ECOlogical observing System in the Adriatic Sea: oceanographic observations for biodiversity

Priority Axis 3: Environment and cultural heritage

Specific Objective 3.2: Contribute to protect and restore biodiversity

D4.2.2 Report on the application of the conceptual model linking oceanographic processes, performance indicators and management questions for target species

WP4– Establishing the Ecological Observing System in the Adriatic Sea (ECOAdS)

4.2 – Integration of ecological observing system with Natura 2000 target species

Project partner in charge / Author: PP1_OGS / F. Gianni, V. Bandelj, B. Cataletto

Other involved partners: LP_CNR / E. Manea, C. Bergami, L. Bongiorni, A. Oggioni, A. Pugnetti
PP8_SHORELINE/ S. Ciriaco, C. Franzosini
PP4_Ente Parco Regionale Veneto del Delta del Po / G. Caramori

Final version

Public

30 June 2021

CONTENT

1. INTRODUCTION

1.1 Activity 4.2 and deliverable 4.2.2

This deliverable is the result of the Activity 4.2 - “Integration of ecological observing system with Natura 2000 target species” prepared by OGS with inputs from CNR and SHORELINE.

Following what is reported in the application form, this deliverable aims to use the relevant oceanographic and ecological data available for the area to test the links among oceanographic processes, explanatory variables, ES, performance indicators and management questions relevant for target species. To protect these sites and the services they provide, these models will be used to understand and predict how the man-induces changes and the resource exploitation could affect the target species at different spatial and temporal scales. The development of case studies on selected Natura 2000 (N2K) sites will also allow testing the usefulness and the relevance of the ecological observing system in the Adriatic Sea (ECOAdS) to support significant management objectives in biodiversity conservation.

1.2 Work outline

The present deliverable will be based on the generic conceptual model developed in the deliverable 3.3.1[1], aimed to identify the key oceanographic processes, variables and performance indicators proper for answering specific management questions on environmental quality, conservation and biodiversity of N2K sites. In the first part of this deliverable, the conceptual model will be recalled and its main focal points, features and objectives will be summarized. In the second section, the model will be used as a framework for building the application models for each N2K case study identified in the ECOSS Project. Each box of the generic model will be filled with information on ecological and oceanographic variables, performance indicators, target species, ecosystem services and management objectives provided by the other partners, available in the previous ECOSS deliverables (3.1.1[2], 3.2.1[3], 3.4.1[4], 4.1.1[5], 4.1.2[6], 4.2.1[7]) and summarized in D3.3.1. Only target species will be considered in this deliverable, while ecological processes will be the subject of the deliverable 4.3.2. Links and relationships among the different elements will be analysed and discussed, highlighting possible pressures, risks, and information gaps that

[1] D3.3.1 Report on the key oceanographic processes and performance indicators for Natura 2000 marine sites

[2] D3.1.1 Assessment of existing ecological monitoring programmes and observing systems

[3] D3.2.1 Report on environmental monitoring, protection strategies and management issues in marine area of the Natura 2000 ecological network.

[4] D3.4.1 Report on the ecosystem services to be used for monitoring ecological processes within N2K sites.

[5] D4.1.1 Report on the characterization of the selected Natura 2000 sites.

[6] D4.1.2 Report on the relationships between ecosystem-level management goals with ecological variables and oceanographic processes and the performance indicators.

[7] D4.2.1 Review of the knowledge of the target species at the selected Natura 2000 sites.

monitoring and management authorities should address to enhance the conservation of N2K sites. Finally, to improve the understanding and practical use of the application models by stakeholders and managers of N2K sites, a simplified version of the models will be built for each case study taking into account, as an example, only a target species of each case study.

1.3 Definitions

Terms and keywords used to identify the single elements of the generic conceptual model are many and can be misinterpreted or not clear. A detailed description of all the terms used in the conceptual model is reported in D3.3.1, however since their definitions are crucial to make understandable each element of the conceptual model and the links among them, here we provide a summary (Tab. 1).

Table 1. Key terms and summary of the related definitions. The full version can be found in Deliverable 3.3.1.

KEY TERMINOLOGY	ECOSS DEFINITION
Target species	All rare, threatened or endemic animals and plants targeted for conservation under the Habitats Directive (HD, 92/43/EEC) and Birds Directive (BD, 2009/147/EC).
Ecological processes	A number of biological, physical, and chemical processes, such as primary production and nutrient cycle, which sustain the ecological systems and their biodiversity and allow production and transfer of matter between organisms and the physical environment.
Ecological variables	Descriptive indicators that give information on the status of ecological processes and target species in selected areas (e.g., spatial distribution, density, abundance and biomass, growth and mortality rate of a species).
Physical ocean processes	Physical phenomena occurring in the world oceans and seas, which regulate trend, transport and flux of water, substances and organisms in the marine system.
Oceanographic variables	Descriptive indicators that include physical parameters (e.g. water temperature, salinity, conductivity, current direction), chemical parameters (e.g. dissolved oxygen, pH, dissolved macronutrient concentration), meteorological parameters, and some biological parameters (e.g. chlorophyll a, phyto- and zooplankton abundance and biomass).
Descriptive indicators or monitoring variables	Indicators that describe the environmental state and its change in space and time. They include ecological and oceanographic variables.

Global changes	They can be various: variation of water temperature, sea level rise, ocean acidification, increased ocean stratification, decreased sea-ice extent, and hypoxia. They affect the environmental conditions and the ecological processes irreversibly altering the marine ecosystems.
Ecological monitoring	The process of periodical observations conducted at different spatial and temporal scales, giving information on environmental status.
Oceanographic observing systems	A network of instruments and facilities designed to monitor the state of the sea and to help predicting how marine environments respond to anthropogenic alterations.
Ecosystem services	The contributions of ecosystem structure and function to human well-being, resulting from the interaction with the social components.
Protected area management goals	A long-term objective that describes or envisages the expected conservation state that protected area policies want to achieve and maintain.
Performance indicators	A component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals.
Protected area management objectives	Specific statements that follow the main goal and set out the conditions that management aims to achieve. They are statements of the desired short-term ‘outcomes’ rather than how to achieve them.
Conservation measures	Management plans or any appropriate statutory, administrative or contractual measures, defined by the law of each Member States, that are finalized to regulate activities, uses and collection of organisms in the protected sites, and maintain biodiversity.
Human activities	All those activities that depend on the ocean and coastal ecosystems for goods and services and that interact and affect the marine habitats and species of the N2K sites.
Public/management authority	Any public institution, private company, NGO, organization or association responsible to manage a protected area.
Stakeholders	All those people who have an interest in the N2K site or its natural resources. Main categories are: government, private sector, and general public.
EU Directives	Legal instruments focused on nature protection and that consider it: the Habitats Directive (HD, 92/43/EEC), the Birds Directive (BD, 79/409/EEC), the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC), Common Fishery Policy (CFP, 1380/2013/EC), Maritime Spatial Planning Directive (MSPD, 2014/89/EU).

ECOAdS	ECOlogical observing system in the Adriatic Sea, which aims at integrating the ecological and oceanographic research and monitoring with the N2K conservation strategies. It is the main outcome of the ECOSS project.

2. GENERIC CONCEPTUAL MODEL

The generic conceptual model presented in D3.3.1 consists of a schematic conceptual model (box-arrow model) that displays and simplifies the most important socio-ecological elements related to the management of N2K sites and their connections. The idea behind the creation of this model was to connect the ecological/oceanographic observing systems with the management of the N2K network. In particular, it highlights the role of ECOAdS in collecting ecological and oceanographic variables that feed performance indicators, which in turn allow assessing if management objectives are being achieved in N2K marine sites. It worth mentioning here that the model has not been designed as a tool to directly manage N2K sites since many other solutions already exist to this aim.

Graphically, the conceptual model consists of several boxes containing the elements related to the management of N2K sites. There is no distinction in terms of the size of the boxes, while the colour defines the kind of elements related to the N2K management: social, ecological, and oceanographic elements. Social elements (yellow boxes in Figure 1) are characterized by all those elements concerning the governance domain of N2K management: EU Directives targeted by ECOSS (i.e. HD, BD, WFD, MSFD), the public/management authority of the N2K sites, the management goals, objectives, conservation measures/action plan, the stakeholders involved in the N2K sites and human activities. Compared to the model presented in D3.3.1, in the box dedicated to conservation measures with also added the keyword 'Action plan' (i.e. management plan), because management bodies may also adopt a management plan whenever the conservation measures are considered not sufficient to reach the conservation objectives. Deliverable 4.2.3 will discuss more in detail this argument and will develop a local action plan for N2K sites, extending it at the basin scale. The ecological elements (green boxes) identified are target species and ecological processes for which N2K sites were designated, the ecosystem services, the ecological monitoring programs, and the ecological variables they measure. Oceanographic elements (blue boxes) include global changes, ocean processes, oceanographic observing system, and the monitored oceanographic variables. Performance indicators constitute a crosscutting element (orange box) since they can be obtained from single ecological or single oceanographic variables, combinations of multiple ecological or multiple oceanographic variables, or even combinations of one or several ecological variables with one or several oceanographic variables. The monitoring programs, the variables, and the performance indicators are all included in the ECOAdS box (red box in Figure 1).

The spatial arrangement of the boxes in the model follows a hierarchical organization: boxes at the top and the bottom of the model refer to global aspects such as EU Directives, wide-scale monitoring programs, and ecosystem services, while in the centre of the model, the elements are related to local aspects of the N2K sites, such as goals, objectives, target species and ecological processes. Arrows indicate the relationships among the elements. They can go in one direction from one box to another or can be bi-directional in case elements are expected to influence each other. Dashed arrows indicate data flow, while solid arrows indicate a causal relationship between two boxes based on the direction of the arrow. Terms upon arrows specify the type of relationship linking two boxes (Figure 1). While the conceptual model was built around the need to manage N2K sites, i.e. with the box 'MPA Management Goal' as an entry point, different users may use different entry points according to their needs: a stakeholder may start at the Stakeholder box, a public authority at the Public/Management authority box, and so on.

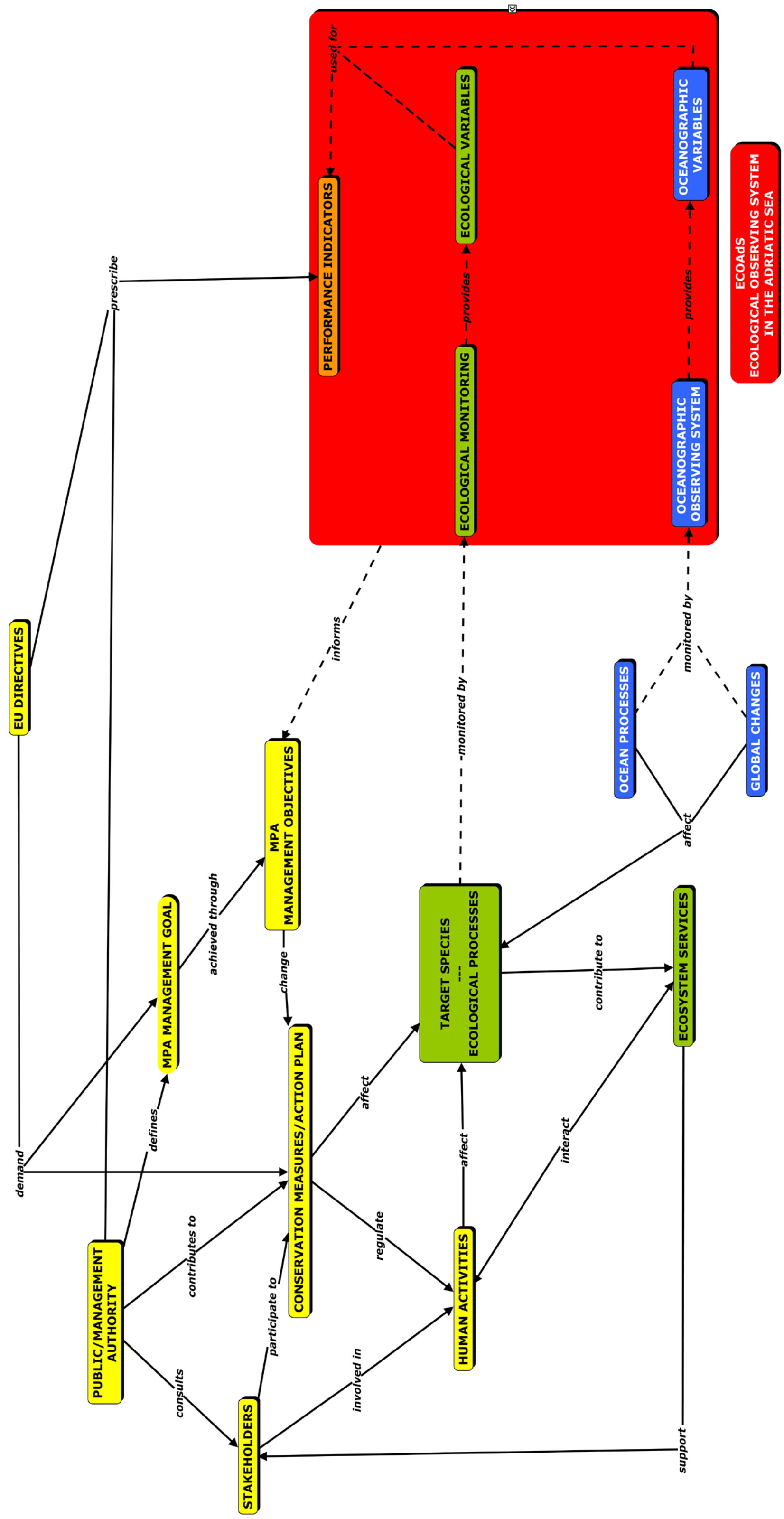

Figure 1. Generic conceptual model linking ECOAdS with N2K site management and EU Directives.

3. APPLICATION MODELS

In this section, the generic conceptual model was applied to all N2K sites selected as case studies in D3.3.1:

Case study 1: N2K sites Cres-Lošinj (HR3000161) and Viški akvatorij (HR3000469).

Case study 2: N2K site Malostonski zaljev (HR4000015).

Case study 3: N2K sites Trezze San Pietro e Bardelli (IT3330009) and Tegnùe di Chioggia (IT3250047).

Case study 4: N2K sites Delta del Po: tratto terminale e delta veneto (IT3270017) and Delta del Po (IT3270023).

Information on the specific elements of each N2K site was mainly derived from deliverable 3.3.1 that summarized the contents of the previous deliverables (3.1.1, 3.2.1, 3.4.1, 4.1.1, 4.1.2, 4.2.1). Information to feed the application models was also obtained from the technical tables in Bologna (First Project Meeting, 11-12/02/2020) and the literature on Google Scholar, in particular as concerns performance and descriptive indicators for target species. In detail, the boxes of the generic conceptual model were filled with target species, ecosystem services, the management body, management goal and objectives, conservation measures/action plan, human uses and stakeholders, ocean processes, and the ECOAdS components (ecological monitoring, ecological variables, oceanographic observing systems and performance indicators) distinctive of each case study. For the aim of this project, only biophysical objectives, related to the ecological components, were considered, while socio-economic and governance objectives were not included. It is worth noting that the list of descriptive/performance indicators that we suggest monitoring for each target species, does not want to be exhaustive, also because management bodies or monitoring programs are missing in most of the N2K sites and detailed knowledge on the status of target species is not available. To make the models clearer, each application model is juxtaposed by a detailed table where each management objective is related to human activities or threats threatening target species, the conservation measures that could be put in place, and the descriptive and performance indicators that should be measured to assess if the management objective considered is fulfilled (Tab. 2, 3, 4, 5).

We also presented and discussed a simplified version of the application model that could help decision-making process of management bodies and stakeholders' understanding. As an example, we applied the simplified version of the model only to one target species per case study (Fig. 3, 5, 7, 9). This operative model is read from right to left: the target species is represented by a green box with the name of the species to be protected. To its left, in yellow rectangles, the threats acting on the species are listed and linked with arrows to specific conservation measures needed to reduce their impact. Conservation measures can be modified according to the management objective of the N2K site, assessed by the performance indicators. Finally, the red box on the left includes the performance indicators and the monitoring activities of ECOAdS. The logical path, which from ECOAdS box leads to the reduction of the threats to the target species, is represented by the sequence of arrows, oriented from right to left.

3.1 Cres-Lošinj (HR3000161) and Viški akvatorij (HR3000469)

The N2K sites of Cres – Lošinj and Viški akvatorij in Croatia are two of the most important feeding and breeding areas for the common bottlenose dolphin (*Tursiops truncatus*) in the Eastern Adriatic Sea and they were both established to protect this species (the only one listed in their respective SDFs).

Even if a management authority has been already designed in both N2K sites (Public institution 'Sea and Karst for Viški akvatorij and Public institution 'Priroda' for Cres – Lošinj) and Blue Water Institute (BWI) carries out periodically monitoring activities on *T. truncatus*, there is still no management plan nor conservation measures in charge to effectively protect the species. Different stakeholders act in this area including fishers, fish farmers, and, most of all, tourism companies due to the high touristic value of the area. Thus, threats for *T. truncatus* in these sites include sailing, potentially causing collisions between boats and dolphins; water pollution; professional fishing, causing bycatch and possibly overexploitation of the preys of dolphins; marine litter; noise pollution; and recreational activity (e.g. nautical sports) (Fig. 2, Tab. 2). Aquaculture may also have an impact on the dolphin population by causing entanglement of individuals inside predator nets around the fish farm cages[1] or a change in habitat use since dolphins become attracted to these areas[2,3]. Other more widespread threats include climate change causing extreme events, alteration of habitats and prey behaviour[4–6], and spread of disease among populations of different areas, reducing the possibility to resist other impacts affecting the species[7]. Conservation measures that could effectively reduce such threats should be primarily focused on regulating all human activities (e.g. marine traffic, interaction with fisheries), removing marine litter, reducing water pollution, raising awareness, also involving the local community, and finally increasing enforcement (Fig. 2, Tab. 2). In addition, the expansion of N2K site size and protected area network beyond Cres-Lošinj and Viški akvatorij, would include the whole home range of the species, enhance genetic exchange between populations and allow the achievement of the main management goal of these protected areas: the preservation of the natural habitat of the common bottlenose dolphin at a favorable status (Fig. 2, Tab. 2).

Research on *T. truncatus* started in 1987 in Cres – Lošinj and has been ongoing since then (deliverable 4.1.1). Until 2004, fieldwork was conducted in summer seasons only, while since 2005 it is performed all year round. The fieldwork is mostly concentrated within the Cres-Lošinj site with significant parts of surrounding areas also covered, albeit with less intensity. Based on the results of the monitoring programs, the Cres-Lošinj N2K site is inhabited by approximately 224 common bottlenose dolphins, which show long-term residency in this area (deliverable 4.2.1). In the Viški akvatorij N2K site, research on the common bottlenose dolphin started in 2007 and has been conducted during the summer seasons. The research effort is highest within the site while surrounding areas are covered with less intensity. Based on the results of the monitoring programs between 2007 and 2018, the population can be considered stable (about 261 individuals) (deliverable 4.2.1).

Variables that are already collected in these sites include population dynamics, population structure, habitat use, abundance, underwater noise, spatial distribution, foraging, survival rate, occurrence of invasive species, presence and area covered by natural habitat (deliverable 3.2.1, 3.1.1). The Croatian Institute of Oceanography and Fisheries (IZOR) also collects data on physicochemical parameters and chlorophyll a, biological quality elements (required by the WFD), specific pollutants (Zn and Cu), hydromorphological alterations and water circulation, chemical status (priority substances in water, sediment, and biota), benthic invertebrate fauna, macro-algae, phytoplankton community, sedimentation, angiosperms, migration/introduction of non-indigenous species, macro-algae community alterations, trophic functioning of the marine food web (deliverable 3.2.1).

Other ecological and oceanographic variables that can be collected include, for instance, contaminant concentration in tissues of carcasses to assess the level of contamination, genetic information, the presence and temporal/spatial extent of diseases/pathogens and the number of deaths/sick individuals, signs of injuries or number of injured individuals due to collision with boats, type, number and proximity of vessels to dolphins and number of boats in a year to understand the disturbance of boat traffic inside the N2K sites (Fig. 2, Tab. 2).

Since the interaction with commercial fishing is particularly relevant for this species[8–10], we also suggest collecting data on fishery catches, fishing effort, type of fishing gears, fishing location, number of interactions of dolphins with fishing boats, dolphin behaviour metrics, signs of injuries on dolphins and damaged nets, site fidelity, group dynamics. These variables can be used to derive performance indicators such as mortality rate from bycatch, the proportion of affected organisms, and their frequency of interactions with fishing boats. On the contrary, performance indicators focused on spawning stock biomass and mortality rate of prey can tell us if commercial fishing is reducing the prey populations of dolphins (Fig. 2, Tab. 2).

The presence of marine litter is also an important issue for the health of the common bottlenose dolphin by causing suffocation, pollution, entanglement, and death[11]. Due to the raising of this issue at the global scale in the last years[12], it is extremely crucial to assess the composition, weight, amount and spatial distribution of litter on the seafloor and water, as well as of the litter ingested, to estimate mortality rate or trends in the number of affected individuals (Fig. 2, Tab. 2).

As regards climate change, ecological variables that can indicate an impact of extreme events or alteration of oceanographic variables on the species may include survival rate of offspring, the population structure of prey, distributions of prey and dolphins, group size, and behaviour metrics (Fig. 2, Tab. 2). In fact, different studies demonstrated that catastrophic alteration of habitats, following marine heatwaves, caused a decline of reproductive success and survival of offspring[5]; while alteration of distribution and behaviour of their prey species due to intense storm events, induces a change in dolphin foraging[6].

At this point, it is important to stress that to allow conservation of the species and assess the efficacy of protection, monitoring activities should be conducted regularly. Nevertheless, as the main deficiency in the existing monitoring program of bottlenose dolphins, PI Sea and Karst highlighted that the monitoring is not conducted on regular basis because of the lack of resources (experts for marine mammals and funds) (deliverable 3.2.1). In the next future, much more effort should be put in place to boost the role of these protected sites in sustaining the Adriatic populations of the common bottlenose dolphin.

The simplified version of the application model for *T. truncatus,* showed in fig. 3, wants to be an example of an operative model to assess the performance of the management process and the status of the species in these two N2K sites. In this case, it was built considering only some of the several threats cited above affecting the status of the species. Water pollution, collisions with boats, noise pollution, bycatch, and marine litter are some of the most important threats to the species that act in the two N2K sites. These threats are linked to specific conservation measures that the management body should define to address the corresponding threats, as described above. The achievement of the management objectives linked to these conservation measures can be assessed by some performance indicators that give an indication on population demography, sea ambient noise variations, trends in the amount of marine litter, frequency of interactions with fishing boats, or trends in the number of boats inside the N2K sites. In turn, performance indicators are measured by collecting ecological and oceanographic variables through field sampling or by using numerical model outputs or remote sensing. For instance, variations in sea ambient noise, that could affect dolphin behavior and home range, can be monitored by measuring sound pressure levels in water, combined with information on the number of boats within 2 km distance from the acoustic station, data on the occurrence rate of dolphins, and duration, frequencies, and characteristics of dolphin’s vocalizations[13,14] (Fig. 3, Tab. 2).

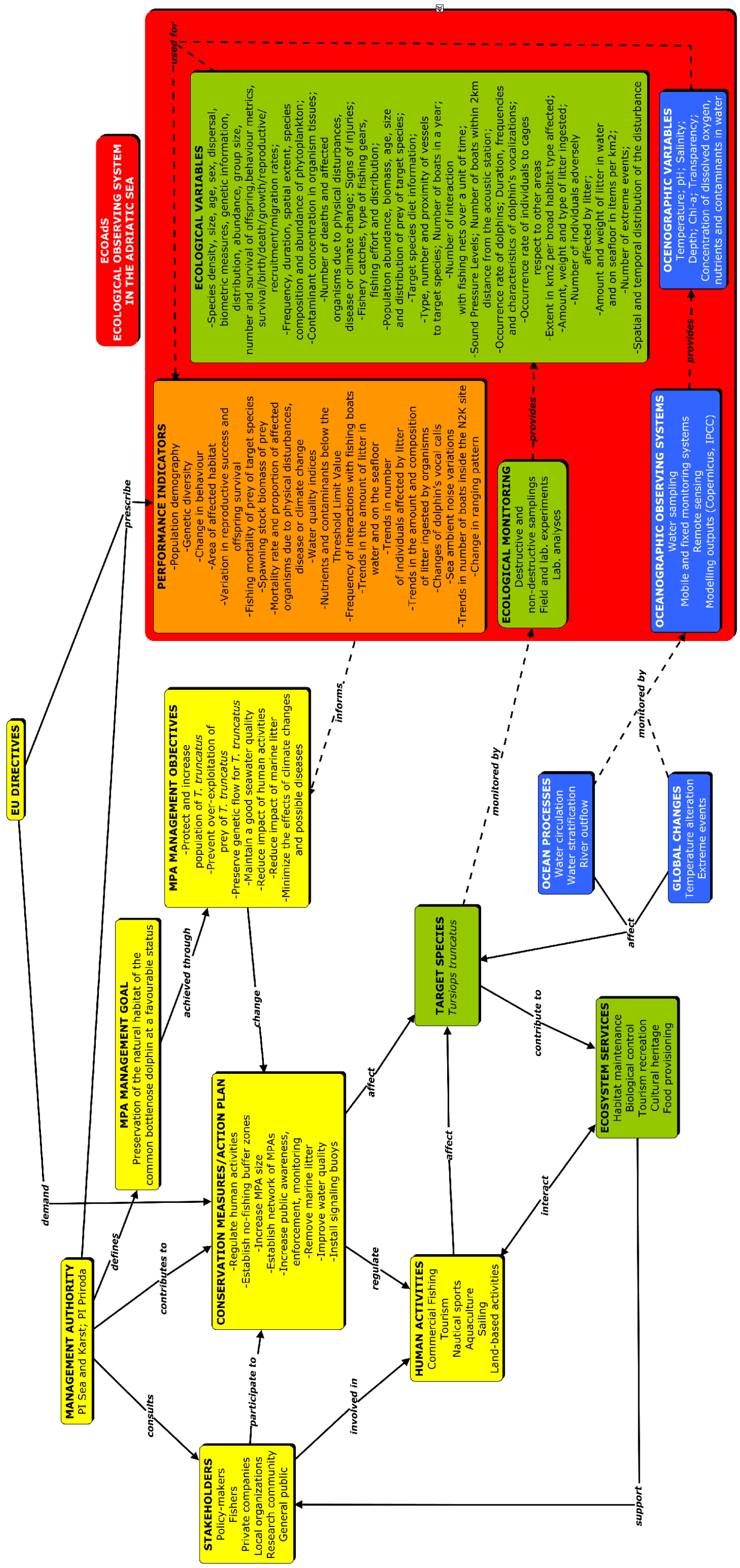

Figure 2. Application model for Cres-Lošinj and Viški akvatorij N2SK sites.

Table 2. Links between descriptor and performance indicators, conservation measures and management objectives addressing threats to target species in the 'Viški akvatorij' and 'Cres-Lošinj' N2K sites.

Management objectives	Human activities/ threats in the N2K sites	Threatened target species	Conservation measures	Performance indicators	Descriptive indicators
Maintenance of a good seawater quality	Land-based activities and sailing causing poor water quality	*Tursiops truncatus*	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, improve water quality	Water quality indices	Frequency, duration, spatial extent, species composition and abundance of phytoplankton blooms, including harmful species
					Dissolved oxygen, depth, chlorophyll-a, transparency, salinity, pH, temperature
				Nutrients and contaminants below the Threshold Limit Value	Nutrient and contaminant concentration in water
					Contaminant concentration in organism tissues
					Spatial extent and duration of significant acute

					pollution/ eutrophication events
				Mortality rate from pollution	Number of deaths, population size, spatial and temporal extent of the disturbance. Sex, age, biometric measures and genetic information from carcasses
				Area of affected habitat	Extent in km2 per broad habitat type affected by water pollution
Prevent over-exploitation of prey of target species	Professional fishing		Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites	Fishing mortality of prey	Fishery catches, type of fishing gears, fishing effort and distribution, population abundance and distribution of prey + target species diet information (stomach content, stable isotope analysis)
				Spawning stock biomass of prey	Biomass, age, size of prey+ target species diet

					information (stomach content, stable isotope analysis)
Decrease/regulate interactions between *T. truncatus* individuals and human activities	Professional fishing potentially causing bycatch/ injuries to individuals		Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, remove marine litter (ghost nets), establish network of N2K sites	Mortality rate from by-catch	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
				Frequency of interactions with fishing boats	Dolphin behaviour metrics, number of interactions with fishing nets over a unit of time (e.g. signs of new holes in nets, presence of damaged fish on nets), site fidelity, group dynamics, and seasonal and yearly occurrence

				Proportion of affected organisms	Population size, number of affected organisms, signs of injuries
				For all the performance indicators	Fishing effort, type of fishing gears, spatial and temporal distribution of the disturbance
	Sailing potentially causing incidental killings/injuries to organisms		Regulate human activities, increase public awareness, increase enforcement, increase monitoring, install signalling buoys, establish network of N2K sites, increase N2K site size	Mortality rate due to physical disturbance	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
					Type, number and proximity of vessels to target species
				Proportion of injured organisms	Population size, number of injured organisms, signs of injuries
					Type, number and proximity of

					vessels to dolphins
				Trends in number of boats inside the N2K site	Number of boats in a year
	Nautical tourism and water sports causing noise pollution			Sea ambient noise variations	Sound Pressure Levels, spatial and temporal extent of noise pollution
					Number of boats within 2 km distance from the acoustic station
					Occurrence rate of dolphins
				Changes of dolphin's vocal calls	Duration, frequencies and characteristics of vocalizations
	Aquaculture			Mortality rate due to entanglement	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
				Change in ranging pattern	Occurrence rate of individuals to cages respect to other areas, group size
Reduce impact of marine litter	Marine litter		Remove marine litter, establish no-fishing buffer zones (to	Trends in the amount and composition	Amount, weight and type of litter ingested (stomach content)

			avoid ghost nets), increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	of litter ingested by organisms	
				Trends in number of individuals affected by litter	Number of individuals adversely affected by litter
				Mortality rate due to litter	Number of deaths, population size, sex, age, biometric measures and genetic information from carcasses
				Trends in the amount of litter in the water column and on the seafloor	composition, weight, amount and spatial distribution of litter and micro-litter in water and on seabed in items per km^2
Minimize the effect of climate change	Effects of climate change		Increase monitoring, establish network of	Variation in reproductive success and	Number of offspring, population size,

			N2K sites, increase N2K site size, remove other stressors	offspring survival	sex, age, survival rate of offspring
					Fishery catches, type of fishing gears, fishing effort, population abundance and distribution of prey + target species diet information (stomach content, stable isotope analysis)
				Change in behaviour	Distributions of prey and target species, group size, behaviour metrics
				For all the performance indicators of climate change	Temperature, number of extreme events, spatial and temporal extent of the disturbance
Minimize the effect of possible diseases	Disease outbreak		Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Mortality rate due to diseases	Number of deaths, population size, spatial and temporal extent of disease. Sex, age, biometric measures and genetic information from

					Carcasses
				Proportion of sick organisms	Population size, number of sick organisms, spatial and temporal extent of disease
Protect or increase the population of *T. truncatus*	All		Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove marine litter, improve water quality, install signalling buoys	Population demography	Population age, sex, abundance, density, distribution, dispersal, biometric measures, survival/ birth/death/growth/ reproductive/ recruitment/ migration rates
Preserve incoming/outgoing genetic flow for *T. truncatus*				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

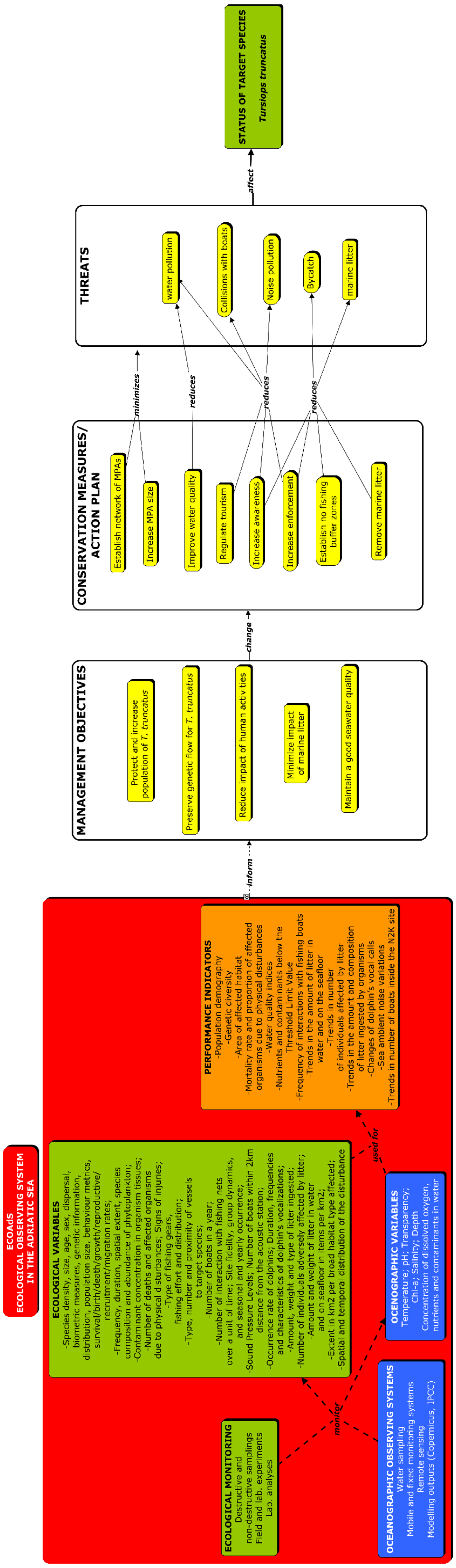

Figure 3. Operative version of the application model for ‘Cres-Lošinj’ and ‘Viški akvatorij’ N2K sites.

3.2 Malostonski zaljev (HR4000015)

The Malostonski zaljev N2K site protects two target habitats listed in the Annex I of the HD: 'Reefs' (1170) and 'Large shallow inlets and bays' (1160). In addition, this area is under significant influence of freshwaters and the specific environmental conditions result in specific biodiversity dominated by the cultivation of the European Flat Oyster, a traditional, protected activity. There is no target species listed in the SDF. However, important target species were identified by expert opinion in the deliverables 4.2.1 and 3.2.1 and during the ECOSS first meeting (Bologna, 11-12/02/2020): *Fucus virsoides, Cymodocea nodosa, Posidonia oceanica, Pinna nobilis, Alosa fallax,* and species forming coralligenous assemblages on the rocky substratum.

The management body of Malostonski zaljev N2K site is the Public institution for the management of protected natural areas of Dubrovnik-Neretva County (PIDNIC), but conservation measures do not have an official definition neither a management plan does exist. As the first conservation strategy, PIDNIC has suggested that the protection objectives are aimed at preserving the traditional values of the area such as shellfish growing together with natural habitats. To make this possible, it is necessary to inventory the components of biodiversity, monitor and periodically evaluate the state of natural values and actively support sustainable bivalve shellfish farming as part of cultural heritage and traditional value. In addition, it is necessary to be more efficient in existing laws implementation in the N2K area to control poaching, especially regarding *Lithophaga lithophaga*[15] (Fig. 4, Tab. 3). The ecosystem in N2K site Malostonski zaljev is under the crucial influence of the mainland, so the surrounding mainland must be monitored and controlled too to reduce water pollution and physical destruction of habitats due to urbanization. Direct human impacts such as trampling on *F. virsoides* or anchoring on *C. nodosa* and *P. nobilis*, can also affect their survival[16] and should be regulated for example by installing mooring buoys. Finally, regular monitoring activities in the area are required also to constantly assess the status of *P. nobilis*, affected by different parasites[17,18] (Fig. 4, Tab. 3). All these conservation measures can only work if there is an involvement of the local population, through communication, education, and sharing of plans and activities (deliverable 3.2.1). Remove invasive species and marine litter, especially coming from aquaculture, restore target species, and establish no fishing buffer zones and increase enforcement represent other conservation measures that can be put in place in this specific site to help the persistence of target species (Fig. 4, Tab. 3).

Monitoring activities in the area are performed by IZOR as regards the assessment of water quality for the evaluation of the state of MSFD descriptors. The activity includes the collection of physicochemical parameters and chlorophyll a, biological quality elements (required by the WFD), specific pollutants (Zn and Cu), hydromorphological alterations and water circulation, chemical status (priority substances in water, sediment, and biota), benthic invertebrate fauna, macro-algae, phytoplankton community, sedimentation, angiosperms, migration/introduction of non-indigenous species, macro-algae community alterations, trophic functioning of the marine food web (deliverable 3.2.1). The biological state elements of the ecosystem in the bay are instead monitored by the University of Dubrovnik, in particular phytoplankton abundance and composition, primary production, the qualitative composition of zooplankton, salinity, temperature, nutrients (deliverable 3.2.1).

Other ecological and oceanographic variables that can be collected in the area to assess the efficacy of protection are listed in Table 3 and Figure 4, together with the corresponding performance indicators.

Regarding aquaculture, descriptive indicators that can give information on its potential negative effects and help to assess alteration of benthic functional diversity and ecosystem functionality include oxygen and nutrients concentration in sediments, abundance and biomass of benthic organisms, diversity indices, sedimentation rate, grain size, redox potential, organic matter content in sediments, sulphides and infaunal trophic index[19–21]. The surface area devoted to aquaculture may also give us an indication of the impact of this activity in the bay.

Incidental killing/damages to organisms caused by divers or some types of fishing gears (e.g. trawling) may also determine severe damages to the benthic organisms by removing entire pieces of substrates, increasing sediment resuspension, reducing species coverage and understorey diversity[22–25]. To monitor the effects of such human activities we suggest collecting data on signs of damages on organisms, population structure, number of contacts of divers over a unit of time, and number of divers per year. Associated pressure variables include fishery catches, fishing effort, type of fishing gear, fishing location. These variables can then be used to derive performance indicators such as mortality rate due to physical disturbance, the proportion of affected organisms, diver contact rate with organisms, number of divers below the carrying capacity of the N2K site[22,26]. Anchoring has a similar effect on benthic habitat reducing survival and coverage of the coralligenous community, seagrasses and *P. nobilis*[16,23,27]. In addition, in this case, we suggest assessing as performance indicators the proportion of affected organisms, mortality rate, and trends in the number of boats anchoring on the sea bottom.

The presence of marine litter is also an important issue for the health of benthic species since it may shade phytobenthos, cause physical damages, death[28] and microplastics may be ingested, for instance by *A. fallax*[29]. Due to the raising of this issue at the global scale in the last years[12], it is extremely crucial to assess the composition, weight, amount, and spatial distribution of litter on the seafloor and water, as well as of the litter ingested to estimate mortality rate or trends in the number of affected individuals.

Poaching of *L. lithophaga* is a well-known practice in the Mediterranean. Its illegal harvesting is carried by breaking the carbonate rocks where the bivalve grows. The impact causes permanent changes in the substrate characteristics, the removal of benthic species, and finally a shift from highly complex to structurally simplified habitats characterized by biological deserts ('barren') dominated by sea urchins[15,30]. To avoid its harvesting and the consequent impact on the benthos, the date mussel has been protected by the EU Habitats Directive and other international agreements (see [30]). The trend of this illegal activity in Malostonski zaljev can be assessed by measuring the percent cover of new benthic habitat destructed by poaching, spatial and temporal extent of the disturbance, together with data on the number of reported offenses with the kilos of date mussels confiscated in a year.

Alteration of physical parameters due to climate change has negative effects on most of the benthic species, in particular for cold-water species, such as *F. virsoides*[31], or those involved in calcification processes (i.e. coralligenous species)[32]. Descriptive indicators we suggest to monitor include all those variables that indicate variation in population structure and dynamics, as well as temperature, pH, number of extreme events, presence/quantity of mucilage and necrotic tissues.

The simplified version of the application model for Malostonski zaljev N2K site (Fig. 5), shows an example of an operative model based on *P. nobilis*. The most important threats for this species in the area are water pollution, anchoring, marine litter, accidental killing by commercial fishing/diving, besides climate change, disease, and invasive species. These threats can be addressed by defining appropriate conservation measures such as improving water quality, regulating touristic visits, establishing no fishing buffer zones, remove marine litter, installing mooring buoys, raising awareness, enforcement, and monitoring. The achievement of the management objectives linked to these conservation measures can be assessed by some performance indicators that give information on population demography, mortality rate from pollution, trends in the number of boats anchoring in the area, trends in the number of individuals affected by litter, area of affected habitat. In turn, performance indicators are measured by collecting ecological and oceanographic variables through field sampling or by using numerical model outputs or remote sensing (Fig. 5, Tab. 3).

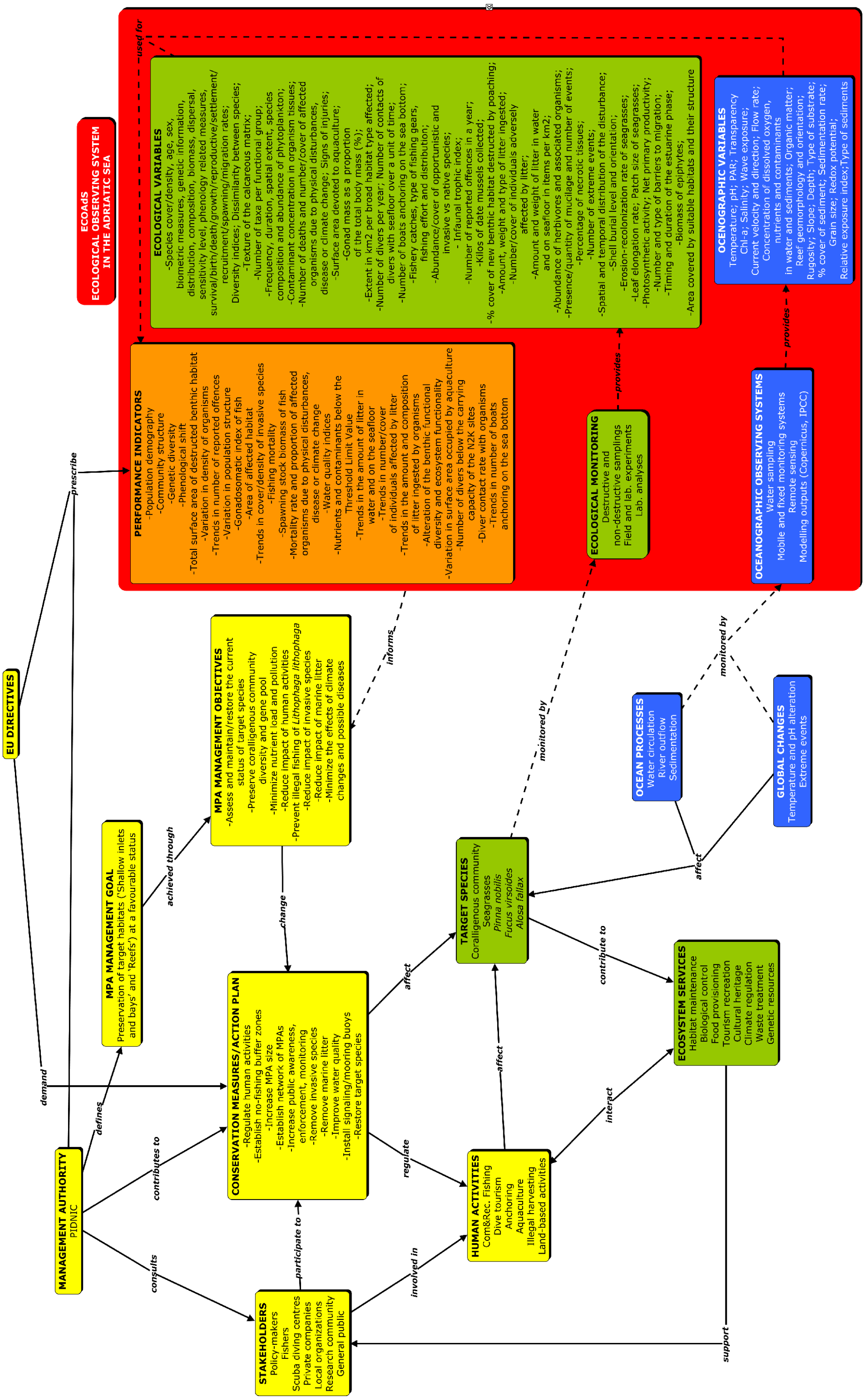

Figure 4. Application model for ‘Malostonski zaljev’ N2K site.

Table 3. Links between descriptor and performance indicators, conservation measures and management objectives addressing threats to target species in the 'Malostonski zaljev' N2K site.

Management objectives	Human activities/ threats in the N2K sites	Threatened target species	Conservation measures	Performance indicators	Descriptive indicators
Prevent high eutrophication and pollution levels in the bay	Land-based activities, aquaculture and sailing causing poor water quality	Coralligenous community, Seagrasses, *Alosa fallax, Fucus virsoides, Pinna nobilis*	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, improve water quality	Water quality indices	Frequency, duration, spatial extent, species composition and abundance of phytoplankton blooms, including harmful species
					Dissolved oxygen, chlorophyll-a, transparency, salinity, pH, temperature
					Species composition, density/ cover and sensitivity level of benthic organisms
				Nutrients and contaminants below the Threshold Limit Value	Nutrient and contaminant concentration in water and sediments
					Contaminant concentration in organism tissues
					Spatial extent and duration of significant acute pollution/ eutrophication events

				Mortality rate from pollution	Number of deaths, population size, age, biometric measures, and genetic information from carcasses, spatial and temporal extent of the disturbance
				Gonadosomatic index of fish	Gonad mass as a proportion of the total body mass (%)
				Proportion of affected organisms	Population size/cover, number/cover of affected organisms, spatial and temporal extent of the disturbance
				Area of affected habitat	Extent in km2 per broad habitat type affected by water pollution
Reduce impact of human activities	Aquaculture	Coralligenous community, Seagrasses, *Pinna nobilis*	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, remove marine litter, improve water quality	Variation in surface area occupied by aquaculture	Surface area devoted to aquaculture
				Alteration of the benthic functional diversity and ecosystem functionality	Oxygen and nutrients concentration in sediments, abundance and biomass of benthic organisms, diversity indices, sedimentation rate, grain size, redox potential, organic

					matter content in sediments, sulphides, infaunal trophic index
	Anchoring	Coralligenous community, Seagrasses, *Pinna nobilis*	Regulate human activities, increase public awareness, increase enforcement, increase monitoring, install signalling/ mooring buoys, establish network of N2K sites, increase N2K site size	Mortality rate due to physical disturbance	Number of deaths, age, biometric measures, population size, spatial and temporal extent of the disturbance
				Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, spatial and temporal extent of the disturbance, signs of injuries
				Trends in number of boats anchoring on the sea bottom	Number of boats anchoring on the sea bottom
	Dive tourism potentially causing incidental killings/damages to organisms	Coralligenous community, *Pinna nobilis*	Regulate human activities, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, spatial and temporal extent of the disturbance, signs of injuries

				Mortality rate due to physical disturbance	Number of deaths, population size, age, biometric measures, spatial and temporal extent of the disturbance
				Diver contact rate with organisms	Number of contacts of divers over a unit of time
				Number of divers below the carrying capacity of the N2K sites	Number of divers per year
	Illegal harvesting by recreational fishing	*Pinna nobilis*	Regulate human activities, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	Variation in density of organisms	Density of individuals, spatial and temporal extent of the disturbance
	Professional fishing potentially causing incidental killing/damages to organisms	Coralligenous community, seagrasses, *Pinna nobilis*	Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, remove marine litter (ghost nets),	Mortality rate due to physical disturbance	Number of deaths, age, biometric measures, population size

			establish network of N2K sites		
				Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, signs of injuries
				For all the performance indicators	Fishing effort, type of fishing gears and spatial and temporal distribution of the disturbance
	Professional fishing	*Alosa fallax*	Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites	Fishing mortality	population size, fish catches, Fishing effort, type of fishing gears, and spatial and temporal distribution of the disturbance
				Spawning stock biomass of fish	Biomass, age, size
Prevent illegal fishing of *Lithophaga lithophaga*	Illegal harvesting by recreational fishing	Coralligenous community	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring	Total surface area of destructed benthic habitat	Percent cover of new benthic habitat destructed by poaching, spatial and temporal extent of the disturbance
				Trends in number of	Number of reported offences in a year, kilos

				reported offences	of date mussels collected
Reduce impact of invasive species	Invasive species	Coralligenous community, Seagrasses, *Fucus virsoides, Pinna nobilis, Alosa fallax*	Remove invasive species, establish network of N2K sites, increase N2K site size, increase monitoring	Trends in cover/ density of invasive vs native species	Cover/density of invasive species and native ones, spatial and temporal distribution of the disturbance
Reduce impact of marine litter	Marine litter	Coralligenous community, Seagrasses, *Alosa fallax, Fucus virsoides, Pinna nobilis*	Remove marine litter, establish no-fishing buffer zones (to avoid ghost nets), increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	Trends in the amount and composition of litter ingested by organisms	Amount, weight and type of litter ingested (stomach content)
				Trends in the amount of litter in the water column and on the seafloor	Amount and weight of marine litter in the water column and on the seafloor in items per km^2
				Trends in number/cover of individuals affected by litter	Number/ cover of individuals adversely affected by litter
				Mortality rate due to litter	Number of deaths, population size, age, biometric measures

Minimize the effect of climate change	Effects of climate change	Coralligenous community, Seagrasses, *Alosa fallax, Fucus virsoides, Pinna nobilis*	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Phenological shift	Phenology related measures
				Proportion of affected organisms	Population cover/ size, number/ cover of affected organisms, percentage of necrotic tissues
				Variation in population structure	Population size, age, biometric measures
				Mortality rate due to climate change effects	Number of deaths, population size, age, biometric measures
				For all the performance indicators of climate change	Temperature, pH, number of extreme events, spatial and temporal extent of the disturbance, presence/quantity of mucilage and number of events
Minimize the effect of possible diseases	Disease outbreak	Coralligenous community, Seagrasses, *Alosa fallax, Fucus virsoides, Pinna nobilis*	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Mortality rate due to diseases	Number of deaths, population size, age, biometric measures, spatial and temporal extent of the disturbance
				Variation in population structure	Population size, age, biometric measures
				Proportion of sick organisms	Population size/ cover, number/ cover of sick organisms, spatial and

					temporal extent of the disease
Assess distribution and status of target species and maintain or restore their populations	All	Coralligenous community, Seagrasses, *Alosa fallax, Fucus virsoides, Pinna nobilis*	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, remove marine litter, improve water quality, install signalling/mooring buoys, restore the species	Population demography	Population age, sex, abundance, cover, biomass, density, abundance, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates, spatial movements
				Additional information to assess the status of species	Current velocity and direction, wave exposure, relative exposure index, reef geomorphology, rugosity, depth, slope, geographic orientation, PAR, type of sediments, percentage cover of sediment, sedimentation rate, type of substrate, density and abundance of herbivores, erosion-recolonization rate of

					seagrasses, leaf elongation rate, patch size of seagrasses, photosynthetic activity, net primary productivity, spawning rate, associated organisms, abundance/cover of opportunistic species, area covered by suitable habitats and their structure, spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions, spatial extent of the suitable habitat which is adversely affected through change in its biotic and abiotic structure and its functions by physical disturbance, spatial and temporal variation of hydrographical conditions, biomass of epiphytes, shell burial level and orientation, number and type of barriers to migration, water flow rate, timing and duration of the estuarine phase, spawning stock biomass, organic matter

				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)
Preserve coralligenous community diversity and gene pool		Coralligenous community		Community structure	Species composition, cover, density, biomass, distribution/dispersion, diversity indices, number of taxa per functional group, abundance/cover of opportunistic species, dissimilarity between species, texture of the calcareous matrix
				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

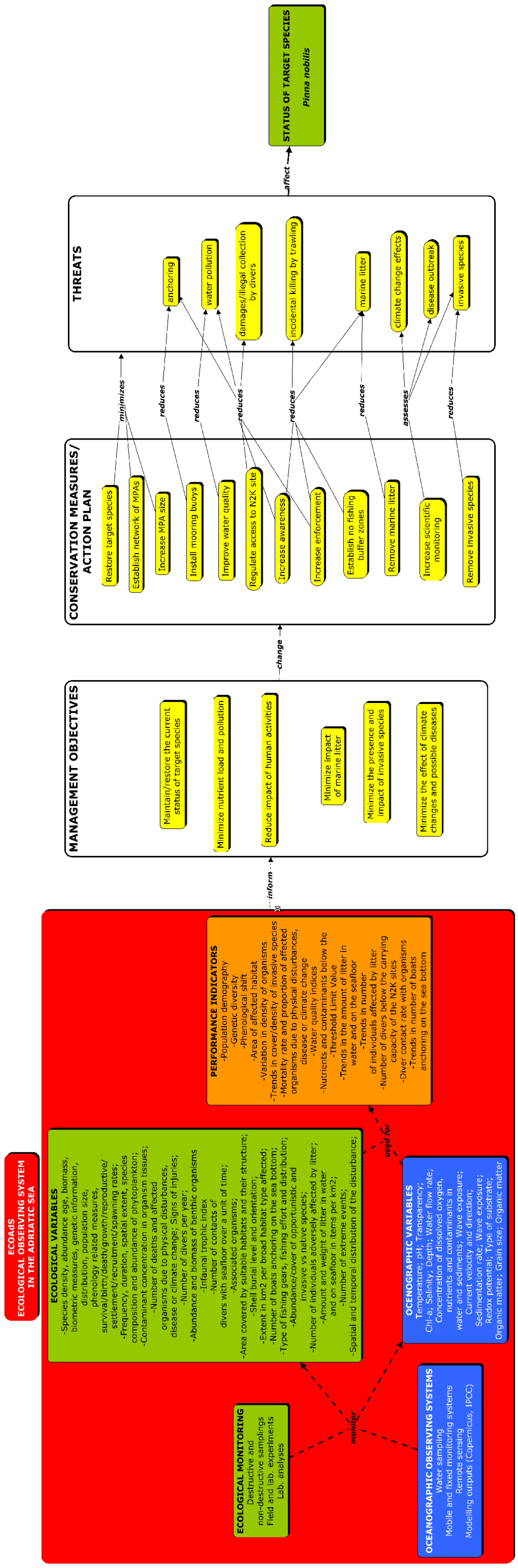

Figure 5. Operative version of the application model for 'Malostonski zaljev' N2K site.

3.3 Trezze San Pietro e Bardelli (IT3330009) and Tegnùe di Chioggia (IT3250047)

Trezze San Pietro e Bardelli and Tegnùe di Chioggia have been established to protect the same habitat type: the mesophotic biogenic reefs of the Northern Adriatic Sea. They also share the same ecological/oceanographic processes and are potentially subject to the same impacts, even if they are more than 40 nm distant[34]. In the SDF of both sites, many benthic species are listed. All together, they contribute to form coralligenous-like concretions and shape these biogenic reefs[34]. Thus, target benthic species for these two sites were here grouped under the name "Coralligenous community" (deliverable 3.3.1). On sediments close to the reefs, the noble pen shell (*P. nobilis)*, listed in the Annex IV of the HD, can be also observed. Some individuals of *Caretta caretta, T. truncatus*, *A. fallax* and seabirds (*Larus melanocephalus; Phalacrocorax aristotelis; Puffinus yelkouan*) have been reported inside the N2K borders, but there is no specific information on their spatial/temporal density and distribution and further monitoring programs should be carried on in these sites.

The management authorities of Tegnùe di Chioggia N2K site are both the Veneto Region and the Italian Ministry of the Environment. The Veneto Region designated as a local authority the Municipality of Chioggia is the only body with an operational role in the management of the site. The managing authority of Trezze San Pietro e Bardelli is the Regione Autonoma Friuli Venezia Giulia - Direzione Centrale Infrastrutture e Territorio - Servizio Paesaggio e Biodiversità. However, both sites, to date, are not effectively managed and there are no management plans or specific conservation measures in action.

Ecological monitoring is performed occasionally, there are no long-term, continued, and consistent data and this represents one of the main deficiencies in the management process. Water quality data, chemical and physical characteristics can be in part derived from monitoring facilities in the proximity (e.g. buoys), or from remote sensing (e.g. chl-a from satellite), or modelling outputs (current field components). This is not true for ecological data (community structure and composition) that were collected only during some projects investigating diversity and connectivity of the biogenic reefs (see deliverable 3.2.1 and 3.1.1). For ecological data, continuous/recurring monitoring should be implemented, also on the adjacent sites outside the N2K sites, since many studies highlighted the high diversity and links between these outcrops[33–35]. Institutions and companies that have performed monitoring activities so far include WWF Miramare (SHORELINE), the National Institute of Oceanography and Applied Geophysics (OGS), ARPAFVG, ARPAVeneto, and the University of Trieste and Bologna. Among the variables that were collected there are benthic organism distribution, community structure and dynamics, diversity, percent cover, abundance, genetic diversity, plankton abundance and biomass, primary and secondary production and physicochemical parameters in water such as nutrient and contaminant concentration in water and sediments, temperature, pH, alkalinity, chlorophyll-a, dissolved oxygen, transparency, and wind speed (for a complete list see D3.1.1).

Possible threats that may affect mesophotic biogenic reefs in these two sites are similar to those already seen for Malostonski zaljev N2K site. Among the variables useful to quantify the potential direct impact of some human activities (e.g. poaching, scuba diving, commercial fishing, anchoring)[22,23,25], we suggest monitoring population cover/density, biometric measures, signs of injuries on organisms, number/cover of affected organisms, spatial and temporal extent of the disturbance, number of boats anchoring on the sea bottom, number of divers per year, number of contacts of divers over a unit of time, number of dead organisms (if we are considering species with easily-recognizable individuals). Bycatch of vertebrates by fishing can be assessed by counting the number of interactions with fishing nets over a unit of time (e.g. signs of new holes in nets, presence of damaged fish on nets), site fidelity, group dynamics, number of deaths and target species behaviour metrics. Conservation measures needed to address such threats may be prohibiting anchorage on the rocky outcrop, professional fishing with high impact nets (i.e. trawls, blowers, dredges, purse seines, etc.) on the coralligenous habitat, establishing no-fishing buffer zones, regulating scuba divers access to the sites and setting mooring buoys or signalling the sites on the nautical chart to easily identify them (Fig. 6, Tab. 4).

Marine litter can also have an impact, not only on benthic communities but particularly on seabirds, sea turtles and dolphins[36,37]. Assessment of the amount, type and weight of litter on the seafloor, in the water and ingested, as well as the number/cover of individuals adversely affected by litter is necessary to quantify such impact and organize, in case, recurrent cleaning and prevention campaigns (Fig. 6, Tab. 4).

Dolphins and sea turtles may be also occasionally subjected to collision with boats and may be disturbed by noise pollution[13,38]. Though this eventuality has not been assessed yet in both N2K sites, regulating access of boats and installing signalling buoys may prevent such an impact. Performance indicators that can be measured in this case may be mortality rate due to physical disturbance, the proportion of injured individuals, trends in the number of boats inside the N2K sites, sea ambient noise variations, and changes in dolphin’s vocal calls (Fig. 6, Tab. 4).

Particularly important for the benthic community is the assessment of the presence, distribution and cover/density of invasive species to outline a trend in their abundance**.** The spread of invasive species can have, in fact, serious impacts on the structure and functioning of ecological systems competing for space and nutrients[39]. Regular monitoring in this case represents an important strategy to report allochthonous species invasions at their first stage and prevent their spread (Fig. 6, Tab. 4).

Alteration of pH and seawater temperature are the main consequences of climate change that interfere with calcification processes and survival of benthic species[32,40]. In addition, both processes have synergistic effects on species[41]. Water acidification affects mainly organisms with calcium carbonate shells and skeletons by reducing calcification and the rates of repair, and by weakening calcified structures[42]. Exceeding limits of tolerance of species to warming and acidification can also have primary effects on growth, body size, behaviour , stress-response mechanisms, feeding, and reproductive success[43,44]. Descriptive indicators we suggest to monitor include all those variables that indicate variation in population structure and dynamics, as well as temperature, pH, number of extreme events, presence/quantity of mucilage and necrotic tissues, and spatial and temporal extent of the disturbance. Regarding seabirds, sea turtles and dolphins, we suggest collecting also other variables such as phenology related measures, since the effects of climate change may also alter behaviour and physiological traits[6,45,46], the number of deaths, survival of offspring, variation in reproductive success, stomach content, prey distribution, abundance and behaviour, and fishery catches, type of fishing gears, fishing effort, as associated data, to get information on the population structure of prey of target species (Fig. 6, Tab. 4).

Finally, one of the main conservation strategies that should be put in place in the area, as also suggested by OGS and SHORELINE (deliverable 3.2.1), is increasing the protected area size and the creation of a network of mutually connected and protected sites in the Northern Adriatic Sea. Different studies have highlighted the high heterogeneity of these reefs and the importance to preserve more sites, that are not currently protected, to guarantee connectivity dispersal of the populations living on them[33]. A network of N2K sites could be predicted to be more effective than smaller areas at conserving biodiversity because they could include more habitat types and have smaller edge effects (i.e. the ratio of area to perimeter contributes to how vulnerable an area is to threats that exist outside of its borders)[47].

The operative model built as an example for the coralligenous community (Fig. 7) highlights a series of conservation actions and management objectives that should be carried on to reduce the threats on coralligenous species in both N2K sites. As already described above, installing mooring/signaling buoys, regulating fishing and access to the sites, increasing monitoring programs and public awareness, adopting ecosystem-based solutions to improve water quality, especially in rivers and on the coastline, are the most important measures to reduce the effect of multiple impacts on these vulnerable biogenic reefs. In addition, a major effort should be done to enhance enforcement in the area and prevent illegal activities. Performance indicators useful to assess the achievement of the management objectives in these areas may include population demography, area of affected habitat, water quality indices, trends in the number of boats anchoring in the area, diver contact rate with organisms and number of divers below the carrying capacity of the N2K site. Particularly important is the assessment of genetic diversity at different spatial scales to have an indication of the degree of connectivity among the reefs and larval dispersal pattern[33] (Fig. 7, Tab. 4).

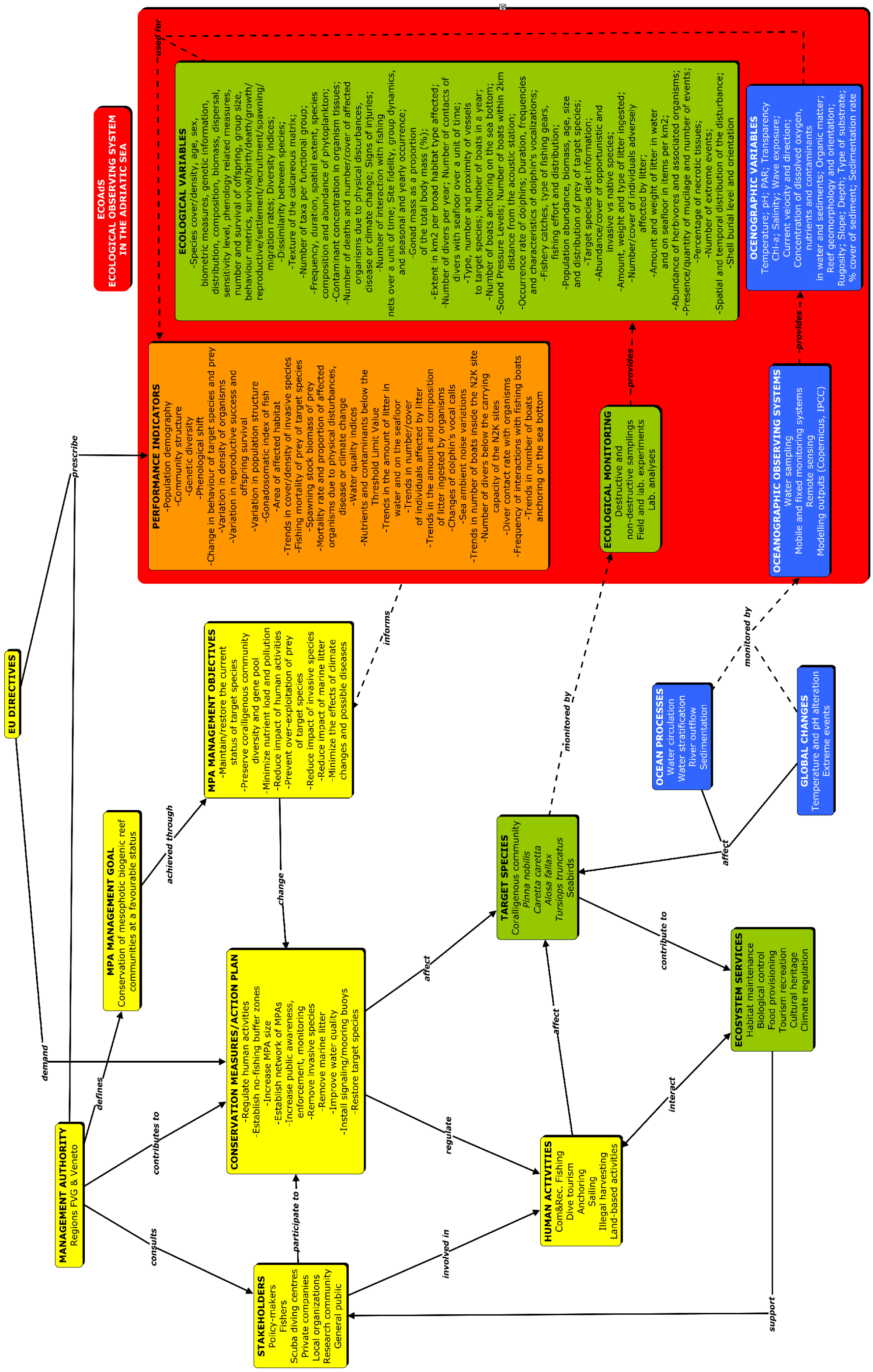

Figure 6. Application model for ‘Trezze San Pietro e Bardelli’ and ‘Tegnùe di Chioggia’ N2K sites.

Table 4. Links between descriptor and performance indicators, conservation measures and management objectives addressing threats to target species in the 'San Pietro e Bardelli' and 'Tegnùe di Chioggia' N2K sites.

Management objectives	**Human activities/ threats in the N2K sites**	**Threatened target species**	**Conservation measures**	**Performance indicators**	**Descriptive indicators**
Minimize nutrient load and pollution	Land-based activities and sailing causing poor water quality	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta caretta, Alosa fallax*	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, improve water quality	Water quality indices	Frequency, duration, spatial extent, species composition and abundance of phytoplankton blooms, including harmful species
					Dissolved oxygen, chlorophyll-a, transparency, salinity, pH, temperature
					Species composition, density/ cover and sensitivity level of benthic organisms
				Nutrients and contaminants below the Threshold Limit Value	Nutrient and contaminant concentration in water and sediments
					Contaminant concentration in organism tissues

					Spatial extent and duration of significant acute pollution/ eutrophication events
				Gonadosomatic index of fish	Gonad mass as a proportion of the total body mass (%)
				Mortality rate from pollution	Number of deaths, population size, spatial and temporal extent of the disturbance. Sex, age, biometric measures and genetic information from carcasses
				Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, spatial and temporal extent of the disturbance
				Area of affected habitat	Extent in km2 per broad habitat type affected by water pollution
Reduce impact of human activities	Professional fishing potentially causing incidental killing/damages to organisms	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta caretta*	Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness,	Mortality rate due to physical disturbance	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses

			increase enforcement, increase monitoring, remove marine litter (ghost nets), establish network of N2K sites		
				Frequency of interactions with fishing boats	Target species behaviour metrics, number of interactions with fishing nets over a unit of time (e.g. signs of new holes in nets, presence of damaged fish on nets), site fidelity, group dynamics, and seasonal and yearly occurrence
				Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, signs of injuries
				For all the performance indicators	Fishing effort, type of fishing gears and spatial and temporal distribution of the disturbance
	Anchoring	*Pinna nobilis*, coralligenous community	Regulate human activities, increase public awareness, increase enforcement,	Mortality rate due to physical disturbance	Number of deaths, age, biometric measures, population size, spatial and temporal extent of the disturbance

			increase monitoring, install signalling/ mooring buoys, establish network of N2K sites, increase N2K site size		
				Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, spatial and temporal extent of the disturbance, signs of injuries
				Trends in number of boats anchoring on the sea bottom	Number of boats anchoring on the sea bottom
	Dive tourism potentially causing incidental killings/damages to organisms	*Pinna nobilis*, coralligenous community	Regulate human activities, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	Proportion of affected organisms	Population size/ cover, number/ cover of affected organisms, spatial and temporal extent of the disturbance, signs of injuries
				Mortality rate due to physical disturbance	Number of deaths, population size, age, biometric measures, spatial and temporal

					extent of the disturbance
				Diver contact rate with organisms	Number of contacts of divers over a unit of time
				Number of divers below the carrying capacity of the N2K sites	Number of divers per year
	Illegal harvesting by recreational fishing	*Pinna nobilis*		Variation in density of organisms	Density of individuals, spatial and temporal extent of the disturbance
	Sailing potentially causing incidental killings/damages to organisms	*Caretta caretta, Tursiops truncatus*	Regulate human activities, increase public awareness, increase enforcement, increase monitoring, install signalling/ mooring buoys, establish network of N2K sites, increase N2K site size	Mortality rate due to physical disturbance	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
					Type, number and proximity of vessels to target species
				Proportion of injured organisms	Population size, number of injured organisms, signs of injuries

					Type, number and proximity of vessels to target species
				Trends in number of boats inside the N2K site	Number of boats in a year
	Nautical tourism causing noise pollution	*Tursiops truncatus*		Sea ambient noise variations	Sound Pressure Levels, spatial and temporal extent of noise pollution
					Number of boats within 2 km distance from the acoustic station
					Occurrence rate of dolphins
				Changes of dolphin's vocal calls	Duration, frequencies and characteristics of vocalizations
	Professional fishing	*Alosa fallax*	Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites	Fishing mortality	population size, fish catches, Fishing effort, type of fishing gears, and spatial and temporal distribution of the disturbance
				Spawning stock biomass of fish	Biomass, age, size

Prevent over-exploitation of prey of target species	Professional fishing	*Tursiops truncatus*	Regulate human activities, establish no-fishing buffer zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites	Fishing mortality of prey	Fishery catches, type of fishing gears, fishing effort and distribution, population abundance and distribution of prey + target species diet information (stomach content, stable isotope analysis)
				Spawning stock biomass of prey	Biomass, age, size of prey + target species diet information (stomach content, stable isotope analysis)
Reduce impact of invasive species	Invasive species	*Pinna nobilis*, coralligenous community, *Alosa fallax,* seabirds	Remove invasive species, establish network of N2K sites, increase M N2K site PA size, increase monitoring	Trends in cover/ density of invasive vs native species	Cover/density of invasive species and native ones, spatial and temporal distribution of the disturbance
Reduce impact of marine litter	Marine litter	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta*	Remove marine litter, establish no-fishing buffer zones (to avoid ghost nets), increase public	Trends in the amount and composition of litter ingested by organisms	Amount, weight and type of litter ingested (stomach content)

		caretta, Alosa fallax	awareness, increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size		
				Trends in the amount of litter in the water column and on the seafloor	Amount and weight of marine litter in the water column and on the seafloor in items per km^2
				Trends in number/cover of individuals affected by litter	Number/ cover of individuals adversely affected by litter
				Mortality rate due to litter	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
Minimize the effect of climate change	Effects of climate change	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta caretta, Alosa fallax*	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Variation in reproductive success and offspring survival	Number of offspring, population size, sex, age, survival rate of offspring
					Fishery catches, type of fishing gears, fishing effort, population abundance and

					distribution of prey + target species diet information (stomach content, stable isotope analysis)
				Change in behaviour	Distributions of prey and target species, group size, behaviour metrics
				Phenological shift	Phenology related measures
				Proportion of affected organisms	Population cover/ size, number/ cover of affected organisms, percentage of necrotic tissues
				Mortality rate due to climate change effects	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
				Variation in population structure	Population size, age, biometric measures
				For all the performance indicators of climate change	Temperature, pH, number of extreme events, spatial and temporal extent of the disturbance, presence/quantity of mucilage and number of events

Minimize the effect of possible diseases	Disease outbreak	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta caretta, Alosa fallax*	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Mortality rate due to diseases	Number of deaths, population size, spatial and temporal extent. Sex, age, biometric measures and genetic information from carcasses
				Variation in population structure	Population size, age, biometric measures
				Proportion of sick organisms	Population size/cover, number/cover of sick organisms, spatial and temporal extent of the disease
Maintain/restore the current status of target species	All	Coralligenous community, seabirds, *Pinna nobilis, Tursiops truncatus, Caretta caretta, Alosa fallax*	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, remove marine litter, improve water quality,	Population demography	Population age, sex, abundance, cover, biomass, density, distribution, dispersal, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates

			install signalling/mooring buoys, restore target species		
				Additional information to assess the status of species	Current velocity and direction, reef geomorphology, rugosity, depth, slope, geographic orientation, percentage cover of sediment, sedimentation rate, PAR, abundance of herbivores, spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance, presence of epibiotics, wave exposure, associated organisms, shell burial level and orientation, spawning rate, organic matter, spatial extent of the suitable habitat adversely affected due to

					alteration of hydrographical conditions, spatial and temporal variation of hydrographical conditions, type of substrate
				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)
Preserve coralligenous community diversity and gene pool		Coralligenous community		Community structure	Species composition, cover, density, biomass, distribution/dispersion, diversity indices, number of taxa per functional group, abundance/ cover of opportunistic species, dissimilarity between species, texture of the calcareous matrix
				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

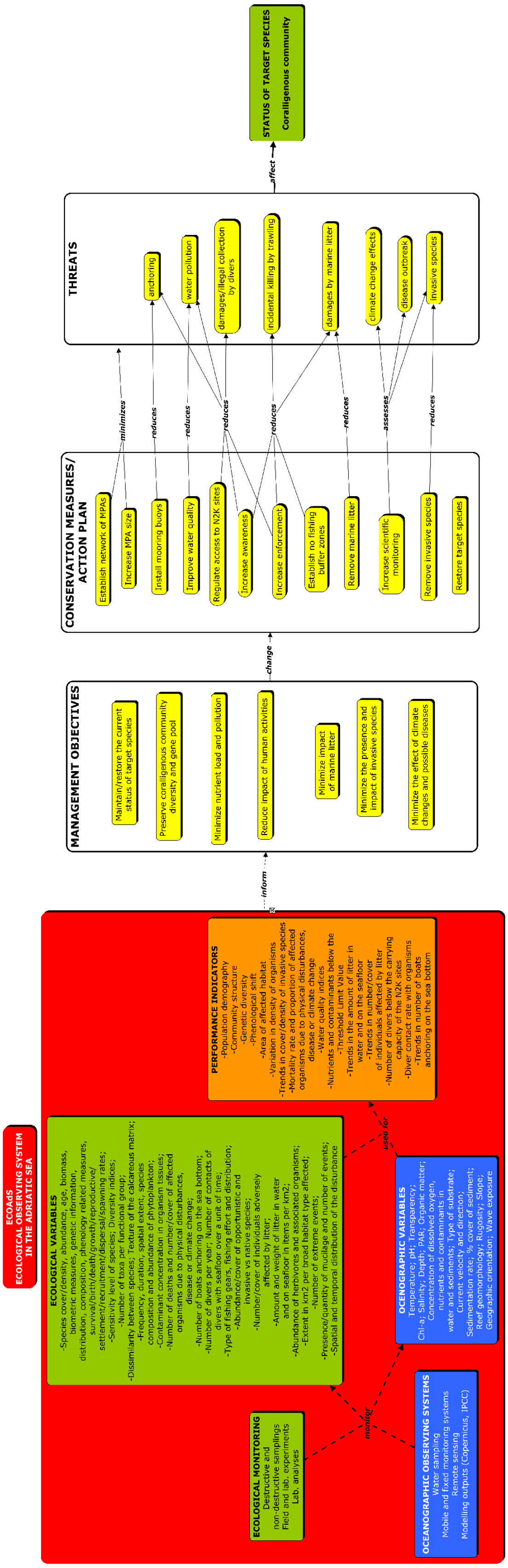

Figure 7. Operative version of the application model for ‘Trezze San Pietro e Bardelli’ and ‘Tegnùe di Chioggia’ N2K sites.

3.4 Delta del Po: tratto terminale e delta Veneto (IT3270017) and Delta del Po (IT3270023)

The two Delta del Po N2K sites geographically overlap and compose a single river-delta-sea system with the same species. The majority of the species are exclusively related to freshwater and terrestrial habitats. For the aim of this project and based on expert opinion, only species strongly dependent on the marine environment, where they can be observed regularly or during some stages of their life cycle, are listed here. Different migratory and sedentary seabirds (*Sterna albifrons; Sterna hirundo; Sterna sandvicensis; Sterna nilotica; Sterna caspia; Larus ridibundus; Larus genei; Larus melanocephalus; Phalacrocorax aristotelis*) all listed in the Annexes I and II of the BD, can be observed in colonies in lagoons, coastal dunes, and on seawater surface, during different seasons while feeding, resting or nesting. Species of particular value are also some anadromous fish (*Alosa fallax, Acipenser naccarii, Petromyzon marinus*) that migrate from the sea to the upper part of the rivers for reproduction. They are all included in the Annex II of the HD. Other marine species that were reported in the Po Delta are three seagrasses (*Cymodocea nodosa*, *Zostera noltii* and *Zostera marina*).

The management body of both N2K sites is the Po Delta Veneto Regional Park Authority (Ente Parco Regionale Veneto del Delta del Po), however, at the moment, the management plan has not yet been approved[48].

ARPAV performs monitoring activities in these N2K sites, assessing temperature, pH, conductivity, salinity, dissolved oxygen, current direction and speed, tide conditions, transparency, depth, chlorophyll-a, sediment density and porosity, granulometry, organic matter in sediments, nutrients and contaminants in water, sediment and biota, composition, diversity, and abundance of phytoplankton, harmful phytoplankton, benthic macroinvertebrates diversity, abundance and composition, and abundance and cover macrophytes, according to the legislative decree n. 152/2006 (aimed to classify the chemical and ecological status of water and to assess the quality of shellfish waters). Occasionally are also monitored by the management authority species spatial distribution, richness, density, coverage, community structure. However, monitoring is not always conducted regularly and there is space for improvement, which means that some lagoons need more monitoring stations (deliverable 3.2.1).

Being both N2K sites extended on a vast terrestrial area characterized by numerous villages, human uses and activities, pressures on target species and habitats are many and diffuse. Rivers, canals and banks are modified by dredging, maintenance works, soil erosion and leaching, dyke and barrier constructions, rising of the salt wedge and water level changes; all inducing alteration of sedimentation rate and water circulation and destruction of habitats. Conservation measures in this context should be focused on increasing awareness of the possible impacts that such interventions may generate, minimizing engineering works, guaranteeing passage for migratory fish, incentivizing sustainable agriculture practices and creating mosaic areas of different cultivated species of plants or woods in river branches, that might also prevent soil erosion and leaching[49] (Fig. 8, Tab. 5). Variables that can be monitored include the spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions, current velocity, depth, amount of precipitations, salinity, water flow rate, seawater level, amount of water abstracted, water flow indicators, spatial and temporal variation of hydrographical conditions, number and type of barriers to migration, the population size of target species (Fig. 8, Tab. 5).

Water quality also may be affected by some of these threats, as well as by aquaculture, discharges, beach nourishment, use of fertilizers/herbicides in agriculture, and pollution from motorboats. To assess if conservation measures put in place to improve water quality are working, we suggest calculating as performance indicators water quality indices, gonadosomatic index of fish, the mortality rate from pollution, proportion of affected organisms, variation of sedimentation rate, nutrients and contaminants below the threshold limit value, trends in the number of boats in canals and basins, and area of affected habitat (Fig. 8, Tab. 5). These indicators require several variables, some of which are already collected by local monitoring agencies, for instance, extent in km2 per broad habitat type affected by water pollution, transparency, number of boats in channels and basins, spatial and temporal extent of the disturbance, population size/cover of target species, number/cover of affected organisms, and gonad mass as a proportion of the total body mass (Fig. 8, Tab. 5).

The Po Delta ecosystems are particularly sensitive to the effects of climate change. The reduction of precipitations and sea-level rise may favour the salt wedge intrusion into coastal zones, change salinity and affect numerous freshwater ecological processes, including the migration of some target species, and the possibility to use water for drinking and soil irrigation[50,51]. It is strictly urgent to adopt measures, regulating water abstraction for different uses at the basin scale, creating phytodepuration basins, promoting the cultivation of plants more resistant to higher levels of salinity, and reducing works that alter hydrological conditions and water flow[48]. These threats are not expected to act alone, due to the simultaneous increase of air and water temperature with climate change[52]. Among the possible variables that can be monitored, we suggest temperature, pH, number of extreme events, amount of precipitations, water flow rate, spatial and temporal extent of the disturbance, phenology related measures, population size/cover of target species, number of deaths, number of offspring, and the survival rate of offspring (Fig. 8, Tab. 5).

Other threats that may have a direct impact on target species of the Delta system are commercial and recreational fishing, including illegal fishing. In the Po river, fishing is a relevant activity, much practised by local people[48]. In some cases, protected species of fish may be bycaught or illegally fished, such as the Adriatic sturgeon. Addressing such threats requires awareness-raising campaigns, more enforcement and species restoration. To monitor fishing impact, information on different variables can be collected such as fishery catches, type of fishing gears, fishing effort and distribution, population abundance and distribution of target species, biomass, age, sex, and also seabirds behaviour metrics, the number of interaction with fishing nets over a unit of time (e.g. signs of new holes in nets, presence of damaged fish on nets), site fidelity and group dynamics, since bycatch of seabirds trying to feed in nets can be common, especially at sea (Fig. 8, Tab. 5).

The Po Delta is also an area of high touristic value due to its natural beauty and the possibility to go trekking, birdwatching, recreational fishing, water sports, cycling, and boating. The natural habitat of seabirds, and in particular the nesting sites, can be subjected to high disturbance and trampling, causing nest abandon or egg destruction, with an impact on seabird reproduction success. The effect of touristic disturbance can be monitored by assessing as performance indicators the trend in the number of visitors during the nesting season and the birth rate (Fig. 8, Tab. 5). As conservation measures, it would be important to regulate human access at different sites, increasing public awareness, enforcement and monitoring, but also, in case, recreating/restoring the optimal habitats of target species in other undisturbed areas[48].

Finally, in terms of conservation measures, the management body highlighted that N2K site Delta del Po might be extended to the sea due to the presence of migratory fish species such as sturgeons, shad (*A. fallax*) and lamprey (*P. marinus*) and because coastal waters and lagoons are trophic ground for *C. caretta.* In addition, they pointed out that conservation strategies should be based on the improvement of sustainable practices addressed towards human activities management (especially agriculture, fishery, climate regulation, regulation of water flows) to preserve the ability of ecosystems to provide ecosystem services.

The simplified version of the application model was applied to the Adriatic sturgeon (*A. naccarii*), an emblematic species of the Delta river (Fig. 9). This species is a priority species since it is endemic in the Adriatic Sea, and its natural population has drastically decreased[53]. Currently, several conservation attempts are trying to restore it, also in the Po Delta, and improve its genetic pool[54,55]. Among the main threats that have caused its decline and may hamper current restoration endeavours, we find illegal fishing, water pollution, barriers to movement (e.g. dykes), climate change effects, disease outbreak, invasive species, habitat degradation, and hydrological alterations. These threats can be addressed by defining appropriate conservation measures such as improving water quality, establishing no fishing buffer zones, removing invasive species, raising awareness, enforcement, and monitoring, minimizing river engineering works, creating passages for migration. The achievement of the management objectives linked to these conservation measures can be assessed by some performance indicators that give information on population demography, genetic diversity, variation in population structure, spawning stock biomass, area of affected habitat, variation of indicators of hydrological alteration, alteration of the benthic functional diversity and ecosystem functionality, and the gonadosomatic index. In turn, performance indicators are measured by collecting ecological and oceanographic variables through field sampling or by using numerical model outputs or remote sensing (Fig. 9, Tab. 5). For instance, the variation of indicators of hydrological alteration can be assessed by measuring regularly hydrological indicators (monthly mean of water flow, magnitude and duration of annual extreme flows, the timing of annual extreme flows, frequency and duration of high and low pulses, rate and frequency of flow changes, spatial and temporal variation of hydrographical conditions[56]) and recording their change over time.

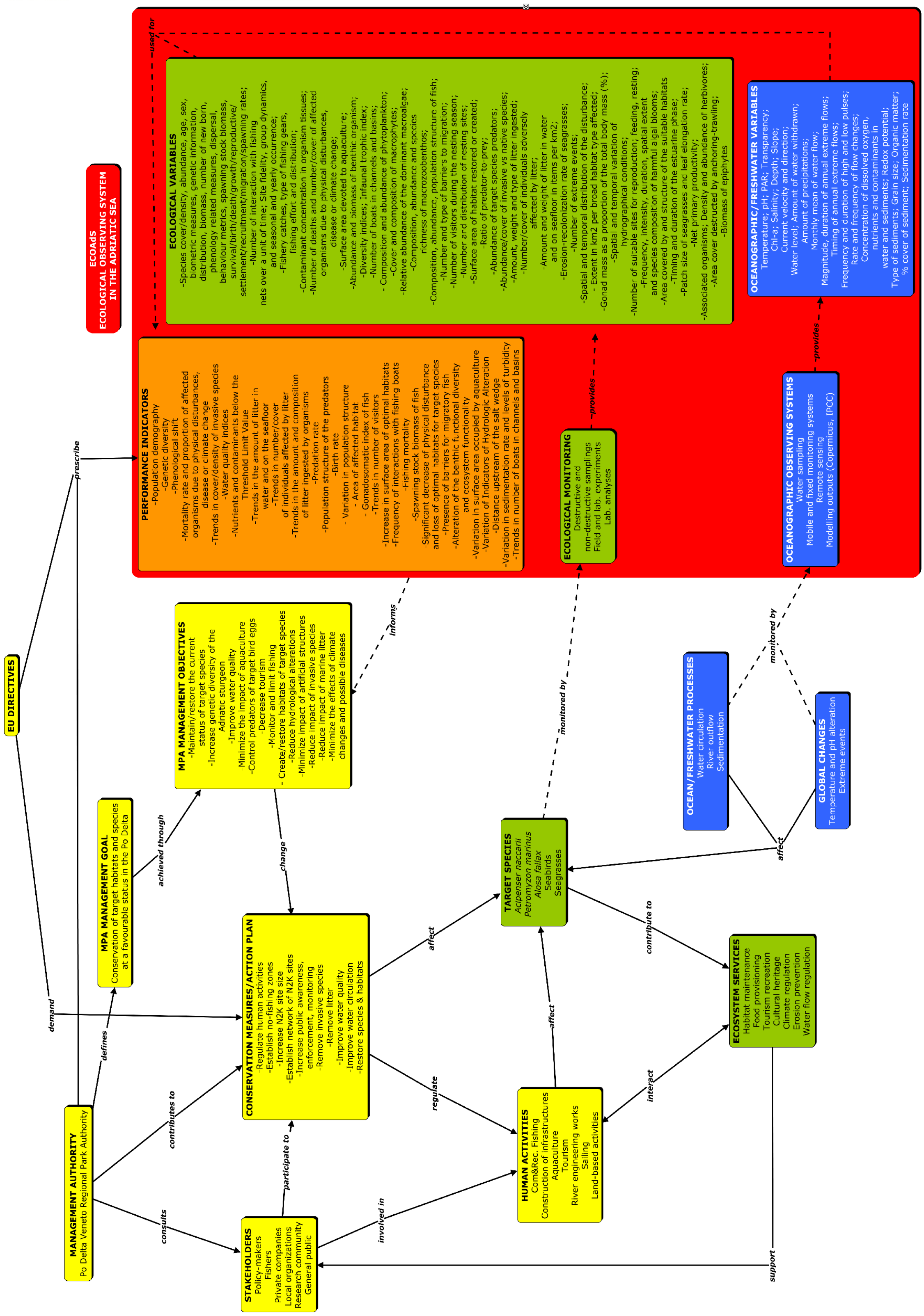

Figure 8. Application model for ‘Delta del Po: tratto terminale e delta Veneto’ and ‘Delta del Po’ N2K sites.

Table 5. Links between descriptor and performance indicators, conservation measures and management objectives addressing threats to target species in the 'Delta del Po: tratto terminale e delta Veneto' and 'Delta del Po' N2K sites.

Management objectives	Human activities/ threats in the N2K sites	Threatened target species	Conservation measures	Performance indicators	Descriptive indicators
Improve water quality	Land-based activities, aquaculture, river engineering works, and sailing causing poor water quality	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, increase water circulation	Water quality indices	Composition and abundance of phytoplankton, biomass as chlorophyll-a, cover and composition of macrophytes, relative abundance of dominant macroalgae, composition, abundance and species richness of macrozoobenthos, composition, abundance and population structure of fish
					Depth, pH, temperature, salinity, dissolved oxygen, transparency
				Nutrients and contaminants below the Threshold Limit Value	Nutrient and contaminant concentration in water and sediments
					Contaminant concentration in organism tissues
					Spatial extent and duration of significant acute

					pollution/ eutrophication events
				Gonadosomatic index of fish	Gonad mass as a proportion of the total body mass (%)
				Mortality rate from pollution	Number of deaths, population size, spatial and temporal extent of the disturbance. Sex, age, biometric measures and genetic information from carcasses
				Proportion of affected organisms	Population size/cover, number/cover of affected organisms, spatial and temporal extent of the disturbance
				Trends in number of boats in channels and basins	Number of boats in channels and basins, spatial and temporal extent of the disturbance
				Variation in sedimentation rate and levels of turbidity	Sedimentation rate, transparency, spatial and temporal extent of the disturbance
				Area of affected habitat	Extent in km2 per broad habitat type affected by water pollution

Reduce hydrological alterations	Construction of infrastructures, river engineering works, excessive water abstraction, climate change	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seagrasses	Regulate human activities, increase awareness, enforcement, monitoring, increase N2K site size, regulate water use and flow, increase water circulation	Distance upstream of the salt wedge	Current velocity, depth, slope, amount of precipitations, salinity, water flow rate, sea water level, amount of water abstracted, spatial and temporal extent of the phenomenon
				Variation of indicators of Hydrologic Alteration	Monthly mean of water flow, magnitude and duration of annual extreme flows, timing of annual extreme flows, frequency and duration of high and low pulses, rate and frequency of flow changes, spatial and temporal variation of hydrographical conditions
				Significant decrease of physical disturbance and loss of optimal habitats for target species	Spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions

Minimize the impact of aquaculture	Aquaculture	*Acipenser naccarii, Petromyzon marinus,* seagrasses	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, remove litter, improve water quality	Variation in surface area occupied by aquaculture	Surface area devoted to aquaculture
				Alteration of the benthic functional diversity and ecosystem functionality	Oxygen and nutrients concentration in sediments, abundance and biomass of benthic organisms, diversity indices, sedimentation rate, grain size, redox potential, organic matter content in sediments, sulphides, infaunal trophic index
Minimize the impact of artificial structures on target species (e.g. electrical cables on birds)	Construction of infrastructures on land and in water causing physical disturbance and habitat loss	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public	Mortality rate due to physical disturbance	Number of deaths, population size, spatial and temporal extent of the disturbance. Sex, age, biometric measures and genetic information from carcasses

			awareness, increase monitoring, increase water circulation		
				Proportion of affected organisms	Population size/cover, number/cover of affected organisms, spatial and temporal extent of the disturbance
				Presence of barriers for migratory fish	Number and type of barriers to migration, spatial position
				Variation in population structure	Population size, age, biometric measures
				Significant decrease of physical disturbance and loss of optimal habitats for target species	Spatial extent of the suitable habitat adversely affected
Monitor and limit fishing	Professional and recreational fishing (also illegal)	*Acipenser naccarii, Alosa fallax*	Regulate human activities, establish no-fishing zones, establish network of N2K sites, increase N2K site size, increase public	Fishing mortality	Fishery catches, type of fishing gears, fishing effort and distribution, population abundance and distribution

			awareness, increase enforcement, monitoring		
				Spawning stock biomass of fish	Biomass, age, size
	Professional fishing potentially causing incidental killing/damages to organisms	*Acipenser naccarii, Petromyzon marinus,* seagrasses, seabirds	Regulate human activities, establish no-fishing zones, increase N2K site size, increase public awareness, increase enforcement, increase monitoring, establish network of N2K sites	Mortality rate due to physical disturbance	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
				Frequency of interactions with fishing boats	Target species behaviour metrics, number of interactions with fishing nets over a unit of time (e.g. signs of new holes in nets, presence of damaged fish on nets), site fidelity, group dynamics, and seasonal and yearly occurrence
				Proportion of affected organisms	Population size/ cover, number/

					cover of affected organisms
				For all the performance indicators	Fishing effort, type of fishing gears and spatial and temporal distribution of the disturbance
Creation/restoration of optimal habitats for target species (e.g. nesting/resting/feeding sites)	Water pollution, river engineering works, construction of infrastructures, invasive species, aquaculture, soil leaching and erosion, trampling by tourists, rising of the salt wedge, litter, climate change	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, improve water quality, restore habitat, increase water circulation	Significant increase in surface area of optimal habitats	Surface area of optimal habitat restored or created
				Birth rate	Population size, number of new born
Decrease tourism-induced disturbance at	Tourism causing trampling and disturbance	Seabirds	Regulate human activities, establish network of	Trends in number of visitors during the nesting season	Number of visitors during the nesting season, number and distribution of nesting sites, spatial

nesting bird sites			N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring		and temporal extent of the disturbance
				Birth rate	Population size, number of new born
Control of the predators of target bird eggs	/			Population structure of the predators	Abundance of the target species predators, spatial and temporal extent
				Predation rate	Ratio of predator-to-prey, abundance of prey and predators, spatial and temporal extent of the disturbance
Reduce impact of invasive species	Invasive species	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Remove invasive species, establish network of N2K sites, increase N2K site size, increase monitoring	Trends in cover/ density of invasive vs native species	Abundance/cover of invasive species and native ones, spatial and temporal distribution of the disturbance
Reduce impact of marine litter	Litter	*Acipenser naccarii, Petromyzon marinus,*	Remove litter, increase public awareness,	Trends in the amount and composition	Amount, weight and type of litter ingested (stomach content)

		Alosa fallax, seabirds, seagrasses	increase enforcement, increase monitoring, establish network of N2K sites, increase N2K site size	of litter ingested by organisms	
				Trends in the amount of litter in the water column and on the seafloor	Amount and weight of litter in the water column and on the floor in items per km^2
				Trends in number/cover of individuals affected by litter	Number/ cover of individuals adversely affected by litter
				Mortality rate due to litter	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
Minimize the effect of climate change	Effects of climate change	*Acipenser naccarii*, *Petromyzon marinus*, *Alosa fallax*, seabirds, seagrasses	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Phenological shift	Phenology related measures
				Variation in reproductive success and offspring survival	Number of offspring, population size, sex, age, survival rate of offspring

				Proportion of affected organisms	Population cover/ size, number/ cover of affected organisms
				Variation in population structure	Population size, age, biometric measures
				Mortality rate due to climate change effects	Number of deaths, population size. Sex, age, biometric measures and genetic information from carcasses
				For all the performance indicators of climate change	Temperature, pH, number of extreme events, amount of precipitations, water flow rate, spatial and temporal extent of the disturbance
Minimize the effect of possible diseases	Disease outbreak	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Increase monitoring, establish network of N2K sites, increase N2K site size, remove other stressors	Mortality rate due to diseases	Number of deaths, population size, spatial and temporal extent of disease. Sex, age, biometric measures and genetic information from carcasses
				Variation in population structure	Population size, age, biometric measures
				Proportion of sick organisms	Population size/ cover, number/ cover of sick organisms, spatial and temporal extent of disease

Maintain/restore the current status of target species	All	*Acipenser naccarii, Petromyzon marinus, Alosa fallax,* seabirds, seagrasses	Regulate human activities, establish no-fishing zones, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, remove litter, improve water quality, restore the species and habitats, increase water circulation	Population demography	Population age, sex, abundance, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates, spawning rate and stock biomass, spatial movements
				Additional information to assess the status of species	Current velocity and direction, water flow rate, water level, percentage cover of sediment, sedimentation rate, type of sediments, organic matter in sediments, PAR, erosion-recolonization rate of seagrasses,

					number of suitable sites for reproduction, frequency, intensity, duration, spatial extent and species composition of harmful algal blooms, area covered by and structure of the suitable habitats, timing and duration of the estuarine phase, number of feeding sites, patch size of seagrasses, leaf elongation rate, net primary productivity, associated organisms, density and abundance of herbivores, area cover destructed by anchoring-trawling, biomass of epiphytes, number of resting sites and features
				Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)
Increase genetic diversity of the Adriatic sturgeon		*Acipenser naccarii*		Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

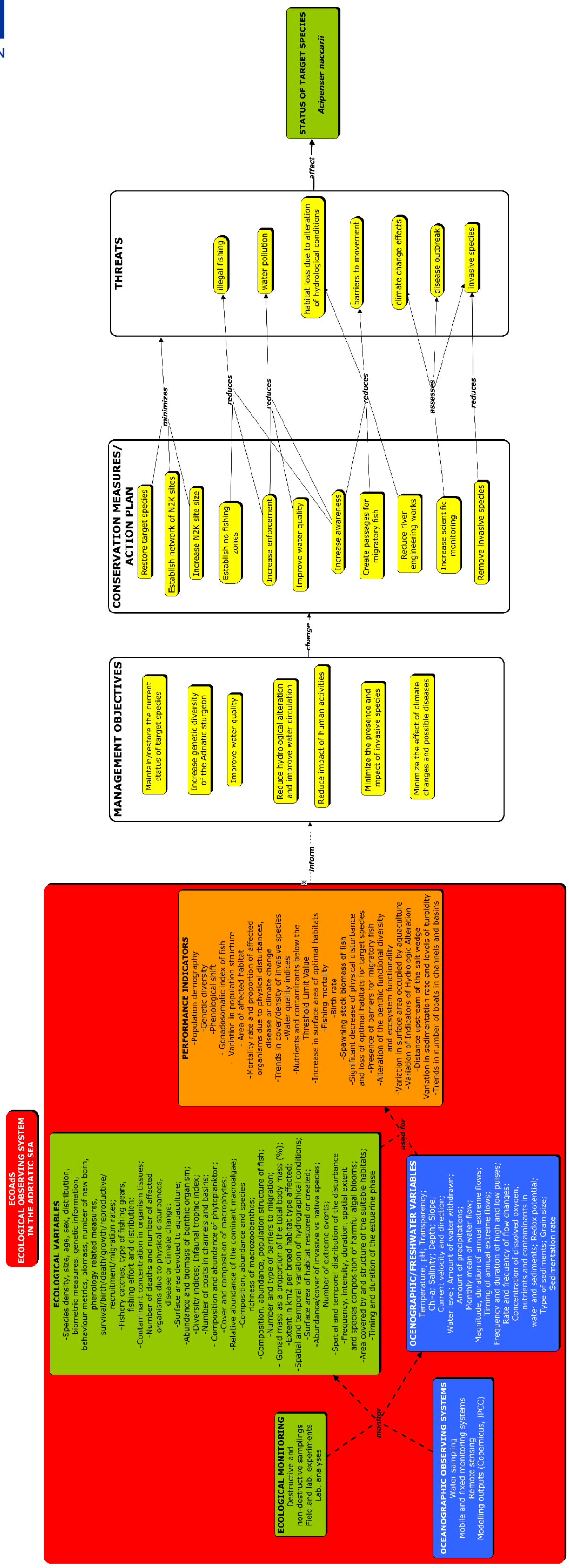

Figure 9. Operative version of the application model for ‘Delta del Po: tratto terminale e delta Veneto’ and ‘Delta del Po’ N2K sites.

4. CONCLUSIONS

In this deliverable, we have applied the generic conceptual model presented in deliverable 3.3.1, to the N2K sites selected as case studies in the ECOSS project. Central to the application model is the development of ECOAdS, an ecological observing system in the Adriatic Sea, aimed to collect periodically data on environmental variables and, through performance indicators, give information on the status of target species and ecological processes in N2K sites. This in turn would help to evaluate the effectiveness of conservation and management actions and feedback into the management and planning process of each N2K site to revise related objectives, plans and outcomes. Such a cyclic process follows an adaptive management strategy, where assumptions are systematically tested, and the results of such testing allow further revision and improvement of management practices. The final aim of adaptive management is to improve effectiveness and increase progress towards the achievement of goals and objectives. Thus, in the N2K site context, ECOAdS plays a prominent role since ecological and oceanographic data provided by this observing system would have in the end a positive impact on the management of the N2K network.

The model also highlighted the importance of ECOAdS, not only in the decision-making process but also in merging different fields: research, monitoring and nature management. In the next future, there will be more and more need for cooperation among different stakeholders to avoid that N2K network remains a stunning idea with no practical application. In this context, data and knowledge exchange is crucial among involved partners. ECOAdS will also likely help in improving the existing monitoring programs in the N2K sites, since, as shown in this report, they are not currently conducted on a regular basis. In order to achieve a wide coverage of the monitored area and focus on specific ecological factors, we suggest including some sampling stations inside the N2K sites and standardizing the monitored variables. ECOAdS, thus, may represent a valid tool to support the conservation of Adriatic habitats and species, but only if we succeed to keep it alive in the long term.

Management of marine N2K sites is not an easy task; N2K site managers should follow an ecosystem-based approach and take into consideration the development of a co-management process of multiple N2K sites in order to create a network of protected areas as conceived in the Habitat Directive. This is particularly true, for instance, in the Po Delta Park where the complexity of the territory and the high number of human interests requires a broader management approach. However, such objectives can be pursued only if a management body is named or become effective in most of the N2K sites. The next step is represented by setting appropriate conservation measures or/and a management plan. In fact, this deliverable, as also the previous ones, highlighted a widespread lack of information on the ecological processes and the conservation status of target species in the considered N2K sites, mainly due to the lack of management plans and management bodies.

Finally, we want to stress that the list of management objectives and the related performance indicators we have outlined for each N2K site does not want to be strict, but represents a starting point for putting in place real management of the N2K sites. In particular, each N2K sites is likely to have a different set of indicators, selected and prioritized according to the objectives, to the types of natural and social components necessary to manage in the site, and to the available human, technical and financial resources.

Management bodies, governments and funding agencies are increasingly demanding information on N2K site management effectiveness to assess whether results are commensurate with their efforts and resources and are in line with policy and management goals. The conceptual model here developed can help in visualizing the links among the ecological and social components that characterize N2K sites and, through ECOAdS, in showing possible unsuccessful conservation strategies in respect to the planned outcomes. It may also represent a baseline for developing a management plan and monitoring programs and can be applied to other N2K sites in the basin.

5. REFERENCES

1. López BD. Bottlenose dolphins and aquaculture: interaction and site fidelity on the north-eastern coast of Sardinia (Italy). Marine biology. 2012;159: 2161–2172.

2. López BD, Methion S. The impact of shellfish farming on common bottlenose dolphins' use of habitat. Marine Biology. 2017;164: 83.

3. Watson-Capps JJ, Mann J. The effects of aquaculture on bottlenose dolphin (*Tursiops* sp.) ranging in Shark Bay, Western Australia. Biological conservation. 2005;124: 519–526.

4. Lusseau D, Williams R, Wilson B, Grellier K, Barton TR, Hammond PS, et al. Parallel influence of climate on the behaviour of Pacific killer whales and Atlantic bottlenose dolphins. Ecology Letters. 2004;7: 1068–1076.

5. Wild S, Krützen M, Rankin RW, Hoppitt WJ, Gerber L, Allen SJ. Long-term decline in survival and reproduction of dolphins following a marine heatwave. Current Biology. 2019;29: R239–R240.

6. Fandel AD, Garrod A, Hoover AL, Wingfield JE, Lyubchich V, Secor DH, et al. Effects of intense storm events on dolphin occurrence and foraging behavior. Scientific Reports. 2020;10: 1–9.

7. Lipscomb TP, Schulman FY, Moffett D, Kennedy S. Morbilliviral disease in Atlantic bottlenose dolphins (*Tursiops truncatus*) from the 1987-1988 epizootic. Journal of Wildlife Diseases. 1994;30: 567–571.

8. Fernández-Contreras MM, Cardona L, Lockyer CH, Aguilar A. Incidental bycatch of short-beaked common dolphins (*Delphinus delphis*) by pairtrawlers off northwestern Spain. ICES Journal of Marine Science. 2010;67: 1732–1738.

9. Jaiteh VF, Allen SJ, Meeuwig JJ, Loneragan NR. Subsurface behavior of bottlenose dolphins (*Tursiops truncatus*) interacting with fish trawl nets in northwestern Australia: Implications for bycatch mitigation. Marine Mammal Science. 2013;29: E266–E281.

10. Slooten E. Effectiveness of area-based management in reducing bycatch of the New Zealand dolphin. Endangered Species Research. 2013;20: 121–130.

11. Panti C, Baini M, Lusher A, Hernandez-Milan G, Rebolledo ELB, Unger B, et al. Marine litter: one of the major threats for marine mammals. Outcomes from the European Cetacean Society workshop. Environmental Pollution. 2019;247: 72–79.

12. Andrady AL. Persistence of plastic litter in the oceans. Marine Anthropogenic Litter. Springer, Cham; 2015. pp. 57–72.

13. Fouda L, Wingfield JE, Fandel AD, Garrod A, Hodge KB, Rice AN, et al. Dolphins simplify their vocal calls in response to increased ambient noise. Biology Letters. 2018;14: 20180484.

14. Rako N, Fortuna CM, Holcer D, Mackelworth P, Nimak-Wood M, Pleslic G, et al. Leisure boating noise as a trigger for the displacement of the bottlenose dolphins of the Cres-Losinj archipelago (northern Adriatic Sea, Croatia). Marine Pollution Bullettin. 2013;68: 77–84. doi:10.1016/j.marpolbul.2012.12.019

15. Guidetti P, Boero F. Desertification of Mediterranean rocky reefs caused by date-mussel, *Lithophaga lithophaga* (Mollusca: Bivalvia), fishery: effects on adult and juvenile abundance of a temperate fish. Marine Pollution Bullettin. 2004;48: 978–982.

16. Vázquez-Luis M, Borg JA, Morell C, Banach-Esteve G, Deudero S. Influence of boat anchoring on *Pinna nobilis*: a field experiment using mimic units. Marine and Freshwater Research. 2015;66: 786–794.

17. Panarese R, Tedesco P, Chimienti G, Latrofa MS, Quaglio F, Passantino G, et al. *Haplosporidium pinnae* associated with mass mortality in endangered *Pinna nobilis* (Linnaeus 1758) fan mussels. Journal of Invertebrate Pathology. 2019;164: 32–37.

18. Carella F, Aceto S, Pollaro F, Miccio A, Iaria C, Carrasco N, et al. A mycobacterial disease is associated with the silent mass mortality of the pen shell *Pinna nobilis* along the Tyrrhenian coastline of Italy. Scientific Reports. 2019;9: 1–12.

19. Valenti WC, Kimpara JM, Preto B de L, Moraes-Valenti P. Indicators of sustainability to assess aquaculture systems. Ecological indicators. 2018;88: 402–413.

20. Lacoste É, McKindsey CW, Archambault P. Biodiversity–Ecosystem Functioning (BEF) approach to further understanding aquaculture–environment interactions with application to bivalve culture and benthic ecosystems. Reviews in Aquaculture. 2020;12: 2027–2041.

21. Grant J, Hatcher A, Scott DB, Pocklington P, Schafer CT, Winters GV. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries. 1995;18: 124–144.

22. Di Franco A, Milazzo M, Baiata P, Tomasello A, Chemello R. Scuba diver behaviour and its effects on the biota of a Mediterranean marine protected area. Environmental Conservation. 2009; 32-40.

23. Piazzi L, Gennaro P, Balata D. Threats to macroalgal coralligenous assemblages in the Mediterranean Sea. Marine Pollution Bulletin. 2012;64: 2623–2629.

24. Ferrigno F, Russo GF, Sandulli R. Coralligenous Bioconstructions Quality Index (CBQI): a synthetic indicator to assess the status of different types of coralligenous habitats. Ecological Indicators. 2017;82: 271–279.

25. Ferrigno F, Appolloni L, Russo GF, Sandulli R. Impact of fishing activities on different coralligenous assemblages of Gulf of Naples (Italy). Journal of the Marine Biological Association of the United Kingdom. 2018;98: 41–50.

26. Davis D, Tisdell C. Recreational scuba-diving and carrying capacity in marine protected areas. Ocean & Coastal Management. 1995;26: 19–40.

27. Francour P, Ganteaume A, Poulain M. Effects of boat anchoring in *Posidonia oceanica* seagrass buds in the Port-Cros National Park (north-western Mediterranean sea). Aquatic Conservation-Marine and Freshwater Ecosystems. 1999;9: 391–400.

28. Consoli P, Andaloro F, Altobelli C, Battaglia P, Campagnuolo S, Canese S, et al. Marine litter in an EBSA (Ecologically or Biologically Significant Area) of the central Mediterranean Sea: Abundance, composition, impact on benthic species and basis for monitoring entanglement. Environmental Pollution. 2018;236: 405–415.

29. Neves D, Sobral P, Ferreira JL, Pereira T. Ingestion of microplastics by commercial fish off the Portuguese coast. Marine Pollution Bulletin. 2015;101: 119–126.

30. Colletti A, Savinelli B, Di Muzio G, Rizzo L, Tamburello L, Fraschetti S, et al. The date mussel *Lithophaga lithophaga*: Biology, ecology and the multiple impacts of its illegal fishery. Science of The Total Environment. 2020; 140866.

31. Kremer BP, Munda IM. Ecophysiological studies of the Adriatic seaweed, *Fucus virsoides*. Marine Ecology. 1982;3: 75–93.

32. Zunino S, Canu DM, Zupo V, Solidoro C. Direct and indirect impacts of marine acidification on the ecosystem services provided by coralligenous reefs and seagrass systems. Global Ecology and Conservation. 2019;18: e00625.

33. Bandelj V, Solidoro C, Laurent C, Querin S, Kaleb S, Gianni F, et al. Cross-scale connectivity of macrobenthic communities in a patchy network of habitats: The Mesophotic Biogenic Habitats of the Northern Adriatic Sea. Estuarine, Coastal and Shelf Science. 2020; 106978.

34. Falace A, Kaleb S, Curiel D, Miotti C, Galli G, Querin S, et al. Calcareous Bio-Concretions in the Northern Adriatic Sea: Habitat Types, Environmental Factors that Influence Habitat Distributions, and Predictive Modeling. Plos One. 2015;10: e0140931. doi:10.1371/journal.pone.0140931

35. Ponti M, Fava F, Abbiati M. Spatial–temporal variability of epibenthic assemblages on subtidal biogenic reefs in the northern Adriatic Sea. Marine Biology 2011;158: 1447–1459. doi:10.1007/s00227-011-1661-3

36. Matiddi M, Hochsheid S, Camedda A, Baini M, Cocumelli C, Serena F, et al. Loggerhead sea turtles (*Caretta caretta*): A target species for monitoring litter ingested by marine organisms in the Mediterranean Sea. Environmental Pollution. 2017;230: 199–209.

37. Galgani F, Hanke G, Werner S, De Vrees L. Marine litter within the European marine strategy framework directive. ICES Journal of Marine Science. 2013;70: 1055–1064.

38. Lusseau D. Male and female bottlenose dolphins *Tursiops* spp. have different strategies to avoid interactions with tour boats in Doubtful Sound, New Zealand. Marine Ecology Progress Series. 2003;257: 267–274.

39. Grosholz E. Ecological and evolutionary consequences of coastal invasions. Trends in Ecology & Evolution. 2002;17: 22–27.

40. Asnaghi V, Mariachiara Chiantore, Luisa Mangialajo, Frédéric Gazeau, Patrice Francour, Samir Alliouane, et al. Cascading effects of ocean acidification in a rocky subtidal community. PLoS ONE. in press.

41. Pörtner HO, Langenbuch M, Michaelidis B. Synergistic effects of temperature extremes, hypoxia, and increases in CO2 on marine animals: From Earth history to global change. Journal of Geophysical Research: Oceans. 2005;110.

42. Gattuso J-P, Hansson L. Ocean acidification: background and history. Ocean Acidification. 2011; 1–20.

43. Zunino S, Canu DM, Bandelj V, Solidoro C. Effects of ocean acidification on benthic organisms in the Mediterranean Sea under realistic climatic scenarios: A meta-analysis. Regional Studies in Marine Science. 2017;10: 86–96. doi:10.1016/j.rsma.2016.12.011

44. Pörtner H-O, Karl DM, Boyd PW, Cheung W, Lluch-Cota SE, Nojiri Y, et al. Ocean systems. Climate change 2014: impacts, adaptation, and vulnerability Part A: global and sectoral aspects contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press; 2014. pp. 411–484.

45. Mazaris AD, Kallimanis AS, Sgardelis SP, Pantis JD. Do long-term changes in sea surface temperature at the breeding areas affect the breeding dates and reproduction performance of Mediterranean loggerhead turtles? Implications for climate change. Journal of Experimental Marine Biology and Ecology. 2008;367: 219–226.

46. Frederiksen M, Harris MP, Daunt F, Rothery P, Wanless S. Scale-dependent climate signals drive breeding phenology of three seabird species. Global Change Biology. 2004;10: 1214–1221.

47. Lundquist CJ, Granek EF. Strategies for successful marine conservation: integrating socioeconomic, political, and scientific factors. Conservation Biology. 2005;19: 1771–1778.

48. Ente Regionale Parcoi Delta del Po Veneto. Piano di Gestione ZPS IT3270023–Delta del Po. 2010 p. 470.

49. Zuazo VHD, Pleguezuelo CRR. Soil-erosion and runoff prevention by plant covers: a review. Sustainable Agriculture. 2009; 785–811.

50. Simeoni U, Corbau C. A review of the Delta Po evolution (Italy) related to climatic changes and human impacts. Geomorphology. 2009;107: 64–71.

51. Maicu F, Bellafiore D, Ferrarin C, Lorenzetti G, Manfe G, Pecora S, et al. Salt wedge intrusion in the Po River delta in the climate changes perspective. Geophysical Research Abstracts. 2019.

52. Ormerod SJ, Dobson M, Hildrew AG, Townsend C. Multiple stressors in freshwater ecosystems. Wiley Online Library; 2010.

53. Meadows D, Coll H. Status Review Report of five foreign sturgeon. Report to the National Marine Fisheries Service, Office of Protected Resources. 2013; 78.

54. Caramori GG, Barbieri C, Galli A, Lombardi C, Marconato E, Arlati G, et al. Il recupero dello storione cobice in Italia – Action Plan Progetto Life 04NAT/IT/000126. 2007.

55. Arlati G, Poliakova L. Restoration of Adriatic sturgeon (*Acipenser naccarii*) in Italy: situation and perspectives. Biology, Conservation and Sustainable Development of Sturgeons. Springer; 2009. pp. 237–245.

56. Lee A, Cho S, Kang DK, Kim S. Analysis of the effect of climate change on the Nakdong river stream flow using indicators of hydrological alteration. Journal of Hydro-environment Research. 2014;8: 234–247.