for considering the effect of any stressors individually or in combination. In fact, evidence suggests that stressors may interact, whereby the effect of individual factors may be, for example, amplified (Mitchell et al., 2015). Furthermore, the intrinsic ecological value of the area is also an important parameter driving the need for conservation actions and determining the magnitude of the potential impact (Sallustio et al., 2017).

Determination of the value of an area for conservation needs to take into account its ecological importance, but also its vulnerability to change (Sallustio et al., 2017). Ecological importance may be determined by taking into consideration elements such as the type of ecosystem supported, but also uniqueness (e.g. the presence of key species) and ecological status (e.g. national or international designation). Similarly, the determination of vulnerability must take into consideration the likelihood of the foreseen effect of one or more stressors manifesting. These elements, in conjunction, may be used to determine priorities for conservation or action, which may focus efforts towards the preservation of key or vulnerable areas.

In the Po River and its delta, anthropogenic stressors are a threat to the balance between the intrinsic ecological and social value of the area and to its long-term preservation. Among these factors, pollution from industrial and agricultural processes, which lead to degradation of water quality by means of increased eutrophication, is expected to play a role. In addition to eutrophication, climate change and the ensuing rise in sea level are also expected to play a major role on estuaries and coastal waters (Mitchell et al., 2015). The effect of sea level rise cannot be considered in isolation. Rather, its impact on the ecosystem needs to be considered in relation to other environmental stressors, in order to determine any potential combined effect (Chiogna et al., 2016; Mitchell et al., 2015). Changes in sea level are expected to amplify the effect of anthropogenic factors on the quality of the environment, by reducing the overall area located above sea level, with consequences on the distribution of populations and on the extent of existing habitats (Nicholls et al., 1999). In view of this, the establishment of criteria for prioritizing conservation efforts is an important primary step towards effective use of resources (Capmourteres and Anand, 2016; Duarte et al., 2016).

In the present study, prioritization criteria for conservation has been determined according to the definition of acceptable change to ecosystem value, which has been determined by taking into consideration the uniqueness and vulnerability of individual areas. In this context, the study presented here addresses the concept of ecosystem value, by determining those parameters that will be important in justifying the conservation value of an area (Capmourteres and Anand, 2016). The study proposes the development and application of an index, which takes into consideration the relation between conservation-relevant characteristics (i.e. ecosystem value and pressures). By comparing ecosystem value with the risk of adverse effect, the study has enabled the identification of areas where conservation action should be prioritized. The proposed approach is in line with previous work in this area (Almeida et al., 2016; Capmourteres and Anand, 2016; Field et al., 2014) but contributes significantly with a new risk-based identification of priority areas within the Biosphere Reserve. This is a key element for conservation, as it may enable coastal managers and coastal planners to focus on areas where risk is highest or where the benefit of conservation actions can be maximized, so that suitable management strategies for the area can be put in place (Figure 1).

In line with the paradigm presented in Figure 1, the occurrence of chemical stressors, as represented by the risk of eutrophication-related event, and physical stressors, as represented by the risk of climate-induced changes in sea level, were the subjects of investigation. Field et al. (2014) described hazards associated with climate change events as relating to their potential effects on the area of interest. They further described how climate change can impact the occurrence of other physical and anthropogenic hazards (e.g. flooding, eutrophication, etc). Accordingly, exposure relates to the presence of communities and elements of interest that could potentially be affected by these hazards. In turn, vulnerability relates to the propensity of the area and its communities to be negatively affected. In the present study, the stressors described above were considered individually or in combination as being representative of (potential) hazard, in relation to the model presented in Figure 1. These stressors affect a number of sites (exposure) that differ in their intrinsic characteristics, as well as in their ability to cope with changing conditions (vulnerability). Thus, the combination of exposure and vulnerability could be considered as being represented by the concept of ecosystem value described previously. Consequently, the combination of hazard, exposure and vulnerability can be used for determining management priorities based on (potential) impact, according to the model presented in Figure 1.

The primary hypothesis (H1) tested by the proposed research was that prioritization based on individual parameters (*i.e.* chemical or physical stressors) may afford a lower level of conservation than prioritization based on these parameters jointly. The results generated by this research may also serve the secondary purpose of providing information for prioritization needs across the whole of the biosphere reserve, which could be used by environmental managers and planners to devise adequate conservation plans.

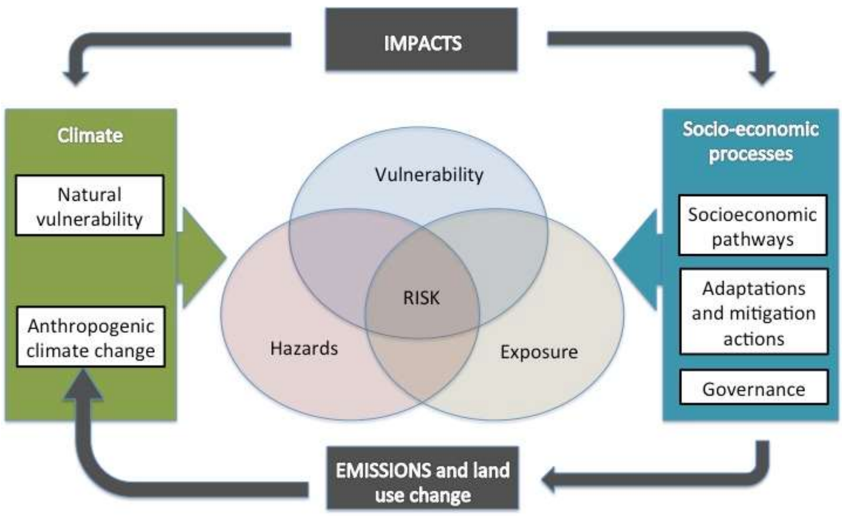


Figure 1. Risk as a combination of hazard, exposure and vulnerability. Each can be influenced by a number of stressors and conditions. Image adapted from Field et al. (2014).

1.2. Research questions

The main aim of the research outlined here was to determine how and to what extent current anthropogenic pressure and the challenges deriving from future changes in climate pose a threat to the Po Delta Biosphere Reserve. On this basis, the present research intended to identify priority areas where management measures towards environmental sustainability and preservation should be put in place. This information may find a range of applications, which could include the definition of adequate management plans for the area. To pursue the main aim, the following objectives have been addressed, each attempting to answer specific research questions:

1) *Identify areas of interest for conservation within the biosphere reserve based on ecosystem characteristics.*
   a) What is the distribution of the main ecosystem types within the study area?
   b) What are the parameters that can be used to determine value for conservation?
   c) What is the distribution of areas of high conservation value?
2) *Analyze the relationship between water quality and areas of high conservation value within the Biosphere Reserve and identify priority areas for conservation.*
   a) Which are the main areas of concern in relation to water quality?
   b) What is the distribution of areas associated with agriculture and farming?
   c) What is the spatial relationship between conservation value and water quality characteristics?
3) *Determine the effect of sea level rise in the area according to relevant Representative Concentration Pathways (RCP) scenarios described in the Special Report on Emission Scenarios of the IPCC and identify priority areas for conservation.*
   a) What are the effects of the best- and worst-case scenarios on land loss?
   b) What is the impact of sea level rise on the distribution of areas of high conservation value within study area under the worst-case scenario?
4) *Identify priority areas for conservation and management within the Biosphere Reserve based on both water quality characteristics and sea level rise vulnerability.*
   a) What is the combined impact of water quality degradation and land loss due to rising sea levels on the distribution of areas of high conservation value within the Biosphere Reserve?

5) *Compare the outcome of the three prioritization criteria and compare the derived priorities with currently identified areas for prioritization within the reserve.*
   a) Which of the three prioritization criteria is most suitable for defining priorities for conservation within the Biosphere Reserve?
   b) Are identified areas aligned with areas currently identified for conservation?

2. STUDY AREA

The Po Delta Biosphere Reserve covers an area of approximately 140 000 hectares, subdivided between 16 municipalities. The municipalities are located between the Regions of Veneto and Emilia-Romagna in Northern Italy and fall under the administrative boundaries of two provinces, Rovigo and Ferrara (Parco-Delta-Po, 2017; Parco-Regionale-Veneto, 2017).

The total area is subdivided according to a core conservation area, a buffer zone and a transition zone. The core conservation area includes approximately 10% of the Biosphere Reserve. It is composed primarily of a combination of sites that are already safeguarded and includes among others, three Ramsar sites, various Natura 2000 sites and other sites of national or regional importance. The buffer area extends over approximately 40% of the Biosphere Reserve and includes some Natura 2000 sites and other areas of locally recognized importance. The buffer area functions as an additional layer of protection for the core areas. Finally, the transition zone covers approximately 50% of the area. It contains areas that are dedicated to human activities (tourism, agriculture) and habitation. The role of the transition area is to promote the social and economic wellbeing of the communities of the Delta (UNESCO, 2015).

Table 1 provides an overview of the main characteristics of the Po Delta Biosphere Reserve. The location of the study area, as well as information on the distribution of individual zones is provided in Figure 2.

Administratively, two independent Park Authorities manage the area, each being responsible within their respective regional boundaries. However, the administrative arrangements within each Authority appear to be currently a source of potential administrative instability, which may hinder the effectiveness of any management measure. The Parco Regionale Veneto del Delta del Po Authority has been under special administration since 2015, thus effectively limiting the scope of work to the day to day administration (Parco-Regionale-Veneto, 2017). The Parco Delta del Po in Emilia Romagna has a more stable administration, yet the executive board of the Authority is composed of the political leaders from the municipalities within the park (Parco-Delta-Po, 2017), which highlights a link between the administrative practices and local political agendas, which may get in the way of effective conservation management.

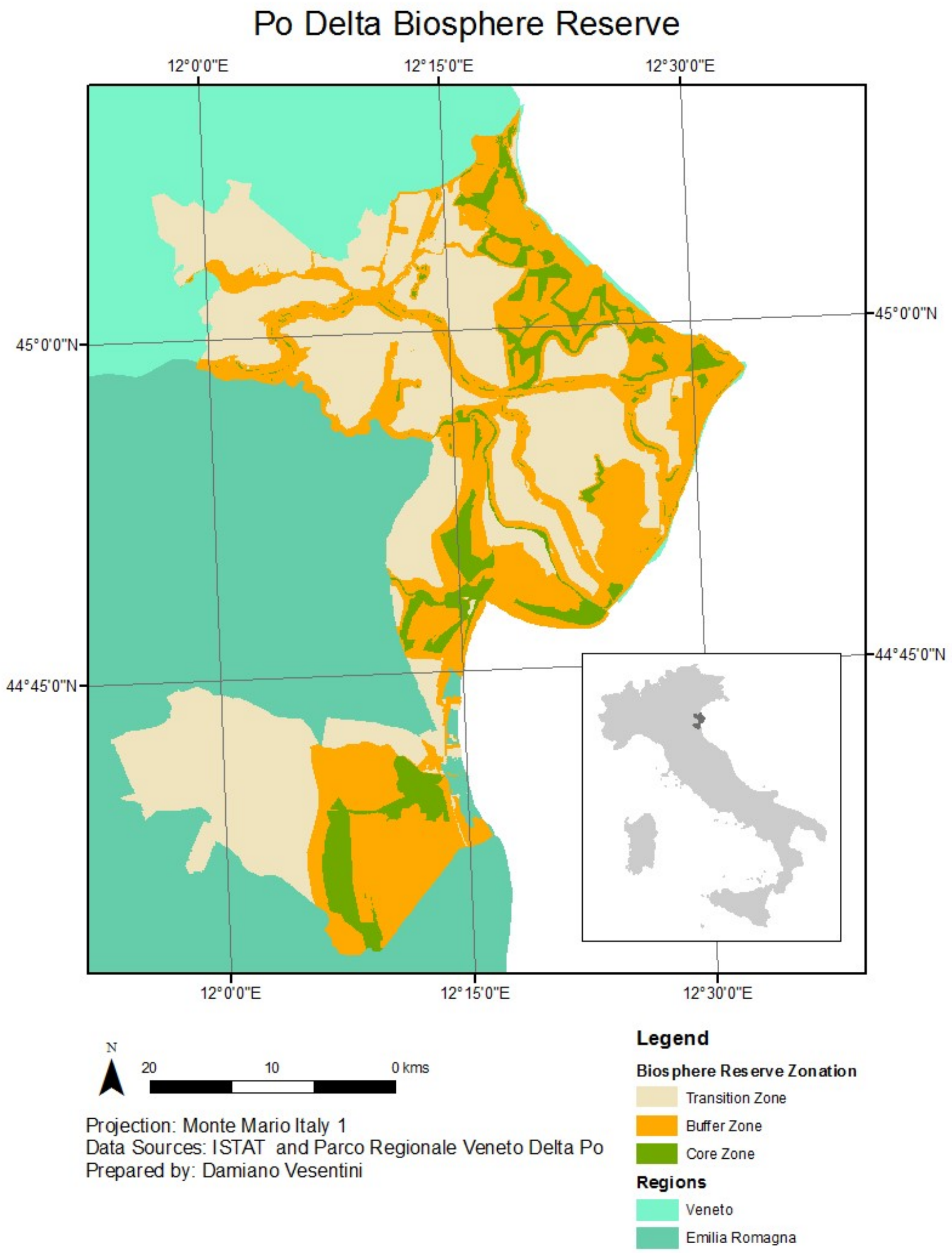


Figure 2. Overview of the Po Delta Biosphere Reserve.

The Po Delta Biosphere Reserve	
Designation date	2015
Surface area – terrestrial and marine	139398 ha (total) 13495 ha (core areas) 55281 ha (buffer zones) 70622 ha (transition zones)
Location	**Latitude:** 44°32’41”N – 45°09’48”N **Longitude:** 11°52’59”E – 12°33’14”E **Midpoint:** 44°51’16”N – 12°13’00”E
Administrative authorities	Po Delta Regional Park of Veneto Region, Institution for parks and biodiversity management Po Delta Emilia-Romagna
Regional authorities	Veneto, Emilia-Romagna
Provincial authorities	Rovigo, Ferrara, Ravenna
Municipal authorities (for each of the three provinces)	**Rovigo:** Adria, Ariano nel Polesine, Corbola, Loreo, Papozze, Porto Tolle, Porto Viro, Rosolina, Taglio di Po **Ferrara:** Comacchio, Argenta, Ostellato, Goro, Mesola, Codigoro **Ravenna:** Ravenna, Alfonsine, Cervia
Ecological characteristics	**Habitats:** river branches, secondary hydrographic network, coastal dune systems and sand formations, sandbars, lagoons, fishing ponds, marshes, fossil dunes, canals and coastal pine forests, brackish wetlands. **Species of interest:** 360 species of birds including the purple heron (*Ardea purpurea*), spoonbill (*Platalea leucorodia*), glossy ibis (*Plegadis falcinellus*), little egret (*Egretta garzetta*) and pink flamingos (*Phoenicoparrus roseus*). The Cervo della Mesola is the only mammal to be found in the reserve — a red deer (*Cervus elaphus*) recognized as genetically distinct from other populations in Europe. **Sites of interest:** the city of Ferrara and three Ramsar wetland sites (Valli di Gorino area, Valli Bertuzzi area and the Valli Residue del Comprensorio di Comacchio).
Socio-economic characteristics	**Population:** 118000 **Economy:** Tourism, agriculture and fish farming **Sites of interest:** The reserve contains many sites of historical and cultural value.

Table 1. Summary information for the Po Delta Biosphere Reserve (Parco-Delta-Po, 2017; Parco-Regionale-Veneto, 2017; UNESCO, 2015).

3. BACKGROUND

3.1. Transitional water systems

Transitional water systems, such as those associated with estuaries and lagoons are important landscapes both for the richness of the ecosystems they support, but also for the urban and industrial activities associated with them (Basset et al., 2013). The use of the term transitional waters first gained visibility in 2000 with the publication of the Water Framework Directive of the European Communities (WFD; 2000/60/EC) (European Commission, 2000), where "transitional waters" are defined as *"bodies of surface water in the vicinity of river mouths which are partially saline in character as a result of their proximity to coastal waters but which are substantially influenced by freshwater flows"* (McLusky and Elliott, 2007). In subsequent work, Tagliapietra et al. (2009) attempted to categorize the rich nomenclature associated with this type of landscape and identified patterns of hydrological and geomorphic characteristics that constituted common elements in this nomenclature. Generally speaking, however, the term transitional waters refers to those systems located between systems that are wholly freshwater or wholly seawater (Duck and da Silva, 2012). According to these descriptions, the study area of the Po Delta Biosphere Reserve fits the characteristics associated with transitional water systems, in view of its semi-enclosed status, which includes canals and lagoons, such as those found in Sacca di Goro and Comacchio areas (Newton et al., 2014).

Transitional water systems are highly variable environmental systems, which offer connectivity between freshwater ecosystems and marine ecosystems and can be characterized according to a number of paradigms, which were presented by Elliot and Wakefield (2011) in an extensive review on the subject. Their functioning is affected mostly by salinity but also by a number of other parameters including their complexity, sediment residence, and water movement. Hydrodynamic factors affect the distribution of nutrients, whereby transitional systems are recipients of nutrients carried by the river and contribute to enriching the usually oligotrophic waters found in the surround marine waters, especially within the Mediterranean basin.

Transitional water systems tend to evolve along a continuum in the absence of human disturbance, whereby lagoons, deltas and estuaries are part of this evolution (Duck and da Silva, 2012). As part of this evolution, it may be possible to identify distinct zones that may be influenced to a more or lesser degree by fluvial or tidal waters. The progressive effect of tidal waters on a fluvial-dominated zone and *vice versa* has been observed. For example, Gugliotta et al. (2017) described zonation along the Mekong river delta in South-East Asia. Zones differed not only in the salinity of their water, but also in channel morphology and sediment characteristics. The authors concluded that despite the presence of localized factors, similar observations could also be applicable to other river delta systems. Similar considerations in relation to zonation have been reported within coastal lagoons, where salinity has been observed to vary along a gradient into distinct salinity zones ranging from fresh water to brackish to high salinity (Duck and da Silva, 2012).

The morphological complexity of transitional water systems and the influence that tides exert on the landscape has been linked to the ecological diversity of transitional water environments. The effect of tides relates to salinity, which plays a role in species richness by affecting the gradient of salinity transition between neighbouring or adjacent water bodies and water types (Galvan et al., 2010). Species need to be highly adaptable in view of the variability of conditions present, but also in view of the high human-induced pressures, which may include both pressures originating internally and externally to the system of interest (Reizopoulou et al., 2014). Transitional water systems are generally associated with low diversity of highly resilient communities, which can cope with the variability of conditions that are typical of this ecosystem (Elliott and Whitfield, 2011). Thus, the greatest amount of ecological and species diversity is associated with more complex systems and with those associated with the greatest tidal influence (Galvan et al., 2010), as these complex landscapes may provide a mosaic of variable conditions supporting increased diversity.

The gradient of salinity change is also relevant. Reizopoulou et al. (2014) associated the occurrence of steeper gradients in salinity to decreased diversity (i.e. the distribution of salinity gradients along spatially limited areas). Thus, the mosaic of water bodies with different levels of salinity typical of transitional water systems and the salinity gradient between them may be interpreted as an important element in explaining their ability to sustain ecological diversity. At the local level, species and community diversity may be low in view of the high-specialization needed to cope with available conditions (Elliott and Whitfield, 2011). However, at the landscape level, landscape complexity and the heterogeneous distribution of tidal influence may have a positive influence on diversity (Galvan et al., 2010).

Although coastal lagoons and estuaries form part of a continuum between continental and marine aquatic ecosystems, these systems cannot be considered entirely comparable. Whilst they are both characterized by high biological productivity and comparable community associations, differences can be clearly observed in relation to fresh water influence, the spatial organization of gradients and environmental variability (Perez-Ruzafa et al., 2011a; Perez-Ruzafa et al., 2011b). Nevertheless, coastal lagoons and estuaries are more similar to each other than to fresh or marine water systems (Perez-Ruzafa et al., 2011b), thus common assumptions and common management paradigms and practices for lagoons and estuaries would seem appropriate as a first step.

Notwithstanding these unique traits and peculiarities, the relevance of transitional waters as an ecosystem of their own right has only been acknowledged in the past forty years or so, having been long disregarded by freshwater and marine scientists alike (Elliott and Whitfield, 2011). It is now clear that estuaries provide a wide variety of ecosystem services, which compete in quantity and diversity with the services provided by other ecosystem types. These services include, among others, coastal protection, water purification, erosion control, maintenance of fisheries and tourism and recreation (Barbier, 2015, 2016). Because of the benefits to society that these services deliver, estuaries are one of the most valuable aquatic ecosystems serving human needs (Barbier, 2015, 2016). Lagoons found in transitional water systems, for example, have been identified as having a role in the development of several aquatic organisms having high ecological and economic relevance, including fish, crustaceans and molluscs, whereby these organisms can thrive during their larval stages in relatively protected and nutrient-rich environments (Ghezzo et al., 2015).

The diversity, complexity and variability of transitional water systems, as well as their dependency on the inputs deriving from fresh water and marine water systems are key elements highlighting their susceptibility to change. Change to these systems may occur as a consequence of internal and external pressure, thus it is important to understand the role of these stressors on the system in order to implement viable management strategies aimed at maintaining their functions.

3.2. Chemical and physical factors affecting estuarine ecosystems

In transitional water systems, several stress factors come into play, which may exert pressure on the ecosystem. Elliot at al. (2014) identified 14 types of hazards to the coastal environment and discriminated them on the basis of their source (e.g. natural vs. anthropogenic) and relationship to the areas of interest (e.g. endogenous vs. exogenous) (Table 2).

Hazard	Hazard sub-type	Cause	Examples
Surface hydrological hazards		Natural but exacerbated by human activities	High tide flooding, spring tide and equinoctial flooding, flash flooding
Surface physiographic removal	Due to natural processes – chronic or long term	Natural but exacerbated by human activities	Erosion of soft cliffs by waves
	Due to human actions – chronic or long term	Anthropogenic	Land claim, removal of wetlands for urban and agricultural area
	Acute or short term	Natural	Cliff failure, undercutting of hard cliffs
Climatological hazards	Acute or short term	Natural but exacerbated by human activities	Storm surges, cyclones, tropical storms, hurricanes, offshore surges, fluvial and pluvial flooding
	Chronic or long term	Natural but exacerbated by human activities	Ocean acidification, sea level rise, storminess, saline intrusion
Tectonic hazard	Acute or short term	Natural	Tsunamis, seismic slippages
	Chronic or long term	Natural	Isostatic rebound
Anthropogenic biohazards	Microbial	Anthropogenic	Sewage pathogens
	Macrobial	Anthropogenic	Alien and invasive species, bloom forming species, GMOs
Anthropogenic technological hazards	Introduced	Anthropogenic	Infrastructure, coastal defences
	Extraction	Anthropogenic	Removal of space, removal of biological populations, seabed extraction, oil/gas/coal extraction
Anthropogenic chemical hazards	Acute or short term	Anthropogenic	Pollution from individual spillages
	Chronic or long term	Anthropogenic	Diffuse pollution, litter, nutrients from land run-off, discharge

Table 2. Overview of hazard typologies affecting transactional water systems. Adapted from Elliott et al. (2014).

Increased importance has been attributed to the consideration of stressors in combination, rather than in isolation, as evidence has been gathered in the scientific community that synergistic relationships may take place, which amplify the effect of individual factors (Boateng, 2012; Christia et al., 2014; Fitch and Crowe, 2010, 2012). The work of Fitch and Crowe (2010, 2012) and the work of Christia et al. (2014) are examples of this trend, whereby multi-parameter water quality indices have been developed and compared with indices based on single parameters, in order to ascertain the effect of multiple stressors on the ecosystem. Boateng (2012) further confirmed the relevance of multiple concurring factors in determining the vulnerability of coastal areas in Vietnam. In their study, they provided a view of how the combination of different natural and anthropogenic factors may affect coastal vulnerability. Vulnerability was associated with climatic factors, whereby the risk of rising sea level would represent significant risk. However, the authors highlighted that the pattern of exploitation of the coastline by human populations, together with natural elements including elevation of the terrain also contributed to the overall vulnerability and consequent ecosystem effects. Thus, it is the combination of these factors that contribute to the overall risk.

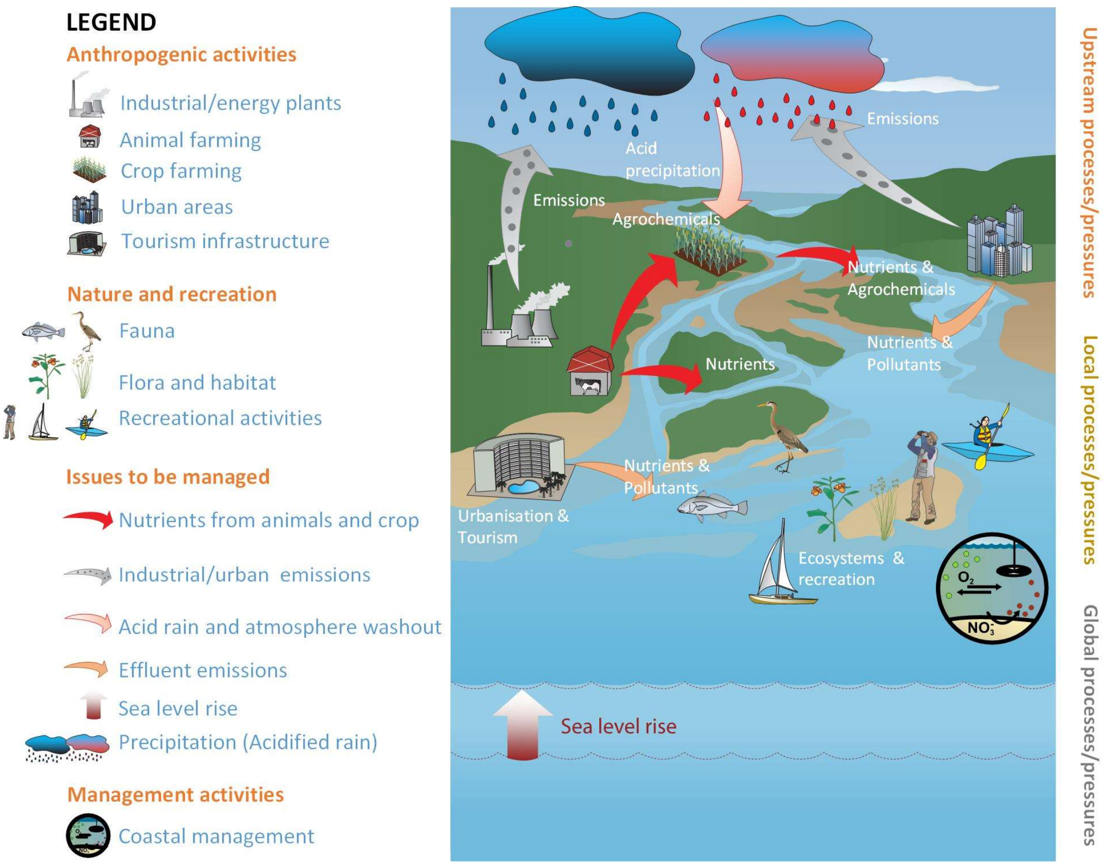


Figure 3. Anthropogenic and physical factors affecting shallow water and estuarine ecosystems.

Figure 3 provides a visual representation of the relationship investigated by this study between anthropogenic and physical factors (i.e. sea level rise), which participate in influencing transitional water ecosystems. Anthropogenic factors may originate upstream and become manifested a long distance downstream, in the coastal areas where transitional waters are located. In transitional water systems, the impact of anthropogenic factors is often amplified by the reduced water exchange occurring within these systems, whereas, at the local level, overexploitation of resources can place considerable pressure both on the ecosystem and on the local human population (Newton et al., 2014).

In addition to anthropogenic factors, increased sea level and flooding may impair the capacity of shallow coastal waters to absorb nutrients, especially in shallow coastal lagoons (Brito et al., 2012a), thus highlighting the tightly bound relation between physical stressors and the ability of the ecosystem to cope with the chemical environment. In turn, vegetation could be expected to be negatively affected by increasing sea levels, especially under conditions of high nutrient availability (Wong et al., 2015). Consequently, when assessing coastal vulnerability it is not only important to take into account physical and developmental factors, but also nutrient availability, as eutrophication may become a prominent issue in certain flooded habitats.

3.2.1. Chemical factors and eutrophication

The purpose of this section is to present an overview of how different chemical factors contribute to the overall water quality and, in turn, to ecosystem quality. Water quality and the risk it represents for the ecosystem is one of the aspects that is considered in the present study. Thus, understanding the individual factors that may affect water quality is crucial, as it will enable the identification of parameters that can be monitored to effectively describe risk.

Nutrient accumulation in water has long been recognized as a major cause of water contamination. At the European level, the Nitrates Directive of 1991 (91/676/EEC) (European Commission, 1991b) and the European Water Framework Directive (WFD; 2000/60/EC) of 2000 (European Commission, 2000) are examples of how governments have attempted to address the problem of water quality and to determine water quality parameters. The WFD takes into consideration several biological quality elements individually, but then combines them to draw some overall conclusions on ecosystem quality. Other regulations have an even more holistic view and focus more on ecosystem function. Yet, despite their different approach, these regulations focus on the improvement in water quality at the European level, by addressing nutrient accumulation and mitigating their impacts at an ecosystem level. Borja et al. (2010) argue that an integrated view on ecosystem quality is necessary, bringing together information from different sources to provide a comprehensive assessment. To this purpose, the application of indices for water quality and status of the communities of benthic organisms may be applied individually or in combination to achieve the determination of the ecosystem overall status (Christia et al., 2014; Ferreira, 2000; Fitch and Crowe, 2010).

The nutrient status of coastal waters is affected by a number of parameters, such as water exchange, nitrogen input and the abundance and diversification of primary producer communities (Castel et al., 1996). The dynamics affecting the relationships between these parameters are complex. Hydrodynamic regime is especially important in semi-enclosed systems, as it plays a role in water exchange across the systems boundaries, which in turn affects parameters such as pH, salinity, nutrient distribution and oxygen availability (Caroppo et al., 2018). More open systems, for example, are more capable of buffering the effect of nutrient accumulation than semi-enclosed or completely enclosed systems (Roselli et al., 2013).

Nutrient status is closely associated to eutrophication. This is caused by the increase in the rate of provision of nutrients to the ecosystem, so the export rate of nutrients and the recycling of nutrients play a key factor. The supply of nutrients takes place primarily via organic matter, which is entering the ecosystem both from external and internal sources. Conversely, export of nutrients includes flushing of the ecosystem, respiration and denitrification, whilst recycling relates primarily to consumption for primary productivity (Pinckney et al., 2001). Factors affecting the sensitivity of coastal areas to eutrophication include nutrient sources such as those deriving from agricultural and farming practices, tourism activities, water residence time, the presence of human infrastructure, such as harbour facilities and wastewater discharge areas (Sebastia and Rodilla, 2013; Sebastia et al., 2012).

Agricultural and farming activities, including the input of fertilizers and the practice of aquaculture and other animal husbandry activities have an impact on nutrient input (Castaldelli et al., 2013; Castel et al., 1996), whereas the type and diversity of primary producer communities have an impact on nutrient cycling, especially where their turnover rate is considered (Christian et al., 1996). Similarly, the occurrence of other human activities and urbanization also affect the nutrient discharge and may be linked to the occurrence of water eutrophication (Canedo-Arguelles et al., 2012; Castel et al., 1996).

According to Eurostat, livestock farming is an indicator of pressure on the environment (Eurostat, 2017). Livestock units (LSU) per utilized agricultural area (UAA) are an indicator of livestock density and therefore an indicator of pressure on the environment. In 2013, in the EU-28 the total livestock density equalled 0.7 livestock units per hectare of UAA, whereby one livestock unit equals one grazing dairy cow in terms of impact. The highest total livestock densities were observed in the Netherlands, Malta and Belgium (> 2.5), whilst the lowest values (equal or less than 0.3) were observed in Slovakia, the Baltic countries and Bulgaria.

The problem of eutrophication in the Po River and, more broadly in the Northern Adriatic Sea has been drawing considerable interest and has been addressed by many researchers. Nutrient distribution in the area tends to be seasonal, with peaks reported in the winter months, and to decrease away from the Po River delta (Giordani et al., 1997). High nitrogen levels within the Po River water have been associated with recurring eutrophication events in the North Adriatic Sea (Corazzari et al., 2016), such as the occurrence of algal blooms in the North Adriatic Sea in the 1990s and 2000s (Sorokin et al., 1996; Sorokin et al., 2006). Several of these factors may affect the observed seasonality. Among them are the variation in water discharge and the input from intensive local economic activities, especially aquaculture (Sorokin et al., 2006).

Aquaculture is understood to have extensive environmental impact on water resources, especially due to the addition of nutrients to the ecosystem, which is typical of fish farms (Sorokin et al., 1999, 2006). Evidence surrounding the impact of shellfish farming on the environment is somewhat contradictory, since shellfish filter-feeding habits have been reported to cause positive effects on nutrient removal (Bricker et al., 2018; Testa et al., 2015). Nevertheless, extensive evidence is also available concerning the negative effects of shellfish farming on the environment, which relate to primarily to oxygen depletion and to the deposition of carbon-rich organic matter (Sorokin et al., 1999, 2006).

Apart from nutrient load, which may be driven by human and economic activities and their yearly cycling (Pitta et al., 2014), oceanographic conditions impact the mixing of waters within the Adriatic Sea and thus promote layering, uneven nutrient distribution and ultimately the occurrence of hypoxic and anoxic events, which are also season-dependent and which are related to partial or total oxygen depletion (Degobbis et al., 2000).

Upstream in the river system, seasonality affects nutrient input and exacerbates the constant input of nutrients and pollutants, which affect the lower parts of the river. The causes of this pattern relate primarily to the intensity of activities in the upper river system and the consequent changes in discharge over time. Nevertheless, changes in the ability of the receiving waters to cope with increased nutrient levels are also important contributing factors (Pitta et al., 2014). Thus, seasonality is important not only because of the direct consequences it has on the physico-chemical environment. It also affects anthropogenic activities, thus determining for example an increase in the use and discharge of fertilizers. Furthermore, in certain areas, the increase of tourism activities also contributes to an increase in the discharge of effluent water and, in some cases, raw sewage (Sierra et al., 2007). Consequently, seasons and their alternation affect a number of environmental parameters, which emphasise the relevance of seasonality to conservation management in transitional waters, including nutrient accumulation (Giordani et al., 1997), oxygen availability (Degobbis et al., 2000), discharge from economic activities (Sorokin et al., 2006) and the intensity of human and economic activities (Pitta et al., 2014).

In addition to seasonality, nutrient load and water exchange, the dynamics occurring at the sediment-water interface play an important role in nutrient exchange, especially in areas like coastal lagoons, where water exchange is restricted (Brito et al., 2010). The relevance of sediment-water interface dynamics is not only limited to nutrient exchange, but more generally to the exchange of ions and cations. Therefore, even in the case of heavy contamination by multiple organic and inorganic compounds, sediment-water interface dynamics may play a role in the exchange capacity within these two aquatic compartments, sometimes mitigating the expected effects (Costa et al., 2016). In transitional water systems with comparable nutrient conditions, the effect of sediment-water dynamics may reflect on the ability of the ecosystem to support diverse communities versus allowing the more resilient and invasive species to overtake (Sfriso et al., 2014). Thus, sediment–water interface dynamics appear to impact the sediment-water exchange as an overall process, which reflects directly on ecosystem quality and species diversity.

The effects of the factors described above on water quality and, in turn, on the quality of the ecosystem, are tangible. Gamito (2008) observed that a combination of anthropogenic and physical factors, including organic matter pollution, on coastal semi-enclosed systems in Southern Portugal affected both the structural and trophic composition of the ecological community supported by the system. This resulted in low species richness and diversity, and in communities dominated by detritivores. Similar effects have been observed in other systems in the Mediterranean basin, whereby the effects of water quality on the community composition and richness have been observed to be long lasting (Khedhri et al., 2016). The duration of the effects beyond the period over which stress conditions are experienced shows sustained impact on the ecosystem (Khedhri et al., 2016), which may indicate the slow adaptation of communities to improved conditions after more competitive species become established. The reasons for these changes in community composition may be explained by a combination of factors. The abundance of nutrients combined with seasonal temperature variation and sulfur compounds in the sediments may promote the occurrence of anoxic conditions, which result in marked effects on especially the most sensitive species in the community (Magni et al., 2005). However, other factors including the residence of water within the system, and by association the residence of contaminants, also play a role in defining community composition, especially in those systems characterized by poor water exchange (Martins et al., 2009).

3.2.2. Climate change and estuarine ecosystems

Further to the predominantly anthropogenic hazards and stressors described above, climate change is another type of external pressure, which may severely impact the management of coastal areas and is particularly relevant to transitional water systems (Newton et al., 2014). In order to fully understand the effects of climate change, it is necessary to take into consideration both the change scenarios and their respective influence on sea level.

The Intergovernmental Panel on Climate Change (IPCC) has produced a number of atmospheric emissions scenarios, which are documented in the Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart, 2000). The IPCC–SRES scenarios are grouped into four classes representing different assumptions and each scenario is associated with a range of foreseen effects on global temperature, with best estimates ranging from 1.8 to 4.0 degrees Celsius, according to the IPCC Fifth Assessment Report (IPCC, 2013). Such an increase in global temperature may result in an increase in sea level of between 0.4 and 0.6 m by 2100 (IPCC Fifth Assessment Report (IPCC, 2013). In the Mediterranean alone, it has been estimated that the increase in sea level may be between 0.098 and 0.256 m by 2040-2050, when elements including terrestrial ice melt, glacio-isostatic and steric sea-level components are considered (Galassi and Spada, 2014). Other estimates, based on IPCC forecasts, have indicated increases in sea level in the Mediterranean of 0.53 and 0.74 m by 2100, with an extreme scenario being considered resulting in an increase of 1.75 m as compared to year 2000 sea level (Jimenez et al., 2017). On a more local scale, Perini et al. (2017) applied estimated changes in sea level of 0.3 – 0.45 m in the Adriatic Sea.

In the most recent IPCC report (5^{th} Assessment Report), the concept of Representative Concentration Pathway (RCP) was adopted to provide a comparative view of total radiative forcing (i.e. the difference between insolation and energy radiating back to space) under different climate conditions scenarios (IPCC, 2013). Each RCP could result from a combination of future trends, relating to factors such as policies, economic factors, demographic development, and technological innovations, which are not necessarily equivalent to the scenarios provided under SRES.

Increasing sea levels are expected to lead to flooding of lowland coastal areas, with resulting effects on the coastal ecosystems. Different studies have proposed varying levels of change, although they all agree that loss of area will be substantial. When the whole of the world's coastal wetland areas are considered, estimates range between 22% and 70% loss of the overall surface by 2080, depending on whether climate change is considered in isolation or in conjunction with other forms of anthropogenic pressures (Nicholls et al., 1999). These results are not an isolated case. It is estimated that at least 60% of the world saltmarshes will be unable to keep pace with the rate of rising sea levels. However, under more extreme scenarios, the expected loss in saltmarsh area may increase to 90% (Crosby et al., 2016). Within the Mediterranean basin, increased temperature and the ensuing sea level rise would result in approximately half of the transitional waters being submerged, thus effectively assuming more prominently marine characteristics (Newton et al., 2014). Consequently, the extent and rate of climate change are important determinants of the ability of the ecosystem to withstand the foreseen change.

Land loss effects of this magnitude would have a profound effect on habitat distribution and connectivity (Bellisario et al., 2014). Based on IPCC predictions, Antonioli et al. (2017) concluded that sea-level rise will have a profound effect on coastal morphology by 2100 in Italy, with the most striking impacts being observed for both the environment and human activities. The effects of land loss on habitat distribution are expected to be particularly evident in the case of coastal ecosystems. As these are typically located by low-lying areas, they are expected to be affected by both flooding due to rising sea levels and flooding due to land subsidence (Alvarado-Aguilar et al., 2012). The latter phenomenon is associated with riverine and estuarine sedimentation, whereby a number of factors can lead to lowering of the earth surface. These include tectonic activity and compaction of sedimentary deposits, but also extraction activities. (Chen and Rybczyk, 2005)

Besides these changes in physical conditions, biochemical changes are also foreseen as a consequence of increasing sea levels. Repercussions of changing sea levels will reflect on the functioning of the ecosystem in coastal and estuarine landscapes, which may reduce their buffering capacity against pollutants and nutrient concentration (Brito et al., 2012b). A reduction in light penetration in shallow waters may be expected, with marked consequences on the photosynthetic ability of plants, algae and phytoplankton characterizing these waters. As a result, nutrient concentrations may increase because of reduced nitrogen consumption by these organisms (Brito et al., 2012a), which in turn could enhance the effects of eutrophication or, at least, lead to ecological imbalance. Similarly, changes in water level and salinity may have an impact on species competition, which may affect community composition. Noto and Shurin (2017) suggested that this effect results in competitive saltmarsh plant species dominating over subordinate species, with a consequent loss of biodiversity.

The effects outlined above may be considered primary, in the sense that they are a direct consequence of climate-induced sea-level rise. Other effects may be considered secondary, in the sense that they are not a direct effect of sea-level rise, but they are caused by events associated with the rise. Secondary effects of sea-level rise involve, for example, the structures set in place to counteract the negative impact that this has on coastal areas and to ensure the viability of human and economic activities. The construction of coastal structures, such as sea walls and bulkheads has been a widespread method of containment and defense, which can result in loss of ecological diversity due to loss of coastal ecosystems and to the overall reduction of the ecological services supported by the coastal ecosystem (Gittman et al., 2016). Similarly, under climate change conditions, increased storminess (Bloeschl et al., 2017) may be considered as not being directly associated to climate-induced sea-level rise, although it may exacerbate the impacts brought upon by rising sea water.

Changes in sea level and climate-induced changes in wind and meteorological patterns have been associated with increased wave energy (Casas-Prat et al., 2016; Casas-Prat and Sierra, 2011, 2013), with cascading effects on the frequency, duration and intensity of storm events and with consequent effects on coastal erosion rates (Cid et al., 2016; Conte and Lionello, 2014; Corre, 1991). Lionello et al. (2017) have reported results from modelling the effects of storminess in the Mediterranean under the IPCC-SRES A and B climate change scenarios. Their results highlight that multiple factors may affect the maximum sea level during storm conditions, especially storminess and the sea level. In turn, the maximum level that water reaches during a storm is a significant factor in affecting coastal defences and coastal erosion. Nevertheless, the effects of altered sea levels are farther reaching still. For example, saltwater intrusion is expected to also affect the availability of groundwater aquifers around the Mediterranean (Carrubba et al., 2015; De Filippis et al., 2016), thus causing additional problems for coastal management.

From the studies reported above, it is evident that adaptation of ecosystems to change may become one of the greatest management challenges associated with climate change. The effect of climate change and the ensuing sea level rise may have profound effects on flooded areas, but also on non-flooded areas affected by storm events and increased salinization (Elliott et al., 2014). Therefore, a combination of coastal preservation measures may be necessary in order to maximize the results in terms of coastal preservation and ecosystem quality (Ivajnsic and Kaligaric, 2014). Several methods have been applied to the identification of the impact of rising sea levels on coastal environments. More complex methodologies take into account parameters including waves, wind, bank characteristics, as well as sea level (Villatoro et al., 2014). Parameters including coastal storms and flash floods have also been considered to explain the risk associated with flooding (Ballesteros et al., 2018), however the focus of these methods has been primarily on flooding and land loss, whereby other effects were not considered.

More complex models have been addressing the overall effects of climate change not only on flooding, but also on ecosystem evolution (Brito et al., 2012b; Crosby et al., 2016; Villatoro et al., 2014). For example, Ivajnsic and Kaligaric (2014) predicted 42% loss in coastal Natura 2000 area at two sites in Slovenia by 2060 by applying IPCC climate scenarios. They attributed this change to be primarily related to the correlation between individual habitats and localized elevation parameters, which would result in the flooding of low-lying coastal areas. Similarly, Gambolati et al. (2002) have prepared GIS models of the effect of climate change on coastal areas in the Northern Adriatic Sea, taking into account climatic changes forecasted to 2100. In their study, they observed that pronounced flooding is to be expected in the lowland area between the Po River delta and Ravenna, although the reliability of the flooding estimation over the 100-year period was found to proportional to the reliability of the climatic change estimations. Thus, in the case of the Po River delta, it may be expected that large areas may be affected by climate-dependent sea level rise, although the exact extension of the area involved may be dependent on the scenario being considered.

In an area such as the North Adriatic Sea, sea level extremes are determined primarily by mean sea level, rather than storm induced oscillations in sea level (Tsimplis and Shaw, 2010; Vousdoukas et al., 2017). Therefore, for the purpose of the current study, the impact of rising sea levels have been estimated based on a simplified approach, relying on the identification of low-lying coastal areas. These are expected to be the most affected by increasing sea level (Ivajnsic and Kaligaric, 2014). In determining the extent of impacted areas, the forecasted sea level rise according to different RCP scenarios (IPCC, 2013) has been applied throughout the study.

3.2.3. Additional challenges to managing pressure in transitional water systems

The management of transitional water systems is influenced by a number of concurrent factors. The stressors described in previous sections may affect the system simultaneously, effectively generating a cumulative or synergistic effect (Mitchell et al., 2015; Pitta et al., 2014). This deserves adequate consideration, especially when the design and implementation of coastal management practices is concerned.

A complicating factor for management of coastal areas is fragmentation and the lack of coordinated activities, which inhibits the efficacy of integrated management. This certainly deserves attention in an area, such as the Po Delta Biosphere Reserve, which is subdivided in a number of municipal, regional and conservation administrations (UNESCO, 2015). Fragmentation and lack of coordinated activities may become manifested through inadequate monitoring of relevant data, as well as through poor stakeholder engagement and governance activities (Buono et al., 2015). The inconsistent and uncoordinated actions across different areas and administrations may lead to the exacerbation of problems deriving from environmental pressures affecting the system (Pitta et al., 2014). At the same time, stakeholder engagement already at the early stages of management decisions is often overlooked or poorly implemented, despite the widely accepted view that engagement is a key factor for the success of Integrated Coastal Zone Management (ICZM) initiatives (Santoro et al., 2013).

In order to promote the effective management of vulnerabilities to stressors in coastal environments, in 2002 the European Commission recommended the application of Integrated Coastal Zone Management (ICZM) in Europe (2002/413/EC) (2002) and laid down the eight principles defining its essential characteristics. These include: broad and long term perspective; adaptive management with local specificity; consideration of ecosystem processes; the engagement of parties and authorities concerned; and the use of available instruments in combination, in order to achieve optimal results.

Root-Bernstein and Frascaroli (2016) proposed that several factors contribute to ensuring the success of restoration ecology initiatives in highly anthropogenic landscapes, although no common framework exists. They argued that fragmentation, stakeholder engagement and expectation, and governance all contribute to the perceived success of the initiative. Consequently the management of transitional water systems has to not only accommodate the causes and consequences of pressures within the system but, more than other ecosystems, they need to respond to the consequences of external natural and anthropogenic influences (Elliott and Whitfield, 2011). This is certainly the case for the Po River delta, where regional and administrative subdivisions (Buono et al., 2015) and the administrative challenges outlined earlier in this study are expected to play a sizeable role. Nevertheless, the difficulties described here do not make the task of effective integrated management impossible. Success stories do exist, such as the restoration of the Goro Lagoon (Corbau et al., 2016), whereby coordination with municipalities, public and private stakeholders was applied in order to obtain the most advantageous balance between ecological and socio-economic outcomes. As a result, improved conditions for the environment and farming activities were obtained, which included a 28% increase in clam production and increased ecological quality.

According to the European Commission (2017), coastal areas are vulnerable to climate change and natural hazard, which have the potential to affect the lives and livelihood of coastal communities. Under these conditions, it is especially important for coastal area managers to have access to reliable and consistent information. Information should take into account the cumulative or synergistic effects of multiple stressors and risks, in order to enable the assessment of hazard, exposure, vulnerability and the overall risk, through a series of iterative processes (Rizzi et al., 2016).

Several methodologies are available which can support decision-making, leveraging the use of GIS technology for the identification of sensitive areas (Valentini et al., 2015), the use of decision support systems (DSS) taking into account ecosystem and socio-economical characteristics (Casini et al., 2015) and the use of the DPSIR conceptual framework for the evaluation of driving forces (D), pressures (P), states (S), impacts (I) and policy responses (R) (Newton et al., 2014). The work proposed here intends to apply these methodologies to assist coastal managers responsible for the Po Delta Biosphere Reserve by identifying the main vulnerable areas within the reserve, which are susceptible to the combination of factors described above (Section 3.2).

3.3. Ecological value and conservation

In considering ecosystem quality, it is important to note that there is a direct dependency between the intrinsic ecological value of the ecosystem, its vulnerability to degradation, and the location and intensity of anthropogenic impacts (Sallustio et al., 2017). In analysing this dependency, it is first necessary to define what we mean by ecological value and the parameters that can help to determine it. It will then be possible to determine the relevance of any conservation efforts, which will be targeted to address vulnerability to actual and potential degradation.

The European Union has set up policies to ensure that the ecological values of ecosystems are maintained and improved, to the benefit of the current and future generations. These policies are at the base of the development of Green Infrastructure in Europe, which aims to establish a network of natural and semi-natural areas to effectively plan, manage and support the delivery of ecosystem services. Policies range from the protection of individual species, to the establishment of habitat networks to protect biodiversity (European Commission, 2017). Among these, the European Habitat Directive (92/43/EEC) (European Commission, 1992) requires Member States to act for the restoration or preservation of habitat types and species recognized by the Directive (Adamo et al., 2016; European Commission, 1992).

Instruments such as those provided by the CORINE Programme of the European Union are valuable tools for the identification of areas displaying characteristics that are deemed of value. The Programme was set up in 1985 to coordinate information on the environment at the European level and currently includes 38 participating countries (Elliott et al., 2014). The CORINE land cover database provides information on land use for all participating countries. Land cover is classified according to 44 classes, over three levels of detail, whereby an accuracy of almost 88% has been reported (Büttner et al., 2012).

Land cover information from the CORINE database is organized in maps with a scale of 1:100000 (Büttner et al., 2012). This level of resolution and the CORINE classification of land cover has been widely used in comparative studies monitoring which is a sufficiently accurate scale for land cover studies at a national level, but may not be sufficiently detailed for studies at a local and regional level (Feranec et al., 2007a; Feranec et al., 2007b). At a more local level, CORINE classifications of land cover have been carried out (Viciani et al., 2016), which can provide information at a resolution of 1:25000 and above.

Whilst the CORINE Programme provides information pertaining to land cover, the association of land cover and ecological value may not always be clear. Certainly, ecosystems like saltmarshes fulfil an invaluable role in the recycling of nutrients and in buffering against eutrophication (Sousa et al., 2008). Conversely, the type of economic activities associated with an area contribute to determining the overall quality of the environment, by potentially introducing environmental contaminants or by placing pressure on species resilience (Delzons et al., 2013). However, other associations may not be so straightforward. Land use changes have a great impact on the suitability of ecosystems to support species diversity and to harbour protected species, with the effects of ecosystem degradation becoming apparent over time (Brambilla et al., 2017; Cai and Pettenella, 2013). Overall, land cover changes are one of the main drivers for species occurrence and habitat decline in Italy. These changes are especially relevant in agriculture-dominated areas, where the effect of abandonment and intensification may be especially visible (Brambilla et al., 2017).

In the present study, information deriving from the CORINE Programme was used as one of the parameters for determining ecological value. To this extent, the relative importance of different land cover types was inferred based, for example, on their level of disturbance by human activity.

Besides information on land cover, the presence of protected species is another element that needs to be taken into consideration when assessing ecological value. The presence of protected species can be determined based on distribution information, when available. To this purpose, the International Union for Conservation of Nature (IUCN) has assembled a large database of information relating to the distribution of species in need of protection, which are collected in the Red List maintained by the Union (IUCN, 2016). Some of these species have been reported in the Biosphere Reserve, some of which are either threatened or endangered, thus requiring enhanced protection (Parco-Delta-Po, 2017; Parco-Regionale-Veneto, 2017; UNESCO, 2015).

The relevance of a site for protected species may further be inferred based on the inclusion of an area within nature conservancy schemes of relevance at the European and International level to promote biodiversity. This may be considered as evidence of the ecological value of a site at an international level in supporting species diversity and integrity (Ramsar Convention, 1971). Linking the occurrence of species of interest to specific habitat types and locations, the European Habitat Directive (92/43/EEC) plays a key role in conservation. In the Directive, habitat types and species are identified, which are recognized as being central for nature conservation efforts. The Directive also sets the basis for establishing a network of protected areas within the European territory: the Natura 2000 Network (European Commission, 1992). The purpose of the network is to promote the preservation of rare and threatened species of interest by promoting sustainable development in the areas it recognizes and that are included in the Network (European Commission, 1992).

Since its inception, Natura 2000 has led to the increase in areas devoted to conservation in Italy, from 11% to 20% of the total area (Maiorano et al., 2007). Nevertheless, there remains a need to integrate the Network with existing nature protection infrastructure and with other international conservation targets (Maiorano et al., 2007). Based on the significance of Natura 2000 for conservation, the inclusion of an area in the Natura 2000 Network is considered in the context of the study presented here as evidence of ecological value.

Despite its importance at European level, Natura 2000 is not the only conservation scheme worth of consideration. Thus, inclusion of a site of interest in other international and national schemes may also provide recognition of its ecological importance. In Italy, Natura 2000 accounts for a fraction of the total amount of sites. Other conservation sites are registered which include the Official List of Protected Areas, containing some 800 sites and the Sites of Community Interest, which contain some 2200 sites. The Special Protection Areas (i.e. the Natura 2000 Network) include approximately 600 sites, which provide the best coverage both in terms of efficiency of habitat coverage and spatial distribution (Rosati et al., 2008).

Italy also hosts 53 Ramsar sites, six of these are located in the Po Delta, in close proximity to or within the Biosphere Reserve. The Ramsar on Wetlands was adopted in 1971 to ensure the protection of wetlands of international relevance, based on their ecological significance for humanity. As such, the recognition of a site in the Ramsar list provides a valuable measure for assessing its conservation value. Currently, there are 2200 Ramsar sites worldwide, covering an area of 2.1 M km^2 (Ramsar Convention, 1971).

The elements outlined above (i.e. land cover, the presence of protected species and the inclusion of a site within a national or international conservation scheme) are but just a few of the elements that may be used for describing and ascertaining ecological and conservation value. Several other elements may be considered, which include for example habitat connectivity and resilience to changing conditions (Barredo et al., 2016; Bellisario et al., 2014), the potential of the area to support high species diversity and the its susceptibility to pressure (Sallustio et al., 2017), or the provision of ecosystem services (Schirpke et al., 2014; Spano et al., 2017). Nevertheless, inclusion of these parameters is not considered in the study presented here, as it would have added much complication in sourcing relevant information. Therefore, these will not be further analysed here, as the focus will remain that of the relationship between ecological value and external pressure.

Several elements of disturbance could also be deemed relevant, which however were also omitted from this study. For example, the disturbance caused by patterns and rates of land use changes in areas that are surrounding formally-designated conservation areas can have substantial negative effects on wildlife and nature conservation (Cai and Pettenella, 2013). This makes it necessary to consider the designation of sites as part of an integrated approach to nature conservation, rather than in isolation, as effort may need to extend beyond the formal boundaries of the identified sites (Viciani et al., 2016). Further to this, implementing conservation management across administrative borders may further hinder the efficacy of nature conservation (Opermanis et al., 2013).

3.4. Concluding remarks

The evidence gathered here points towards the vulnerability of transitional water systems, a very diverse ecosystem which act as ecotone (transition) between terrestrial fresh water and marine systems. Often associated with shallow waters and poor water exchange, these systems accumulate nutrient and contaminants from sources located upstream. This renders them very susceptible to change, especially in highly anthropogenically-affected contexts, which are capable of placing added pressure at a local level (e.g. due to tourism and farming activities). Additionally, the current climatic trends and associated scenarios indicate that further threats to these low-lying coastal ecosystems are envisaged for the not-so-distant future.

The high degree of ecological diversity of transitional waters makes them valuable for nature conservation. In some cases, these areas also have a high cultural value, as in the case of the Po River delta (UNESCO, 2015). It is therefore necessary to balance the intrinsic value of these areas with the challenges that lay ahead in terms of environmental quality and external threats. Taking into account the combined effect of these challenges is key for the achievement of sustainable and effective conservation efforts, ensuring continued viability of the transitional water ecosystems (Newton et al., 2014).

In the work presented here, the current knowledge is be applied for the determination of conservation priorities in the Po Delta Biosphere Reserve, taking into account the elements outlined in previous sections. The outcome may constitute relevant input for conservation management activities in the area.

4. DATA SOURCES

The data sources on which the present study is based are listed below. For each group of data, the specific data type and the source of information are listed.

1. **Administrative boundaries**
    - Country – *Istituto Italiano di Statistica (ISTAT)*
    - Provinces – *Istituto Italiano di Statistica (ISTAT)*
    - Municipalities – *Istituto Italiano di Statistica (ISTAT)*
    - Atlante Statistico dei comuni – *Istituto Italiano di Statistica (ISTAT)*

      http://dati.istat.it/Index.aspx
2. **Land cover**
    - Land cover/Land use – *Copernicus Land Monitoring Service*

      https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-corine
3. **Protected areas**
    - Natura 2000 – *Copernicus Land Monitoring Service*

      https://land.copernicus.eu/local/natura
    - Ramsar areas – *World Database of Protected Areas (WDPA)*

      https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas

      https://protectedplanet.net/
    - Other protected areas

      https://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas

      https://protectedplanet.net/

      https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-13

    - IUCN Red List species – *International Union for the Conservation of Nature (IUCN)* https://www.iucnredlist.org/resources/spatial-data-download

- BirdLife International and Handbook of the Birds of the World (2017) Bird species distribution maps of the world. Version 7.0. Available at

  http://datazone.birdlife.org/species/requestdis

4. **Digital Elevation Model**
   - DEM (10m) – (Tarquini et al., 2007; Tarquini and Nannipieri, 2017; Tarquini et al., 2012)

     http://tinItaly.pi.ingv.it

5. **Population**
   - Italy population mask data – *Centre for International Earth Science Information Network (CIESIN), Earth Institute, Columbia University 2000*

     http://sedac.ciesin.columbia.edu/data/set/gpw-v4-basic-demographic-characteristics-rev10

     http://dati.istat.it/Index.aspx

6. **Economic activities and infrastructure**
   - Tourism accommodation infrastructure – *Istituto Italiano di Statistica (ISTAT)*

     http://dati.istat.it/Index.aspx

   - Aquaculture production sites – *European Marine Observation and Data Network*

     http://www.emodnet.eu/geonetwork/emodnet/eng/catalog.search#/metadata/d72b9826-9282-419d-b953-d02c66e09869

     http://www.emodnet.eu/geonetwork/emodnet/eng/catalog.search#/metadata/d32d7b01-4d38-4e44-9206-42d5a5fe705b

     http://www.emodnet.eu/geonetwork/emodnet/eng/catalog.search#/metadata/5026492f-5e70-4975-ba86-40e2d21ebc99

   - Livestock load – *Istituto Italiano di Statistica (ISTAT)*

     http://dati-censimentoagricoltura.istat.it/Index.aspx

- Organic agriculture area – *Istituto Italiano di Statistica (ISTAT)*

  http://dati-censimentoagricoltura.istat.it/Index.aspx

- Density of agricultural registered businesses – *Istituto Italiano di Statistica (ISTAT)*

  http://dati-censimentoagricoltura.istat.it/Index.aspx

7. **Water quality**

- Nutrient levels – *European Environment Agency*

  https://www.eea.europa.eu/data-and-maps/data/wise-eionet-spatial

- Transitional Waters Contaminants (TCM Waterbase database) – *European Environment Agency*

  https://www.eea.europa.eu/data-and-maps/data/waterbase-transitional-coastal-and-marine-waters-11

- Bathing waters quality – *European Environment Agency*

  https://www.eea.europa.eu/data-and-maps/data/bathing-water-directive-status-of-bathing-water-10

- Bathing waters quality – *European Marine Observation and Data Network*

  http://www.emodnet-bathymetry.eu/data-products

- Urban Waste Water Treatment Directive data – *European Environment Agency*

  https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-5

8. **Biosphere zonation**

- Delta Po Map – *Biosfera delta del Po*
  http://www.biosferadeltapo.org/documentazione-e-download/

5. METHODOLOGY

The overall methodology for the proposed study is presented as a flowchart in Figure 4. Details of individual aspects of the methodology are provided in the sections below.

5.1. Characterization of the Biosphere Reserve area

Administrative boundaries for Italy and administrative boundaries for the Po Delta Biosphere reserve were used to carry out initial characterization of the study area. Administrative boundaries for the Biosphere Reserve were only available as a .pdf document. The information was converted to shapefile by using an online converter (https://mygeodata.cloud/converter/pdf-to-shp). The relevant layers were used to construct a boundary map for the Biosphere Reserve and for identifying the distribution of core, buffer and transition zones within the reserve.

Information relating to land cover was used together with information relating to the distribution of economic activities in order to further characterize of the study area. In addition to this, information relating to the designation of conservation areas within the study Biosphere Reserve was also used, as was information relating to the distribution of sensitive species included within the IUCN Red List. Finally, digital elevation model (DEM) information was used to determine the extent of flooding under present and climate change conditions.

Relevant layers were combined using the operation of overlay in ArcGIS. Combined layers allowed for the spatial contextualization of all information needed throughout the study to the Biosphere Reserve boundaries.

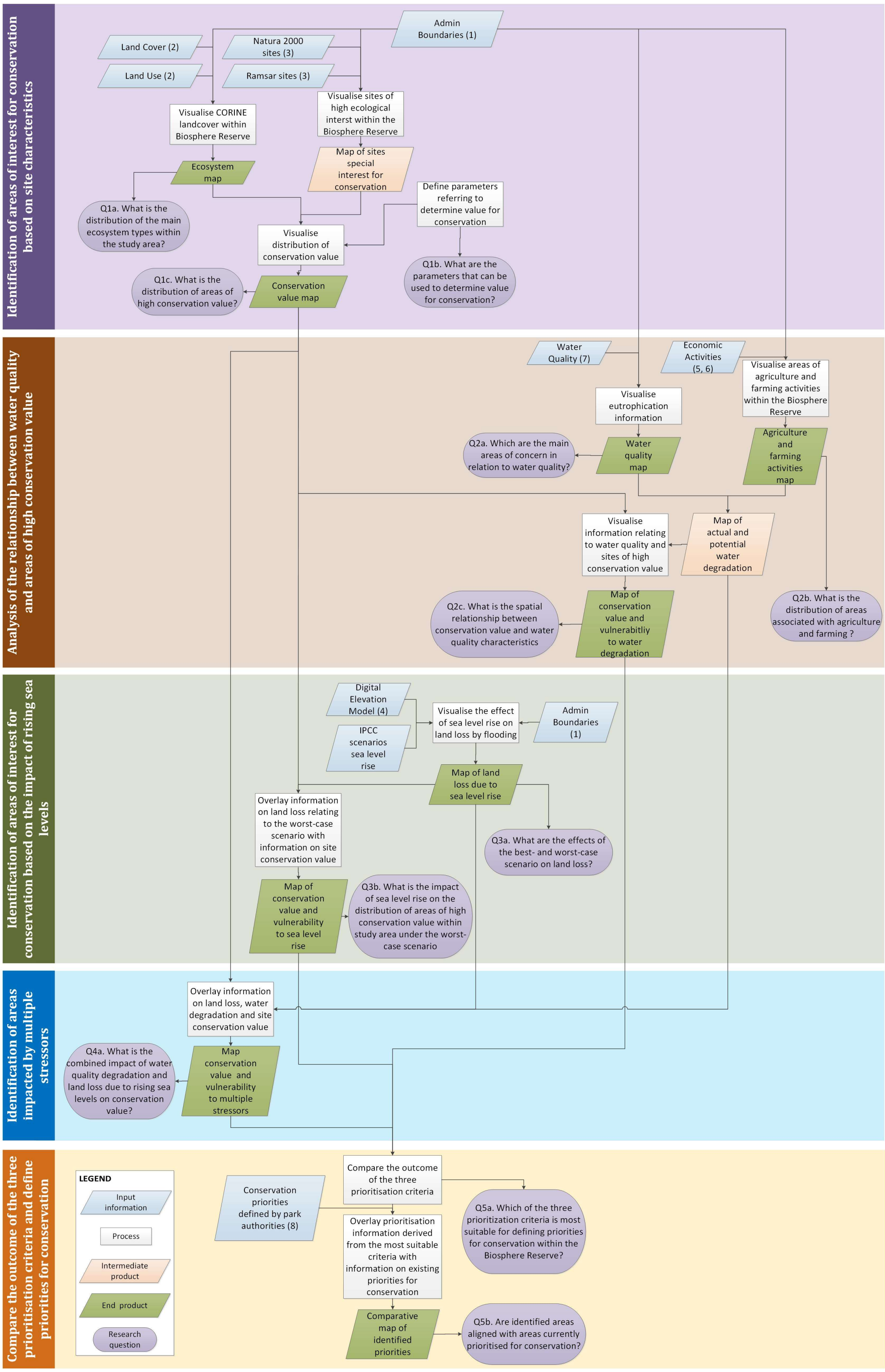


Figure 4. Methodology flowchart for the study. The numbers in bracket relate to the data sources used for each part of the study, as described in Section 4.

5.2. Definition of parameters for determining conservation value

The primary purpose of this part of the study was to address the first objective: *Identify areas of interest for conservation within the biosphere reserve based on ecosystem characteristics.* In doing so, the research questions associated with this objective were also addressed. This part of the study further lays the basis for identifying the relationship between areas of interest for conservation and the occurrence of risk to water quality and climate-induced increasing sea levels.

Areas of high conservation values were defined by taking into consideration several parameters, which were weighed in order to provide an overall numerical value for conservation. This is in line with the review of Capmourteres and Anand (2016), whereby conservation value can be determined based on elements such as habitat integrity, naturalness, the occurrence and richness of species. Similar approaches have been applied in similar contexts numerous times and with good results, hence giving assurance of their validity (Bastos et al., 2016; Brunbjerg et al., 2016; Delzons et al., 2013; Pulido et al., 2017). For example, The Danish high nature value (HNV) farming indicator includes parameters associated with landscape structure, occurrence of natural and semi-natural habitats, land use and the presence of threatened species (Brunbjerg et al., 2016).

In the context of the present study, three parameters were used for the determination of conservation value, which are broadly based on HNV: land cover, conservation management type (i.e. the presence of formal conservation areas) and the presence of species of interest for conservation (Brunbjerg et al., 2016). Thus, ecosystem characteristics (i.e. the occurrence of semi-natural areas and agricultural/use regime) are considered to be valuable for supporting species richness, whilst the presence of sensitive species is indicative of high nature value (Brunbjerg et al., 2016).

The first parameter relates to land cover, which was defined according to the CORINE classification. In applying this parameter, a progression in value for conservation was attributed as we move away from bare and industrialized land towards more natural and semi-natural land cover types, such as scrub and forest. This reflects current findings in relation to factors such as landscape resilience to change and the ability to support sensitive species (Carre et al., 2009; Rodriguez-Rodriguez and Martinez-Vega, 2017; Sandru et al., 2017)

The second parameter relates to the management practices established for the area, whereby the relevance of an area for conservation was established. The assumption here was that the transition from local to international conservation importance is associated with an increase in the relative value of the area. Thus, provincial and regional conservation areas scored lower values than areas such as Ramsar sites (Ramsar Convention, 1971) or areas designated for example in the scope of EU Directives (e.g. Habitat Directive and Birds Directive) (European Commission, 1992).

Finally, the third parameter relates to the presence of animal species included in the IUCN Red List and that are recognized as being threatened. In this context, progressive scoring has been attributed for each of the reported species according to the level of threat. Thus, species of least concern were perceived as being of relatively lower concern than vulnerable, endangered or critically endangered species.

The approach followed by the Danish government in assessing HNV for agriculture does not apply the concept of weights. Instead, a threshold of 5 points (out of 13) is set for identifying those areas where at least some key parameters worthy of conservation can be found (Brunbjerg et al., 2016). Conversely, the approach followed in the study was different because applying equal weight to all variables might have resulted in a misrepresentation of the overall conservation value, where a higher incidence of relevant parameters of the same type could be observed (e.g. the occurrence of multiple IUCN Red List species). Consequently, weights were set in order to account for the quality of the landscape (i.e. landcover and the presence of areas of recognized conservation relevance) and the presence of species of value for conservation. Details of how weights were established for the determination of conservation value are provided in the results section and contextualized to the definition of parameters for defining conservation value.

In practical terms, for each parameter of interest, shapefiles were converted to raster and these were reclassified according to the allocated score. Conservation Value Index (CVI) was calculated by overlay analysis of the raster layers obtained.

5.3. Identification of areas of concern for water quality

The primary purpose of this part of the study was to address the second objective: *Analyze the relationship between water quality and areas of high conservation value* *within the Biosphere Reserve and identify priority areas for conservation.* In doing so, the research questions associated with this objective were also addressed, where necessary by combining information on risk to water quality with information on the distribution of areas of value for conservation (objective 1).

Information from the Waterbase dataset of the European Environment Agency was used to discern areas within the Biosphere Reserve according to their sensitivity to nutrient accumulation (i.e. nitrogen and phosphorus) (EEA, 2016). Nevertheless, information on nutrient sensitivity can be of limited use, as the information provided by the European Environment Agency covered large areas such as the catchment, the whole of the transitional and the coastal waters). More meaningful information could be obtained by analyzing the distribution of activities potentially leading to sensitivity. Specifically the focus was on agricultural activities and tourism.

5.3.1. Impact of agricultural activities

The impact of agriculture was based on the pressure exerted by crop agriculture and animal husbandry on the area. This took into consideration the usable agricultural area (UAA) for each municipality. The intensity of crop agriculture was determined based on the percentage of UAA dedicated to crop. Low-density agriculture included areas where less than 30% of the UAA was dedicated to cropping. Medium density agriculture included cropping areas ranging from 30-50% of total UAA and high-density agriculture included cropping areas of above 50% of UAA.

Similarly, the potential impact of animal agriculture was based on the determination of livestock loading per hectare. This took into account the number of livestock units (LSU) in the municipality of interest and the UAA.
A high livestock density means a large number of animals per ha of UAA and a higher risk that the manure produced by the animals cannot be spread on the area of the holding and there may be an increased need for manure storage or export of manure from the holding (European Commission, 2013; Eurostat, 2013).

In this study, three levels of livestock density were identified, based on the information provided by Eurostat: Low density (< 0.5), Medium density (0.5-1.0) and high density (1.0 – 1.5) (Eurostat, 2017).

The impact area associated with (shell) fish farming was estimated based on information on the distribution of shell fish farms. For each fishery, it was estimated that an influence on water quality would take place within 1500 m from the source, whereby the effect of carbon deposition via sediment and oxygen depletion could be accounted for. This distance was estimated based on the recommendations and information reported by the Food and Agriculture Organization and World Bank, which refer to practices and guidelines for different countries. In this context, this distance represents an optimistic view of the effect of fisheries (José et al., 2017). However, the value was deemed to be appropriate for the purpose of this study, as the main focus was on the assessment of a number of agricultural related parameters, rather than the precise definition of the effect of individual ones.

5.3.2. Impact of tourism

The aggregated number of available accommodation per municipality was obtained from ISTAT and the number of available beds was used to determine tourism-related pressure. The information relating to available beds in traditional and non-traditional tourism infrastructure was compared to the number of inhabitants in the municipality in order to obtain an indication of tourism intensity. Thus, values of 0.5 beds per inhabitant or greater, were associated with high intensity; values of 0.1-0.5 beds per inhabitant were associated with medium intensity and values < 0.1 beds per inhabitant were associated with low intensity (tourism irrelevant) (EEA, 2001).

5.3.3. Prioritization of areas for action

Information relating to the distribution and intensity of agricultural practices and tourism activities were taken into consideration to determine the risk to the quality of water resources. For each parameter, different levels of intensity were given scores, which were proportional to the level of intensity. Furthermore, parameters were attributed a weight, providing a perspective of their relevance, with agricultural-related activities having a relatively higher relevance for overall water quality than tourism (Table 3).

Different thresholds were established to determine water quality via identifying a combination of risk factors that could potentially affect it. These thresholds enabled the classification of water quality risk factors into three categories: low, medium and high. Low risk for water quality was associated with the occurrence of mostly low levels of activity in farming and tourism. Typical values < 4 are associated with this level of risk. Medium risk was associated with the occurrence of a combination of low and medium intensity activities, or with the occurrence of one individual high intensity activity which resulted in water quality risk values ranging between 4 and 8. High risk was associated with the occurrence of intense animal farming activities, associated with another economic activity e.g. fish farming or tourism. Alternatively, moderate low or moderate levels of animal farming plus two additional activities (i.e. both fish farming and tourism) were associated with high risk to water quality. Values of 8 or higher reflect this level of risk.

Parameter	Intensity	Value	Weight
Tourism			
	Low	1	1
	Medium	2	
	High	4	
Farming			
Fish farming		2	2
Animal	Low	1	2
	Medium	2	
	High	3	
Crop production	Low	1	1
	Medium	2	
	High	4	

Table 3. Overview of the importance of water quality parameters based on their significance and level of intensity.

The distribution of water quality risk factors was compared to the distribution of areas value for conservation.

5.4. Determination of land loss under increasing sea levels

The primary purpose of this part of the study was to address the third objective: *Determine the effect of sea level rise in the area according to relevant Representative Concentration Pathways (RCP) scenarios described in the Special Report on Emission Scenarios of the IPCC and identify priority areas for conservation.* In doing so, the research questions associated with this objective were also addressed, where necessary by combining information on risk deriving from increasing sea level with information on the distribution of areas of value for conservation (objective 1).

In order to determine land loss under increasing sea level, the predictions of IPCC Special Report on Emission Scenarios were considered (IPCC, 2013). The flooding risk deriving from climate-related sea level rise was estimated according to the projections of the IPCC Representative Concentration Pathways (RCPs). RCPs have been adopted in the Fifth Assessment Report of the IPCC to provide a comparative view of total radiative forcing (i.e. the difference between insolation and energy radiating back to space) under different climate conditions scenarios. Each representative RCP could result from a combination of future trends, relating to factors such as policies, economic factors, demographic development, and technological innovations. Table 4 provides information about the range of RCP scenarios provided in the Fifth Assessment Report of the IPCC (IPCC, 2013).

For the purpose of the study presented here, RCP 2.6, 6.0 and 8.5 were considered as low, medium and high impact scenarios. RCP 4.5 was not considered, as mean sea level rise values were comparable with RCP 6.0 (0.47 m and 0.48 m, respectively). According to the predicted levels of sea level rise, portions of land that would be flooded under changing climatic conditions were defined. Elevation information from a 10 m DEM (Tarquini et al., 2007; Tarquini and Nannipieri, 2017; Tarquini et al., 2012) was used to identify flooded areas and to compare the variation in potentially flooded areas (i.e. areas located below present and future sea level). Specifically, the minimum sea level projections from RCP 2.6 were considered as a best case scenario, whilst the maximum sea level projections from RCP 8.5 were considered as a worst case scenario. Mean sea level values were taken into account to provide a comparative view of the scenarios.

Information on land loss was used in conjunction with information on conservation value. The percentage of risk areas in relation to land loss was estimated and key areas for conservation were identified.

RCP Scenario	**Estimated mean temp rise 2100 (deg C)**	**Radiative forcing 2100 (W m-^{2})**	**Estimated increase in sea level 2100 (m) mean and (range)**
RCP 2.6	1	2.6	0.4 (0.26 – 0.55)
RCP 4.5	1.8	4.5	0.47 (0.32 – 0.63)
RCP 6.0	2.2	6.0	0.48 (0.33 – 0.63)
RCP 8.5	3.7	8.5	0.63 (0.45 – 0.82)

Table 4. Climate change, radiative forcing and estimated sea level rise for different Representative Concentration Pathways scenarios.

5.5. Determination of the impact of combined pressure

This part of the study addresses the fourth objective: *Identify priority areas for conservation and management within the Biosphere Reserve based on both water quality characteristics and sea level rise vulnerability.* In doing so, the research questions associated with this objective were also addressed, where necessary by combining information on risk relating to water quality and increasing sea level with information on the distribution of areas of value for conservation (objectives 1, 2, 3).

In completing the steps described for meeting objectives 1-3, it was possible to determine the extent of the effect of deterioration of water quality characteristics and increasing sea levels on the distribution of areas that have an intrinsic value for conservation. Therefore, in this phase of the study, the combined risk of flooding deriving by sea level rise predictions under the worst case scenario (RPC 8.5 max) and predicted risk to water quality due to agricultural and other human activities were evaluated together in relation to the distribution of areas of different conservation value (as determined by CVI) within the study area.

The information relating to CVI, flooding risk and water quality risk used in previous parts of this study were reclassified in order to support a comparatively analysis. Thus, CVI was reclassified according to four intervals with incremental increases of 100, whereby a value of 100 was associated with low CVI and 400 was associated with a very high CVI. Similarly, flooding risk was classified using three intervals with incremental increases of 10, whereby a value of 10 was associated with no flooding, 20 with elevation below sea level under present day scenarios and 30 with areas of flooding under the RPC 8.5 max scenario. Finally, risk to water quality was reclassified according to three intervals, whereby a value of 1 was associated with low risk, a value of 2 with medium risk and a value of 3 with high risk to water quality. The resulting information was used to define priorities, whereby for each unit area, the cumulative effect of both flooding and water quality risk was taken into consideration.

5.6. Setting priorities for conservation

In this final part of the study, the fifth objective was addressed: *Compare the outcome of the three prioritization criteria and compare the derived priorities with currently identified areas for prioritization within the reserve.* In doing so, the research questions associated with this objective were also addressed by analyzing information derived from objectives 1, 2, 3 and 4, in order to derive a comparative view of changes in conservation priorities according to the scenarios that were postulated.

Prioritization for conservation was determined by comparing directly the outputs addressing objectives 2, 3 and 4. Taking into account the outcome of the study, high priority areas were associated with the combination of the higher conservation value classes (high and very high CVI) in association with medium and high levels of (combined) pressure. Conversely, medium priority areas were associated with medium CVI values under high pressure, and high and very high CVI values under low pressure scenarios (Table 5).

5.6.1. Comparison with priorities defined by the Biosphere Reserve authorities

The predicted distribution of areas with high conservation priority identified in this study were compared to conservation priorities set by the two administration authorities governing the Po Delta Biosphere Reserve. For this purpose, the outcome of most appropriate scenario for prioritization was taken into account, which was compared to information relating to the location and distribution of core and buffer areas pertaining to the Biosphere Reserve.

Zonation within the Biosphere reserve is based on the legislative status of different areas, which reflects the characteristics of the area in terms of ecosystem and the presence of valuable species of interest. Thus, core areas are protected by law for ensuring long-term viability of ecosystems and the species they support. As such, they are often associated with formally recognized conservation status. Buffer areas are set up in proximity to core areas in order to ensure that the management of development and natural resources is in line with ecosystem management requirements. Thus, activities allowed within buffer areas are restricted and aligned with the need to support sustainable ecosystem management. Finally, transition areas are not protected by specific legislation for the purpose of ensuring nature conservation.

Rather, these areas promote the presence of anthropogenic activities tailored to supporting sustainable practices and development (Biosfera Delta-Po, 2017).

In the assessment, core areas identified by the park administration would be estimated to correspond to high priority areas and buffer areas to medium priority areas.

In order to facilitate comparison, no priority and low priority areas were considered jointly. Comparison between the two prioritization datasets occurred by subtracting the newly defined priorities from current priorities. In doing so, conclusions were drawn on the adequacy of the prioritization for conservation currently implemented, especially in view of its long-term sustainability.

Priority	Flooding risk	Water risk	CVI
Medium			
		Low	High or Very High
		Medium	High or Very High
		High	Medium
	BSL		High or Very High
	RCP 2.6		Medium
	RCP 8.5		Medium
	BSL	Low	High or Very High
	BSL	Medium	High or Very High
	BSL	High	Medium
	RCP 2.6	Low	High or Very High
	RCP 8.5	Low	High or Very High
	RCP 2.6	Medium	Medium
	RCP 8.5	Medium	Medium
	RCP 2.6	High	Low
	RCP 8.5	High	Low
High			
		Medium	High or Very High
		High	High or Very High
	RCP 2.6		High or Very high
	RCP 8.5		High or Very high
	BSL	High	High or Very high
	RCP 2.6	Medium	High or Very High
	RCP 8.5	Medium	High or Very High
	RCP 2.6	High	Medium
	RCP 8.5	High	Medium
	RCP 2.6	High	High or Very High
	RCP 8.5	High	High or Very High

Table 5. Determination of medium and high priority for action based on risk factors and conservation value.

6. RESULTS

6.1. Identification of areas of interest for conservation

6.1.1. Ecosystem distribution

In defining the distribution of areas of interest for conservation, an initial assessment was performed looking at the distribution of CORINE land cover types. These are presented in Figure 5.

The Western part of the Po Delta Biosphere Reserve was associated with predominantly agricultural land cover types, which are interspersed with urban areas. Conversely, the Eastern areas of the Biosphere Reserve were associated with higher land cover diversity, supporting wetlands, forested areas, beaches and dune systems. The relative areas of different land cover types is presented in Table 6. Land use types are grouped according to similarities in their level of naturalness, which is reflected in the scores provided in Table 7.

Land use	**Area (ha)**
Industrial areas, mining areas and construction sites	1065
Urban areas	93698
Agricultural areas	
Artificial non-agriculture vegetation	
Pasture	60
Scrub	3494
Forest	
Marine and Inland Wetlands	41095
Marine and Inland Waters	
Beaches and other open spaces with limited vegetation	

Table 6. Relative areas associated with different land use types within the Po Delta Biosphere Reserve. Land use types are grouped to reflect similarities in their level of naturalness.

The information presented in Figure 5 and Table 6 was used to address the first research question in the scope of this work: *What is the distribution of the main ecosystem types within the study area?* Heavily anthropogenic ecosystems, especially associated with agriculture and urbanization are located primarily in the West of the Biosphere Reserve and make up approximately 68% of the total area. Natural and semi-natural ecosystems are located primarily on the Eastern side of the Biosphere Reserve. These ecosystems account for approximately 32% of the total area. When considering natural and semi-natural ecosystems, marine and inland waters, wetlands and coastal sparsely vegetated areas (e.g. beaches and dune systems) comprise the majority of the area, accounting for approximately 92% of the total. Other ecosystems associated with forest/scrubland make up the remaining 8%.

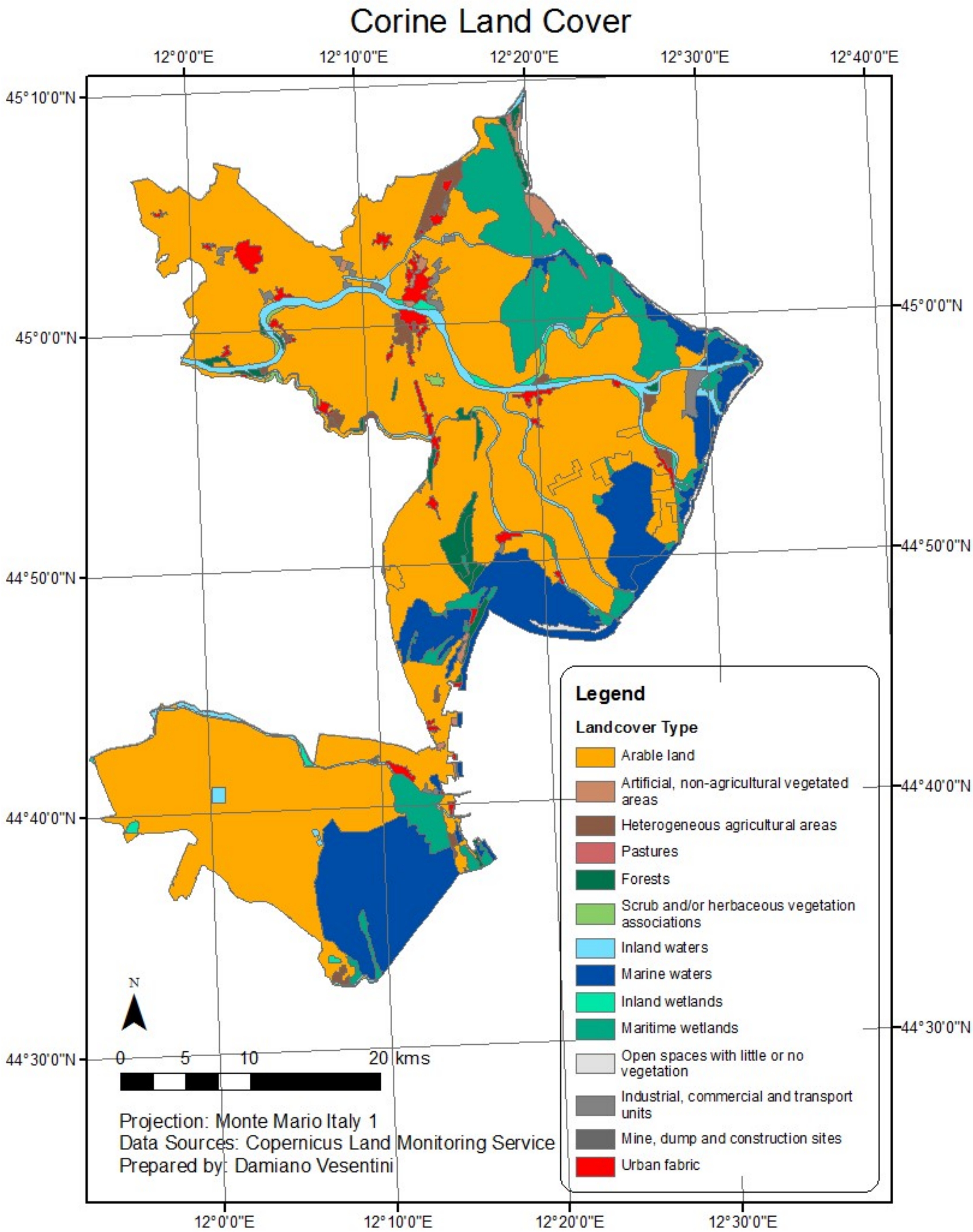


Figure 5. Distribution of CORINE land cover types within the Po Delta Biosphere Reserve.

6.1.2. Definition of parameters for determining value for conservation

A further step in the identification of areas of interest for conservation within the Po Delta Biosphere Reserve was the definition of suitable parameters.

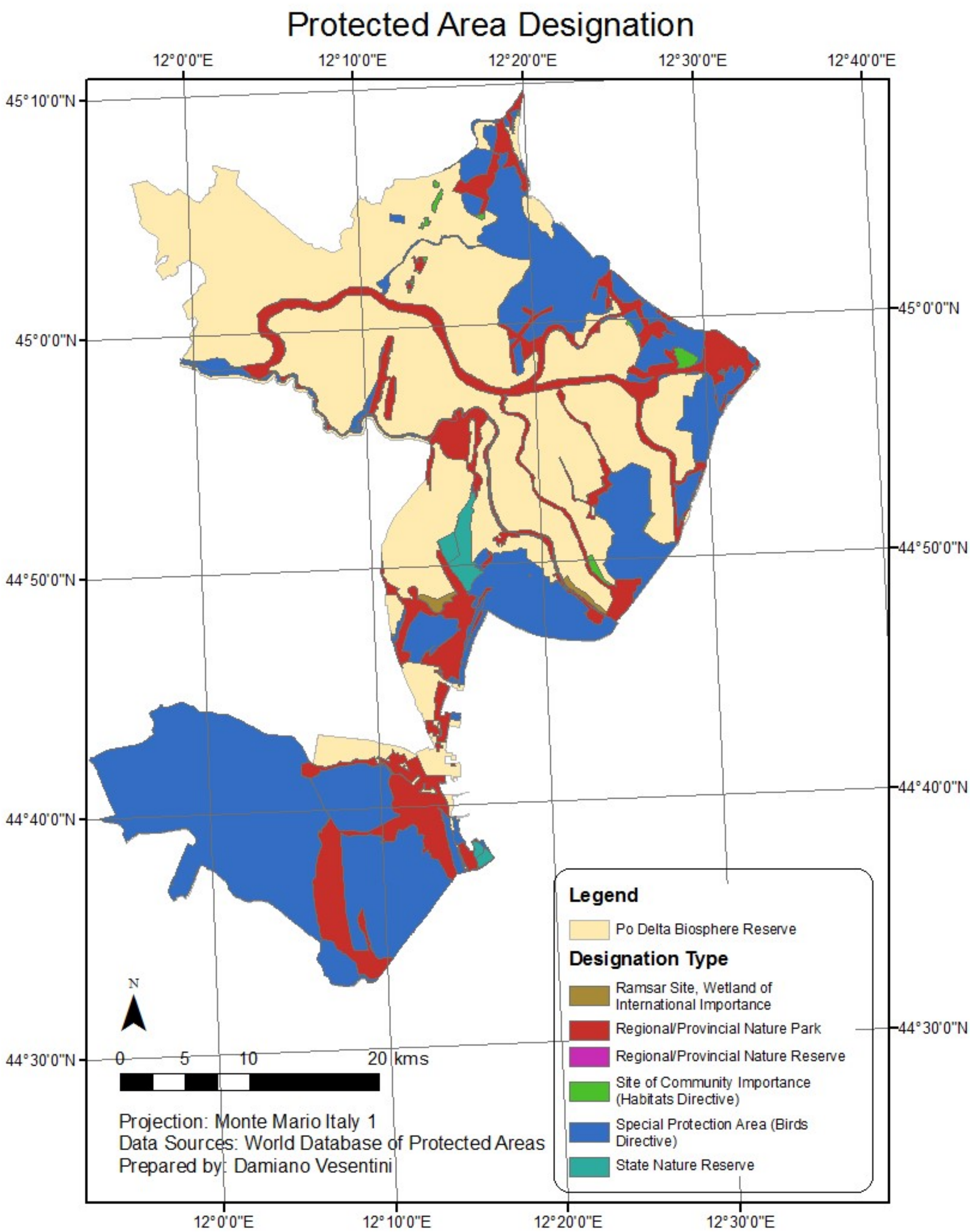


Figure 6. Distribution of designated nature conservation areas within the Biosphere Reserve.

During the inception phase of this study, it was determined that value for conservation would be determined based on the land cover characteristics, the type of management (i.e. the presence of formally recognized areas for conservation) and, finally, the presence of threatened species. The former two parameters provide a view of the ecosystem integrity, which would be able to sustain species diversity and possibly species of interest in the long term. The latter parameter gives an indication of the distribution of threatened animal species, which may add additional value to a specific area, beyond the ecosystem integrity alone. The distribution of land cover types determined according to the CORINE classification has been described in the previous section and shown in Figure 5. The distribution of conservation areas of regional, national and international importance is shown in Figure 6.

Parameter	Sub-parameter	Score	Weighted score
Land cover			
	Industrial areas, mining areas and construction sites	0	0
	Urban areas	2	4
	Agricultural areas	2	4
	Artificial non-agriculture vegetation	2	4
	Pasture	3	6
	Scrub	4	8
	Forest	4	8
	Marine and Inland Wetlands	5	10
	Marine and Inland Waters	5	10
	Beaches and other open spaces with limited vegetation	5	10
Management			
	Regional/Provincial Reserve or Park	1	2
	State Reserve	2	4
	Ramsar Site	3	6
	Special Protection Area (Birds Directive)	4	8
	Site of Community Importance (Habitat Directive)	4	8
IUCN Red List			
	Least concern	1	1
	Nearly threatened	2	2
	Vulnerable	3	3
	Endangered	4	4
	Critically endangered	5	5

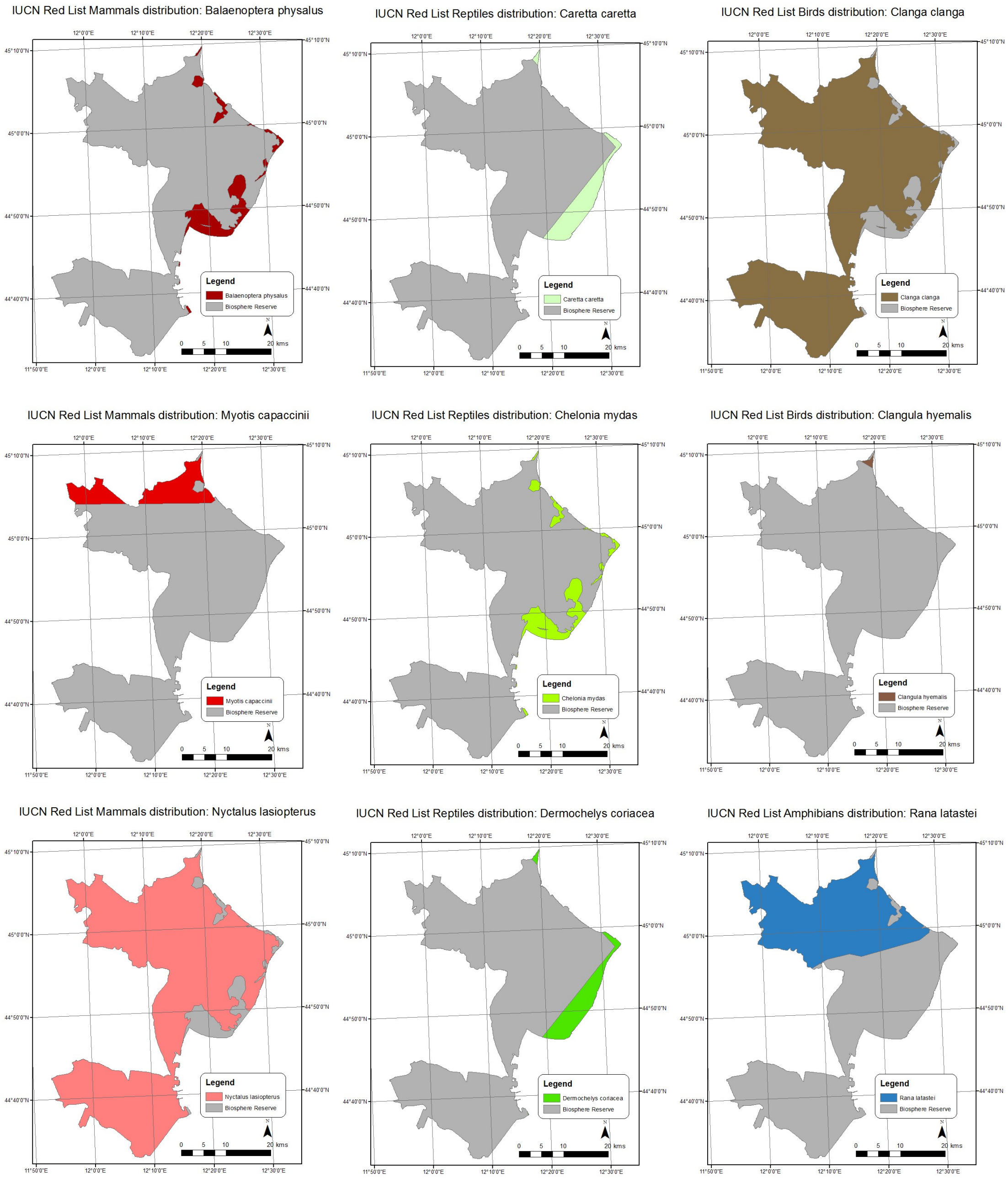
Table 7. Scoring used for the determination of conservation value within the Biosphere Reserve.

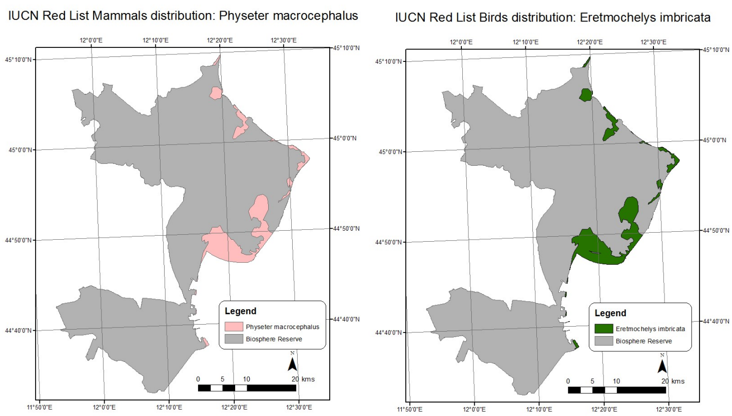
In defining conservation value, scores were attributed to each parameter in order to derive a Conservation Value Index (CVI). Scores for each land cover and management type increased with increasing level of naturalness and increased levels of relevance for conservation. Thus, natural and semi-natural areas scored higher than

urban and agricultural areas, whilst areas managed under international schemes scored higher than areas managed under provincial and regional schemes (Table 7).
When species are concerned, the initial intention was to use the presence of animal species included in the Red List and present within the Biosphere Reserve, in order to use their observed presence as an additional parameter describing the value for conservation. However, this task proved more difficult than expected, since many species were distributed extensively over the area of Biosphere Reserve. Overall, the Biosphere Reserve provides shelter and habitat for over 40 IUCN Red List animal species, whereby 11 are considered threatened species (Table 8), i.e. either Vulnerable, Endangered and Critically Endangered. For the purpose of this study, only species that are recognized as being threatened were taken into consideration and the contribution of each was taken into account in the determination of CVI. Applying this restriction enabled better use of the available data, as extensive overlap of species displaying low level of threat would have potentially skewed the importance of species distribution in calculating CVI. Despite this modification to the intended approach, the range of several species of interest overlapped (Figure 7).

Class	Total Red list species	Threatened species	List of threatened species	Status of threatened species
Amphibians	12	1	*Rana latastei*	Vulnerable
Reptiles	16	4	*Caretta caretta* *Chelonia mydas* *Dermochelys coriacea* *Eretmochelys imbricata*	Vulnerable Endangered Vulnerable Critically endangered
Mammals	9*	4	*Balaenoptera physalus* *Myotys capaccinii* *Nyctalus lasiopterus* *Physeter macrocephalus*	Endangered Vulnerable Vulnerable Vulnerable
Birds	5*	2	*Clanga clanga* *Clangula hyemalis*	Vulnerable Vulnerable

Table 8. IUCN Red list animal species reported within the boundaries of the Po Delta Biophere Reserve. *For mammals and birds, species of least concern are not included.





Projection: Monte Mario Italy 1

Data Source: IUCN and Birdlife International

Prepared by: Damiano Vesentini

Figure 7. Distribution of threatened IUCN animal species within the Po Delta Biosphere Reserve.

Priority for conservation	CVI value	Rationale	Example combinations
Low	≤ 11	Area offers a basic combination of at least two key parameters defining CVI	Natural/seminatural areas (CVI = 6); Basic level of protection (CVI = 2); At least one vulnerable species (CVI = 3) or Agricultural/urban areas (CVI = 4); Enhanced level of protection (CVI ≥ 6); No vulnerable species (CVI = 0)
Medium	11-17	Area offers an enhanced combination of at least two key parameters defining CVI	Natural/seminatural areas (CVI ≥ 6); Basic level of protection (CVI = 2); At least two vulnerable species (CVI = 6) or Natural areas (CVI ≥ 8); Enhanced level of protection (CVI ≥ 6); No vulnerable species (CVI = 0)
High	17-20	Area offers a combination of three key parameters defining CVI, with at least one of them representing high value conditions and the others representing enhanced value conditions. Alternatively, the area offers a combination of at least two key parameters defining CVI, with both representing high value conditions.	Natural areas (CVI ≥ 8); Enhanced level of protection (CVI ≥ 6); At least one vulnerable species (CVI = 3) or High value natural areas (CVI = 10); Area of EU relevance (CVI = 8); No vulnerable species (CVI = 0)
Very high	> 20	Area offers a combination of three key parameters defining CVI, with at least two of them representing high value conditions	Natural areas (CVI ≥8); Enhanced level of protection (CVI ≥6); At least one vulnerable and one endangered species (CVI =7) or High value natural areas (CVI = 10); Area of EU relevance (CVI =8); Two or more vulnerable species (CVI ≥6)

Table 9. Threshold parameters for the definition of prioritization according to CVI values.

On the basis of the abundance of threatened species within the Biosphere Reserve, it was estimated that in the absence of a weighted score between the ecosystem integrity (based on two parameters, land cover and management type) and the occurrence of threatened species, the latter parameter would have played heavily towards the calculation of the overall CVI. Thus, a weight of 2 was applied to both land cover and management type scores, whilst a weight of 1 was applied to the score attributed to each of the threatened species within the Biosphere Reserve.

The resulting CVI ranged from 0 to 46. In order to identify priority areas, different threshold values were applied, which are shown in the Table 9. The thresholding was a way to organize data according to assumed level of priority, whereby the combination of multiple parameters at a significant level could be assured. Some examples of these combinations are provided in Table 9.

The information presented in Table 7, Table 8 and Table 9 was used to address the second research question in the scope of this work: *What are the parameters that can be used to determine value for conservation?* As derived from the information reported above, land cover, area management typology and the presence of threatened species are suitable parameters for the definition of conservation value.

6.1.3. Areas of high conservation value

The definition of CVI values described in the previous section, enabled the identification of areas of high conservation value. The data reported below addresses the following research question: *What is the distribution of areas of high conservation value?*

Weighted CVI component scores for each of the parameters used for determining overall CVI were evaluated and are shown in Figure 8. Both components relating to ecosystem integrity indicated a clear Eastern concentration, with the majority of semi-natural and natural land uses located in these areas. Similarly, the majority of conservation management of international relevance also occurs in the same area, as well as in the Southern part of the Biosphere Reserve. Conversely to the pattern observed for the two parameters relating to land use and management type, the CVI component scores for threatened species presence had a different distribution. In this case, a general South to North increasing trend could be observed, whereby the highest scores, associated with the highest occurrence of species could be discerned in the Northern and Eastern areas of the Biosphere Reserve.

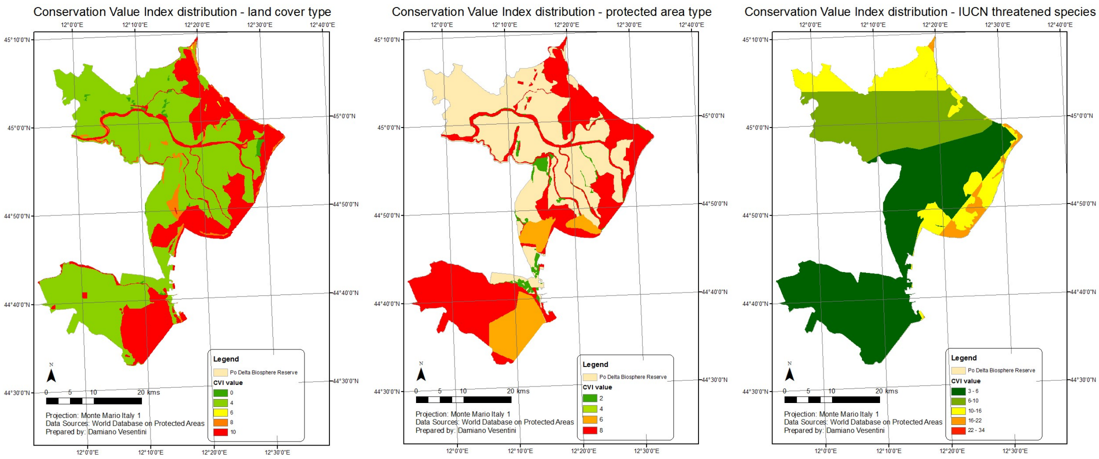


Figure 8. Distribution of individual CVI values for each of the three parameters used in the determination of conservation value.

When the overall CVI was considered, which took into account all of the component parameters that were used to define it, it was observed that approximately half of the total area of the Biosphere Reserve could be identified as being of high or very high priority based on its conservation value (Table 10). The distribution of CVI values within the Biosphere Reserve is shown in Figure 9, whereby a clear localization of high and very high value areas in the Eastern part of the reserve is evident. At the same time, it can be observed from comparing results in Figure 8 and Figure 9 that in some instances, e.g. the Southern part of the Biosphere Reserve, the combination of ecosystem characteristics and protected status are the main factors leading to the observed high conservation value.

Priority based on CVI	CVI value range	Area (ha)	%
Low	< 11	25878	18.54
Medium	11-17	44118	31.61
High	17-20	23732	17.01
Very high	> 20	45818	32.84

Table 10. Size distribution of areas within the Biosphere Reserve based on value for conservation (CVI).

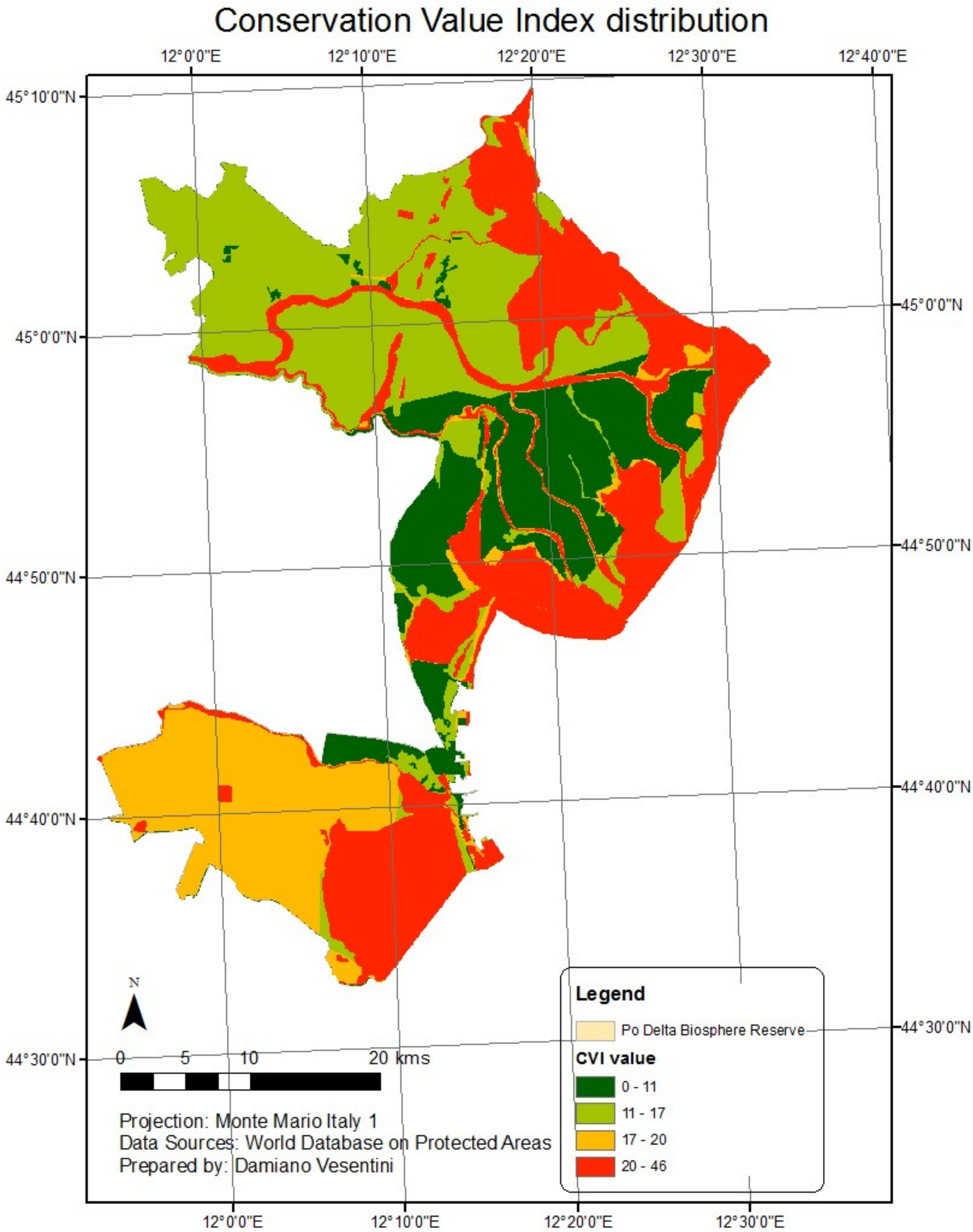


Figure 9. Distribution of conservation value (CVI) within the Biosphere Reserve.

6.2. Identification of areas of concern for water quality

In this section, results are presented, relating to the distribution of parameters that may potentially affect water quality. The data reported below addresses the following research question: *Which are the main areas of concern in relation to water quality?*

According to data made available by the European Environment Information and Observation Network (EIONET), the whole of the Po Delta Biosphere Reserve area is sensitive to nutrient contamination by nitrogen, phosphorous or both. Sensitivity has been observed to occur at all scales, including the catchment as a whole, as well as transitional and coastal waters (Figure 10), thus the significance of this result in determining areas of concern for water quality is limited.

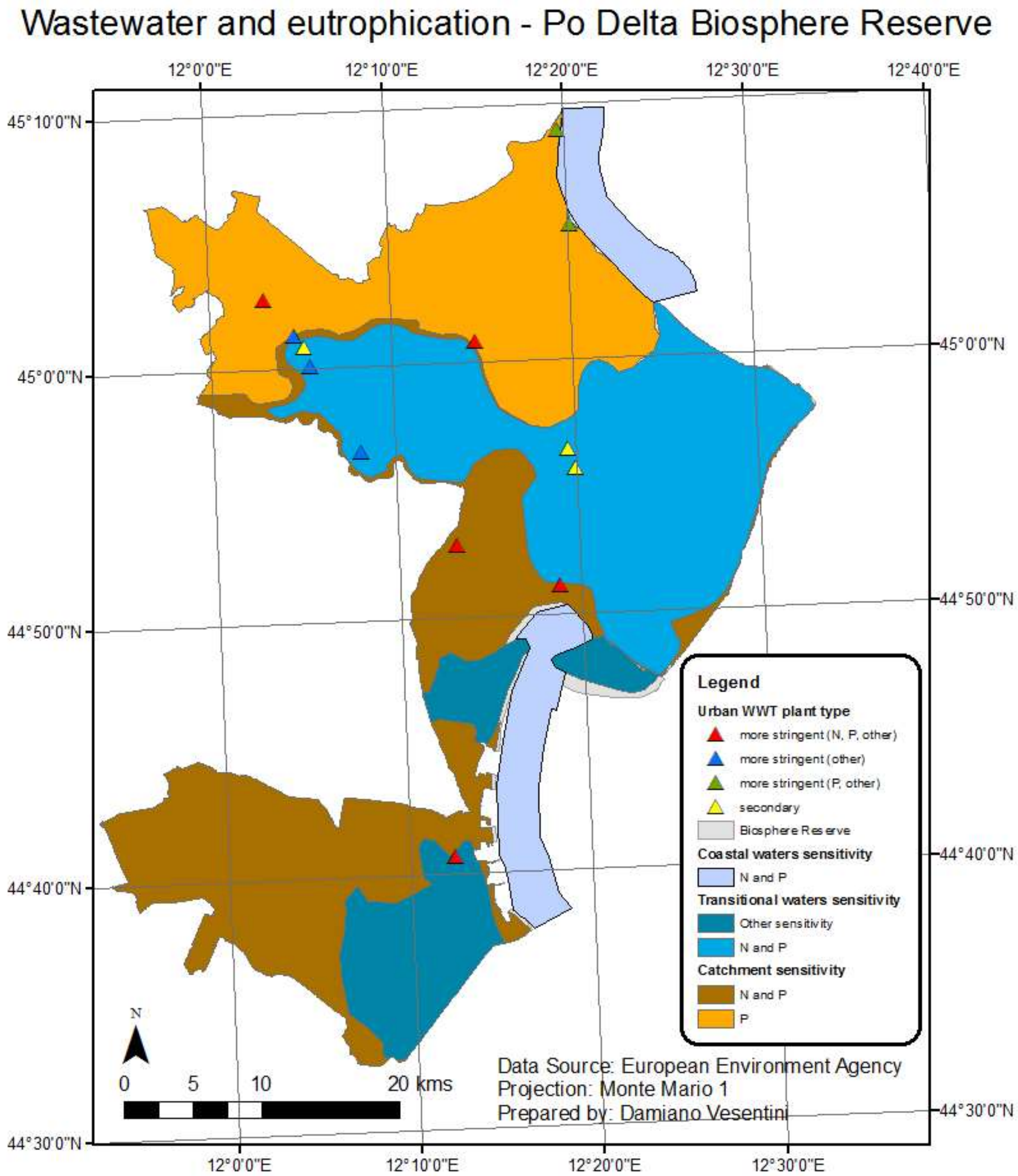


Figure 10. Sensitivity to nutrient accumulation and distribution of wastewater treatment plants in the Po Delta Biosphere Reserve.

On a local scale, the occurrence of wastewater treatments plants (secondary and tertiary water treatment) is one of the measures put in place to defend water quality and to comply with the Urban Waste Water Treatment Directive (91/271/EEC) (European Commission, 1991a). Nevertheless, the distribution of sensitivity and contamination, as well as the available information on the quality of bathing waters (Figure 11), are important symptoms indicating that other factors may influence water quality within the Biosphere Reserve. Bathing waters display poor quality, especially in the Northern part of the Biosphere Reserve, whereby the quality of bathing waters has been reported to be of low quality at least in one instance since records began in 1991.

In view of the above, it is important to consider broad-reaching factors in the determination of water quality. Specifically, the next sections will focus on the distribution of agriculture and tourism activities, since these anthropogenic activities may lead to deterioration of water quality, especially when occurring at high levels.

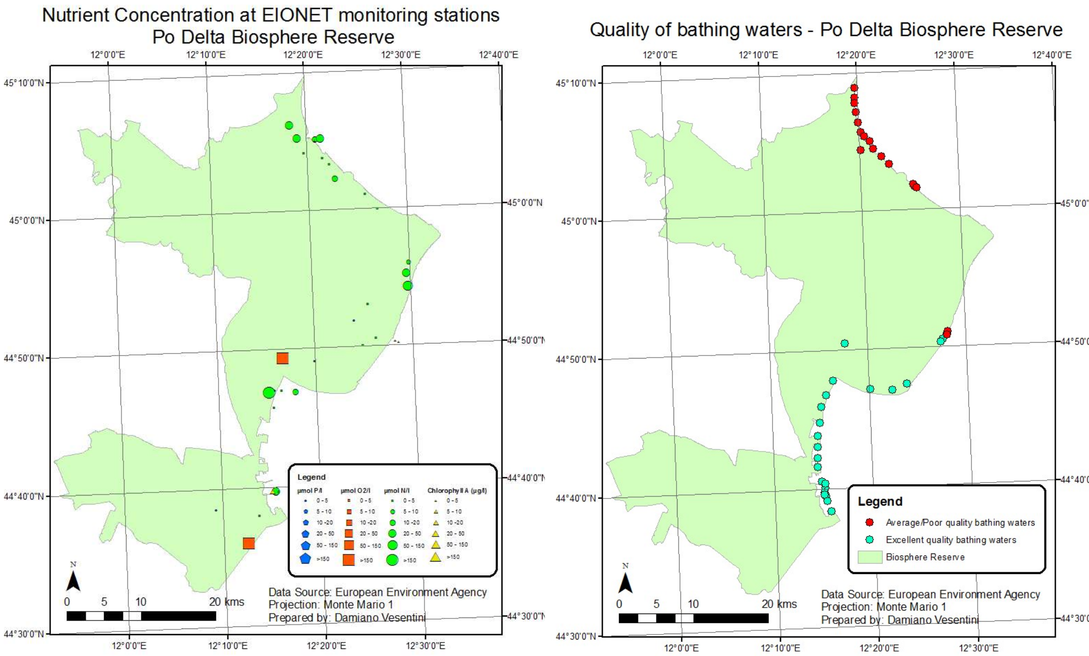


Figure 11. Distribution of nutrient contamination and status of bathing waters quality in the Po Delta Biosphere Reserve.

6.2.1. Agricultural activities

The Po Delta Biosphere Reserve fulfils an important role for agriculture, which provides employment and sustenance to part of the local population. Table 11 provides an overview of the number of agricultural enterprises and average land size for the municipalities of the Biosphere Reserve. At first glance, it is evident that the relevance of agriculture in the two regions comprising the Biosphere Reserve is different, with Emilia Romagna dedicating more human resources and drawing more income from agricultural activities. The data reported below addresses the following research question: *What is the distribution of areas associated with agriculture and farming?*

Municipalities	No. farms km^2	Average UAA per farm (ha)	No. People in agriculture per 1000 residents	Average no. annual work units per farm	Output per farm (Euros)
Veneto					
Adria	4.72	15.78	46.77	0.41	38776.28
Ariano nel Polesine	3.39	16.25	110.4	0.56	67370.86
Papozze	4.17	14.9	79.36	0.46	31779.53
Corbola	6.31	9.72	71.71	0.47	20451.78
Loreo	3.71	19.53	78.18	0.75	51718.87
Porto Tolle	1.4	44.74	75.31	0.95	97974.37
Porto Viro	0.95	40.81	17.41	0.69	109865.76
Rosolina	2.64	10.18	68.19	0.76	48019.98
Taglio di Po	2.51	35.34	48.73	0.84	286065.3
Emilia Romagna					
Argenta	2.5	29.93	114.82	1.00	202208.17
Codigoro	1.93	33.41	79.27	1.00	189052.89
Comacchio	1.03	34.24	78.8	2.00	224641.54
Goro	0.76	26.6	12.93	1.00	69464.35
Mesola	3.35	16.72	110.43	1.00	107948.79
Ostellato	2.01	33.97	186.49	1.00	162494.18
Portomaggiore	2.56	30.98	92.49	1.00	147193.73

Table 11. Overview of the economic relevance of agriculture in the municipalities of the Po Delta Biosphere Reserve.

In assessing the impact of agriculture on the potential risk to water quality, the distribution of crop agriculture and animal husbandry were taken into account, as well as the distribution of aquaculture activities (Figure 12). Since the information about crop agriculture and animal husbandry distribution was available by municipality, the scale of the information determined the level of detail that could be determined for the foreseen impact of agriculture. Overall, the municipalities in the Veneto region were less dedicated to crop agriculture than the municipalities in the Emilia Romagna region, with the municipalities of Codigoro, Comacchio and Mesola dedicating more than 60% of the usable agricultural area to crop production. Conversely, animal agriculture was more prominent in the Veneto region, with the municipalities of Taglio di Po supporting a livestock density > 1 livestock units (LSU), followed by Ariano nel Polesine (> 0.75 LSU) and the municipalities of Loreo and Rosolina (LSU > 0.6). In Emilia Romagna, only Portomaggiore supported a livestock density > 1, with the other municipalities oriented primarily to crop agriculture.

When aquaculture was considered, the area of the Biosphere Reserve and its immediate coastal vicinity included 30 shellfish farms, whereby 22 farms specialized in bottom clam farming (21 in Veneto and 1 in Emilia Romagna) and 8 farms specialized in long line mussel farming (6 in Veneto and 2 in Emilia Romagna). The majority of these farms (23) were found within 1500 m from the shoreline.

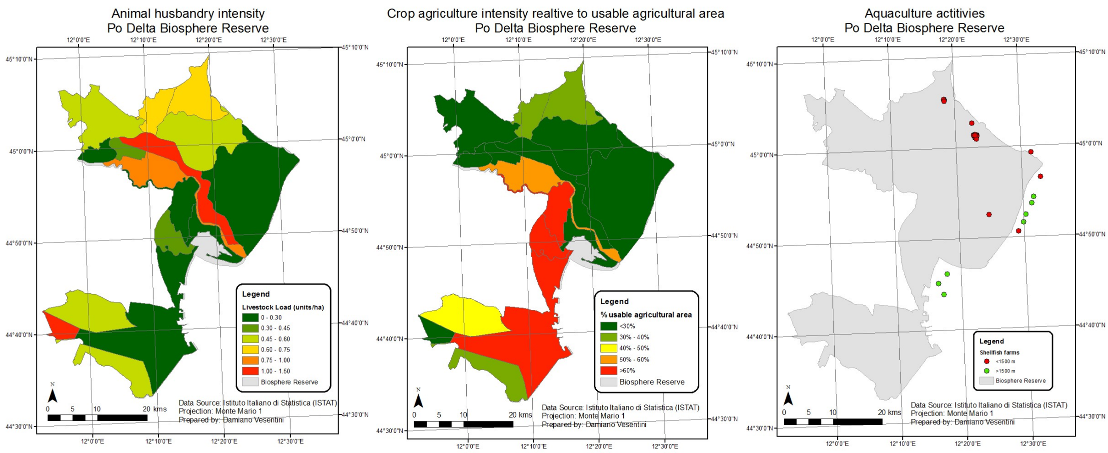


Figure 12. Distribution of agricultural activities in the Po Delta Biosphere Reserve. Aquaculture activities are identified according to their distance from the coastline.

Overall, agriculture activities were found to be widely distributed within the Biosphere Reserve, with 5 out of 16 municipalities presenting high levels of agriculture in relation to cropping or animal farming and one municipality presenting medium levels of agriculture in relation to both animal and crop farming. Areas broadly corresponding to the interface between the river and its access to the sea were often associated with low levels of agriculture, but in these cases the presence of fish farming activities became more prominent.

6.2.2. Tourism

Besides information strictly pertaining to the distribution of agriculture activities, the distribution of tourism was considered as a further determinant of risk to water quality in the area. Consequently, despite not being a direct research question addressed in this study, this factor was taken into consideration when determining water quality risk.

The number of available beds was used to determine tourism-related pressure. Overall, two coastal municipalities in the Veneto region (Rosolina and Porto Tolle) and one municipality in the Emilia Romagna region (Comacchio) showed the highest number of available beds, which reached some 23000 in Rosolina and some 47000 in Comacchio. In 2016, Porto Tolle recorded approximately 172000 overnight stays, whilst Rosolina recorded over 1.1 million overnight stays. Similarly, Comacchio recorded about 2.05 million overnight stays. These numbers provide an idea about the relevance of the area for tourism, with these three municipalities alone receiving some 3.4 million overnight stays in 2016 (ISTAT, 2017).

Municipality	Inhabitants	Total no. beds	No. beds per inhabitant	Expected impact
Veneto				
Adria	19436	427	0.02	*Low*
Ariano nel Polesine	4241	80	0.02	*Low*
Papozze	1455	9	0.1	*Medium*
Corbola	2372	9	0.05	*Low*
Loreo	3459	166	0.05	*Low*
Porto Tolle	9663	3328	0.34	*Medium*
Porto Viro	14298	268	0.02	*Low*
Rosolina	6456	23834	3.69	*High*
Taglio di Po	8271	284	0.03	*Low*
Emilia Romagna				
Argenta	21521	408	0.2	*Medium*
Codigoro	11740	199	0.2	*Medium*
Comacchio	22188	46238	2.08	*High*
Goro	3742	90	0.02	*Low*
Mesola	6778	206	0.03	*Low*
Ostellato	6030	246	0.4	*Medium*
Portomaggiore	11630	182	0.02	*Low*

Table 12. Overview of the availability of tourism infrastructure and their expected impact on the risk to water quality in the municipalities of the Po Delta Biosphere Reserve.

In a more detailed analysis, the level of tourism impact was based on the number of available beds, which were categorized from low to very high impact, according to Table 12. In this case, the municipalities of Rosolina and Comacchio displayed the highest density of beds per inhabitant, highlighting the touristic relevance of these localities. Among the other localities, tourism had mostly a low relevance, with the exception of Papozze and Porto Tolle in Veneto and Argenta, Codigoro and Ostellato in Emilia Romagna.

6.2.3. Impact of the risk to water quality on conservation value

Previous sections (6.2.1 and 6.2.2) reported information relating to water sensitivity to nutrient accumulation in the Po Delta Biosphere Reserve and associated risk factors. The distribution of activities that could impact water quality and nutrient release has also been considered. Whilst the information relating to sensitivity to nutrient accumulation could only be reported over broad areas (e.g. catchment area), it remained important to determine how the potential risk to water quality could be used to establish priorities for conservation. For this purpose, information relating to the distribution and intensity of agricultural activities and tourism was used to derive a risk factor, which together with the information relating to conservation value could support prioritization of actions for conservation. The data reported below addresses the following research question: *What is the spatial relationship between conservation value and water quality characteristics?*

Overall, the Southern part of the Biosphere Reserve was associated with predominant areas of high conservation importance and high risk, whereas the Northern part of the Biosphere Reserve was associated with predominantly low to medium risk areas and low to medium CVIs. In the Northern area, within the municipality of Rosolina, an area of very high CVI and very high risk can also be observed, which represents one of the two exceptions to the general trend (the other being broadly corresponding to the municipality of Ariano nel Polesine). Finally, on the Eastern sea border areas of conservation importance associated with medium risk can be observed (Figure 13). When examining the extension of areas associated with different combinations of risk and conservation value (Table 13), the quantitative effect of risk becomes evident. Overall, 75% of the Biosphere Reserve area was associated with medium or high risk of deterioration of water resources, as a consequence of the risk factors considered, whilst 28% of the area is associated with high risk.

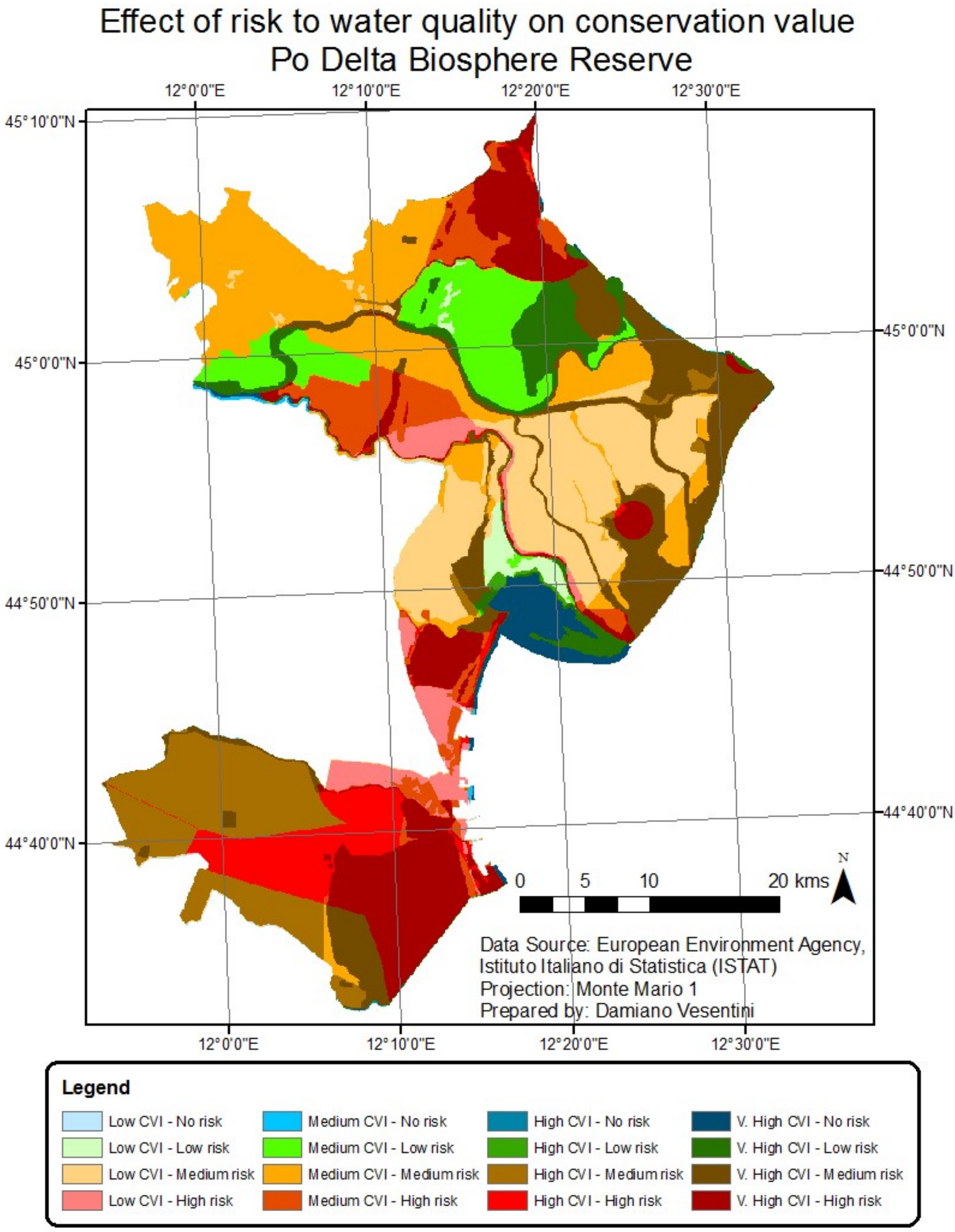


Figure 13. Water quality degradation in relation to conservation value. Overview of the possible effect on the distribution of areas of different conservation value.

Upon further examination of the data, it also becomes apparent that approximately 18% of high value areas (i.e. areas with high or very high CVI) were exposed to high risk deriving by the deterioration of water quality. Similarly, over 23% of high value areas were exposed to medium risk. This implies that over 40% of the high value areas were associated to significant level of risk. Conversely, only 8% of high value areas for conservation are associated with no risk or low risk. This five-fold increase in the potential risk associated with human activities in the area provides a sense of the magnitude of the problem facing the management of the Biosphere Reserve.

Risk level	Conservation value	Area (ha)	%
No Risk			
	Total	***4119.3***	***2.95***
	Low	132.9	0.10
	Medium	302.2	0.22
	High	34.9	0.02
	Very high	3649.3	2.62
Low risk			
	Total	***19182.8***	***13.76***
	Low	1625.6	1.17
	Medium	10482.7	7.52
	High	378.9	0.27
	Very high	6695.6	4.80
Medium risk			
	Total	***76670.3***	***54.95***
	Low	19253.0	13.80
	Medium	24430.4	17.51
	High	15546.5	11.14
	Very high	17440.4	12.50
High risk			
	Total	***39565.5***	***28.35***
	Low	4866.8	3.49
	Medium	8902.2	6.38
	High	7771.7	5.57
	Very high	18024.8	12.92

Table 13. Effect of potential risk to water quality according to the conservation value of the area.

6.3. Identification of areas of concern for land loss under increasing sea levels

In this section, data on elevation is presented in conjunction with predictions of sea level rise under different scenario in order to estimate land loss and its effect on areas of high conservation value. The first research question that is addressed in this section is: *What are the effects of the best- and worst-case scenarios on land loss?*

When considering land loss due to sea level rise according to the RCPs discussed here, it is important to note that in the territory occupied by the Biosphere Reserve, elevation ranges from approximately -5.5 m to approximately 10.5 m above sea level (Figure 14). The majority (75.3%) of the area covered by the Biosphere Reserve is below sea level, with only a minor area that represents emerged land. This low-lying area is not currently fully submerged, but it is rather a combination of marshes, beaches and low-lying aquatic environments.

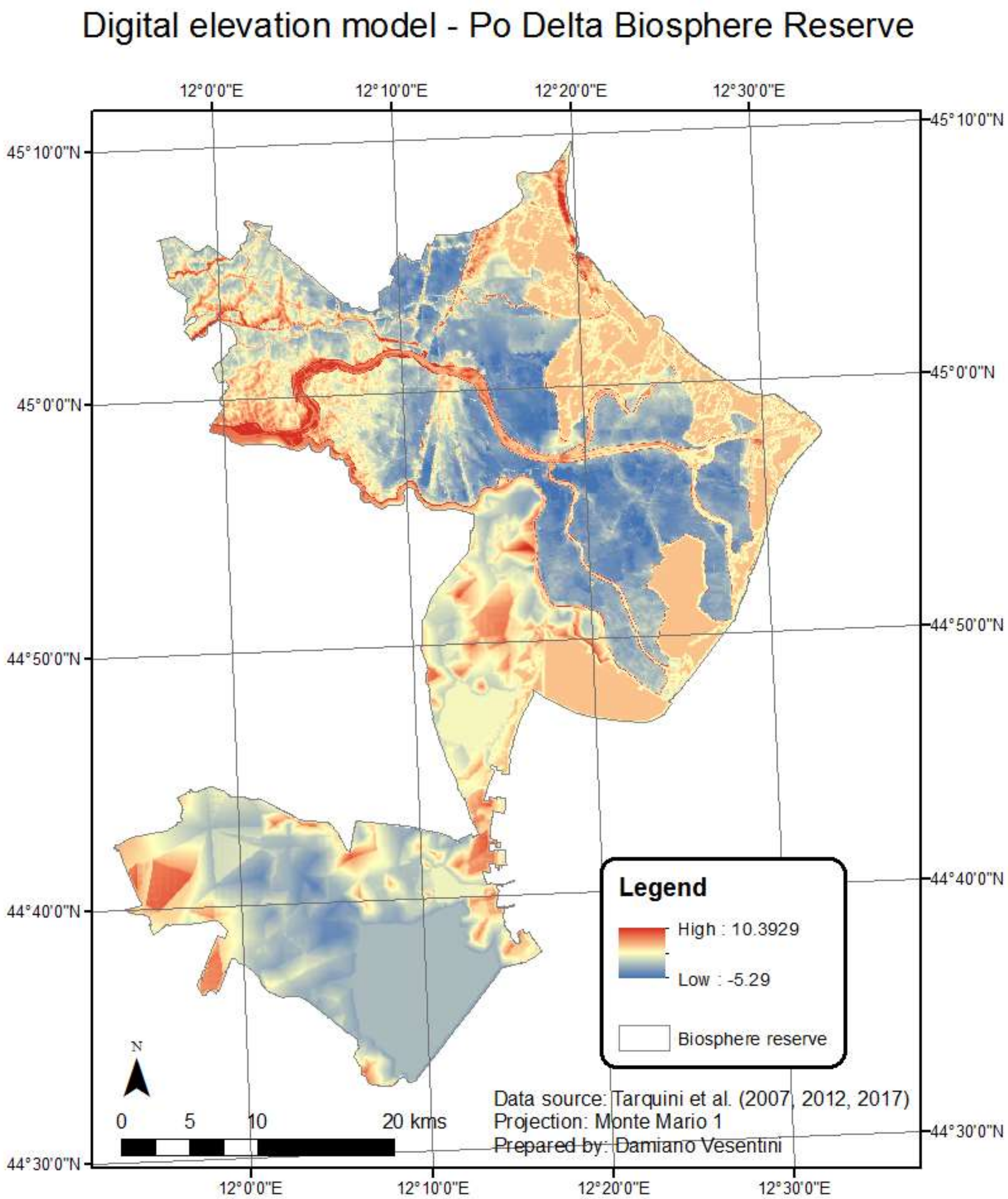


Figure 14. Digital elevation model for the Po Delta Biosphere Reserve.

The impact of increasing sea level is presented in Figure 15 and in Table 14. Overall, it is evident that under increasing scenarios of sea level rise, the extent of areas lying below sea level will increase, by up to 10.6% in the case of RCP 2.6 under the most optimistic prediction and by 15.5 to 19.2% in the case of RCP 8.5 under the worst conditions represented by the maximum value in the range. Thus, under best and worst case conditions we could expect an increase in flooded areas to approximately 81.3% (RCP 2.6 minimum sea level) and 89.7% (RCP 8.5 maximum) of the total. This would mean that only approximately 10-20% of the total area would remain unaffected by climate-induced sea level rise. The effect of increasing sea levels on areas that are currently located above sea level is clear. However, it is equally important to note that increasing sea levels would also cause a shift in the water levels of marshes and other low lying areas, which would potentially see longer, if not permanent flooding periods.

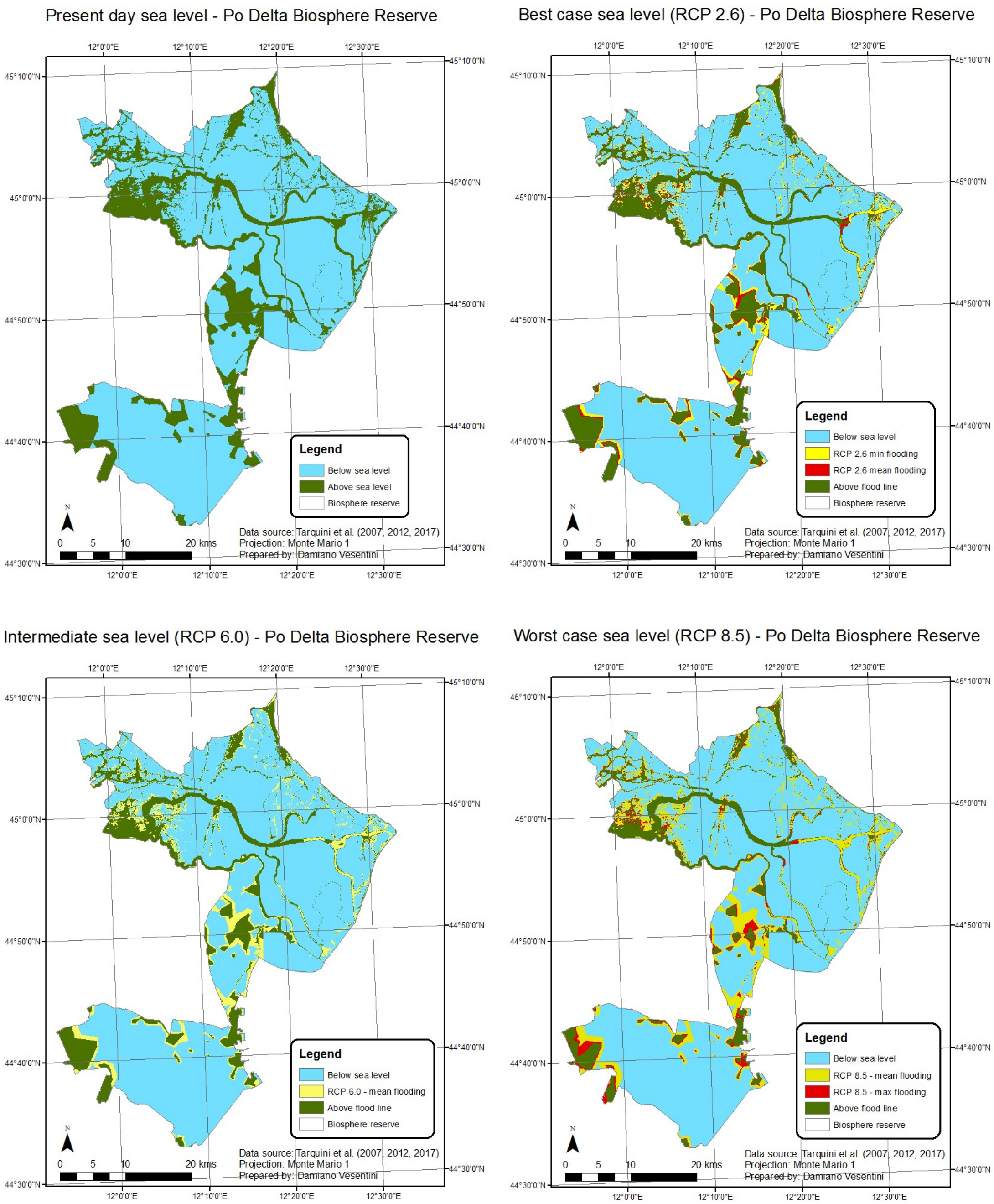


Figure 15. Effect of sea level rise on land loss under different Representative Concentration Pathway scenarios.

The second research question that needs to be addressed in relation to the impact of sea level rise on the biosphere reserve is the following: *What is the impact of sea level rise on the distribution of areas of high conservation value within study area under the worst-case scenario?*

Sea level rise scenario	Estimated increase in sea level 2100 (m)	Area below sea level			Flooded area (% of total) –
		Total area (ha)	Variation from current values (ha)	Variation from current values (%)	
Current level	0	105002.2	0	0	75.3
RCP 2.6 – minimum	0.26	112959.7	+7857.5	+7.48	81.0
RCP 2.6 – mean	0.4	116169.3	+11167.1	+10.63	83.3
RCP 6.0 – mean	0.48	118134.2	+13132.0	+12.51	84.7
RCP 8.5 – mean	0.63	121332.3	+16330.1	+15.56	87.0
RCP 8.5 - maximum	0.82	125148.2	+20146	+19.18	89.7
No risk of flooding		**14252.7**			

Table 14. Impact of increasing sea levels on land loss in relation to different Representative Concentration Pathway scenarios.

Taken in isolation, the impact of sea level rise on land loss does not reflect the consequences that sea level rise has on specific areas of varying value for conservation. When sea level rise and conservation value are taken into consideration (Figure 16 and Table 15), it becomes manifest that climate-induced sea level rise may have considerable impacts on areas of high and very high conservation value. Specifically, under RPC 2.6 conditions, a total of 15.5% more high or very high value areas will be found under sea level, as compared to the current extent. The situation becomes even more dramatic under RPC 8.5 conditions, in which case the value increases to over 26%.

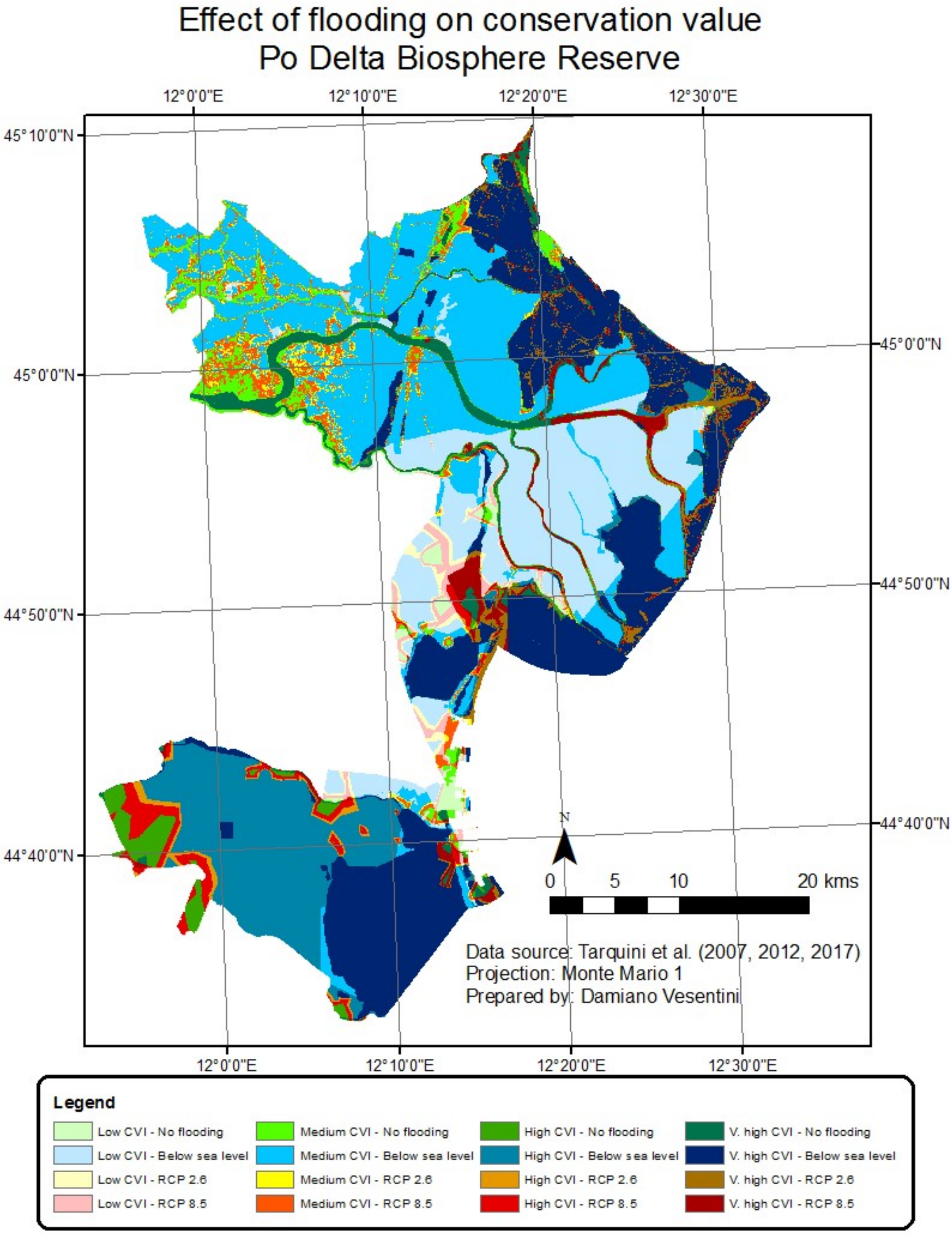


Figure 16. Sea level rise in relation to conservation value. Overview of the possible effect of land loss on the distribution of areas of different conservation value under best and worst case scenario conditions.

Scenario	Conservation value	Area (ha)	Area loss (ha)	Variation (%)
Below sea level				
	Low	21210.9	-	-
	Medium	32953.3	-	-
	High	17024.3	-	-
	Very high	33804.2	-	-
RCP 2.6 - min				
	Low	22475.3	-1264.4	-5.96
	Medium	35279.7	-2326.4	-7.06
	High	18122.0	-1097.7	-6.45
	Very high	36979.3	-3175.0	-9.39
RCP 8.5 - max				
	Low	24264.1	-1788.8	-8.43
	Medium	39485.7	-4206.0	-12.76
	High	20809.8	-2687.8	-15.79
	Very high	40573.5	-3594.2	-10.63
Above flood line				
	Low	1505.6	-	-
	Medium	4606.7	-	-
	High	2920.2	-	-
	Very high	5218.3	-	-

Table 15. Effect of sea level rise on potential land loss according to the conservation value of the area. Estimates are based on Representative Concentration Pathway scenarios.

6.4. Combined effect of water quality degradation and sea level rise

In this part of the study, the combined effects of multiple risk factors associated with water quality and flooding due to sea level rise are considered. The following research question is addressed: *What is the combined impact of water quality degradation and land loss due to rising sea levels on the distribution of areas of high conservation value within study area under the worst-case scenario?*

Results are presented in Figure 17 and Table 16. Interpretation of the figure allowed observation of the distribution of CVI areas within the Biosphere Reserve and their relationship with the distribution of combined risk. Essentially > 85% of the Biosphere Reserve area was associated with the occurrence of combined risk. Differences however may be observed in the severity of combination or in the type of areas affected. It is worth noting that areas currently located below sea level (BSL) were included in the calculation of combined risks because low elevation may be having impacts similar to those following sea level rise, especially when combined with other risk factors. For example, low-lying areas might be subject to longer or permanent periods of submersion or increases in overall water depth. These factors could in turn have an impact on the overall ecosystem integrity and function. In Figure 17, the distribution of very high value areas is following the coastline and is associated with different levels of combined risk. These are mostly areas that are located below sea level, which are at risk of being impacted by human activities that may affect water quality.

Additionally, Figure 17 displays, along the coastline, areas impacted by only one risk type (i.e. areas where No Combined Risks were observed; NCR) and areas that could be subjected to increasing sea level, in combination with the risk of human-induced degradation of water resources.

Areas of high value for conservation were more widespread and included mostly locations in the lower part of the Biosphere Reserve, although some Northern locations were also included. These areas were equally affected by combined risks as very high CVI areas, but differed in their distribution, which was not always following the coastal line.

Numerical values relating to the potential effects of combined risks on conservation value are provided in Table 16. When examining the information in detail, different interpretations may be applied. For example, if only high and very high value areas are considered, based on CVI, the combined effects associated with risks deriving from increased sea level and degradation of water resources extend over an area of approximately 52 700 hectares. This corresponds to approximately 38% of the total area of the Biosphere Reserve. Thus, approximately 17 000 hectares of high or very high conservation value areas were found to not be affected by the combined effects of the risks described here.

Similarly, examining combined risks as a primary factor of interest, the study showed that approximately 121 500 hectares in the Biosphere Reserve (87%) could be exposed to some level of combined risk. Among these, approximately 36 000 hectares could be exposed to high risk (as determined by the occurrence of high water risk, HWR). Further, approximately 69 000 were associated with medium risk (as determined by the occurrence of medium water risk, MWR) and approximately 16 000 hectares with low water risk (LWR). In percentage, this equates to a distribution of 30% for HWR, 57% for MWR and 13% for LWR.

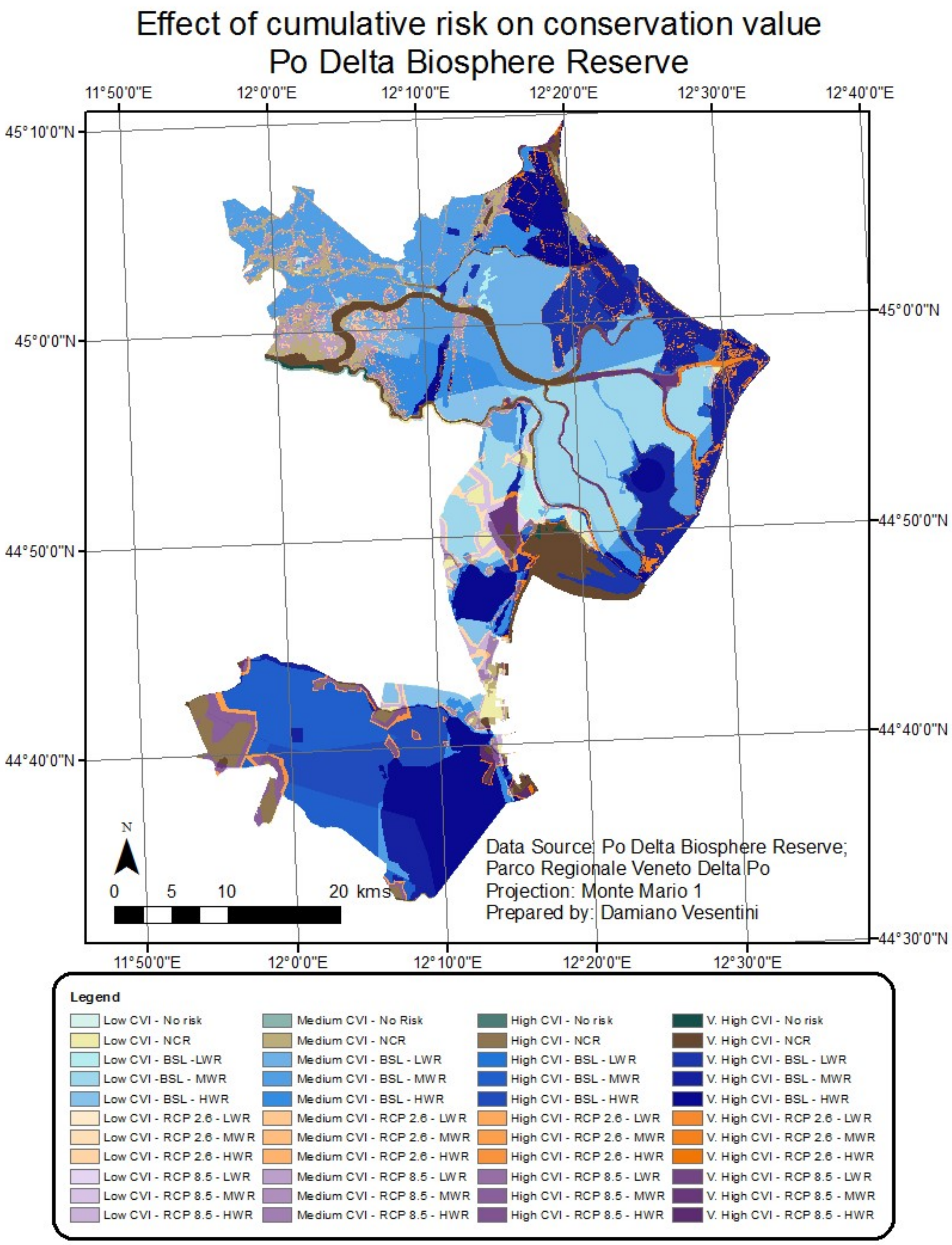


Figure 17. Combined risk deriving from water quality degradation and sea level rise in relation to conservation value. Overview of the possible effect on the distribution of areas of different conservation value. Values relating to sea level scenarios (RCP 2.6 and RCP 8.5) and current low elevation (BSL) are included. Also, values relating to low, medium and high water risk are also included (LWR, MWR and HWR, respectively). Finally, areas of no risk and areas where no combined risks (NCR) were observed are also reported.

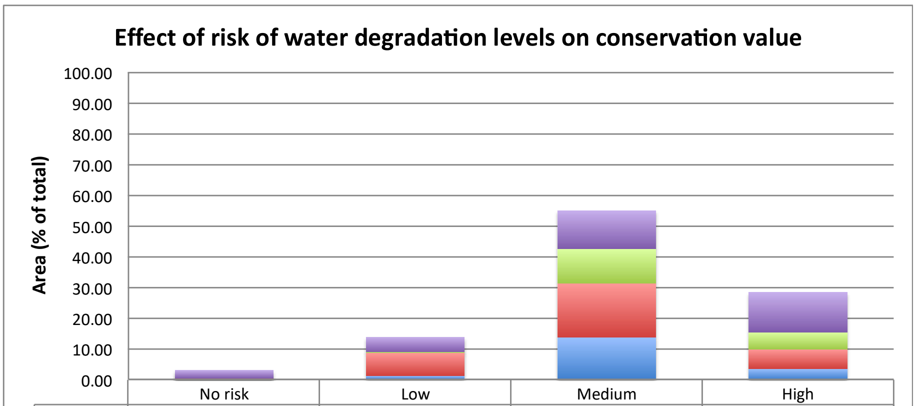
Scenario	CVI	No Risk			NCR	
		Area (ha)	%		Area (ha)	%
No/Low risk	***Subtotal***	***537***	***0.38***		***17450.3***	***12.51***
	Low	78.0	0.06		1591.2	1.14
	Medium	190.0	0.14		4554.1	3.26
	High	8.1	0.01		2940.9	2.11
	Very High	260.9	0.19		8364.1	5.99

	CVI	LWR		MWR		HWR	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
BSL	***Subtotal***	***13339.5***	***9.56***	***57674.2***	***41.33***	***31130.4***	***22.31***
	Low	1146.6	0.82	16769.4	12.02	3263.8	2.34
	Medium	7892.6	5.66	18898.9	13.54	6101.7	4.37
	High	118.3	0.08	10559.3	7.57	6328.4	4.54
	Very High	4181.9	3.00	11446.6	8.20	15436.5	11.06
RCP 2.6	***Subtotal***	***1256.6***	***0.90***	***4288.9***	***3.07***	***1861.2***	***1.33***
	Low	120.7	0.09	729.9	0.52	405.8	0.29
	Medium	597.8	0.42	1209.8	0.87	485.2	0.35
	High	40.2	0.03	679.0	0.49	374.3	0.27
	Very High	297.9	0.36	1670.2	1.20	595.9	0.45
RCP 8.5	***Subtotal***	***1652.4***	***1.18***	***7298.1***	***5.23***	***3049.5***	***2.19***
	Low	199.6	0.14	1008.6	0.72	564.7	0.40
	Medium	1014.6	0.73	2046.9	1.47	1126.0	0.81
	High	71.4	0.05	1981.9	1.42	630.1	0.45
	Very High	366.8	0.26	2260.7	1.62	728.7	0.52

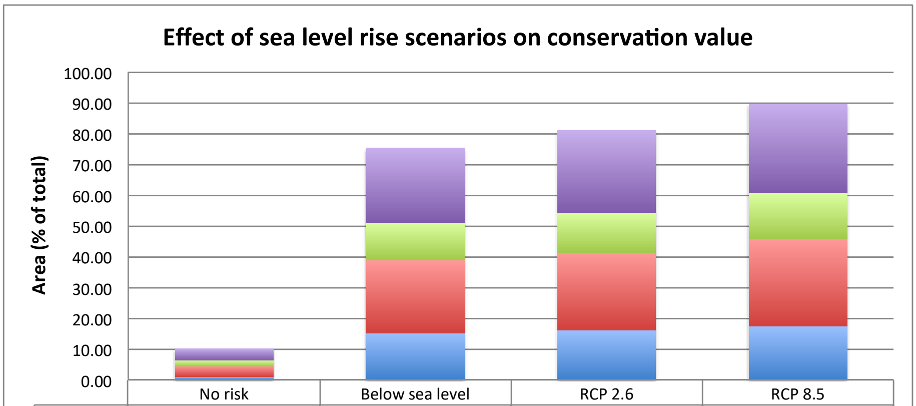
Table 16. Combined effect of risk of water degradation and sea level rise induced by climate change on conservation value. Values relating to sea level scenarios (RCP 2.6 and RCP 8.5) represent the increment compared to areas below sea level (BSL). Values relating to low, medium and high water risk are also included (LWR, MWR and HWR, respectively), as well as areas of where no combined risks (NCR) were observed.

6.5. Identification of priority areas for conservation

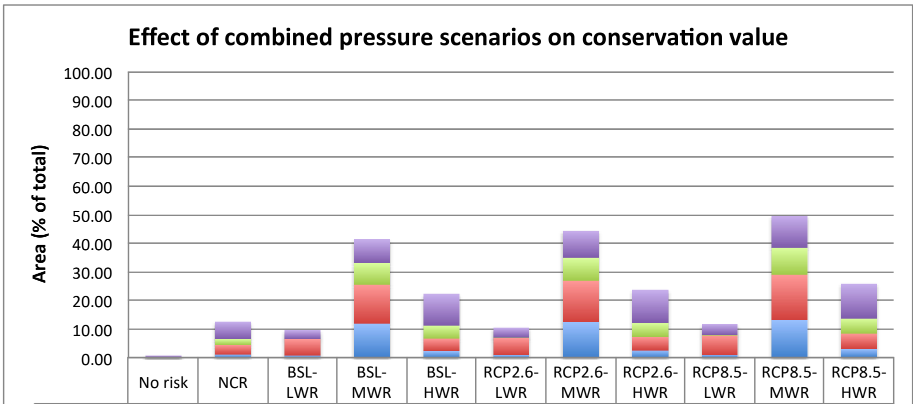
Consideration of the effect of pressure factors on conservation value provided an overview of the direct impact/risk that these factors represent. A comparative view of individual and combined pressure factors is illustrated in Figure 18.



	No risk	Low	Medium	High
Very High	2.62	4.80	12.50	12.92
High	0.02	0.27	11.14	5.57
Medium	0.22	7.51	17.51	6.38
Low	0.10	1.16	13.80	3.49



	No risk	Below sea level	RCP 2.6	RCP 8.5
Very High	3.74	24.25	26.53	29.11
High	2.10	12.21	13.00	14.93
Medium	3.31	23.64	25.31	28.33
Low	1.08	15.22	16.12	17.41



	No risk	NCR	BSL-LWR	BSL-MWR	BSL-HWR	RCP2.6-LWR	RCP2.6-MWR	RCP2.6-HWR	RCP8.5-LWR	RCP8.5-MWR	RCP8.5-HWR
Very High	0.19	5.99	3.00	8.20	11.06	3.35	9.40	11.49	3.62	11.02	12.01
High	0.01	2.11	0.08	7.57	4.54	0.11	8.05	4.80	0.16	9.47	5.26
Medium	0.14	3.26	5.66	13.54	4.37	6.08	14.41	4.72	6.81	15.88	5.53
Low	0.06	1.14	0.82	12.02	2.34	0.91	12.54	2.63	1.05	13.26	3.03

Figure 18. Comparison between the effect of individual and combined pressure factors on conservation value. The y axis and the tables display values relating to the distribution of conservation value within each risk category.

When the risk to water quality is considered, results indicate that:

- Low and medium risk areas were composed of approximately 5% and 23% high and very high CVI areas respectively;
- This value increased to approximately 18% within high risk areas, with approximately 6% relating to medium CVI;
- No risk areas, these were composed of only 2.6% high and very high value areas.

Comparatively, when RPC 2.6 and RCP 8.5 sea level rise scenarios were considered:

- The percentage of high and very high value areas within the affected areas increased to 40% and 44%, for both scenarios, respectively;
- Medium value areas accounted for 25% and 28%, respectively;
- The cumulative percentage of high and very high CVI areas located in zones located below sea level (BSL) was over 36%.
- In no risk areas, the amount of risk-free areas displaying high or very high CVI increased to approximately 5.8% (value refers to areas that are above sea level under present and future conditions);

Finally, when combined pressures were considered, affected areas could be subdivided according to the following:

- Under the RCP 2.6 scenario, 17.5% and 16% of the areas exposed to medium and high risk of water degradation respectively had high or very high conservation value;
- Under the RCP 8.5 scenario, the percentage of high and very high conservation value increased to 20.5% and 17% of the areas exposed to medium and high risk of water degradation respectively;
- Finally, when combined effects were considered, no risk areas were composed only for 0.2% by high and very high value areas; the value increased to approximately 8% of areas affected by individual pressure factors only.

Similar patterns may be observed in relation to low and medium value areas, however, these are not analyzed in detail, in view of their lower interest for conservation. Nevertheless, detailed information is reported in previous sections and summarized in Figure 18.

On the basis of these results, there is an indication that the combination of both the risk to water quality and the risk deriving from climate change-induced increasing sea levels represent a more stringent estimate of the risks to which the Biosphere Reserve is exposed to. The combination of these two factors represents the biggest potential impact on the Po delta biosphere Reserve. Observing only the areas affected by any type of flooding and exposed to a high risk of water degradation, high and very high value areas correspond to approximately 57% of the area of interest. Similarly, observing only the areas affected by flooding under RCP 8.5 conditions and exposed to medium and high water degradation, the corresponded areas is constituted of approximately 37% by high and very high conservation value areas.

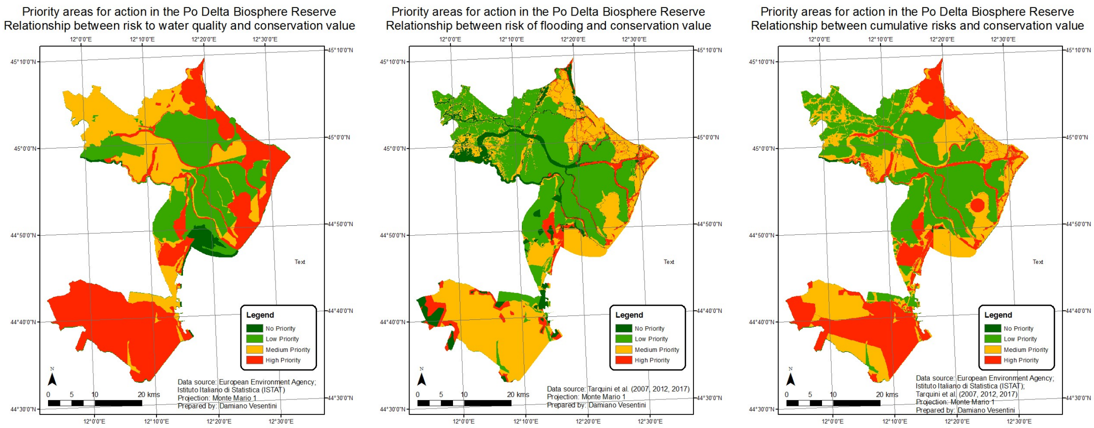


Figure 19. Comparative view of conservation priorities defined for the Po Delta Biosphere Reserve under different pressure scenarios.

An approach for prioritization of the areas and effects of different pressure scenarios identified in this study is presented below (Figure 19 and Table 17). The prioritization relies on the attribution of a priority class (no priority, low, medium and high priority) based on the severity of effects occurring either individually or in combination. Overall, when prioritization is taken into account, it is evident that climate-induced sea level rise was associated with the least conservative prioritisation, with medium and high priority areas accounting for approximately 50% of the total. Conversely, prioritization based on the risk to water quality by human activities provided the most conservative results, whereby medium and high priority areas accounted for approximately 70% of the total. Finally, prioritization based on combined factors laid somewhat in the middle of these two extremes, with medium and high priority areas accounting for approximately 60% of the total.

Priority	Water deterioration		Sea level rise		Combined	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
No priority	4523.92	3.23	14250.72	10.22	955.08	0.68
Low	38435.88	27.46	57217.44	41.05	54289.92	38.79
Medium	38199.44	27.30	57360.96	41.15	45664.76	32.63
High	58783.40	42.01	10554.80	7.58	39046.44	27.90

Table 17. Comparative results from the determination of conservation priorities under different pressure scenarios in the Po Delta Biosphere Reserve

The results presented here address the need to compare the effect on conservation value of individual and combined risks evaluated in this study. Thus, they permitted answering the first of the research questions pertaining to the fifth objective of this study: *Which of the three prioritization criteria is most suitable for defining priorities for conservation within the Biosphere Reserve?*

Based on the results above, it was considered that the effects of individual combinations of pressure factors were more suitable for the identification of priority areas (Figure 18 and Table 16), as it afforded a more realistic (2-factor based) view of the risk. The aggregated results by prioritization class provided a level of approximation, which was less suitable for comparing the results of different pressure scenarios (Figure 19 and Table 17). Nevertheless, the latter results supported a simpler categorical view, which could be used for comparing the output of this study with outputs from other studies in a clearer manner. For this reason, this approach was used for comparing the priorities identified in this study with the priorities for conservation set by the Biosphere Reserve park authorities. Nonetheless, in light of the results described in (Figure 18 and Table 16), the combined scenario was used for comparison, as it was considered to be most appropriate for further investigation, even under the simplified priority class approach.

6.5.1. Comparison between new and established priorities

After having established the most suitable scenario for prioritization, it was possible to address the last of the research questions for this study: *Are identified areas aligned with areas currently identified for conservation?*

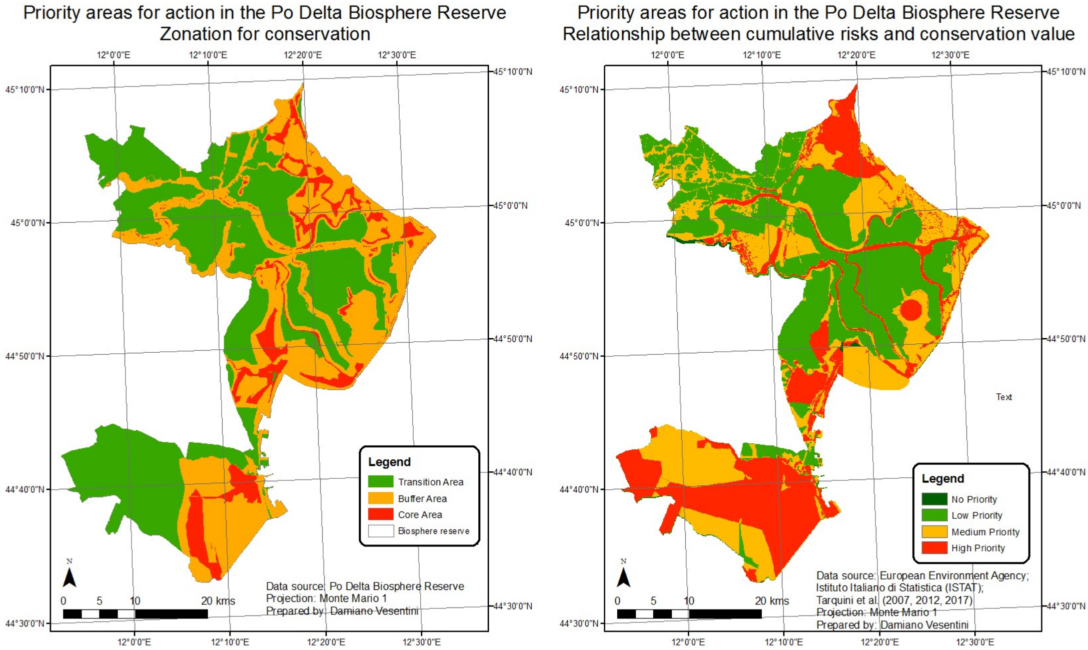


Figure 20. Comparative view of prioritisation for action in the Po Delta Biosphere Reserve under established and newly defined criteria.

For this purpose, the results of prioritization based on the combined risk effect on CVI were compared to the current distribution of core, buffer and transition conservation areas within the Biosphere Reserve (Figure 20 and Table 18). These areas are defined based on their legislative status, which reflects the characteristics of the area and increases progressively between transition, buffer and core areas, and their role in supporting and promoting sustainable practices for ecosystem and species conservation. In setting up the comparison between newly established and current priorities, it was considered that Core and Buffer management areas would be equivalent to high priority areas under the proposed prioritization. The comparison allowed the identification of areas aligned with the current prioritization but, most relevantly, areas that were not aligned. Overall, the newly proposed prioritization method based on the combined effect of combined pressures on CVI distribution was found to afford increased protection to the Biosphere Reserve. Notably, medium and high priority area under the combined pressure approach covered approximately 60% of the total area. Conversely, according to the current zonation, these accounted for approximately 50% of the total area.

Priority	Biosphere Reserve zonation		Combined	
	Area (ha)	**%**	**Area (ha)**	**%**
No priority	-	-	955.08	0.68
Low	70129.76	50.30	54289.92	38.79
Medium	55745.84	39.99	45664.76	32.63
High	13536.76	9.71	39046.44	27.90

Table 18. Comparative view of prioritization under current zonation and combined pressure prioritization.

The final aspect of the comparison between the two prioritization methods consisted of identifying areas of change, for which results are presented in Figure 21. The generalized distribution of changes revealed that a decrease in prioritization was observed in the areas along the Po River, whereby areas became reduced in their extension, especially buffer areas. Conversely, in the Northern and Southern regions of the Biosphere Reserve, a generalized increase in priority could be observed. A quantitative evaluation of the change revealed that under the newly proposed prioritization, approximately 50% of the Biosphere Reserve would experience no change in priority. However, approximately 36% would experience a positive change (6.34% much improved and 30% improved prioritization), whilst 13% would experience a negative variation (12.95% decreased and 0.2% much decreased prioritization).

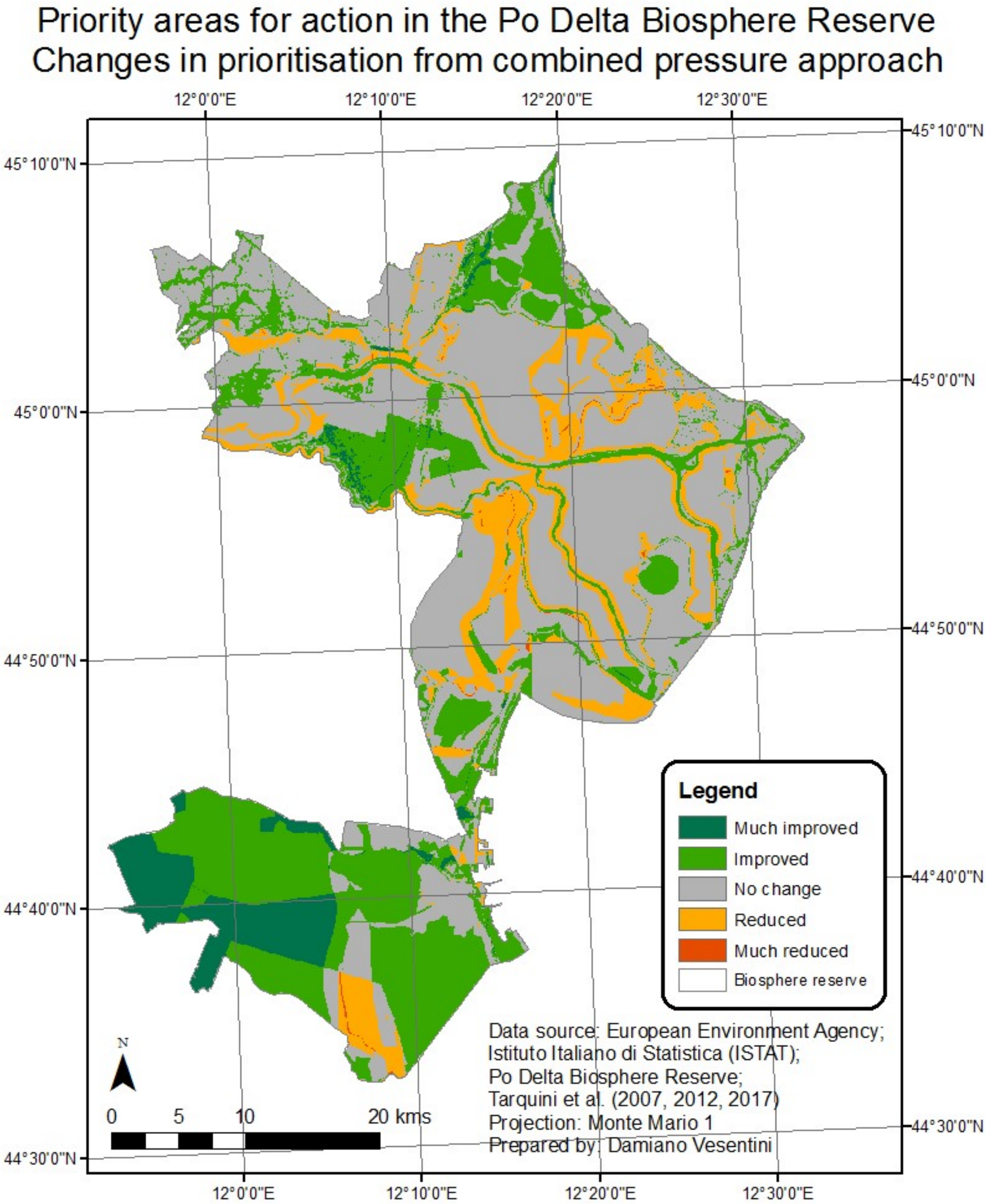


Figure 21. Changed prioritization deriving from the application of the combined pressures method, as compared to currently established zonation priorities.

7. DISCUSSION

The results presented in this study allow a broad overview of the risks and threats affecting the Po Delta Biosphere Reserve. By providing a detailed assessment of the risks deriving from individual and combined risks, the results enable the identification of primary risk factors under different scenarios. Nevertheless, this information is only relevant when contextualised from the point of view of ecosystem value, which is presented here by means of a purposely-developed index, the CVI.

7.1. Conservation value

The use of indices finds broad application in the derivation of common characteristics for multi-parametric comparisons. Its purpose, especially in the field of nature conservation, has been extensively reviewed (Capmourteres and Anand, 2016). In this study, derivation of an index describing conservation value has been based on three primary elements: land cover, the presence of formally designated sites for nature conservation, and the occurrence of endangered species. This reflects the approach described by Brunbjerg et al. (2016), whereby ecosystem characteristics are considered valuable for supporting species richness and the occurrence of sensitive species is considered as an indicator of high nature value.

Land cover was considered to be an element of primary importance, as it determines the type of ecosystem that an area can support. This consideration is well established and has been on occasion at the centre of the development of nature value indicators. For example, the Danish high nature value (HNV) farming indicator has adopted landscape structure and the occurrence of natural and semi-natural habitats among its key parameters for nature value definition (Brunbjerg et al., 2016).

Land cover types based on CORINE classification were used to determine the level of naturalness of the landscape. Naturalness in the landscape is important, as it associated both with the resilience of the landscape to change (Rodriguez-Rodriguez and Martinez-Vega, 2017; Rodriguez-Rodriguez et al., 2011) and to the ability to support sensitive species (Carre et al., 2009). In this study, the progression of naturalness from urban to agricultural to forests and marsh areas was used as a basis to attribute increase scoring to these land cover types, thus highlighting their increasing relevance for nature conservation.

The presence of formally designated areas for nature conservation was the second parameter used in the assessment of value for conservation. In this instance, information relating to the distribution of formally recognized areas was obtained, in accordance with different conservation schemes. In doing so, a hierarchical value of different area types was established, whereby the basic assumption was that areas recognized at international or national level had higher importance that areas recognized at regional or local level. Thus, conservation schemes at European (European Commission, 1992) and international level (Ramsar Convention, 1971) were considered to have higher conservation relevance, because of their strategic role for nature conservation.

The third parameter used in the determination of CVI was the occurrence of endangered animal species, as recognized by IUCN (IUCN, 2016). The approach followed in the study is in line with that described for naturalness and formally designated areas of conservation. Thus, the value of reported species was based on their IUCN status, whereby vulnerable, endangered and critically endangered species were considered increasingly valuable (IUCN, 2016).

The contribution of individual species to the overall CVI was considered, which resulted in a cumulative aggregation for all species according to their status. This approach may be perceived as having potential flaw, as in areas where multiple species occur, the overall contribution of species distribution to CVI can be somewhat exaggerated. Nevertheless, it is important to highlight that the concept of conservation value measurement has never been formally defined in the academic or regulatory world (Capmourteres and Anand, 2016). Rather, it has been applied to different studies in order to measure everything from species abundance and distribution to habitat quality to the capacity of the landscape to support communities (Capmourteres and Anand, 2016). In order to mitigate the potential cumulative contribution to CVI from the presence of multiple Red List species, a weighted sum of the three parameters composing CVI was calculated. According to the weighing, both the land cover type (i.e. naturalness) and the occurrence of formally recognized areas for conservation were considered to be higher contributors to CVI calculation. Areas characterized by the occurrence of multiple Red List species still scored high, but it was perceived that in this instance the occurrence of several species would be in itself a valuable input to CVI. An alternative approach, in this case, would have been for example, to determine the contribution of Red List species to CVI based on the number of species reported per area. In this case, areas with increasing number of species would have increasing relative relevance.

The CVI derivation allowed the identification of four classes of priority for conservation, whereby different combinations of parameters composing CVI could be expected. This threshold-based classification allowed simplified comparison of results and ensured a common starting point for the determination of risk-based effects.

7.2. Individual and aggregated risk

Having defined concepts and measures for conservation value, the study progressed in defining the extent of risk to the Biosphere Reserve area deriving from the nutrient status of water resources and sea level rise. In this work, the definition of multi-parameter indices for each of the pressure types took into consideration several elements, which may have different weight according to their relative contribution to the whole (Fitch and Crowe, 2010, 2012). Multi-parametric methods were developed for taking into account the joint effect of anthropogenic activities on water quality and the effect of climate-induced sea level rise. The method relied on the definition of sub-parameters, especially in relation to the definition of risk to water quality. This approach was similar to that described previously for the definition of CVI and allowed the definition of individual pressure types and the estimation of pressure effect on ecosystem value. The latter was made possible by the combination of the pressure-related outputs with information relating to ecosystem value (CVI).

Transitional water systems are fragile ecosystems, which can be affected by a number of parameters having a direct influence on ecological communities, in view of their (semi) enclosed nature and low water exchange (Castel et al., 1996). Nutrient accumulation is closely associated with ecosystem health (Caroppo et al., 2018), as the poor water exchange capacity of transitional waters make them especially vulnerable to eutrophication (Roselli et al., 2013). The occurrence of anthropogenic activities has been linked to the accumulation of nutrients. This has been reported to have long-lasting effects on the functioning and composition of ecological communities, which may extend well beyond the time period when stress conditions were experienced (Gamito, 2008; Khedhri et al., 2016). Hence, in this study, the determination of nutrient status in the area was considered an important indicator of ecosystem health.

Direct determination of the nutrient status in the study area was hampered by the fact that information on nutrient accumulation was not readily available. Furthermore, the distribution of nutrients tends to be seasonal, as the intensity and types of nutrient-generating activities change throughout the year (Giordani et al., 1997; Sorokin et al., 2006). The European Environment Agency distributes information and data on nutrient sensitivity at a macro-scale level, whilst also providing limited information and data at monitoring station level. Nevertheless, application of this data to the study was challenging and not useful for the purposes of prioritization, as only three major subdivisions were available, resulting in equal sensitivity to nutrient accumulation, i.e. river basin, coastal waters and transitional waters. As a consequence of these limitations, the approach followed in this study took into consideration the distribution of activities that have a direct impact on water quality, especially in view of their link to nutrient emissions.

Hence, crop farming, animal husbandry and fish farming were taken into account as being representative of the effects of agricultural activities. These activities are linked to input of fertilizers and animal-derived nutrients (Castaldelli et al., 2013; Sorokin et al., 1999, 2006), which may alter the nutrient balance and affect the functioning of ecological communities and primary producers (Castaldelli et al., 2015). Within the study area, agricultural and farming activities were widely distributed. Crop farming was found primarily in the Emilia Romagna municipalities, whilst Veneto municipalities were mostly dedicated to animal husbandry. Also, the majority of the fish farming activities were located in the Northern areas of the Biosphere Reserve, which broadly equates to the Veneto region.

Besides agricultural activities, tourism was also taken into account, as its relevance for the area was evident. Tourism had an overall low impact on the area, with the exception of the municipalities of Porto Tolle, Rosolina and Comacchio. The latter two municipalities had the strongest tourism vocation, accounting for over 3 million overnight stays in 2016 (ISTAT, 2017).

Whilst the effect of seasonality was not fully accounted for in this study, some compensation was put in place. Multiple sources have indicated how seasonality may affect both the intensity of nutrient-generating activities like farming (Giordani et al., 1997; Sorokin et al., 2006) and tourism (Sierra et al., 2007), but also the intrinsic buffering capacity of the ecosystem(Pitta et al., 2014). Thus, in this study it was assumed that in defining the effect of anthropogenic activities on water quality, agricultural and farming activities would have a higher weight than tourism. This was justified based on the seasonality of tourism activities in the area, which have a limited temporal impact in comparison, for example with animal farming and aquaculture.

A further type of risk to the Biosphere Reserve and its ecosystems is represented by climate-induced sea level rise. According to the IPCC, climate change is estimated to lead to an increase in global temperatures between 1.8 and 4.0 degrees Celsius by 2100, which would result in an increase in sea level between 0.4 and 0.6 m (IPCC, 2013). Although later studies have revised these estimations or provided a more localised estimate (Jimenez et al., 2017; Perini et al., 2017), the IPCC 5th Assessment report (IPCC, 2013) remains the most authoritative of estimates on climate change.

The Po Delta Biosphere Reserve is a primarily low-elevation area, where the majority of the area (75.3%) is located below sea level. Under current conditions, marshes, semi-submerged areas and shallow waters occupy low-lying areas. In the present study, it was estimated that as a consequence of sea level rise, an increase in sea level between 0.26 m and 0.82 m could be expected for RPC 2.6 and RCP 8.5, respectively. The increase would result in an additional 10-20% of the study area being located below sea level, under the best- and worst-case scenario, respectively. These findings are in line with previous research and fall within the variability reported at global and local scale. For example, Nicholls et al. (Nicholls et al., 1999) estimated a global loss in wetland areas ranging from 22-70% by 2080, whilst later studies increased this estimate, whereby 60-90% of global saltmarshes would be lost (Crosby et al., 2016).

In the Mediterranean, approximately 50% of transitional waters are expected to be affected by increasing sea levels. (Newton et al., 2014). The latter estimate is somewhat lower than the observations reported in this study. Yet, a few elements are worth noting. Firstly, 75% of the study area is located below sea level already under current conditions. Secondly, increased sea level may lead to a shift in ecosystems, whereby the location of areas currently considered as transitional waters may also shift. Lastly, it is worthy of consideration that the study focuses on an individual transitional water area within the Mediterranean basin, whereby any location-specific effect may render the comparison with Mediterranean-wide results less meaningful.

Apart from flooding, which may be considered as a primary effect, climate-induced sea level rise is associated with a number of secondary effects such as storminess (Casas-Prat et al., 2016; Casas-Prat and Sierra, 2011, 2013), erosion (Cid et al., 2016; Conte and Lionello, 2013) and intrusion in groundwater aquifers (Carrubba et al., 2015; De Filippis et al., 2016). Thus, the complexity of the effects scenarios deriving from sea level rise warrant special attention when implementing coastal management measures (Ivajnsic and Kaligaric, 2014), which involve adequate conservation plans for both flooded and non-flooded areas (Elliott et al., 2014). In the context of the present study, attention was given to what are described here as primary effects of sea level rise, i.e. flooding, as addressing other (secondary) effects may have warranted a purposely-defined study with a narrower scope than the one reported here.

Having defined the individual risks associated with water quality and increasing sea level, the study took into consideration the combined effects of these two pressure types. Numerous reports exist in the literature relating to the investigation of stress factors on ecosystem health and integrity and the work of Elliot et al. (2014) provides an excellent summary of the knowledge in the field. Nevertheless, the real interesting challenge comes from the identification of combined effects, which can be investigated by implementing multi-parameter indices and methodologies (Christia et al., 2014; Fitch and Crowe, 2010, 2012). Therefore, the application of multi-factorial parameters such as those described for the definition of CVI and for the definition of risk to water quality could also be used for determining the effect of combined stress types on the area.

The outcome of the work is relevant to the study area, since both the pressure types considered represent a real threat to ecosystem integrity. The occurrence of multiple simultaneous stressors on the environment has been associated with a reduced ability to cope with change (Wong et al., 2015), which may greatly impact species and communities, with important downstream effects on the ecosystem services supported (Barbier, 2015, 2016).

7.3. Risk-based prioritization for conservation

The next step following the identification of risk areas was to determine the potential risk that each pressure type represented for ecosystem quality. This enabled the identification of priority areas for each pressure type and enabled the comparison of the proposed prioritisation method with current non-risk based prioritisation.

Determination of the risk-based prioritisation scenarios described here was purely based on publicly available information. This approach proved to be ineffective on occasion (i.e. in the case of sensitivity to nutrient accumulation) due to the lack of data at relevant scales. Despite these limitations, the study still succeeded in applying generalised approaches for multi-parametric assessment in line with previous research (Brunbjerg et al., 2016; Fitch and Crowe, 2010, 2012) and succeeded in establishing comparative relationships between three risk-based prioritisation scenarios.

The first scenario was based on anthropogenic-induced risks to water quality and specific effects were discussed in the previous section. Under this scenario, it was identified that approximately 40% of medium (23%) and high risk (18%) areas consisted of high to very high value areas. In accordance with the meaning attributed to the terminology in this study and in line with the paradigm described in the HNV prioritisation method from the Danish government (Brunbjerg et al., 2016), this implies the occurrence of highly valuable parameters including semi-natural areas capable of supporting species diversity, the occurrence of suitable conservation management measures in the form of protected areas, and the presence of valuable (threatened) species.

The second scenario was based on physically-induced risk deriving from increased sea level as a consequence of climate change. In this case, it was only possible to assess high risk effects, as the scenario was based on the maximum extent of flooding under changing conditions. Any medium risk effect could only be associated, if relevant, with areas currently located below sea level. Under RCP 8.5 conditions, almost 90% of the total area is considered at risk of flooding, based on its altimetry profile, of which 44% includes areas of high and very high conservation value. Given the nature of the land cover in the study area, high value areas are likely to include inland and maritime waters and wetlands. This can be observed by visually comparing Figure 5 and Figure 9. Therefore, the results presented here are in line with the findings of Nicholls et al. (1999) estimating losses of coastal wetlands ranging between 22% and 70% by 2080, and the findings of Crosby et al. (Crosby et al., 2016) which estimated a 60% to 90% loss in saltmarshes at global level.

The third prioritization scenario took into account the combined effect of both risks. Overall, 87% of the biosphere reserve could be exposed to any level of combined risk. This was to be expected, given the broad extent of risk to water quality (at all levels) and the extent of flooding under RCP 8.5 (approximately 97% and 90% of the total area, respectively. Under this scenario, approximately 37% of the total area was composed of high and very high conservation value areas exposed to both the effect of flooding and medium to high risk of water degradation. The percentage increases to 57% when low risk areas for water degradation are also included.

The results related to the combined risk scenario highlight the direct dependency between the intrinsic ecological value of the ecosystem and its vulnerability to various forms of degradation (Sallustio et al., 2017). Mitchell et al. (Mitchell et al., 2015) and Pitta et al. (Pitta et al., 2014) described the cumulative or synergistic effects of stressors affecting a system simultaneously. In the present study, cumulative or synergistic effects were expected, which were not so clearly evident from the results. It attempting to explain these observations, it is tempting to speculate several reasons for the lower-than-expected synergy, including the way in which the combined data was interpreted. An alternative reason may lay the fact that the prioritisation exercise presented here is based on temporally-distant conditions, whereby it could be difficult to predict how the synergistic or cumulative relationships described could unfold (Mitchell et al., 2015; Pitta et al., 2014). Nevertheless, none of these explanations seem sufficiently convincing.

In a further attempt to prove the hypothesis that prioritization based on cumulative risks is more suited for setting priorities for conservation, the output of the three prioritization scenarios were simplified and areas were attributed a value of low, medium and high. Once again, the predicted effect under combined risk was not as high as that relative to the risk to water quality alone.

Based on the result, it would seem appropriate to refute the hypothesis of the study, as the combined risk approach was not the one associated with the most conservative estimates. Nevertheless it could be argued that the most appropriate method for prioritization may not necessarily be the most conservative, but rather the most truthful or the one that taking into account multiple factors provides a more solid basis for estimation (Cabral et al., 2012; Caruso et al., 2010). This argumentation is in line with evidence reported in the literature in relation to the creation of multi-parametric indices (Almeida et al., 2016; Cabral et al., 2012; Luo et al., 2016; Mitchell et al., 2015). The argumentation above also positively compares with the results of Boateng (2012), associating vulnerability with both climatic factors and the combination of natural and human elements, which contributed to the overall ecosystems effects. On this basis, the conclusion that the combined risk approach is the preferred approach for prioritization of areas for conservation within the study area seems appropriate under the present circumstances.

The last part of the study compared the results of prioritisation based on the combined risk approach method with the current priorities set for the Po Delta Biosphere Reserve (Biosfera Delta-Po, 2017; UNESCO, 2015). Current priorities are set based on area characteristics and management status, with the presence of indicator species potentially contributing to defining the management status for the area (BiosferaDelta-Po, 2017; UNESCO, 2015). The findings reported in the present study are suggestive of improved prioritisation associated with the inclusion of risk elements in the determination of priorities for conservation, whereby the total priority areas would increase from 50% to 60% of the total area. Consequently, it is recommended that these should be taken into account in any future revision of conservation priorities within the Po Delta Biosphere Reserve.

8. CONCLUSIONS

The study presented here enabled the comparison of the effect of different pressure types on the Po Delta Biosphere Reserve. In order to assess the effect of pressure types on the study area, an index for determining conservation value was adopted, the CVI, which took into consideration various elements including ecosystem characteristics and the occurrence of threatened species. It is acknowledged that refinements to the index may be possible, and even desirable for certain applications, however in the present study the CVI proved fit for its purpose.

The study effectively addressed the hypothesis that prioritisation methods based on multiple factors are more suitable for conservation management than prioritisation methods based on individual factors. Although, results could not clearly prove the hypothesis, they were in line with previous reports relating to the application of multi-parametric indices to prioritisation. Thus, the combined effect of risk to water quality derived by anthropogenic activities and of the risk of flooding due climate-induced sea level rise supported the view that these could effectively applied for prioritisation of the study area. The study also proved effective in critically evaluating current priorities for conservation, whereby improvements could be proposed.

The currently established prioritisation method for the Po Delta Biosphere Reserve is based on the identification of core, buffer and transition management areas, which are broadly based on landscape characteristics and conservation status. Comparison of the proposed prioritisation method with currently established priorities indicated that the former is more suited for establishing priorities for conservation, in view of its broad scope. Consequently, application of the proposed method resulted in an increased in priority areas from 50 to 60% of the total area.

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