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

D4.3.2 Report on the application of the models linking oceanographic processes and management questions

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

4.3 – Integration of ecological observing system with Natura 2000 ecological processes

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

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CONTENT

1 INTRODUCTION

1.1 Activity 4.3 and deliverable 4.3.2

This deliverable is the result of the Activity 4.3 - “Integration of ecological observing system with Natura 2000 ecological processes” 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 variable, ES, performance indicators and management questions relevant for ecological processes. 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 ecological processes 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, ecological processes, 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], 4.3.1[7]) and summarized in D3.3.1. Only ecological processes will be considered in this deliverable, while target species will be the subject of the deliverable 4.2.2. Links and relationships among the different

[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] D4.3.1 Review of the knowledge of the ecological processes at the selected Natura 2000 sites.

elements will be analysed and discussed, highlighting possible pressures, risks, and information gaps that 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 an ecological process 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, etc.

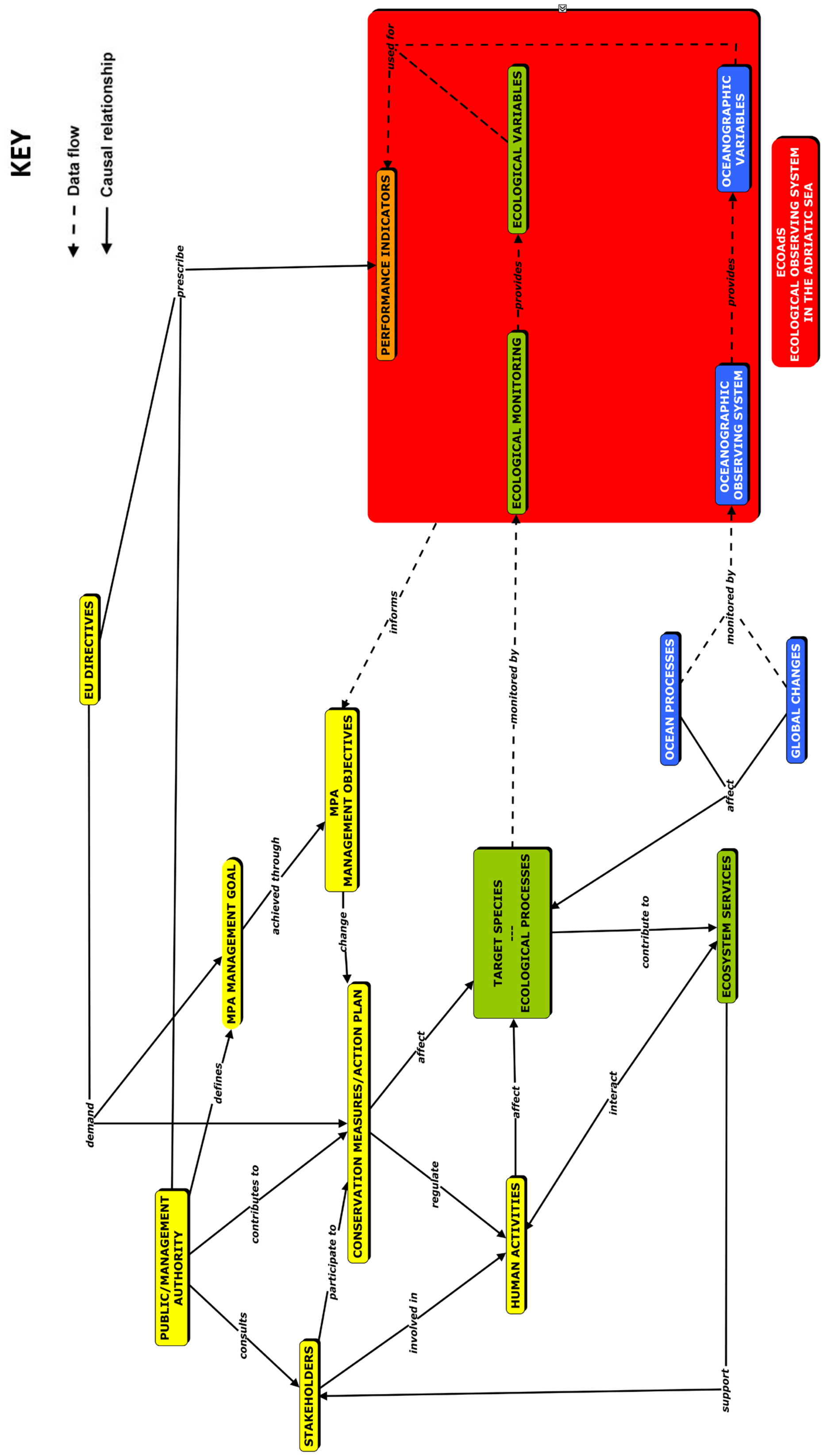

Figure 1. Generic conceptual model linking ECOAdS with N2K site management and EU Directives.

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, 4.3.1). 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 ecological processes. In detail, the boxes of the generic conceptual model were filled with ecological processes, 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 ecological process 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 ecological processes 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 persistence of ecological processes, 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 ecological process per case study (Fig. 3, 5, 7, 9). This operative model is read from right to left: the ecological process is represented by a green box. To its left, in yellow rectangles, the threats 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 ecological process, is represented by the sequence of arrows, oriented from right to left.

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

Ecological processes identified in D3.3.1 in Cres – Lošinj and Viški akvatorij N2K sites are 'movements of organisms', 'interactions between organisms' and 'climate processes'. These processes are particularly related to the ecology of the common bottlenose dolphin (*Tursiops truncatus*): the sole target species listed in the Standard Data Forms of both sites.

Even if a management authority has been already designated in both N2K sites (Public institution 'Sea and Karst for Viški akvatorij and Public institution 'Priroda' for Cres – Lošinj) and Blue World Institute (BWI) carries out periodically monitoring activities, there is still nor a management plan neither conservation measures in place to effectively protect the sites. 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, the ecological processes 'interactions between organisms' and 'movements of organisms' in these sites can be potentially affected by sailing, 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 movements and interactions of dolphins by causing entanglement of individuals inside predator nets around the fish farm cages [1], a change in habitat use since dolphins become attracted to these areas [2,3], habitat destruction under the cages [4] and water eutrophication in case of fish farms [5]. Effects of climate change may induce alteration of the climate-related processes, modifying trends in sea level and temperature, ph, dissolved oxygen [6–8], cause spread of disease [9] and affect food web integrity [10]. Conservation measures that could effectively reduce such threats should be primarily focused on regulating all human activities (e.g. marine traffic, interaction with fisheries), to manage the derived pressures (e.g., removing marine litter and reducing water pollution), raising awareness, and increasing enforcement (Fig. 2, Tab. 2). Fishing buffer zones around the protected areas could be established to reduce the impact of fishing, while the access to the sites can be limited to a certain number of tourists per day and awareness campaigns on marine litter could be organized. In addition, the expansion of N2K site size and protected area network in the Adriatic Sea beyond Cres-Lošinj and Viški akvatorij, would allow protection of multiple habitats, include the whole home range of the target species, and preserve movement and interactions of individuals on a large spatial scale (Fig. 2, Tab. 2).

The BWI has been performing monitoring on *T. truncatus* since 1987 in Cres – Lošinj (deliverable 4.1.1). The fieldwork is mostly concentrated within the Cres-Lošinj site with significant parts of surrounding areas also covered, albeit with less intensity. 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 (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, the 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).

As regards 'movements of organisms' and 'interactions between organisms', other ecological variables that should be collected to assess the degree of dispersion and genetic exchanges between populations include genetic information of individuals, the number of immigrates and emigrates, movement pathways, and distance and timing of movements (Fig. 2, Tab. 2).

The ecological process 'interactions between organisms' comprises different species relationships: predation, herbivory, competition, parasitism, mutualisms, facilitation; they not only determine the spatial distribution and demographic structure within populations but also ease other ecological processes such as pollination, seed dispersal and nutrient cycling [11]. Preservation of these connections would allow maintaining the food web integrity and the ecosystem services provided by the marine environment to these sites (D3.4.1). Performance indicators that can be measured to assess this ecological process may be energy transfer efficiency, ecological network analysis indices, variation of population demography and distribution and variation in home range patterns (Fig. 2, Tab. 2). Estimating the energy transfer efficiency may be important since it may help highlighting energy flow alteration in trophic levels resulting from variation in biomass or abundance of different species in more than one trophic level [12]. In addition, multiple ecological network analysis indices (e.g. structural information, average path length, ascendency) may be used to assess the flows and input-output relationships between the various nodes of the food web [13]. To estimate the trophic exchanges, an estimate of the biomass of each component; information on the diets of all feeding species; rates of export from the system; estimates of consumption, respiration, excretion; and the intensities of flows between compartments and their external surroundings are needed as ecological variables [14] (Fig. 2, Tab. 2).

To monitor possible modifications of climate processes in both N2K site, we suggest continuing monitoring periodically temperature, pH, dissolved oxygen at different depths and locations to have data on multiple years and analyse their trends. Important ecological variables that can indicate an impact of extreme events may include the number of offspring of dolphins, population size, sex, age and the survival rate of offsprings, together with the abundance and distribution of prey and dolphins, fishery catches, type of fishing effort, 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 [15]; while alteration of distribution and behaviour of their prey species due to intense storm events, induces a change in dolphin foraging [16]. These impacts, in turn, will influence ecological processes like the movement of organisms and their interaction.

The simplified version of the application model for the ecological process ‘interaction between organisms’ showed in fig. 3, represents an example of an operative model to assess the performance of the management and the status of the ecological processes in these two N2K sites. Water pollution, invasive species, collisions with boats, noise pollution, bycatch, and marine litter are some of the most important threats to the different species in the two N2K sites, and in particular for *T. truncatus*. These threats are linked to specific conservation measures that the management body should put in place, such as removing invasive species that might negatively affect the original ecological balance, installing signalling buoys to alert sailors of the presence of a protected area, establishing no-fishing buffer zones surrounding the sites, increasing enforcement and monitoring. The achievement of the management objective (‘preserve organism interaction and food web integrity’), identified for the ecological process here considered as an example, can be tested by several performance indicators, already described in the previous paragraph. 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 home range patterns can be monitored by collecting data on sex, abundance, distribution of individuals, occurrence rate, home range size and use of habitat (Fig. 3, Tab. 2).

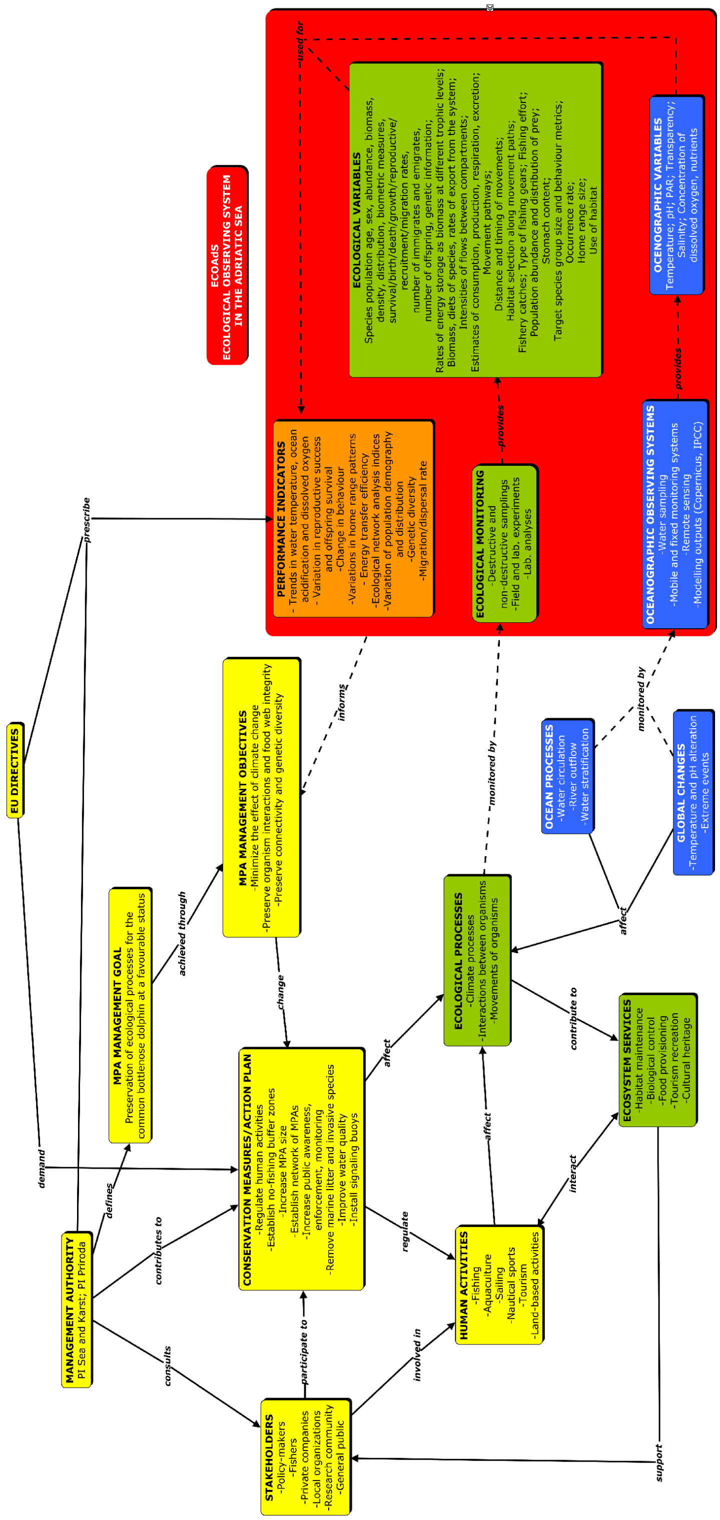

Figure 2. Application model for Cres-Lošinj and Viški akvatorij N2SK sites.

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

Management objectives	Human activities/ threats in the N2K sites	Ecological processes	Conservation measures	Performance indicators	Descriptive indicators
Minimize the effect of climate change	Climate change	Climate processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, enforcement, reduce other stressors	Trends in water temperature	Monthly temperature at different depths and locations
				Trends in ocean acidification	Monthly pH at different depths and locations
				Trends in dissolved oxygen	Monthly dissolved oxygen at different depths and locations
				Variation in reproductive success and offspring survival	Number of offspring, population size, sex, age, survival rate
					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
Preserve organism interactions and food web integrity	Climate change, fishing, disease, poor water quality, invasive species, noise pollution, sailing, aquaculture, marine litter, urbanization	Interactions between organisms	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, improve water quality, install signalling buoys, remove marine litter	Energy Transfer efficiency	Rates of energy storage as biomass at different trophic levels
				Ecological network analysis indices	Biomass, diets of species, rates of export from the system, intensities of flows between compartments, estimates of consumption,

					production, respiration, excretion
				Variation of population demography and distribution	Population age, sex, abundance, density, distribution, dispersal, biometric measures, survival/ birth/death/ growth/ reproductive/ recruitment/ migration rates
				Variations in home range patterns	Sex, abundance and distribution of individuals, occurrence rate, home range size, use of habitat
				For all the performance indicators	Dissolved oxygen, Temperature, Nutrient concentration, PAR, Transparency, Salinity, pH
Preserve connectivity and genetic diversity	Climate change, fishing, poor water quality, disease, noise pollution, sailing, aquaculture, marine litter, urbanization	Movements of organisms	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size,	Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

			increase monitoring, enforcement, awareness, install signalling buoys, remove marine litter		
				Migration/ dispersal rate	Number of immigrates and emigrates, population size
				Variations in home range patterns	Movement pathways, distance and timing of movements, sizes of home range, habitat selection along movement paths

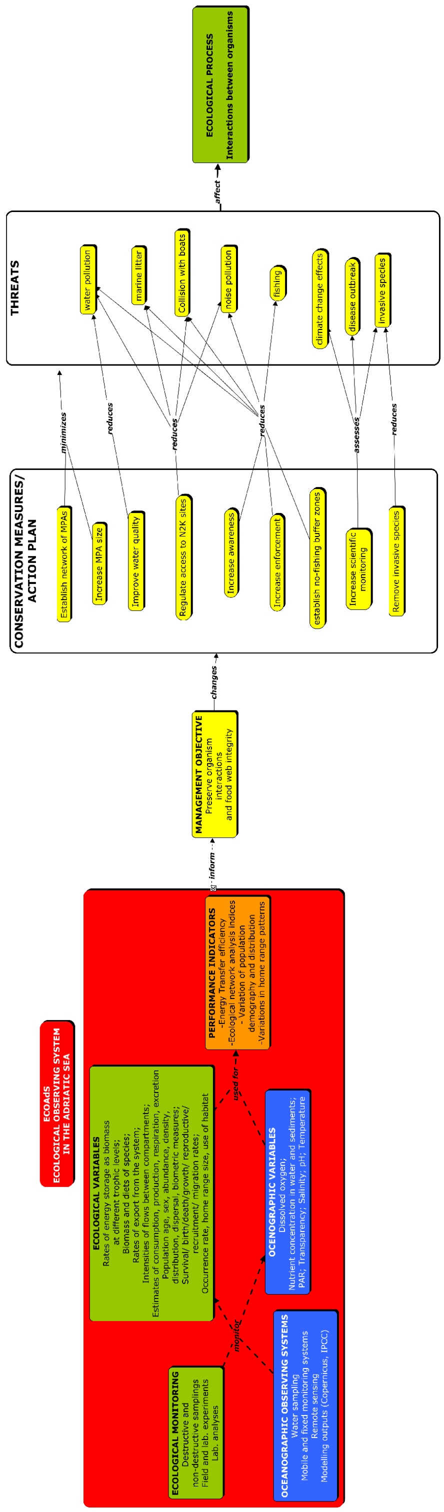

Figure 3. Operative version of the application model for 'Cres-Lošinj' and 'Viški akvatorij' N2K sites.

3.2 Malostonski zaljev (HR4000015)

The Malostonski zaljev N2K site is an area under the significant influence of freshwaters and seawater currents. The ecological conditions in the bay are greatly influenced by the surface and groundwater run-offs from the mainland, and by the sea currents. The influence of the Neretva River is occasionally more pronounced in the outer and middle part of Mali Ston Bay, while strong underwater freshwater springs have a more significant impact in the inner part of the bay. Owing to the nutrient concentration and the amount of phytoplankton, Mali Ston Bay is also a naturally moderate eutrophic ecosystem. Thus, 'hydrological processes' and 'space/time variability in primary productivity' are two of the most significant ecological processes on this site. Since one of the target species identified in D3.3.1 in Malostonski is the coralligenous community, other important ecological processes related to the different species that compose this community are: 'formation of biophysical habitats', 'movements of organisms' and 'interactions between organisms'. Finally, Mali Ston Bay bay, as the other N2K sites selected as case studies in the ECOSS project, is subjected to different climate processes linked to the global effects of climate change (Fig. 4, Tab. 3).

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. 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). The ecosystem in N2K site Malostonski zaljev is particularly under the crucial influence of the mainland, so the surrounding mainland must be also monitored and controlled to reduce water pollution and physical destruction of habitats due to urbanization.

Ecological processes like 'movements of organisms', 'interactions between organisms' and 'formation of biophysical habitats' are subjected to multiple pressures in Mali Ston Bay. Some human activities such as anchoring, scuba diving or destructive fishing practices may cause a physical disturbance to benthic target species and reduce their larval production, density, dispersal ability and interaction occurrence, as well as their contribution to the formation of biogenic reef habitats [17–19]. Similarly, the accumulation of litter on the seafloor may reduce light to macrophytes, cause damages to benthic organisms and cover suitable substrates for species recruitment [20,21], while microplastics may be ingested by *Alosa fallax* [22]. Poaching of *Lithophaga lithophaga* has been also reported by PIDNIC. The illegal harvesting is carried by breaking the carbonate rocks where the bivalve grows. This activity causes long-lasting damages, 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 [23,24]. Water pollution, eutrophication and high sedimentation rates caused by urbanization, river runoff and boat traffic are other stressors that favour stress-tolerant or invasive species, replacing benthic habitat-forming species, like seagrasses, macroalgae and invertebrates [25]. The Mali Ston Bay is also known for traditional and extensive oyster farming. This activity may reduce the light reaching the sea bottom, cover the seafloor with shells, increase the benthic organic loading and consequently altering benthic functional diversity and ecosystem functionality [4,26,27]. The ecological process 'movements of organisms' may be also obstructed by physical barriers. This is, for instance, the case of *A. fallax*, an anadromous target species for Malostonski N2K site that migrates to freshwaters to breed. Finally, large-scale threats such as climate change and alteration of hydrological conditions represent additional stressors to these ecological processes characterizing this site (Fig. 4, Tab. 3).

To monitor if the 'movements of organisms' are preserved in the protected area, the management body may collect data on genetic information, connectivity metrics, water circulation direction and velocity, larval dispersal, reproductive timing, settlement and recruitment rate, movement pathways, number and type of barriers to migration, diversity indices, community structure, number of species per functional group and phenology related measures that can indicate if any species phenological traits, such as time of reproduction, have been modified by some stressing conditions [28] (Fig. 4, Tab. 3). Similarly, to monitor 'interactions of organisms', the ecological variables that could be collected include rates of energy storage as biomass at different trophic levels, the diet of species, rates of export from the system, intensities of flows between compartments, estimates of consumption, production, respiration and excretion, data on population and community structure (species composition, cover, density, biomass, age, sex, size, distribution, etc.), besides physicochemical variables that are already collected by the monitoring agency.

Different species contribute to the 'formation of biophysical habitats' in the Mali Ston Bay. In particular, coralligenous reefs are the result of a continuous process of bioconstruction, by species deposing calcium carbonate (e.g. encrusting algae, bryozoans, molluscs), and bioerosion, mainly performed by endolithic sponges degrading the biogenic matrix [29]. This is maybe one of the most important ecological processes since several studies demonstrated the ecological role of the coralligenous habitat in sustaining local biodiversity and ecosystem productivity [29–31]. The performance indicators we suggest to measure for monitoring this ecological process are: bioerosion and bioconstruction rates, shift in the structural complexity, and coralligenous bioconstructions quality index [32] (Fig. 4, Tab. 3). These indicators are obtained by collecting data on species composition, volume of calcium carbonate eroded/produced in a year, number of species, cover of morphofunctional groups, diversity indices, coralligenous cover, percentage of frames presenting lost fishing gears or signs of impact (Fig. 4, Tab. 3).

Alteration of physical parameters and climate processes due to climate change has negative effects on most of the benthic species, in particular for cold-water species, such as *F. virsoides* [33], or those involved in calcification processes (i.e. coralligenous species, *Pinna nobilis*) [34]. Descriptive indicators we suggest to monitor include all those variables that indicate variation in population structure and dynamics (cover, abundance, size, age, migration, birth, death, reproductive rates, etc.), phenology-related measures, number/cover of affected organisms, signs of damages on organisms (e.g. necrotic tissues), as well as monthly temperature, pH and dissolved oxygen at different depths and locations (Fig. 4, Tab. 3).

Hydrological processes and space/time variability in primary productivity, as already mentioned, are two ecological processes strictly linked to the characteristics of the bay. Alteration in hydrological patterns may be mainly due to the installation of barriers in the rivers, the presence of aquaculture cages, engineering works on the seafloor/river bed or the coast. These may cause the increase of sedimentation or alter current velocity/direction in some areas, potentially burying or dislocating some individuals. Ecological variables that can be monitored include sedimentation rate, transparency, nutrient concentration, current velocity and direction, benthic species composition and distribution and metrics related to the variation of water flow (e.g. mean, magnitude, duration of flow, timing of extreme flows, frequency and rates). Primary productivity also depends on the hydrological processes. In fact, nutrient inputs from rivers and local discharges modify local patterns of primary productivity, influencing phytoplankton, benthic macrophytes and seaweeds [35]. In return, also abundance of their consumers (i.e. zooplankton, benthic herbivores and the farmed *Ostrea edulis*) are modified [36]. Variation in net primary production can be monitored by measuring gross primary production and respiration rates, dry weight of algae, frequency, duration, spatial extent, biomass, species composition and abundance of phytoplankton, cover and composition of macrophytes, relative abundance of dominant macroalgae, composition, abundance and species richness of macrozoobenthos, cover of seagrasses and shoot density (Fig. 4, Tab. 3).

Conservation measures that the management body should put in place to guarantee such ecological processes should address the regulation of human activities (fishing, aquaculture, scuba diving, organism collection, sailing, urbanization) inside the borders of the protected area, the increase of monitoring and enforcement, the improvement of water quality and circulation, the eradication of any invasive species that might threaten native species, the installation of mooring/signalling buoys, and the restoration of target species if necessary (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).

The simplified version of the application model for Malostonski zaljev N2K site (Fig. 5), shows an example of an operative model based on the ecological process 'space/time variability in primary productivity'. The most important threats for this ecological process in the area are water eutrophication that alters productivity patterns, anchoring that may eradicate seagrass reducing meadow density, the spread of invasive species and pathogens that may reduce native species population, and climate change effects that alter physicochemical parameters linked to primary production. These threats can be addressed by defining appropriate conservation measures such as improving water quality, removing invasive species, installing mooring buoys/regulating access to the N2K site, raising awareness, enforcement, and monitoring. The achievement of the management objective ('Preserve primary productivity of the shallow inlets and bays and the reef habitats') linked to these conservation measures and threats can be assessed by measuring the variation in primary production over time, based on the ecological variables described above for this ecological process (Fig. 5, Tab. 3).

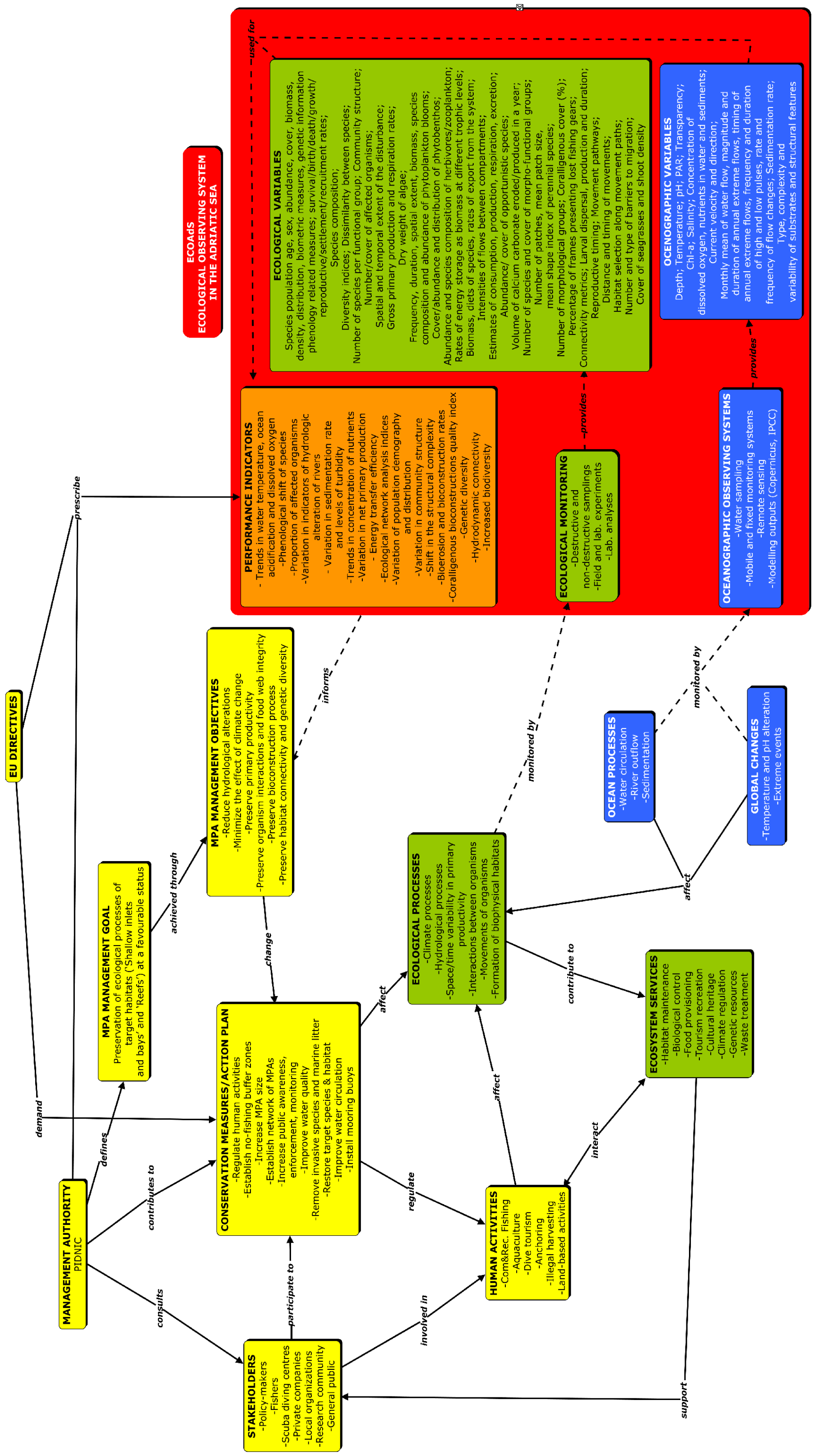

Figure 4. Application model for 'Malostonski zaljev' N2K site.

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

Management objectives	Human activities/ threats in the N2K sites	Ecological processes	Conservation measures	Performance indicators	Descriptive indicators
Minimize the effect of climate change	Climate change	Climate processes	Regulate human activities, establish network of MPAs, increase N2K site size, increase public awareness, monitoring, enforcement, reduce other stressors, restore target species & habitat	Trends in water temperature	Monthly temperature at different depths and locations
				Trends in ocean acidification	Monthly pH at different depths and locations
				Trends in dissolved oxygen	Monthly dissolved oxygen at different depths and locations
				Phenological shift of species	Phenology related measures
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/

					settlement/ recruitment/ migration rates
				Proportion of affected organisms	Population cover/ size, number/ cover of affected organisms, signs of damages
Reduce hydrological alterations	Climate change, alteration in hydrological patterns and physical barriers to water circulation in rivers, sedimentation,urbanization, invasive species	Hydrological processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, remove invasive species, improve water quality, restore target species & habitat, improve water circulation	Variation in indicators of hydrologic alteration of rivers	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
				Variation in sedimentation rate and levels of turbidity	Sedimentation rate, transparency, spatial and temporal extent of the disturbance
				Trends in concentration of nutrients	DIC, NO2, NO3, PO4 concentration in water
				For all the performance indicators	Temperature, salinity, dissolved oxygen, benthic species composition and

					distribution, current velocity and direction
Preserve primary productivity	Climate change, poor water quality, alteration in hydrological patterns, invasive species, sedimentation, disease, urbanization, aquaculture	Space/time variability in primary productivity	Regulate human activities, establish network of MPAs, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, improve water quality, restore target species & habitat, improve water circulation	Variation in net primary production	Gross primary production and respiration rates, dry weight of algae, frequency, duration, spatial extent, biomass, species composition and abundance of phytoplankton blooms, cover/abundance and distribution of phytobenthos, abundance and species composition of herbivores/zooplankton, Cover of seagrasses and shoot density
					Dissolved oxygen, chlorophyll-a, nutrient concentration in water, PAR, transparency, salinity, pH, temperature
Preserve interactions and food web integrity	Climate change, fishing, poor water quality, alteration in hydrological patterns,	Interactions between organisms	Regulate human activities, establish no-fishing buffer zones, establish network of N2K	Energy Transfer efficiency	Rates of energy storage as biomass at different trophic levels

	invasive species, disease, dive tourism, aquaculture, urbanization		sites, increase N2K site size, increase monitoring, enforcement, awareness, remove invasive species, restore target species & habitat, improve water circulation and quality		
				Ecological network analysis indices	Biomass, diets of species, rates of export from the system, intensities of flows between compartments, estimates of consumption, production, respiration, excretion
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates
				Variation in community	Species composition,

				structure	cover, density, biomass, distribution/dispersion, diversity indices, number of taxa per functional group, abundance/ cover of opportunistic species
				For all the performance indicators	Dissolved oxygen, Temperature, Nutrient concentration, PAR, Transparency, Salinity, pH
Preserve bioconstruction process	Climate change, fishing, poor water quality, disease, invasive species, marine litter, alteration in hydrological patterns, dive tourism, anchoring, aquaculture, illegal harvesting, sedimentation, urbanization	Formation of biophysical habitats	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase monitoring, enforcement, awareness, remove invasive species, improve water quality, restore target species & habitat, install mooring buoys	Bioerosion and bioconstruction rates	species composition, volume of calcium carbonate eroded/produced in a year
				Shift in the structural complexity	Number of species and cover of morpho-functional groups,

					diversity indices, species composition, landscape metric indices
				Coralligenous Bioconstructions Quality Index	Number of morphological groups, coralligenous cover (%), percentage of frames presenting lost fishing gears
				For all the performance indicators	Salinity, temperature, transparency, dissolved oxygen, pH, PAR, nutrient/pollutant s concentration, current velocity and direction, magnitude, seasonality, rate of river flow, sedimentation rate, type, complexity and variability of substrates and structural features, depth, slope, spatial distribution and cover/abundance of species
Preserve habitat connectivity and genetic	Climate change, fishing, poor water quality, alteration in	Movements of organisms	Regulate human activities, establish no-fishing buffer	Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

diversity	hydrological patterns, invasive species, disease, dive tourism, aquaculture, urbanization		zones, establish network of N2K sites, increase N2K site size, increase monitoring, enforcement, awareness, remove invasive species, restore target species & habitat, improve water circulation and quality		
				Phenological shift	Phenology related measures
				Hydrodynamic connectivity	Connectivity metrics, water circulation direction and velocity, larval dispersal, reproductive timing, settlement and recruitment rate, type of substrate, reef geomorphology and orientation
					Movement pathways, distance and timing of movements, shapes, habitat selection along movement paths, number and type of barriers to migration in rivers

				Increased biodiversity	Diversity indices, dissimilarity between species, number of species per functional group, community structure

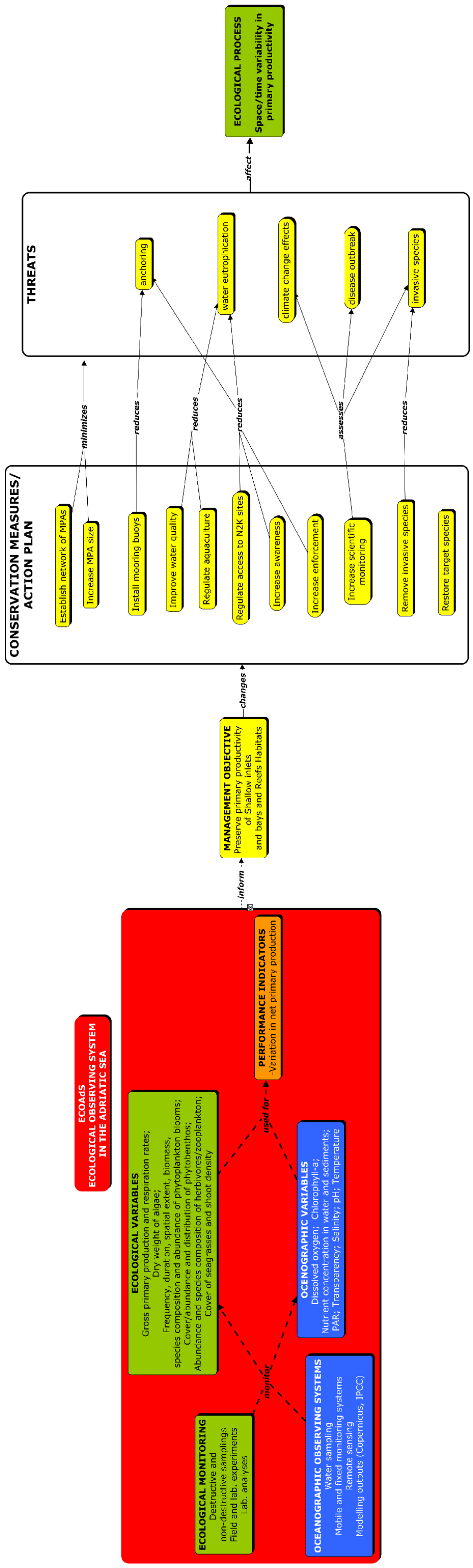

Figure 5. Operative version of the application model for ‘Malostonski zaljev’ N2K site.

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, deeply shaped by coralligenous-like species [37,38] (see D3.3.1 for more details). They also share the same ecological/oceanographic processes and are potentially subject to the same impacts, even if some are more than 40 nm distant from each other[37]. The ecological processes identified in these sites include 'climate processes', 'movements of organisms', 'interactions of organisms', 'formation of biophysical habitats', 'hydrological processes' and 'space/time variability in primary production'.

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. chlf-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 the 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 [37,39,40]. 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 the ecological processes of the mesophotic biogenic reefs are similar to those already seen for Malostonski zaljev N2K site. In addition, in these sites, marine litter and boat traffic may represent further threats for some target species such as dolphins, sea turtles and seabirds [41–44]. Among the variables useful to quantify the potential direct impact of some human activities (e.g. poaching, scuba diving, commercial fishing, anchoring) on 'formation of biophysical habitat' (i.e. coralligenous) [17–19], we suggest monitoring species composition, volume of calcium carbonate eroded/produced in a year, the number of species and cover of morpho-functional groups, diversity indices, species composition, landscape pattern indices [45], number of morphological groups, coralligenous cover (%), percentage of frames presenting damages. These variables should be coupled to a long list of oceanographic variables that influence the survival and the ecological role of the coralligenous community such as salinity, temperature, pH, transparency, PAR, current velocity, nutrient/pollutant concentration, depth, sedimentation rate (Fig. 6, Tab. 4).

Movements and interactions of organisms on these reefs are also highly important since these processes influence species composition, dominance and habitat formation [46,47]. Bandelj et al. [39] found that species with different pelagic propagules duration follow greatly different dispersal dynamics and that the network of studied outcrops is only partially connected to coastal benthic populations. The authors also evidenced gaps in the existing network of protected biogenic reef habitats in the Northern Adriatic Sea. However, to have a more realistic view of the species dispersion ability and connectivity among biogenic reefs, collecting data on water circulation, geomorphology, reef position and distance is not sufficient. It is strictly important to get data on genetic, larval production, dispersal and duration in water, reproductive timing, settlement and recruitment rate. This would also allow studying the interaction dynamics between different species and the biological processes at small scales that favour the recruitment of species. Knowing the number of immigrates and emigrates and population size of highly motile species, such as sea turtles and dolphins, will also help understanding their movements in the entire Adriatic subregion and develop management plans extended to multiple N2K sites frequented by these species (Fig. 6, Tab. 4).

Mesophotic biogenic reefs sustain rich biodiversity, providing food and shelter to numerous organisms at different life stages [30,38]. Such a condition determines the provision of important ecosystem services: increase in fish stocks available to humans, recycle of nutrients, attractive scuba diving spots, cultural heritage and climate regulation. Thus, due to their high economic value, the management bodies of both sites should assess the status of the entire food web linked to these reefs by measuring different performance indicators as the energy transfer efficiency, the ecological network analysis indices, variation of population demography and distribution and variation of reef community structure. The same ecological variables cited for assessing the integrity of the food web sustained by the coralligenous habitat in Malostonski bay applies to these biogenic reefs (Fig. 6, Tab. 4).

Hydrological processes and space/time variability in primary productivity are also two ecological processes particularly important for these reefs. The link between these habitats with the Po River and other minor rivers in the region has been recognised in numerous studies [37,40,48–52]. Strong river runoff and the associated seasonal and interannual variability in temperature, salinity, nutrients and sediments, regulate the presence of species. Opportunistic species characterize reefs closest to the coast, which are affected by stronger currents, river inputs and sediment resuspension, while sensitive species forming coralligenous-like assemblages are located offshore [37,40] (Fig. 6, Tab. 4). Possible alteration in hydrological patterns may be mainly due to the installation of barriers in the rivers, or to engineering works that modify the river bed. These may cause an increase in sedimentation rate and/or alter current velocity/direction and change the dominant species on these reefs. Ecological variables that can be collected to monitor such a process include sedimentation rate, transparency, nutrient concentration, the distance of reefs from rivers, dissolved oxygen, current velocity and direction, benthic species composition and distribution and metrics related to the variation of water flow (e.g. mean, magnitude, duration of flow, the timing of extreme flows, frequency and rates). These ecological variables will help to detect variation in sedimentation rate and levels of turbidity, trends in the concentration of nutrients and variation in indicators of hydrologic alteration of rivers (Fig. 6, Tab. 4).

Primary productivity also depends on the hydrological processes. In fact, nutrient inputs from rivers and local discharges modify local patterns of primary productivity, influencing phytoplankton, benthic macrophytes and seaweeds. In return, also the abundance of their consumers (i.e. zooplankton and benthic herbivores) are modified [36]. Variation in net primary production can be monitored by measuring gross primary production and respiration rates, dry weight of algae, frequency, duration, spatial extent, biomass, species composition and abundance of phytoplankton, cover and composition of phytobenthos, abundance and species composition of herbivores/zooplankton (Fig. 6, Tab. 4).

Alteration of pH and seawater temperature are the main consequences of climate change that interfere with calcification processes [34,53]. In addition, both processes have synergistic effects on species [54]. Water acidification affects mainly organisms with calcium carbonate shells and skeletons by reducing calcification and the rates of repair, and by weakening calcified structures [55]. 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 [8,56]. Descriptive indicators we suggest to assess for monitoring variation in climate processes include monthly temperature, pH and dissolved oxygen at different depths and locations, species population cover, size, number/cover of affected organisms, signs of damages, as well as presence/quantity of mucilage, phenology-related measures, population structure and dynamics, number and survival of offspring, age, sex. Phenology-related measures and survival of offspring may be particularly informative, since the effects of climate change, as reported in literature [16,57,58], can alter individual behaviour, physiological traits and the possibility to survive extreme events, especially for the weaker age classes (Fig. 6, Tab. 4).

Conservation measures needed to address such threats may be prohibiting anchorage on the rocky outcrop and 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, removing invasive species and collecting marine litter, setting mooring buoys or signalling the sites on the nautical chart to easily identify them, regulating access of boats to reduce noise pollution and collision events with dolphins and sea turtles. In a perspective of an ecosystem-based management approach (see definition in Box 1 of D4.4.1), management bodies of these N2K sites should then consider collaborating with authorities of other parks on the mainland to improve water quality and hydrological processes of rivers that influence chemico-physical conditions of adjacent marine N2K sites (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 [39]. 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 [59] (Fig. 6, Tab. 4).

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 the ecological process ‘formation of biophysical habitats’ in both N2K sites. As already described above, installing mooring/signalling 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, removing/reducing marine litter or invasive species, are the most important measures to reduce the effect of multiple stressors on these vulnerable biogenic reefs and preserve the bioconstruction process. 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 bioerosion and bioconstruction rates, shift in the structural complexity and coralligenous bioconstructions quality index. Performance indicators are measured by collecting ecological and oceanographic variables through field sampling or by using numerical model outputs or remote sensing (Fig. 7, Tab. 4).

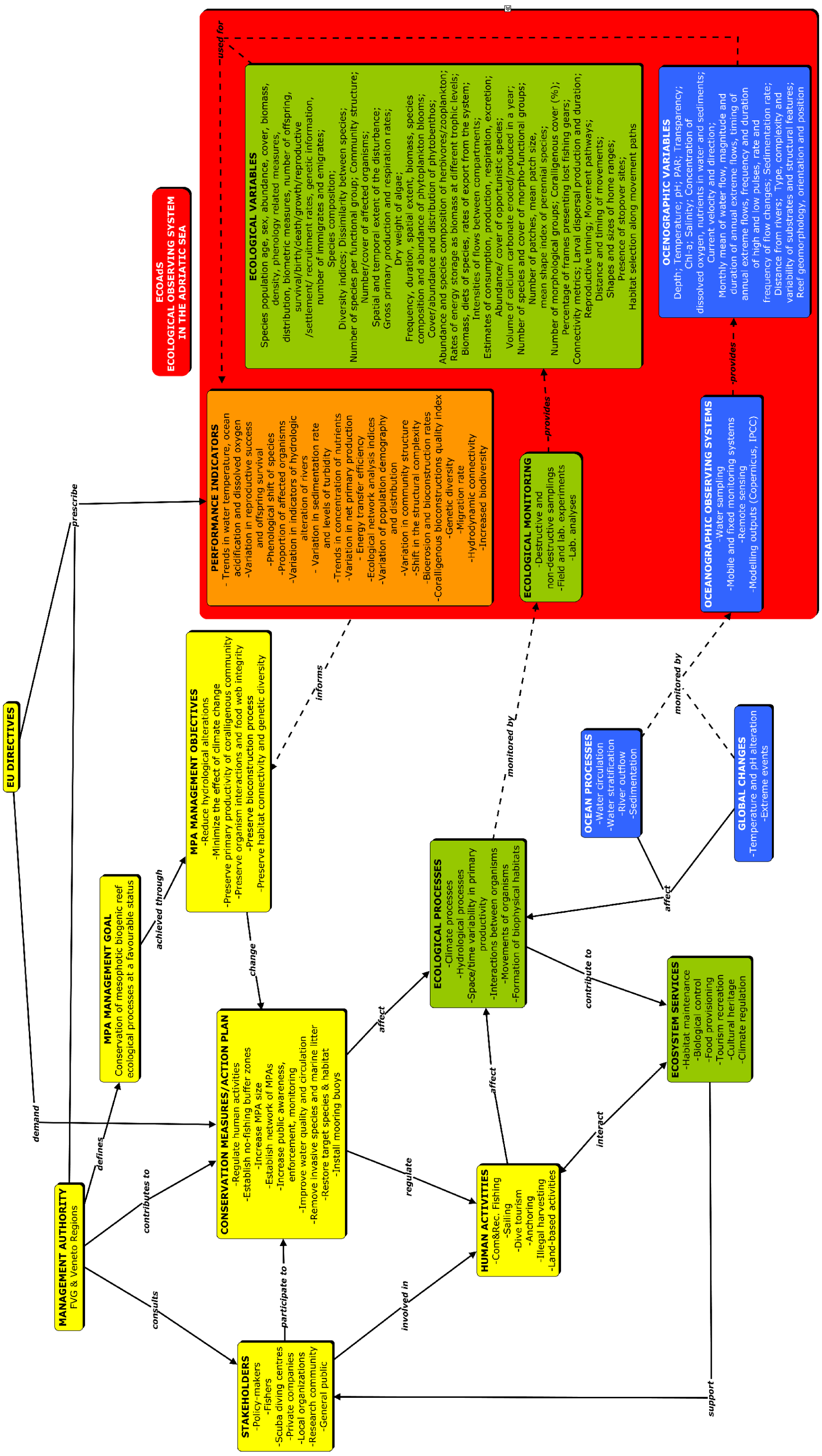

Figure 6. Application model for ‘Trezze San Pietro e Bardelli’ and ‘Tegnùe di Chioggia’ N2K sites.

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

Management objectives	Human activities/ threats in the N2K sites	Ecological processes	Conservation measures	Performance indicators	Descriptive indicators
Minimize the effect of climate change	Climate change	Climate processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, enforcement, reduce other stressors, restore target species & habitat	Trends in water temperature	Monthly temperature at different depths and locations
				Trends in ocean acidification	Monthly pH at different depths and locations
				Trends in dissolved oxygen	Monthly dissolved oxygen at different depths and locations
				Variation in reproductive success and offspring survival	Number of offspring, population size, sex, age, survival rate
				Phenological shift of species	Phenology related measures
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric

					measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates
				Proportion of affected organisms	Species population cover/ size, number/ cover of affected organisms, signs of damages
Reduce hydrological alterations	Climate change, alteration in hydrological patterns and physical barriers to water circulation in rivers, sedimentation, urbanization, invasive species	Hydrological processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, remove invasive species, improve water quality, restore target species & habitat, improve water circulation in rivers	Variation in indicators of hydrologic alteration of rivers	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
				Variation in sedimentation rate and levels of turbidity	Sedimentation rate, transparency, spatial and temporal extent of the disturbance
				Trends in concentration of nutrients	DIC, NO2, NO3, PO4 concentration in water, distance from rivers
				For all the performance indicators	Temperature, salinity, dissolved oxygen, benthic species

					composition and distribution, current velocity and direction
Preserve primary productivity of coralligenous community	Climate change, poor water quality, alteration in hydrological patterns, invasive species, sedimentation, disease, urbanization, sailing	Space/time variability in primary productivity	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 target species & habitat, improve water circulation in rivers	Variation in net primary production	Gross primary production and respiration rates, dry weight of algae, frequency, duration, spatial extent, biomass, species composition and abundance of phytoplankton blooms, cover/abundance and distribution of phytobenthos, abundance and species composition of herbivores/ zooplankton
					Dissolved oxygen, chlorophyll-a, nutrient concentration in water, PAR, transparency, salinity, pH, temperature
Preserve interactions and food web integrity	Climate change, fishing, disease, poor water quality, invasive species, noise pollution, dive tourism, marine litter,	Interactions between organisms	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase public awareness,	Energy Transfer efficiency	Rates of energy storage as biomass at different trophic levels

	urbanization, sailing		increase enforcement, monitoring, remove invasive species, improve water quality, remove marine litter, restore target species & habitat, install signalling/mooring buoys		
				Ecological network analysis indices	Biomass, diets of species, rates of export from the system, intensities of flows between compartments, estimates of consumption, production, respiration, excretion
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates
				Variation in community	Species composition, cover,

				structure	density, biomass, distribution/dispersion, diversity indices, number of taxa per functional group, abundance/ cover of opportunistic species
				For all the performance indicators	Dissolved oxygen, Temperature, Nutrient concentration, PAR, Transparency, Salinity, pH
Preserve bioconstruction process	Climate change, fishing, poor water quality, disease, invasive species, marine litter, alteration in hydrological patterns, dive tourism, anchoring, sedimentation, urbanization	Formation of biophysical habitats	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase monitoring, enforcement, awareness, remove invasive species, improve water quality, restore target species & habitat, install signalling/mooring buoys	Bioerosion and bioconstruction rates	species composition, volume of calcium carbonate eroded/produced in a year
				Shift in the structural complexity	Number of species and cover of morpho-functional groups, diversity indices, species composition, landscape metric indices

				Coralligenous Bioconstructions Quality Index	Number of morphological groups, coralligenous cover (%), percentage of frames presenting lost fishing gears
				For all the performance indicators	Salinity, temperature, transparency, dissolved oxygen, pH, PAR, nutrient/pollutants concentration, current velocity and direction, magnitude, seasonality, rate of river flow, sedimentation rate, type, complexity and variability of substrates and structural features, depth, slope, spatial distribution and cover/abundance of species
Preserve habitat connectivity and genetic diversity	Climate change, fishing, poor water quality, alteration in hydrological patterns, invasive species, disease, noise pollution due to	Movements of organisms	Regulate human activities, establish no-fishing buffer zones, establish network of N2K sites, increase N2K site size, increase monitoring, enforcement, awareness, remove	Genetic diversity	Genetic information (e.g. microsatellites, mtDNA)

	sailing, dive tourism, marine litter, urbanization		invasive species, remove marine litter, restore target species & habitat, install signalling/mooring buoys		
				Phenological shift	Phenology related measures
				Migration/ dispersal rate	Number of immigrates and emigrates, population size
				Hydrodynamic connectivity	Connectivity metrics, water circulation direction and velocity, larval dispersal production and duration, reproductive timing, settlement and recruitment rate, type of substrate, reef geomorphology, orientation and position
					Movement pathways, distance and timing of movements, shapes and sizes of home ranges, presence of stopover sites, habitat selection along movement paths

				Increased biodiversity	Diversity indices, dissimilarity between species, number of species per functional group, community structure

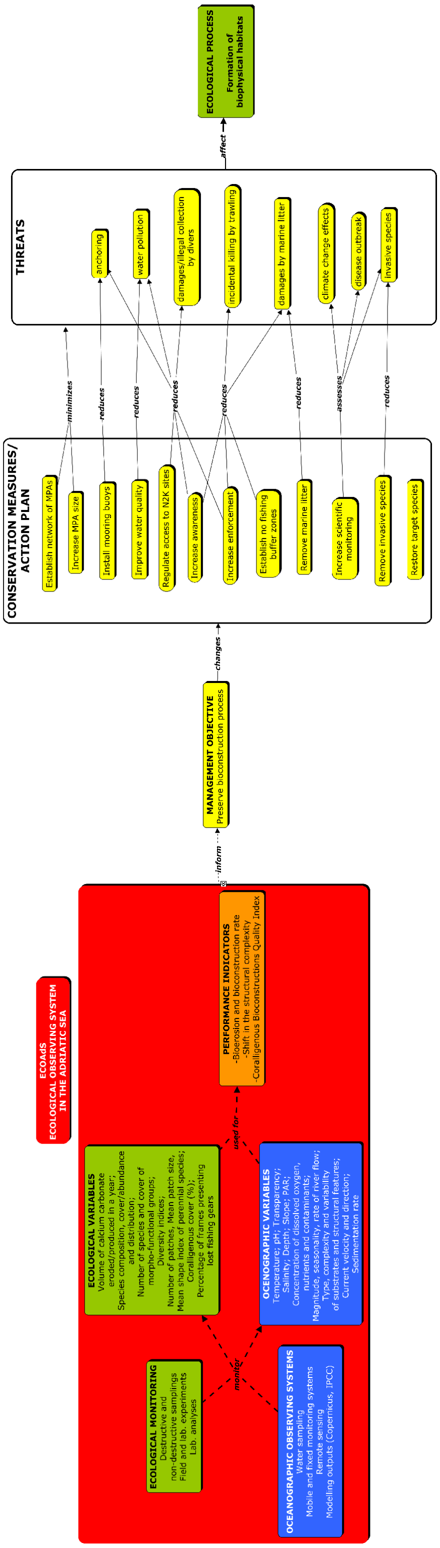

Figure 7. Operative version of the application model for ‘Trezze San Pietro e Bardelli’ and ‘Tegnùe di Chioggia’ N2K sites.

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 and ecological processes. The ecological processes were identified for these sites in deliverables 3.3.1 and 4.3.1 are ‘climate processes’, ‘hydrological processes’, ‘interactions between organisms’, ‘movements of organisms’, ‘formation of biophysical habitats’, ‘space/time variability in primary productivity’ and ‘natural disturbance regimes’.

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. 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, the management authority monitors species spatial distribution, richness, density, coverage, community structure (deliverable 3.2.1).

Being both N2K sites extended on a vast terrestrial area characterized by numerous villages, human uses and activities, pressures on habitats and the ecological processes are many and diffuse. Rivers, canals and banks are modified by dredging, regulation works, soil erosion and leaching, dyke and barrier constructions, rising of the salt wedge and water level changes; all inducing alteration of sedimentation rate, water circulation and space/time variation in primary production. Conservation measures in this context should be focused on increasing awareness of the possible impacts that such interventions may generate, minimizing engineering works, regulating water abstraction, 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 [60] (Fig. 8, Tab. 5).

Performance indicators that may help to assess alteration of hydrological processes include: variation in indicators of hydrological alteration of rivers, distance upstream of the salt wedge, variation of population demography and distribution, variation in sedimentation rate and levels of turbidity, trends in the concentration of nutrients. The ecological variables necessary to measure such performance indicators are many and a complete list can be found in table 5. In general, they comprise chemico-physical variables such as current velocity and direction, depth of channels, water flow metrics, seawater level, salinity, amount of water abstracted, sedimentation rate, nutrient concentration and more strictly ecological variables that give an indication of population demography (Fig. 8, Tab. 5). For assessing variation in primary production, we suggest collecting the same variables already cited for the other N2K case studies such as chlorophyll-a, nutrient concentration, PAR, transparency, temperature, gross primary production and respiration rates, abundance of phytoplankton, cover and composition of macrophytes.

Alteration of hydrological processes and regulation works in rivers also physically destruct habitats for species. In the Po Delta, the complex fluvial system is the main driver of habitat creation. Coastal dunes, wetlands, lagoons, fishing ponds, sandbars and river islands are all generated by continuous processes of erosion, flooding and supply of sediments and debris by the river flow [61]. These hydrological processes interact with the biotic components to further shape the estuarine habitats and create hygrophilous forests, reeds, swamps with floating vegetation, belts of psammophilous and halophilous vegetation where numerous species find refuge and appropriate sites for nesting [62,63]. Habitat formation and modification in the Po Delta is an unceasing process and several variables can be measured to monitor it: surface area and type of habitat, vegetation cover and composition, presence and abundance/cover of invasive and opportunistic vs native species, ecological variables to obtain direct information on the possible variation of community structure (i.e. species composition, biomass, distribution, diversity indices, the dissimilarity between species, etc.), and chemico-physical variables such as salinity, temperature, pH, transparency, PAR, nutrient concentration, type, complexity and variability of substrates and structural features (Fig. 8, Tab. 5).

Other consequences of water flow and land regulations made to fit the territory to human activities is the simplification of estuarine habitats and the natural disturbance regimes disruption. Natural disturbance regimes (i.e. the combination of frequency, duration, intensity and extent of disturbances such as fire, floods, drought, storm waves) are fundamental to alter periodically ecosystems by creating spaces for colonisation, re-setting to an earlier successional stage, releasing and redistributing resources, and altering mortality rates of species [11,64,65]. When such events are reduced, alteration of community structure and dynamics is expected, and natural events become less frequent but more severe, with often uncontrollable consequences (e.g. large scale fires and extreme floodings). Authorities should manage these N2K sites and the surrounding area with an ecosystem approach recognizing that each component of the river system (salt marshes, floodplains, groundwaters, etc.) are based on sustaining, rather than suppressing, environmental heterogeneity [65]. Possible performance indicators useful to assess the persistence of natural disturbance regimes include variation in mortality rate of species, variation in community structure and species diversity. These indicators can be measured for instance by collecting data on the number of deaths, population size, species composition, abundance, cover, density, biomass, presence of invasive/opportunistic species, plant biomass and longevity, dominant taxa, diversity indices (Fig. 8, Tab. 5).

Maintenance of the ecological process 'movements of organism' is particularly important in this complex river system. Numerous species of anadromous and catadromous fish use rivers to breed, grow and migrate from and to the seawater, for instance, the Adriatic sturgeon (*Acipenser naccarii*) and the twaite shad (*Alosa fallax*): two target species identified for these N2K sites (D3.3.1). Numerous colonies of different species of water birds also spend winter in this area or arrive at spring to breed. Threats to this species are not only the alteration of water circulation and habitat destruction but also barriers to migration such as dams and culverts or electric cables and disturbance by tourists at nesting and feeding sites. Possible performance indicators that help to quantify movements of organisms include genetic diversity, phenological shift of species, migration/dispersal rate, variation in species diversity and hydrodynamic connectivity (Fig. 8, Tab. 5).

The interactions between organisms and the associated food web can be preserved only if movements of organisms and hydrological processes are maintained. In the Po Delta, many colonial species interact, such as gulls and terns, due to similar habitat preferences, obtaining mutual advantages in terms of defence from predators and exchange of information for food acquisition. On the other hand, colonial birds may compete for resources, and colonies may attract predators [62]. Similarly, the Adriatic sturgeon population has been impacted by the presence of highly competitive alien fish introduced recently in the rivers for recreational fishing (e.g. *Silurus glanis*) [66]. Interactions between multiple organisms are also important since they determine the complexity of the food web and their strength is essential for understanding how ecological communities are organized and respond to human exploitation. The stability of ecological communities largely depends on the strength of interactions between predators and their prey. As for the other N2K case studies already presented in this report, to assess the status of this ecological process, it is necessary to monitor the exchange of energy, the rate of energy storage as biomass at different trophic levels, and use different ecological network analysis metrics, widely used in literature and food web modelling [13]. Indication of food web integrity and maintenance of interactions of organisms may also be detected by assessing variation of population demography and distribution, and variation in community structure.

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 [67,68]. It is strictly urgent to adopt measures, regulating water abstraction for different uses at the basin scale, creating phytodepuration basins, promoting the cultivation of more resistant plants to higher levels of salinity, and reducing works that alter hydrological conditions and water flow [69]. These threats are not expected to act alone, due to the simultaneous increase of air and water temperature with climate change [70] that also alter climate processes in this area. Among the possible variables that can be monitored, we suggest temperature, 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).

The simplified version of the application model was applied to the 'hydrological processes' (Fig. 9), one of the most important ecological processes in the Po Delta system. As already specified before, among the main threats related to these ecological processes we mention climate change effects, alteration of water flow due to several land and river modifications by human activities, soil erosion and flooding and the rising of the salt wedge due to improper use of water in the region and the reduction of precipitations in the last decade. These threats can be addressed by defining appropriate conservation measures such as raising awareness, enforcement, minimizing river engineering works, regulating water abstraction, removing invasive species that alter water circulation, restoring native habitats and preventing soil erosion. The achievement of the management objectives linked to these conservation measures can be assessed by some performance indicators already described in the previous paragraphs. 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 [71]) and recording their change over time (Fig. 9, Tab. 5).

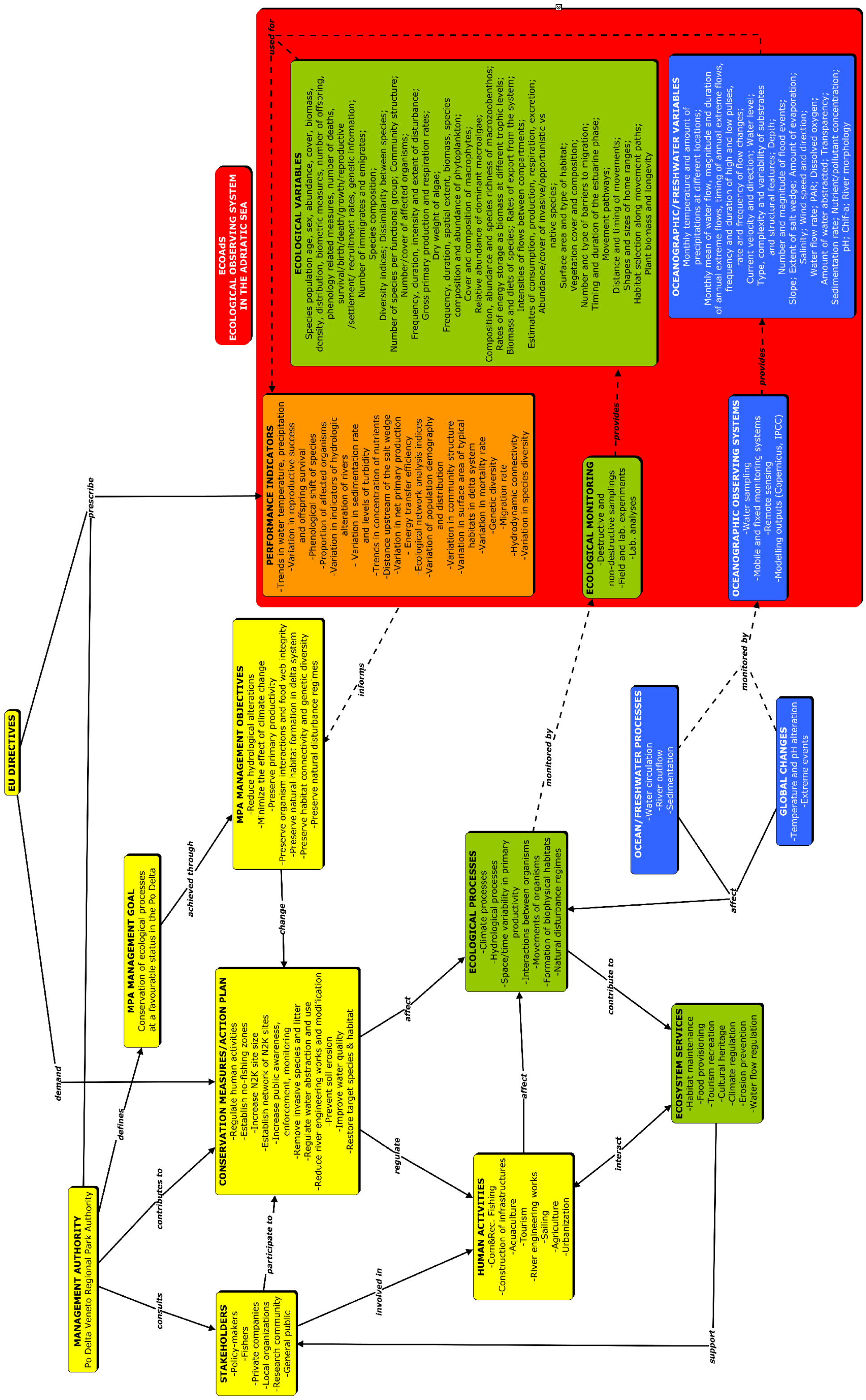

Figure 8. Application model for ‘Delta del Po: tratto terminale e delta Veneto’ and ‘Delta del Po’ N2K sites.

Table 5. Links between descriptor and performance indicators, conservation measures and management objectives addressing threats to ecological processes 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	Ecological processes	Conservation measures	Performance indicators	Descriptive indicators
Minimize the effect of climate change	Climate change	Climate processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, enforcement, reduce other stressors, restore target species & habitat	Trends in water temperature	Monthly temperature at different locations
				Trends in precipitation	Monthly amount of precipitation
				Variation in reproductive success and offspring survival	Number of offspring, species population size, sex, age, survival rate
				Phenological shift of species	Phenology related measures
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/

					death/ growth/ reproductive/ settlement/ recruitment/ migration rates
				Proportion of affected organisms	Species population cover/ size, number/ cover of affected organisms
Reduce hydrological alterations	Climate change, construction of infrastructures in rivers, rising of the salt wedge, excessive water abstraction, river engineering works and modification, sedimentation, soil erosion, invasive species, urban expansion	Hydrological processes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, monitoring, enforcement, regulate water abstraction and use, reduce river engineering works and modification, prevent soil erosion, remove invasive species, restore target species & habitat	Variation in indicators of hydrologic alteration of rivers	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
				Distance upstream of the salt wedge	Current velocity and direction, 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 population demography and distribution	Species species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates
				Variation in sedimentation rate and levels of turbidity	Sedimentation rate, transparency, spatial and temporal extent of the disturbance
				Trends in concentration of nutrients	DIC, NO2, NO3, PO4 concentration in water
Preserve primary productivity	Climate change, poor water quality, construction of infrastructures in rivers, river engineering works and modification, invasive species, sedimentation, aquaculture,	Space/time variability in primary productivity	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species,	Variation in net primary production	Gross primary production and respiration rates, dry weight of algae, frequency, duration, spatial extent, biomass, species composition and abundance of phytoplankton, cover and composition of

	soil leaching and erosion, rising of the salt wedge, disease, urban expansion, sailing		improve water quality, reduce river engineering works and modification, prevent soil leaching and erosion, regulate water abstraction and use, restore target species & habitat		macrophytes, relative abundance of dominant macroalgae, composition, abundance and species richness of macrozoobenthos
					Dissolved oxygen, chlorophyll-a, nutrient concentration in water, PAR, transparency, salinity, pH, temperature
				Trends in concentration of nutrients	DIC, NO2, NO3, PO4 concentration in water
Preserve organism interactions and food web integrity	Climate change, fishing, poor water quality, invasive species, disease, litter, rising of the salt wedge, soil leaching and erosion, aquaculture, urban expansion, sedimentation,	Interactions between organisms	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,	Energy Transfer efficiency	Rates of energy storage as biomass at different trophic levels

	construction of infrastructures in rivers, river engineering works and modification, sailing		improve water quality, remove litter, reduce river engineering works and modification, prevent soil leaching and erosion, regulate water abstraction and use, restore target species & habitat		
				Ecological network analysis indices	Biomass, diets of species, rates of export from the system, intensities of flows between compartments, estimates of consumption, production, respiration, excretion
				Variation of population demography and distribution	Species population age, sex, size, cover, biomass, density, distribution, biometric measures, survival/ birth/ death/ growth/ reproductive/ settlement/ recruitment/ migration rates

				Variation in community structure	Species composition, cover, density, biomass, distribution/dispersion, diversity indices, number of taxa per functional group, abundance/ cover of opportunistic species
				For all the performance indicators	Dissolved oxygen, Temperature, Nutrient concentration, PAR, Transparency, Salinity, pH
Preserve natural habitat formation in delta system	Climate change, poor water quality, invasive species, disease, rising of the salt wedge, soil leaching and erosion, aquaculture, urban expansion, sedimentation, construction of infrastructures in rivers, river engineering works and modification, agriculture,	Formation of biophysical habitats	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, improve water quality, reduce river engineering works and modification, prevent soil	Variation in surface area of typical habitats in delta system	Surface area and type of habitat, vegetation cover and composition, presence and abundance/cover of invasive/opportunistic vs native species

	sailing		leaching and erosion, regulate water abstraction and use, restore target species & habitat		
				Variation in community structure	Species composition, cover, density, biomass, distribution, diversity indices, number of taxa per functional group, dissimilarity between species
				For all the performance indicators	Salinity, temperature, transparency, dissolved oxygen, pH, PAR, nutrient/pollutants concentration, current velocity and direction, magnitude, seasonality, rate of river flow, sedimentation rate, type, complexity and variability of substrates and structural features
Preserve habitat connectivity	Climate change, fishing, poor	Movements of organisms	Regulate human activities, establish no-	Genetic diversity	Genetic information (e.g. microsatellites,

and genetic diversity	water quality, invasive species, disease, litter, rising of the salt wedge, soil leaching and erosion, aquaculture, urban expansion, sedimentation, construction of infrastructures in rivers, river engineering works and modification, sailing		fishing zones, establish network of N2K sites, increase N2K site size, increase public awareness, increase enforcement, monitoring, remove invasive species, improve water quality, remove litter, reduce river engineering works and modification, prevent soil leaching and erosion, regulate water abstraction and use, restore target species & habitat		mtDNA)
				Phenological shift of species	Phenology related measures
				Migration/dispersal rate	Number of immigrates and emigrates, species population size
				Hydrodynamic connectivity	Water circulation, direction and velocity, water level, number and magnitude of flood event, magnitude of

					water flow, number and type of barriers to migration, extent of salt wedge, timing and duration of the estuarine phase, wind speed, wind direction, precipitation and evaporation, river morphology, depth
					Movement pathways, distance and timing of movements, shapes and sizes of home ranges, habitat selection along movement paths
				Variation in species diversity	Diversity indices, dissimilarity between species, number of species per functional group, community structure
Preserve natural disturbance regimes	Climate change, invasive species, all human modifications and stressors acting in the area that	Natural disturbance regimes	Regulate human activities, establish network of N2K sites, increase N2K site size, increase public awareness, increase	Variation in mortality rate	Number of deaths, species population size

	affect natural regime		enforcement, monitoring, remove invasive species, improve water quality, reduce river engineering works and modification, prevent soil leaching and erosion, regulate water abstraction and use		
				Variation in community structure	Species composition, abundance, cover, density, biomass, distribution, abundance/ cover of opportunistic and invasive species, plant biomass, plant longevity, number of taxa per functional group
				Variation in species diversity	Diversity indices, dissimilarity between species, number of species per functional group, community structure
				For all the performance indicators	Frequency, duration, intensity and extent of disturbance, salinity,

					temperature, transparency, dissolved oxygen, pH, PAR, nutrient/pollutants concentration, current velocity and direction, magnitude, seasonality, rate of river flow, sedimentation rate

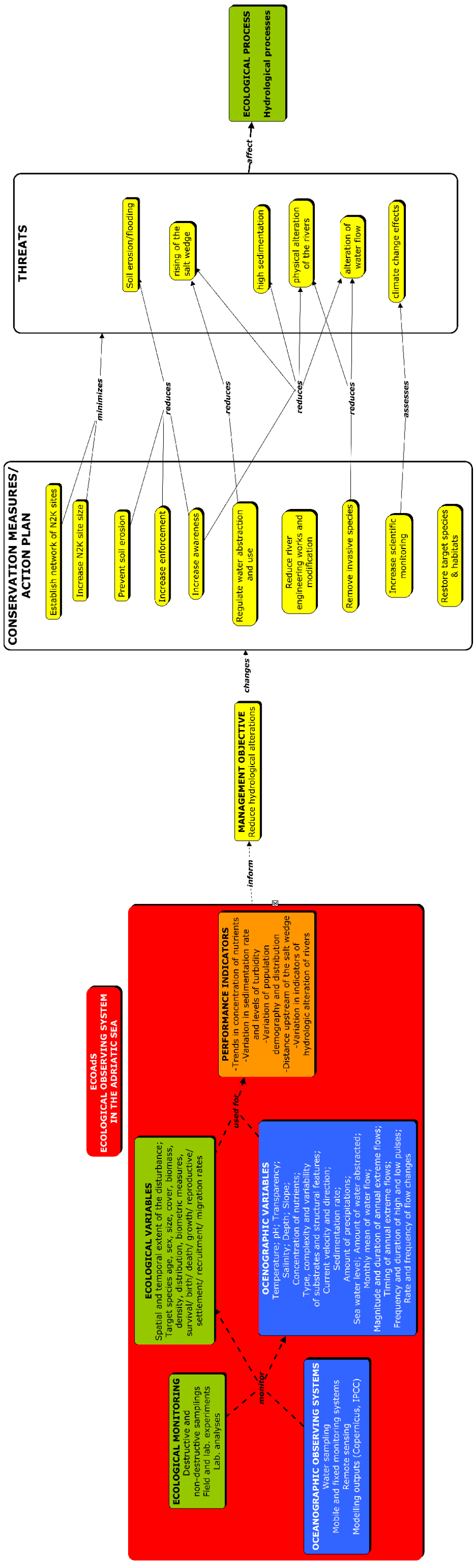

Figure 9. Operative version of the application model for ‘Delta del Po: tratto terminale e delta Veneto’ and ‘Delta del Po’ N2K sites.

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, the ecological observing system in the Adriatic Sea, aimed to collect periodically data on environmental variables and, through performance indicators, to 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 to provide 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 (see definition in Box 2 of D4.4.1), 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 marine conservation 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 programmes in the N2K sites, since, as shown in this report, they are not currently conducted on 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 do not want to be strict, but represent a starting point for putting in place real management of the N2K sites. In particular, each N2K site is likely to have a different set of indicators, selected and prioritized according to the objectives, the types of changes wanted, and 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 Adriatic basin.

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