

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

D4.3.1 Review of the knowledge of the ecological processes in the selected Natura 2000 sites

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

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

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1. INTRODUCTION

Within the frame of the Activity 4.3 “Integration of ecological observing system with Natura 2000 ecological processes”, this report aims to review the available knowledge on key ecological processes at the base of the main management questions at the selected Natura 2000 sites, focusing on relevance for ecosystem services (ES) and the whole Adriatic area.

The report was drafted using primarily information from other deliverables of the project. In particular we made use of:

- D3.1.1 Report on the assessment of existing ecological monitoring programs and observing systems

in order to associate the monitoring programs to Natura 2000 sites and to understand the ecological processes involved in the monitoring (3. EXISTING ECOLOGICAL MONITORING PROGRAMS RELEVANT FOR NATURA 2000 SITES).

We used the reports specified below to complete information in regard to Natura 2000 sites:

- D4.1.1 Report on the characterization of the selected Natura 2000 sites
- D4.1.2 Report on the relationships between ecosystem-level management goals with ecological variables and oceanographic processes and the performance indicators

Moreover, we focused on the main management challenges at the Northern Adriatic Sea scale. This means that we have analyzed and discussed also the ecosystem alterations due to the human impacts, which affects the ecological processes (4. MAIN CHALLENGES IN THE MANAGEMENT OF SELECTED NATURA 2000 SITES AT NORTHERN ADRIATIC SEA SCALE). Then, we characterized each Natura 2000 site-case study with its own ecological processes and other elements of interest, like human disturbance (5. KEY ECOLOGICAL PROCESSES AT NATURA 2000 SITE SCALE: A MANAGEMENT POINT OF VIEW). Finally, we highlighted the main ES related to each case study site and its relevance at the Northern Adriatic Sea basin scale (6. MAIN ECOSYSTEM SERVICES PROVIDED FROM NATURA 2000 SITES).

Taking into account all the entities involved in this step of the project (Natura 2000 sites, key ecological processes, monitoring programs and management questions), we created a matrix in which to insert the known information on these topics, in particular focusing on the ecological monitoring programs. Thanks to this work, we made a list of the ecological processes involved in the considered Natura 2000 sites, based on the parameters monitored by each program.

At this point, it is necessary to define what is an ecological process and how it relates to ES. Ecological processes are intrinsic ecosystem characteristics whereby an ecosystem maintains its integrity. All the ecological systems are sustained by a number of biological, physical, and chemical processes, including primary production and the associated cycling of carbon, nutrients (nitrogen, phosphorus), hydrogen/oxygen and other elements from the physical environment (air, water, land) through biological organisms and back into the physical environment. Collectively, ecological processes lead to the production of organic matter and to the transfer of carbon and nutrients; they drive soil formation and enable organisms to reproduce (EPA 1999; Millennium Ecosystem Assessment 2005). According to Bennet et al. (2009), there are different ways in which to group ecological processes, depending on the ways they contribute to and sustain biodiversity. Here we report the categorization specified by Bennet et al. (2009), in order to better define what is an ecological process and which are the biotic or abiotic components involved (Table 1).

Table 1. Categories of ecological processes with examples of their role in sustaining ecosystems (modified from Bennet et al. 2009)

Category	Examples
Climatic processes	Climatic variables such as precipitation, evaporation and temperature influence the distribution of plant and animal species, both directly (e.g. physiological tolerances) and indirectly (e.g. water column stratification and mixing patterns, spatial patterns of vegetation cover, phenology, availability of food) Climate influences seasonal and inter-annual availability of resources such as nutrient availability from land and from ocean upwellings.
Space / time variability in primary productivity	Spatial and temporal variability in water column structure, nutrients availability and temperature determine variation in primary productivity among ecosystems (e.g. in overall biomass, seasonal and annual variability in biomass, species composition and photosynthetic efficiency)

Category	Examples
Hydrological processes	<p>Flow regimes in streams (magnitude, seasonality, rate of flow) influence the connectivity, physical chemical condition of aquatic habitats</p> <p>Nutrient inputs from rivers and marine upwellings transport and distribute nutrients to plankton and other biotic communities and modify local patterns of primary productivity</p>
Formation of biophysical habitats	<p>The type, complexity and variability of substrates (sand, silt, rock) and structural features (boulders, logs) determine local habitat diversity</p> <p>Sediment structure and properties influence phyto and zoobenthos, composition which in turn provides habitat components</p> <p>Small-scale processes at the sediment/water interface enhance micro-habitats</p> <p>Physico-chemical gradients together with oceanographic processes lead to the formation of distinct pelagic habitats along the water column thus influencing phyto- and zooplankton communities' diversity and distribution</p>
Interactions between organisms	<p>Interactions between individuals determine the spatial distribution and demographic structure within populations</p> <p>Interactions between species (e.g. predation, herbivory, competition, parasitism, mutualisms) alter the structure of communities, influencing and modulating processes such as nutrient cycling and organisms' dispersal.</p>
Movements of organisms	<p>Organisms move at different scales and for many purposes: to find food and shelter, for social interactions, to track resources that vary irregularly in space and time, for seasonal migration, and to disperse and establish in new locations</p> <p>Movements of propagules (e.g. eggs or larvae of aquatic taxa) may be facilitated by animal vectors, currents, wind and water flows</p>
Natural disturbance regimes	<p>Natural disturbances (floods, drought, storm waves) and severe weather events (cyclones, frost, extreme temperatures) alter ecosystems by creating spaces for colonisation, re-setting to an earlier successional stage, releasing and redistributing resources, and altering mortality rates of species</p> <p>Disturbance regimes (i.e. the combination of frequency, duration, intensity and extent of disturbance) have greater long-term influence than single events</p>

Ecosystem integrity is a key concept for preserving those structure and processes that are necessary for the maintenance of the self-organizing capacity of ecological systems (Burkhard et al. 2008; Burkhard and Muller 2008). Ecosystem health and ecological integrity are very closely linked concepts: integrity is focusing on more pristine, self-organized systems, whereas health is referring rather to systems under human use (Burkhard et al. 2008). Human-driven processes, that are influenced either directly or

indirectly by human activity, like (i) degradation of habitat quality, (ii) alteration of species distribution and abundance, (iii) degradation of natural ecological processes, contribute to the ecological integrity decreasing (EPA 1999). In detail, ecosystem integrity is mainly threatened by habitat destruction, overexploitation of resources, entrance of exotic species, environmental pollution, and global climate change. Bennet et al. (2009) identified six groups of threats that stand out for their importance:

- climate change
- degradation, fragmentation and loss of habitats
- alterations to hydrological flows and reduction of aquatic connectivity
- nutrient and chemical additions to ecosystems
- unsustainable harvesting of natural resources
- impacts of introduced and invasive species

Assessing the effects of and the links among major threats to ecosystem processes is necessary also for identifying their effects on ES (Banerjee et al. 2012). In fact, the natural ecosystem processes also play an important role in providing all the ES on which socio-economic prosperity and human health rely, thus directly contributing to human well-being (Millennium Ecosystem Assessment 2005).

According to the Millennium Ecosystem Assessment (2005) and TEEB (2010), from a wider point of view, ecosystem services are the benefits people obtain from nature. These include *provisioning* services, such as food, water, timber, and fiber; *regulating* services that affect climate, floods, disease, wastes, and water quality; *cultural* services that provide recreational, aesthetic, and spiritual benefits; and *habitat* or *supporting* services, such as soil formation, photosynthesis, and nutrient cycling and genetic diversity. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the provisioning of ES.

What underpins the delivery of these services is a suite of ecological functions that must be understood and preserved in a first step to ensure, value, and manage the long-lasting ES provision (Banerjee et al. 2012). From a human perspective, the function is the capacity of natural processes and components to provide goods and services that generate human utility (de Groot 1992). From the nature perspective, the functions are all those processes that allow the existence of working and healthy ecosystems able to deliver ES, and which are supported by the biological diversity (Balvanera et al. 2006). So, the strong

interlink between biodiversity, ecosystem functioning, and ES supply highlights the need to preserve in good state of the natural ecosystems for the sake of ensuring humans' health and prosperity.

In this context, the Natura 2000 network plays a key role in preserving ecosystems functionality and connectivity through the protection of marine areas of priority for conservation and their ability to deliver key ES. In order to support and take advantage of the ecosystem services offered by natural environments to ensure human health, recognizing, understanding and monitoring the ecological processes involved in ecosystem functionality is the first step.

2. ECOLOGICAL PROCESSES AND MANAGEMENT QUESTIONS IN THE SELECTED NATURA 2000 SITES

Seven Natura 2000 sites were selected in the ECOS project as case studies (Figure 1):

- HR3000161 Cres-Lošinj (SCI)
- HR4000015 Malostonski zaljev (SCI)
- HR3000469 Viški akvatorij (SCI)
- IT3330009 Trezze San Pietro e Bardelli (SIC)
- IT3250047 Tegnue di Chioggia (SAC)
- IT3270017 Delta del Po: tratto terminale e delta Veneto (SAC)
- IT3270023 Delta del Po (SPA)

As highlighted in the deliverable D4.1.2, some of these sites have similarities. The two Po Delta sites (IT3270017 and IT3270023), for instance, are closely connected and cover almost the same area. They compose a single river-delta-sea system, they share many of the habitats and species, and they are also managed by the same authority (Ente Parco Regionale Veneto Delta del Po).

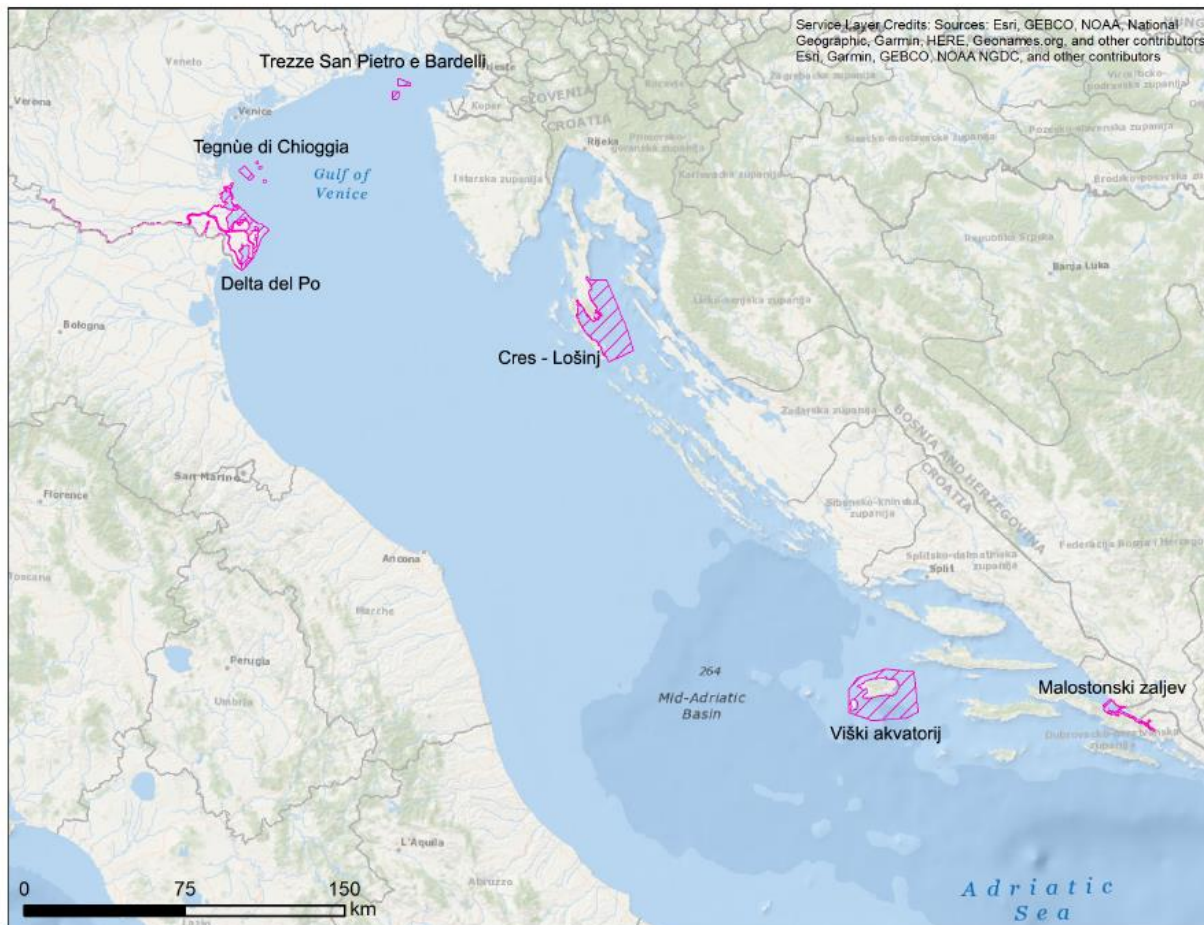


Figure 1. Map of the Natura2000 sites selected in the ECOS project

IT3330009 Trezze San Pietro e Bardelli and IT3250047 Tegnùe di Chioggia are designed to protect the same habitat type, the rich hard substrate communities that lie on these mesophotic biogenic reefs, in the same area, the Northern Adriatic Sea. They share many characteristic species and are subjected to similar forcing and pressures.

HR4000015 Malostonski zaljev is located in the sea area of Dubrovnik-Neretva County. The ecological conditions in the bay depend mostly on the influences from the mainland and partly from the open sea. Strong underwater freshwater springs in the inner part of the bay have a great impact on hydro-physical and ecological characteristics in the bay. Moreover, that area is the most important place for the cultivation of oysters in Croatia.

Finally, HR3000469 Viški akvatorij and HR3000161 Cres-Lošinj were instituted to protect populations of the same species, the bottlenose dolphin (*Tursiops truncatus*). They are both areas surrounding islands characterized by important touristic and other anthropic activities, and share similar chemical and physical water characteristics.

Below we report a summary of the main information on the selected Natura 2000 sites (Table 2). All the sites have not yet a management plan and, in some cases, not even a management authority (e.g. Trezze San Pietro e Bardelli and Tegnùe di Chioggia). This affects the availability of ecological knowledge on these Natura 2000 sites and, of course, their management effectiveness. Actually, middle-long term management plans are essential for implementing conservation actions and ensuring continuity in the protection of natural areas. Possible management questions and performance indicators are indicated, as examples: they will be detailed in deliverable 3.3.1.

Table 2. Summary of the main information on the selected Natura 2000 sites, from D4.1.2. M.P. = Management plan.

N2K site	Main marine/transitional waters species/habitats from SDF	Standard data form (SDF)	M.P. (Y/N)	Key ecological processes (D4.1.2)	Possible examples of management questions (D.4.1.2)	Possible examples of performance indicators (D4.1.2)
HR30001 61 Cres – Lošinj	<i>Tursiops truncatus</i>	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=HR3000161	N	Not studied	<ul style="list-style-type: none"> - Has the dolphin population in this Natura 2000 site a healthy demographic structure? - Are the natural habitats inside this Natura 2000 site efficiently protected? 	<ul style="list-style-type: none"> - The demographic structure of the <i>T. truncatus</i> population inside the protected area - The spreading of specimen outside the Natura 2000 sites
HR30004 69 Viški akvatorij	<i>Tursiops truncatus</i>	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=HR3000469	N	Not studied	<ul style="list-style-type: none"> - Is the population of <i>T. truncatus</i> increasing outside this Natura 2000 site - Is there sufficient incoming/outgoing genetic flow? 	<ul style="list-style-type: none"> - The genetic variability in the populations
HR40000 15 Malostonski zaljev	1120-Posidonia beds, 1160-Large shallow inlets and bays, 1170-Reefs	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=HR4000015	N	Influences from the mainland and open sea; Freshwater inputs; Moderate eutrophication, Filtration by organisms	<ul style="list-style-type: none"> - Is the enforcement of protection measures efficient enough? - Are human activities well-managed and ecologically sustainable in the protected areas? 	<ul style="list-style-type: none"> - The structure and composition of selected benthic communities (filtering organisms, especially corals) in large shallow inlets and bay - Health and structure of <i>Pinna nobilis</i> population - Health and integrity of <i>Lithophaga lithophaga</i>'s habitat - The presence of a healthy populations of benthic algal floral on the reef

N2K site	Main marine/transitional waters species/habitats from SDF	Standard data form (SDF)	M.P. (Y/N)	Key ecological processes (D4.1.2)	Possible examples of management questions (D.4.1.2)	Possible examples of performance indicators (D4.1.2)
IT3330009 Trezze San Pietro e Bardelli	1110-Sandbanks which are slightly covered by sea water all the time, 1170-Reefs; <i>Caretta caretta</i> , <i>Tursiops truncatus</i> , <i>Alosa fallax</i> (Birds: <i>Larus melanocephalus</i> , <i>Phalacrocorax aristotelis desmarestii</i> , <i>Puffinus yelkouan</i>)	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=IT3330009	N	Reproduction and settlement of several benthic, pelagic and demersal species	- Is the protected area large enough to achieve the main goal, which is the conservation of the biodiversity of communities on the reefs? - Does the MPAs constitute a connected network of sites, where long-term resistance and resilience of the communities can be ensured by the dispersal of species?	The community structure and composition, and the presence of a healthy population of two species (<i>Lithophaga lithophaga</i> and <i>Pinna nobilis</i>) from Annex IV, present in both sites, and one species (<i>Phymatolithon calcareum</i>) from Annex V of Habitat Directive (2009/147/EC)
IT3250047 Tegnùe di Chioggia	1170-Reefs; <i>Caretta caretta</i> , <i>Tursiops truncatus</i>	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=IT3250047	N	Reproduction and settlement of several benthic, pelagic and demersal species	- Is the enforcement of the protection measures efficient enough to prevent habitat degradation and biodiversity loss?	

N2K site	Main marine/transitional waters species/habitats from SDF	Standard data form (SDF)	M.P. (Y/N)	Key ecological processes (D4.1.2)	Possible examples of management questions (D.4.1.2)	Possible examples of performance indicators (D4.1.2)
IT3270017 Delta del Po: tratto terminale e delta veneto	1110-Sandbanks which are slightly covered by sea water all the time, 1130-Estuaries, 1140-Mudflats and sandflats not covered by seawater at low tide, 1150-Coastal lagoons; <i>Acipenser naccarii</i> , <i>Alosa fallax</i> , <i>Knipowitschia panizzae</i> , <i>Petromyzon marinus</i> , <i>Pomatoschistus canestrinii</i> , <i>Salicornia veneta</i> (Birds)	http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=IT3270017	N	Water, sediment and nutrients inputs from the river, water circulation due to the river and from sea tide	- Are Natura2000 sites effectively protecting target habitats and species listed in the Standard Form? - Are human activities well-managed and ecologically sustainable in the protected areas?	- The community structure of selected target species, through the assessment of the diversity, status and coverage of the different habitats - The Ecological status of water bodies, according to WFD - The assessment of the amount of sustainable food production
IT3270023 Delta del Po		http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=IT3270023	N			

The lack of management plans leads also to the fact that the ecological processes affecting the species and habitats are not defined and monitored. Even less it is known on how the numerous human pressures, acting on these sites, can influence and alter such ecological processes.

Cres – Lošinj and Viški akvatorij are subject to a high anthropic pressure during the summer period due to tourism and there is no quantification of the damages from human recreational activities.

At Malostonski zaljev there are no information on the effects of near-shore human activities, related to mussel farming and oyster cultivation, to the rich biodiversity of the bay. By the way, Malostonski zaljev is a farming area for the native European oyster (*Ostrea edulis*), with an abundant population of fan

mussel (*Pinna nobilis*) which is endangered by the parasite *Haplosporidium pinnae* (Catanese 2020). Moreover, the rocky shore and the coastal reefs are under pressure because of date mussel (*Lithophaga lithophaga*) poaching.

The two Natura 2000 offshore sites, Trezze San Pietro e Bardelli and Tegnùe di Chioggia, are characterized by a peculiar seabed life and they represent biodiversity hotspots in a generally flat, sandy or muddy sea bottom. For this reason, they are very important from the biological point of view, hosting a rich macrozoobenthic and macrophytobenthic community, they have great importance for several pelagic and demersal species, both as spawning areas and nurseries and as refuge for adult specimens. The information on these areas comes mainly from sporadic studies not coherently organized.

Finally, the two Po River Delta Natura 2000 sites are characterized by a very low percentage of marine area (1%), but by a huge portion of transitional waters. This means the presence of a wide number of birds of European relevance listed in the Bird Directive (Directive 2009/147/EC). This type of environment is influenced by an important contribution of freshwater and debris. Here, the physical components at the base of the ecological processes are of primary importance. The management plan of this area has been produced but it is not yet in force.

3. EXISTING ECOLOGICAL MONITORING PROGRAMS RELEVANT FOR NATURA 2000 SITES

On the following pages we discuss about the monitoring programs currently implemented by the two countries involved in the ECOS project, both locally and nationally. For each monitoring program, we identify the Natura 2000 sites that can potentially be affected by monitoring (if they are not already), we report the observed parameters and we define the species and habitats involved in monitoring. Finally, we propose a list of possible ecological processes that affect Natura 2000 sites, thanks to which we can obtain information and data and, at a later time, establish the ECOlogical observing system in the Adriatic Sea (ECOAdS). We also propose a list of threats and alterations able to affect the ecological processes, in order to identify the main possible drivers of ecosystems' functioning alterations in the selected Natura 2000 sites.

From the comparison among existing ecological monitoring programs and Natura 2000 sites, it emerges that monitoring activities are manifold, in both countries. Each monitoring presents a pool of investigated parameters, in accordance with the most important European directives. However, according to the deliverable 3.1.1, when comparing the sampling sites of the various monitoring programs, there is a lack of overlapping between monitored areas and N2000 sites (sections 3.1, 3.2, 3.5, 3.6, 3.7, 3.9, 3.10). Moreover, from the analysis carried out, it is clear that not all the existing monitoring programs actually cover the Natura 2000 sites being mainly focused on coastal waters and not including the off-shore sites (section 3.8). In addition, the positions of monitoring sites and sampling stations are often not available, so it is difficult to know with certainty whether the monitoring actually concerns the selected Natura 2000 areas. The link among the current monitoring activities and the Natura 2000 sites will be addressed in deliverable 3.3.1 and, in specific case studies, in WP4, through the development and application of an *ad hoc* conceptual model.

However, existing monitoring programs consider a large number of ecological parameters: physical, chemical and biological. These parameters could provide useful information to reconstruct and to frame the ecological processes they describe. Therefore, our suggestion is to rethink the sampling design for each monitoring programs and to include in the activity a series of stations within each Natura 2000 site. Furthermore, we suggest the definition of a pool of parameters common to all sites and an additional pool that specifically characterizes each site. In fact, as already indicated, Natura 2000 sites could be very different among each other if we consider: (i) the ecological processes that support the biodiversity they host; (ii) their position in the Adriatic basin and their different environmental characteristics; (iii) the reason for their protection i.e. the conservation objective (habitat or species) for which the area was established (just think of the difference between “Trezze” site and an area like Malostonski zaljev); (iv) the human activities that are present, relying on the benefits these sites deliver and that affect them. The pool of parameters common to all sites could be used to describe the main common ecological processes for all areas, while the accessory pool could serve to characterize each site. This is to increase the understanding of the area and to better direct management efforts towards well-targeted actions.

In the following sections, the analysis of each monitoring program reported in the deliverable D.3.1. is summarized in a series of tables, with reference to: (i) the Natura 2000 site involved, (ii) the Adriatic sub-region and the geographical coverage, (iii) the links of the monitored parameters with the directives

(MSFD, WFD, HBD), (iv) the species, habitat and ecological processes involved and (v) the main threats and alterations. By "threat" we mean source of potential harm (ISO Guide 73:2009, Selzenmüller et al. 2018). Threats are factors that could affect ecosystems (including habitats and species), leading to a significant and observable alteration. "Alteration" also defined as "effect", on the contrary, is a deviation from the expected (Judd 2015; Jones 2016; ISO Guide 73:2009, Selzenmüller et al. 2018). It refers to a significant and observable change of (i) the characteristics, (ii) the fundamental functioning and (iii) the internal and external relations of an ecosystem (for example habitat, community structure and composition). Alterations follow a threat when this evolves from being a potential harm to a real pressure or multiple pressures, which could compromise the functioning of an ecosystem in a reversible or even non-reversible way.

In the past, geological and physical changes lied at the root of the most dramatic changes in biodiversity in the Mediterranean Sea. Today, human activities are essential elements to consider because they play a strong role in the cause-effect chain involving environmental degradation, since they threaten marine diversity. Indeed, according to Coll et al. (2010c), changes in diversity are partially driven by anthropogenic factors, in addition to natural forces.

3.1. Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfillment of obligations of the Republic of Croatia according to MSFD

N2K site involved	Croatian SCI (Cres – Lošinj; Malostonski zaljev; Viški akvatorij)
Adriatic sub-region and geographical coverage (D3.1.1)	5 marine reporting units (MAD-HR-MRU1; MAD-HR-MRU2; MAD-HR-MRU3; MAD-HR-MRU4; MAD-HR-MRU5) (whole Croatian waters)
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	D5 and partly D1, D2, D4, D7, D10 and D11 from MSFD

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Introduction of non-indigenous species; - Phytoplankton species compositions and its geographical and seasonal variability; - Zooplankton species compositions and its geographical and seasonal variability; - Biological effects of contaminants; - Concentration of contaminants; - Marine litter; - Nutrient concentrations; - Oxygen; - Salinity; - Temperature; - Underwater noise

Parameters of the Water Framework Directive (WFD) (D3.1.1)

- Angiosperms: Abundance, Cover; - Benthic invertebrate fauna: Presence of sensitive taxa, Abundance, Composition; Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition; - Phytoplankton: Abundance, Composition, Diversity; - Specific synthetic pollutants; - Specific non-synthetic pollutants; - Ammonium; - Nitrates; - Nutrient Conditions; - Oxygenation; - Bed Structure; - Bed Substrate; - Conductivity; - pH; - Salinity; - Temperature; - Transparency

Parameters of the Habitats Directive (HD) (D3.1.1)

/

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

/

Species and habitats involved in the monitoring

Phyto- and zooplankton community; Benthic invertebrate fauna; Angiosperms; Macroalgae

Ecological process involved

- Interactions between species
- Movement of organisms and propagules
- Climatic processes
- Space/time variability in primary productivity
- Hydrological processes
- Formation of biophysical habitats
- Natural disturbance regimes

Threats

- Migration/introduction of non-indigenous species
- Ocean warming and climate change
- Degradation, fragmentation and loss of habitat

Alterations

- Angiosperms/Benthic invertebrate fauna/Macroalgae community alterations
- Strong eutrophication
- Alterations in the trophic functioning of marine food web
- Alterations in freshwater inputs and salinity due to flood events

3.2. Systematic research of water quality in transitional and coastal waters of the Republic of Croatia

N2K site involved	Croatian SCI (Cres – Lošinj; Malostonski zaljev; Viški akvatorij)
Adriatic sub-region and geographical coverage (D3.1.1)	25 transitional water bodies; 26 coastal water bodies (whole Croatian waters)
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	The main purpose of this program is to establish the ecological status of water bodies/taking into account the status of: - supportive physical-chemical parameters and chlorophyll a, - biological quality elements (required by the WFD), - specific RB pollutants (Zn and Cu); - hydromorphological alterations; - chemical status (priority substances in water, sediment and biota)
Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)	/
Parameters of the Water Framework Directive (WFD) (D3.1.1)	- Benthic invertebrate fauna: Presence of sensitive taxa, Abundance, Composition; Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition; - Phytoplankton: Abundance, Bloom frequency/Intensity, Composition, Diversity; - Specific synthetic pollutants; - Acidification; - Ammonium; - Nitrates; - Nutrient Conditions; - Oxygenation; - Conductivity; - Direction of dominant currents; - pH; - Salinity; -Temperature; - Transparency
Parameters of the Habitats Directive (HD) (D3.1.1)	/
Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)	/
Species and habitats involved in the monitoring	Benthic invertebrate fauna; Macro-algae; Phytoplankton community
Ecological process involved	<ul style="list-style-type: none"> - Climatic processes - Space/time variability in primary productivity - Hydrological processes - Natural disturbance regimes
Threats	<ul style="list-style-type: none"> - Ocean warming and climate change - Nutrient and chemical additions to ecosystems

Alterations

- Strong eutrophication and strong algal bloom
- Alterations in freshwater inputs and salinity due to flood events

3.3. Adriatic Dolphin Project

N2K site involved

Croatian SCI (Cres – Lošinj; Viški akvatorij)

Adriatic sub-region and geographical coverage (D3.1.1)

Alongshore from Istra to Lastovo, extending to a few miles SW of the outer stretch of islands

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Biological: Population dynamics, Population structure, Habitat use, Spatial distribution, Foraging; **Physical** (Cres-Lošinj archipelago only): underwater noise

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Marine mammals: Actual range, Natural range, Population dynamics, Status; - Non-indigenous or exotic species occurrence; - Other protected species: Actual range, Natural range, Population dynamics, Status; - Underwater noise

Parameters of the Water Framework Directive (WFD) (D3.1.1)

/

Parameters of the Habitats Directive (HD) (D3.1.1)

- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

- Nature and species conservation sites and protected areas; - Scientific research

Species and habitats involved

Bottlenose dolphins (*Tursiops truncatus*)

Ecological process involved

- Interactions between organisms
- Movements of organisms
- Climatic processes

Threats

- Climate change
- Degradation, fragmentation and loss of habitats
- Unsustainable harvesting of natural resources
- Impacts of introduced and invasive species

Alterations

- Alterations in the trophic functioning of marine food web

3.4. Monitoring of sea turtles in the Adriatic (unofficial name)

N2K site involved	All 6 SCI-case studies (Cres – Lošinj; Malostonski zaljev; Viški akvatorij; Tegnùe di Chioggia; Trezze San Pietro e Bardelli; Delta del Po)
Adriatic sub-region and geographical coverage (D3.1.1)	Whole Adriatic Sea
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	Biological: Spatio-temporal distribution, Migrations, Abundance, Survival rates
Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)	- Sea turtles: Actual range, Natural range, Population dynamics, Status; - Non-indigenous or exotic species occurrence; - Other protected species: Actual range, Natural range, Population dynamics, Status
Parameters of the Water Framework Directive (WFD) (D3.1.1)	/
Parameters of the Habitats Directive (HD) (D3.1.1)	- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest
Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)	- Nature and species conservation sites and protected areas; - Scientific research
Species and habitats involved	Sea turtles
Ecological process involved	<ul style="list-style-type: none"> - Interactions between organisms - Movements of organisms - Climatic processes
Threats	<ul style="list-style-type: none"> - Climate change - Degradation, fragmentation and loss of habitats - Unsustainable harvesting of natural resources - Impacts of introduced and invasive species
Alterations	<ul style="list-style-type: none"> - Alterations in the trophic functioning of marine food web

3.5. Long-Term Ecological Research network (LTER-Italy); site “Northern Adriatic Sea”

N2K site involved	Italian SCI (no SCI is directly involved but the network covers areas in proximity of theme)
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Adriatic sub-region and geographical coverage (D3.1.1)

Northern Adriatic Sea, from the Gulfs of Trieste and Venice to the Delta del Po and Romagna Coast and to the area off-shore Senigallia

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Physical parameters (atmosphere and sea): air humidity, air temperature, air pressure, wind direction, wind speed, wind gust, precipitation rate; pressure, current speed, current direction, wave height, wave period, wave direction, water temperature, water salinity, water transparency, conductivity, fluorescence, turbidity, CDOM.

Chemical parameters: dissolved oxygen, pH, dissolved organic carbon, colored dissolved organic carbon, inorganic carbon, dissolved macronutrient concentration (N-NH₄, N-NO₃, NNO₂, P-PO₄, Si-SiO₄). **Biological parameters:** chlorophyll a, phyto- and zooplankton abundance and biomass, biodiversity, change in population size over time, community pattern, community structure, underwater video-monitoring of pelagic communities (e.g. fish, megazooplankton), benthic foraminifera abundance

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Introduction of non-indigenous species; - Phytoplankton species compositions and its geographical and seasonal variability; - Zooplankton species compositions and its geographical and seasonal variability; - Nutrient concentrations; - Oxygen; - Salinity; - Temperature; - Turbidity
- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence; - Biological effects of contaminants

Parameters of the Water Framework Directive (WFD) (D3.1.1)

- Phytoplankton: Abundance, Bloom frequency/Intensity, Composition, Diversity; - Ammonium; - Nitrates; - Oxygenation; - Conductivity; - pH; - Salinity; - Temperature; - Transparency
- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition

Parameters of the Habitats Directive (HD) (D3.1.1)

- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

- Nature and species conservation sites and protected areas; - Scientific research; - Tourism

Species and habitats involved	Phyto- and zooplankton communities, pelagic communities, benthic foraminifera
Ecological process involved	<ul style="list-style-type: none"> - Space/time variability in primary productivity - Interactions between organisms - Movements of organisms - Climate processes - Hydrological processes - Natural disturbances regimes
Threats	<ul style="list-style-type: none"> - Climate change, ocean warming and acidification - Impacts of introduces and invasive species
Alterations	<ul style="list-style-type: none"> - Strong eutrophication - Fish and plankton communities alterations - Alterations in the trophic functioning of marine food web - Alterations in freshwater inputs and salinity due to flood events

3.6. Regional Water Protection Plan - Monitoring of marine waters

N2K site involved	Presumably Trezze San Pietro e Bardelli (it isn't clearly specified if monitoring stations are on "Trezze" SCI; some points of the monitoring programme appear near the "Trezze" area)
Adriatic sub-region and geographical coverage (D3.1.1)	Gulf of Trieste (from Muggia to the mouth of Tagliamento River) - physical parameters: in 53 sampling stations (only 39 active stations at present); nutrients: in 21 sampling stations; contaminants in water: in 22 sampling stations; contaminants in sediment: in 19 sampling stations. All stations are included in 19 marine water bodies
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	Physical (air and water temperature, Salinity, Density, pH, dissolved oxygen, DO%, PAR, KPAR, REPAR, %PAR, Turbidity, Conductivity, speed of sound in water), chemical (nitrate, nitrite, ammonia, silicate, orthophosphate, TP, TN, contaminants in water and sediments (heavy metals, Organochlorines, trace metals)), biological (biodiversity and density of phytoplankton, including toxic and alien species, jellyfish aggregations). Trophic index (TRIX), assessment of the ecological status of surface waters

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Angiosperms species composition and its annual/seasonal variability;
- Habitats' (predominant, special, protected and endangered) characteristics;
- Invertebrate bottom fauna species composition and its annual/seasonal variability;
- Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence;
- Biological effects of contaminants

Parameters of the Water Framework Directive (WFD) (D3.1.1)

- Angiosperms: Cover, Depth distribution;
- Benthic Invertebrate Fauna: Abundance, Composition, Diversity;
- Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition

Parameters of the Habitats Directive (HD) (D3.1.1)

- Natural range of natural habitat types of community interest;
- Area covered by natural habitat types of community interest;
- Status of conservation of species in natural habitat types of community interest;
- Presence of habitat for animal and plant species of community interest

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

- Nature and species conservation sites and protected areas;
- Scientific research;
- Tourism

Species and habitats involved

Phytoplankton community, jellyfish

Ecological process involved

- Space/time variability in primary productivity
- Interactions between organisms
- Movements of organisms
- Climate processes
- Hydrological processes

Threats

- Climate change, ocean warming and acidification
- Impacts of introduced and invasive species
- Nutrient and chemical additions to ecosystems

Alterations

- Strong eutrophication
- Phytoplankton community alterations
- Alterations in the trophic functioning of marine food web

3.7. Monitoring of water and shellfish quality in shellfish farming areas

N2K site involved

Presumably Trezze San Pietro e Bardelli (from the available map of the monitoring programme, we observe that the covered area is over "Trezze" SCI)

Adriatic sub-region and geographical coverage (D3.1.1)

Gulf of Trieste, 52 sampling stations

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

Parameters of the Water Framework Directive (WFD) (D3.1.1)

Parameters of the Habitats Directive (HD) (D3.1.1)

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

Species and habitats involved

Ecological process involved

Threats

Alterations

Microbiological and chemical analyses of water and shellfish and shellfish toxicology analyses to investigate the presence of toxic phytoplankton

- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence; - Biological effects of contaminants

- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition

- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

- Nature and species conservation sites and protected areas; - Scientific research; - Tourism

Shellfish

- Space/time variability in primary production
- Hydrological processes
- Climatic processes
- Natural disturbance regimes
- Climate change and ocean warming
- Nutrient and chemical additions to ecosystems
- Strong eutrophication
- Alterations in the trophic functioning of marine food web
- Alterations in freshwater inputs and salinity due to flood events

3.8. Bathing water quality monitoring

N2K site involved

Presumably Trezze San Pietro e Bardelli (no SCI is directly involved but the network covers local coastal waters in "Trezze" SCI proximity)

Adriatic sub-region and geographical coverage (D3.1.1)

Gulf of Trieste, 55 sampling stations along the coast

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

Parameters of the Water Framework Directive (WFD) (D3.1.1)

Parameters of the Habitats Directive (HD) (D3.1.1)

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

Species and habitats involved

Ecological process involved

Threats

Alterations

Density of *Escherichia coli* and *Enterococcus* spp., diversity and density of phytoplankton, including toxic microalgae, air and water temperature, currents, waves, wind

- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence; - Biological effects of contaminants

- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition

- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

- Nature and species conservation sites and protected areas; - Scientific research; - Tourism

Bacterial species, phytoplankton community

- Climate processes
- Hydrological processes
- Space/time variability in primary production
- Movements of organisms
- Climate change and ocean warming
- Nutrient and chemical additions to ecosystems
- Strong eutrophication and strong algal bloom
- Alterations in the composition of the marine food web
- Phytoplankton community alterations

3.9. Visual census of the seafloor by ROV

N2K site involved

Presumably Trezze San Pietro e Bardelli (monitoring programme's stations are unknown but we assume that "Trezze" SCI is involved due to the subject of the research, that is maerl/rodolithes)

Adriatic sub-region and geographical coverage (D3.1.1)	Gulf of Trieste, in three areas (one area designed to study Maerl habitat and two areas to study human impacts on the seafloor). Every area has three sampling stations
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	Calcareous red-algae (Maerl/Rodoliths) distribution and human impacts on the seafloor (e.g. trawling)
Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)	- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence; - Biological effects of contaminants
Parameters of the Water Framework Directive (WFD) (D3.1.1)	- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition
Parameters of the Habitats Directive (HD) (D3.1.1)	- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest
Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)	- Nature and species conservation sites and protected areas; - Scientific research; - Tourism
Species and habitats involved	Maerl/Rodoliths
Ecological process involved	<ul style="list-style-type: none"> - Climate processes - Hydrological processes - Formation of biophysical habitats - Interaction between organisms - Movements of organisms
Threats	<ul style="list-style-type: none"> - Climate change - Degradation, fragmentation and loss of habitats - Unsustainable harvesting of natural resources - Impact of introduced and invasive species
Alterations	<ul style="list-style-type: none"> - Bioconstructions and seafloor alterations - Alterations in fish, macro-algae and benthic communities

3.10. Seagrasses and macroalgae monitoring UNITS and FVG Region

N2K site involved	Tegnùe di Chioggia and Trezze San Pietro e Bardelli
Adriatic sub-region and geographical coverage (D3.1.1)	Gulf of Trieste
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	<p>Biological parameters: spatial distribution, species richness, density, coverage, community structure and dynamic</p> <p>Physical parameters (atmosphere): air humidity, air temperature, air pressure, wind direction, wind speed, wind gust</p> <p>Physical parameters (sea): pressure, water temperature, water salinity, water transparency, conductivity, fluorescence, turbidity</p> <p>Chemical parameters: dissolved oxygen, pH, alkalinity, dissolved organic carbon, dissolved organic nitrogen, dissolved organic phosphorus, inorganic carbon, particulate organic carbon, particulate nitrogen, particulate phosphorus, dissolved macronutrient concentration (N-NH₄, N-NO₃, N-NO₂, P-PO₄, Si-SiO₄)</p> <p>Biological parameter: chlorophyll a, zooplankton abundance, microphytoplankton abundance, microzooplankton abundance, picoplankton abundance, nanoplankton abundance, biomass, microphytobenthos abundance, macrozoobenthos abundance, meiobenthos abundance</p> <p>Biological processes: primary production, secondary production, exoenzymatic activities in water and sediment</p>
Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)	<ul style="list-style-type: none"> - Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition - Non-indigenous or exotic species abundance and occurrence; - Biological effects of contaminants
Parameters of the Water Framework Directive (WFD) (D3.1.1)	<ul style="list-style-type: none"> - Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition
Parameters of the Habitats Directive (HD) (D3.1.1)	<ul style="list-style-type: none"> - Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

- Nature and species conservation sites and protected areas; - Scientific research; - Tourism

Species and habitats involved

HB: *Posidonia oceanica* as Habitat 1120 (SIC Posidonia Grado), Coralligenous as Habitat 1170 (SIC Trezze-Tegnue); MSFD: - Coralligenous (Trezze and Tegnue) monitored by ARPA-FVG

Ecological process involved

- Climatic processes
- Formation of biophysical habitats
- Space/time variability in primary productivity
- Hydrological processes
- Interactions between organisms
- Movements of organisms

Threats

- Climate change
- Habitats degradation
- Nutrient and chemical additions to ecosystems

Alterations

- Bio-communities alterations
- Alterations of the structure and functioning of the marine food web

3.11. Coralligenous monitoring UNITS; TRECORALA; PRIN ReefReseArch Resistance and resilience of Adriatic mesophotic biogenic habitats to human and climate change threats Research project of national interest

N2K site involved

Tegnùe di Chioggia and Trezze San Pietro e Bardelli

Adriatic sub-region and geographical coverage (D3.1.1)

Gulf of Trieste

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Biological parameters: spatial distribution, species richness, density, coverage, community structure and dynamic

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition; - Non-indigenous or exotic species: Abundance, Occurrence; - Biological effects of contaminants

Parameters of the Water Framework Directive (WFD) (D3.1.1)	- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition
Parameters of the Habitats Directive (HD) (D3.1.1)	- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest
Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)	- Nature and species conservation sites and protected areas; - Scientific research; - Tourism
Species and habitats involved	MDFD: Coralligenous (Trezze and Tegnue) monitored by ARPA-FVG; HB: - Coralligenous as Habitat 1170 (SIC Trezze-Tegnue)
Ecological process involved	<ul style="list-style-type: none"> - Climatic processes - Formation of biophysical habitats - Interactions between organisms - Movements of organisms
Threats	<ul style="list-style-type: none"> - Climate change - Degradation, fragmentation, and loss of habitats - Impacts of introduced and invasive species
Alterations	<ul style="list-style-type: none"> - Bioconstructions and seafloor alterations - Alterations of the structure and functioning of the marine food web - Angiosperms, macro-algae, benthic invertebrate fauna communities alterations

3.12. Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006 (aimed to chemical and ecological status classification and to assessment of the quality of shellfish waters - specific destination waters)

N2K site involved	Delta del Po
Adriatic sub-region and geographical coverage (D3.1.1)	Coastal lagoons of Caleri, Marinetta, Vallona, Barbamarco, Canarin, Scardovari; Mouths of Po River (Po di Maistra, Po di Pila, Po di Tolle, Po di Gnocca, Po di Goro)

Ecological parameters monitored (physical, chemical and biological) (D3.1.1)

Physical parameters: Current direction, Current speed, Air temperature, Wind direction, Wind speed, Air pressure, Air humidity, Sky coverage, Solar radiation, Tide conditions, Water coloration (visual analysis), Transparency, Depth, Water temperature, pH, Salinity, Dissolved oxygen (%), Dissolved oxygen (ppm), Conductivity, Chlorophyll "a" CTD, Sediment density, Sediment porosity

Biological, microbiological and chemical parameters : Water nutrients (nitrate, nitrite, ammonia, orthophosphate), Phytoplankton, Potentially toxic Phytoplankton, Macrophytes, Benthic macroinvertebrates, Chlorophyll "a", Contaminants in water, sediments and biota (fish and molluscs) - D.Lgs. 172/2015, Color Pt/Co, Suspended solid, AVS/Lfe in sediment, Granulometry and organic matter in sediment, Ecotoxicological tests in sediment, Microbiological analyses of shellfish, Shellfish toxicology analyses (PSP)

Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)

- Angiosperms species composition and its annual/seasonal variability; - Habitats' (predominant, special, protected and endangered) characteristics; - Invertebrate bottom fauna species composition and its annual/seasonal variability; - Macro-algae species composition; - Non-indigenous or exotic species: Abundance, Occurrence; - Biological effects of contaminants

Parameters of the Water Framework Directive (WFD) (D3.1.1)

- Angiosperms: Cover, Depth distribution; - Benthic Invertebrate Fauna: Abundance, Composition, Diversity; - Macro-algae: Presence of sensitive taxa, Abundance, Cover, Depth distribution, Species composition

Parameters of the Habitats Directive (HD) (D3.1.1)

- Natural range of natural habitat types of community interest; - Area covered by natural habitat types of community interest; - Status of conservation of species in natural habitat types of community interest; - Presence of habitat for animal and plant species of community interest

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)

- Nature and species conservation sites and protected areas; - Scientific research; - Tourism

Species and habitats involved

Phytoplankton, macrophytes, benthic macroinvertebrates, shellfish

Ecological process involved

- Climate processes
- Space/time variability in primary production
- Hydrological processes
- Natural disturbance regimes
- Interactions between organisms
- Movements of organisms

- | | |
|--------------------|--|
| Threats | <ul style="list-style-type: none"> - Climate change - Nutrient and chemical additions to ecosystems - Degradation of habitats due to sedimentation |
| Alterations | <ul style="list-style-type: none"> - Strong eutrophication and strong algal bloom - Phytoplankton, macrophytes, benthic invertebrate fauna communities alterations |

3.13. Arpae Emilia-Romagna

N2K site involved	Delta del Po
Adriatic sub-region and geographical coverage (D3.1.1)	Emilia-Romagna coast, Sacca di Goro
Ecological parameters monitored (physical, chemical and biological) (D3.1.1)	<p>Physical (temperature, Salinity, Density, pH, dissolved oxygen), chemical (nitrate, nitrite, ammonia, silicate, orthophosphate, chlorophyll).</p> <p>Biological (abundance of total phytoplankton and of phytoplankton main groups). Harmful algal blooms, eutrophication related phenomena, mucilage occurrence, macroalgal blooms, jellyfish</p>
Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1)	- Oxygen; - Salinity; - Temperature
Parameters of the Water Framework Directive (WFD) (D3.1.1)	/
Parameters of the Habitats Directive (HD) (D3.1.1)	/
Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1)	/
Species and habitats involved	Macro-algae, jellyfish
Ecological process involved	<ul style="list-style-type: none"> - Climatic processes - Space/time variability in primary production - Interactions between organisms - Movements of organisms

- | | |
|--------------------|---|
| Threats | <ul style="list-style-type: none"> - Climate change - Nutrient and chemical additions to ecosystems |
| Alterations | <ul style="list-style-type: none"> - Strong eutrophication and strong macroalgal bloom - Phytoplankton community alteration - Alterations of the marine food web |

3.14. Other reported projects

- | | |
|---|---|
| N2K site involved | Extra areas "SCI-case studies" but located in the northern Adriatic Sea, useful to better understand how the whole marine ecosystem works and built a complete observing network |
| Existing ecological monitoring programmes (D3.1.1) | <ul style="list-style-type: none"> a) project Ritmare-SOLVE, Sistema Osservativo della Laguna di Venezia (Venice lagoon observingsystem) b) project Venezia 2021, Research Program for a "regulated" lagoon c) project Life REDUNE, Restoration of dune habitats in Natura 2000 sites of the Veneto coast d) Interreg project AdriSmartFish, Valorisation of Small-scale ARTisanal FISHERY of the Adriatic coasts, in a context of sustainability |
| Adriatic sub-region and geographical coverage (D3.1.1) | a) - b) Venice lagoon; c) Penisola del Cavallino (IT3250003), Laguna del Mort, Pinete di Eraclea (IT3250013); and Laguna di Caorle - Foce del Tagliamento (IT3250033); d) Northern Adriatic (GSA 17) |
| Ecological parameters monitored (physical, chemical and biological) (D3.1.1) | a) - b) within the project, our working group has been in charge of the assessment of ecosystem services; c) extent and species composition of dune habitats; ecosystem services assessment before and after the project's restoration actions; d) monitoring of small-scale artisanal fishery |
| Parameters of the Marine Strategy Framework Directive (MSFD) monitoring programme (D3.1.1) | / |
| Parameters of the Water Framework Directive (WFD) (D3.1.1) | - Phytoplankton: Abundance, Bloom Frequency/Intensity, Composition, Diversity; - Acidification; - Ammonium; - Nitrates; - Nutrient conditions; - Oxygenation; - Conductivity; - Depth variation; - Direction of dominant currents; - pH; - Salinity; - Temperature; - Transparency |

Parameters of the Habitats Directive (HD) (D3.1.1) /

Human activities related to the Maritime Spatial Planning (MSP) (D3.1.1) /

Species and habitats involved

- a) - b) The project is connected with these directives as it quantifies some of their relevant parameters, in particular, it maps the area covered by natural habitat types of community interest (HD) and it maps fishing areas (MSPD)
- c) HD (the project is connected with the HD as it maps the area covered by habitat types of community interests and it implements activities aimed at the restoration of these habitats)
- d) EUSAIR, MSPD (the project is directly relevant to pillar 1 of EUSAIR (Blue growth) and is connected to the MSP as it maps fishing areas)

4. MAIN CHALLENGES IN THE MANAGEMENT OF SELECTED NATURA 2000 SITES AT NORTHERN ADRIATIC SEA SCALE

Describing ecological processes in selected Natura 2000 sites it is difficult because, as already mentioned, some information on these sites is missing, mainly due to the absence of (i) management plans and (ii) monitoring programs inclusive of Natura 2000 sites. Anyway, to focus on the management issues that each selected Natura 2000 site has to face, we identified three *challenges* which fit with the main management questions at the Natura 2000 sites-case study (Table 2). We selected these three topics due to their relevance at the basin level (Adriatic Sea) and for the amount of information from numerous studies and research activities.

Furthermore, ecological processes are complex and have a wide range of components to consider. In accordance with Bennet et al. (2009) (see Table 1) each ecological process concerns a different aspect of the environment, including the interactions that characterize it in terms of physical, chemical and biological peculiarities. Climate, primary productivity, hydrological system, habitats, organisms and natural events interact among them and play a role in sustaining biodiversity.

In this section, due to the complexity in describing a particular ecological process, we considered only the Northern Adriatic Sea (NAd), focusing on some management challenges in which one or more ecological processes are involved.

Here we presented these *challenges* as alterations of the ecosystem due to human impact. Several threats are pointed out in this part of the deliverable as causes of ecosystems' alterations. These threats are: (i) nutrient and chemical addition/reduction to ecosystem, which cause respectively strong eutrophication and cultural oligotrophication; (ii) impacts of introduced and invasive species, which test the resilience of habitats and indigenous species; (iii) unsustainable harvesting of natural resources and degradation, fragmentation and loss of habitats, which cause changes in the marine food web.

Finally, climate change also plays a role in threatening ecosystems' integrity. In fact, according to Giani et al. (2012), combined effects of the anthropogenic impact and regional climate changes are causing modifications of the physical and chemical oceanographic characteristics of the NAd, influencing its biota. These modifications are well-documented and their analysis are important to clarify the current state of the NAd marine ecosystem and to address future research.

4.1. Eu- and oligotrophication

In terms of nutrient load, the trophic level of an ecosystem is the result of the interaction among different ecological processes such as Space/time variability in primary productivity, Climatic processes (i.e. seasonality) and Hydrological processes (see Table 1). In this section we discussed about eu- and oligotrophication and how these phenomena affect the NAd.

Historically, the NAd basin was long considered as one of the most productive area of the Mediterranean Sea in which the largest source of nitrogen and phosphorous was the Po River, as well as the main freshwater source (Sournia 1973; Degobbis and Gilmartin 1990). Hopkins et al. (1999) replaced this simplification by the division of the NAd into eutrophic, mesotrophic and oligotrophic regions, with only western coastal waters considered as eutrophic.

When eutrophication occurs, there is an enrichment of water with nutrients, primarily nitrogen and phosphorus, which stimulates primary production. In some cases, this phenomenon leads to visible

blooms and accumulation of submerged and floating organic material in the water (Vollenweider 1992). Phytoplankton is very sensitive to environmental changes and, therefore, provides good insight into water quality before it becomes visible on higher trophic levels and the excessive eutrophication of certain areas starts (Brettum and Andersen 2005).

Seasonal variations in planktonic availability affect distribution, abundance and growth of all direct and indirect consumers, both in the water column and in benthic ecosystems. Besides the planktonic primary production, high value macroalgae such *Cystoseira* spp. and seagrasses such as *Posidonia* and other phanerogames species contribute to increase primary production, though only in selected sectors of the basin, namely the eastern coasts and the southern basin (RAC/SPA 2015).

This high plankton production causes at times large algal blooms, including some toxic events, during the whole year that deposit on the bottom creating a sort of mat and high turbidity during most of the year. In fact, most of the benthic communities are filter feeders that are constantly active. On the other hand, this great production may translate in local severe or less severe hypoxia events, which together with the increasing farming can get to be almost constant in the northern area. Benthic hypoxia and complete anoxia can occur in large areas of the NAd due to falling to low level of bottom oxygen (Degobbis et al. 2000).

Eutrophication can origin due to natural or anthropogenic forcing. The causal link between anthropogenic sources of nutrients and the eutrophication of the system is generally accepted (McQuatters-Gollop et al. 2009; Smith 2006), but it is very important to take into account systems-specific features of a certain area to distinguish changes in the ecosystem resulting from natural seasonal and interannual dynamics. Given the scale, the eutrophication process could be beneficial for the ecosystem, but it could have adverse effects depending on the different characteristics of each ecosystem (Crossetti et al. 2008; Marasović and Pucher-Petković 1985; Skejić et al. 2014; Su et al. 2015).

The responses of phytoplankton to the eutrophication process have been described mostly through chlorophyll *a* (Chl *a*) concentrations measure (Edwards et al. 2003; Gowen et al. 1992; Vollenweider 1976). The phytoplankton biomass (expressed as Chl *a*) is a common indicator of eutrophication because it provides consistent insights of a certain area, but it should be monitored with the compositional changes of the community structure (McQuatters-Gollop et al. 2009; Ninčević Gladan et al. 2015). In

fact, the phytoplankton community structure is not only influenced by the spatial and temporal variations of abiotic parameters but it is also regulated by an endogenous clock and phenology (RAC/SPA 2015). Moreover, the Water Framework Directive (WFD, 2000/60/EC; Directive on Environmental Quality Standards 2008/105/EC) states that phytoplankton and its biodiversity are one of the crucial biological elements in the assessment of the ecological status of the sea.

Recently, authors confirmed the hypothesis of an inverse trend toward oligotrophication of the basin, during certain periods of the year. Solidoro et al. (2009) analyzed a database obtained by compiling and integrating biogeochemical data collected over 20 years founding evidences on a reduction in the values of ammonia and phosphate. They suggested that these observations could be a result of both climatic factors and anthropogenic pressures (i.e. cultural oligotrophication) since the main features emerging from this analysis were the increment in salinity. This might be interpreted as a consequence of both reduced outflows from rivers (higher salinity in coastal areas) and a more sustained ingression of Levantine water (higher salinity in open waters), with a clear reduction in the concentration of phosphate and ammonia in coastal areas.

Furthermore, Mozetič et al. (2010) considered a 38 years long dataset of Chl *a* concentration. According to the authors, there is a tendency for Chl *a* surface concentration to decrease, which is more marked in the eutrophic western area than in the center of the basin and the eastern coast, which have always presented mesotrophic or oligotrophic characteristics. Reductions in the outflow of the Po and Isonzo rivers, phosphorous banishment by Italian law in the mid-1980s and the general improvement in sewage treatment could have had a strong influence on nutrient concentrations in the coastal area (Mozetič et al. 2010 and references therein). Mozetič et al. (2010) stated that their results constitute one of the first documented cases of cultural oligotrophication of coastal waters.

Moreover, observations on increased abundance of small nanoflagellates and reduced diatom peak abundance during blooms in the last 5 years in the southern part of the Gulf of Trieste can be seen as a response of phytoplankton community to changes in nutrient concentrations and in nutrient ratio. The lack of a strong warming signal at this stage gives more support for the effect of cultural oligotrophication on the phytoplankton community (Mozetič et al. 2010).

4.2. Maintenance/resilience of species and habitats and nonindigenous species (NIS)

In this section, we discuss about how organisms and habitats face changes in their environment. Ecological processes involved in this section are Interactions between organisms and movement of organisms (Table 1). Moreover, we focused also on the impacts of introduced and invasive species, one of the main threats to the maintenance and resilience of species and habitats.

Anthropogenic disturbance is one of the major drivers of biological invasions (Elton 1958; Cohen and Carlton 1998; Occhipinti-Ambrogi and Savini 2003; Crooks et al. 2011). Severe human-driven disturbances are fast events that can influence the rates of evolutionary adaptations and can shift selection regimes to conditions different from those in which native species evolved, typically reducing their fitness. In contrast, some non-indigenous species (NIS) may be more adapted to the recipient disturbed conditions, managing to settle and thrive better than competing native species (the “selection regime modification” mechanism, Byers 2002).

However, untangling the selectivity of environmental conditions on invasions requires tracing them over longer periods and at fine-scale temporal resolution. Additionally, the interplay of more than one type of disturbance is rarely directly addressed: experiments usually focus on a single causative factor, and detailed observations often begin only after NIS introduction. The result is that little knowledge is available on the factors that influence establishment success (Albano et al. 2017).

For example, Albano et al. (2017) tested whether the occurrence in the late 20th—early 21st century of hypoxic events driven by human-induced eutrophication in the NAd (Justić 1991; Giani et al. 2012) caused a regime shift in favor of hypoxia-tolerant species and facilitated the establishment of the hypoxia-tolerant invasive bivalve *Anadara transversa* (Say 1822). This is one of the most invasive species in the Mediterranean Sea (Streftaris and Zenetos 2006), but its native range is eastern and southern North America (Albano et al. 2009). Albano et al. (2017) found that (i) the onset of major eutrophication in the 1970s shifted communities towards species tolerating hypoxia, and (ii) *A. transversa* was introduced in the 1970s but failed to reach reproductive size until the late 1990s because of metal contamination, resulting in an establishment and detection lag of ~25 years. Their study provides strong evidence that in ecosystems subject to multiple disturbances, invasion success can be difficult to predict because it is the outcome of the complex interplay between multiple selection regimes. Disturbance can

shift such regimes even beyond non-indigenous species tolerance limits, causing significant time lags in establishment.

As regard of changes in **macrobenthos**, submerged macrophytes that were dominant primary producers in shallow-water soft-bottom areas of the NAd have become much less abundant over the last century Giani et al. (2012). Algal vegetation on the rocky coast in the eastern NAd has also declined since the 1970s (Newell and Ott 1999). The cause of these reductions has been attributed to an increased turbidity of the waters and to the overgrazing by flourishing sea urchin populations (Falace et al. 2010). Furthermore, also repeated events of hypoxia and anoxia are responsible of mass mortalities of benthic macrofauna, in particular during the 1970s and 1980s. Benthic organisms are stressed and damaged even from deposition of mucilage aggregates (Stachowitsch et al. 1990; Castelli and Prevedell 1992; Devescovi and Ivesa 2007), though the concurrence of hypoxic conditions can obscure the role of mucilage in causing mortalities of benthic organisms.

About NIS, a spreading of more than 40 of them was observed in the NAd (Occhipinti-Ambrogi 2002). It included 14 macrophytes (Orlando-Bonaca 2010 and references therein), as well as 26 animals: among them, only two were non-benthic species. This phenomenon was mainly caused by shipping/maritime transport, aquaculture activities or by diffusion through the Suez Canal or Gibraltar Strait (Crocetta 2011). Most of these species are of Indo-Pacific or Australian origin. The number of taxonomic units involved in bio-invasions is probably underestimated and their effects on the local ecosystems are still poorly known.

Macroepifauna communities are widely distributed in the NAd and largely consist of interspecific high biomass multispecies clumps (Fedra et al. 1976). Shelly hard substrates provide the base for sessile, suspension feeding colonizers (mostly sponges, ascidian, anemones or bivalves), which in turn serve as substrate for additional vagile or hemisessile organisms (Riedel et al. 2008). The clumps of epibenthic organisms which characterized the area of the Gulf of Trieste before the mid 1970s, declined after the mass mortality of 1983, without a subsequent recover because of a following anoxic crisis in 1988 and of trawling fishing activity (Kollmann and Stachowitsch 2001). In particular, the trawling fishing has been shown to cause severe impact on benthic biocenoses also in other areas of the NAd such as the soft-bottom ones (Giovanardi et al. 1998).

Changes of benthic macrofauna along the Emilia Romagna coast in 1985 were observed with respect to previous analyses in 1934-36 (Crema et al. 1991). The new biocenoses showed a large abundance of *Corbula gibba*, a species typical of the transition zone between detrital and muddy bottoms. This dominance and the good richness in biodiversity were interpreted as an immature, transitory successional stage due to intermittent recovery after periodic disturbances. Analyzing the seasonal variations of macrobenthic community from 1996 to 2000 in the same area, Occhipinti-Ambrogi et al. (2002) observed a shift in the community structure, mainly due to the substitution of *C. gibba* by *Ampelisca*, which was related to an increase of oxygen concentration and of sand content in the sediments. This shift was further confirmed by observations carried out from 2004 to 2006 (N'Siala Massamba et al. 2008). The long-term decline of the *Chamelea gallina* clam fishery in the western NAd has been instead attributed to the reduction of riverine nutrients and of primary producers, although overfishing might have played a role (Romanelli et al. 2009).

A 20 year-long study carried out in the eastern NAd showed that soft-bottom polychaete declined after the anoxic event of 1989 leading the macrobenthic communities to an instability with the dominance of bivalves (Mikac et al. 2011). During the recovery the contribution of bivalves to the overall diversity and abundance decreased gradually. Also, on a local scale (e.g. the Bay of Muggia, Gulf of Trieste) a general recover of the macrobenthic community was observed in 1994 in respect to 1981, which in turn was in worst conditions than in 1975 (Solis-Weiss et al. 2004).

Taking into account changes in **fish communities**, the NAd is one of the most productive area of the Mediterranean and one of the most relevant fishing ground. Significant changes in fish community composition and in abundances of many species have been certainly occurring - and accelerating - during last decades, after the 1950s (Giani et al. 2012). In particular, it has been observed a decline of elasmobranches (sharks, rays and skates) tuna, swordfish, marine mammals and large demersal, and, more generally, of large-sized and late-maturing species proportion in fish composition as well as diadromous fish (eel, sturgeon) and small pelagics (Grbec et al. 2002; Santojanni et al. 2006; Ferretti et al. 2008; Coll et al. 2010a; Fortibuoni et al. 2010; Lotze et al. 2011; and references therein). Coll et al. (2010a) highlighted that fish community has not recovered in the last two decades and actually a decreasing trend is still going on in total biomass, in the average trophic level of fish community and in

the demersal/pelagic ratio for many species, including both demersal, and pelagic ones. Also small pelagic catches were not recovering too (Grbec et al. 2002; Coll et al. 2010a).

Changes in fish abundance and community composition might result from the superposition of fishing effects, driven by technological evolution and market dynamic and by environmental effects, influenced by anthropogenic and natural stressors. Beside direct effects, such as fishing mortality or changes in habitat suitability, pressures can induce indirect effects, such as the modification of nursery areas, changes in juvenile survival, potentially induced by changes in phenology and consequent lack of synchronization (match-mismatch) between predators requirements and presence of prey, successful invasion of alien species, evolutionary changes. As an example of direct effect, an increasing trend of thermophilic taxa, which appear to expand northward, has been reported in the Adriatic Sea (Dulčić et al. 2004; Azzurro et al. 2011 and references therein), concurrently with changes in oceanographic properties. As an example of indirect effect, changes in environmental conditions, and in particular in river discharges, clearly influence the recruitment of anchovy in the northern and central Adriatic (Santojanni et al. 2006)

Nowadays, several modifications of the environmental conditions in the NAd are occurring, mainly due to climatic fluctuations and changes of the anthropogenic pressure. These environmental changes had relevant consequences for the ecosystem and, according to Giani et al. (2012), they are indicative of an oligotrophication process, similarly to what happen in other European seas (Carstensen et al. 2006; Soetaert et al. 2006; McQuatter-Gollop et al. 2009). Some of these changes highlighted by Giani et al. (2012) are: (1) a macrobenthos recovery in areas previously impacted by eutrophication; (2) decreasing trend in total biomass of target demersal fishes; (3) decreasing trend in small pelagic fish (e.g. anchovy) catches; (4) reduction of the average trophic level of fish community

However, changes in fish community structure did occur, possibly decreasing the ecosystem efficiency and resilience. The reversal in the eutrophication trend (oligotrophication process), and the consequent reduction in plankton productivity, altered this balance, possibly increasing the risk of collapse of fisheries and increasing the probability of occurrence of major changes in ecosystem structure and functioning. The increasingly frequent outbreaks of jellyfishes (Kogovšek et al. 2010), the endangerment of keystone species, the replacement of top predator species, the decrease in small pelagic catches are examples of such changes. Also the fact that the demersal/pelagic ratio has not been increasing, despite

the reductions in the eutrophication processes and in the frequency of hypoxia events might be seen as a symptom of the lack of resilience of the system (Giani et al. 2012).

4.3. Marine resources: food web changes

Marine resources availability is the results of many ecological processes. As showed in Table 1, Climatic processes, Variability in primary productivity, Habitats formation, Interactions and Movements of organisms, all play a role in defining the characteristics of resources that the marine ecosystem offers. In this part we discussed mainly about the changes that occur in marine food web and how these changes affect the exploitation of resources by humans too. The structure and composition of the marine food web are closely connected to the fishing effort, which is one of the biggest threats to marine ecosystems' integrity.

The Northern and Central Adriatic Sea is an important area for the reproduction of small pelagic fish (Agostini & Bakun 2002; Morello & Arneri 2009) and a strategic region for marine vertebrates' conservation (e.g. Zotier et al. 1999; Bearzi et al. 2004). Changes of pelagic and benthic marine communities have been described in the Adriatic Sea (e.g. Jukić-Peladić et al. 2001; Vrgoc et al. 2004). These changes are, at least in part, related to fishing (e.g. Pranovi et al. 2001; Bombace & Grati 2007), environmental factors (e.g. Marasović et al. 1995; Dulčić et al. 1999; Santojanni et al. 2006; Grbec et al. 2008), and other anthropogenic impacts such as eutrophication (e.g. Barmawidjaja et al. 1995; Sangiorgi & Donders 2004).

Furthermore, changes in marine resources due to natural or anthropogenic factors can be perceived at the food web level and have the potential to affect the structure and function of marine ecosystems with consequences for the management of natural resources (Coll et al. 2010a). In their research, Coll et al. (2010a) showed there were important changes taking place in the Northern and Central Adriatic Sea from the mid-1970s to the early-mid 2000s. In several cases, decreasing trends in target species were observed, in line with results from stock assessments indicating that several target and non-target demersal species are overexploited in the area (e.g. Jukić-Peladić et al. 2001; Vrgoc et al. 2004; Bombace & Grati 2007). These results suggest the trends occurred in parallel with a steady increase in fishing

effort, as well as an increase in the Human Development Index and changes in the environment, such as an increase in seawater temperature and changes in regional and global factors.

In addition to the general decreasing trends, Coll et al. (2010a) observed that several biomass and catch series increased from the mid-1970s to the early 1980s, before a strong decline was registered. This first increase could be due to indirect trophic effects such as trophic cascades (i.e. decrease in competition and predator release) as it was described for the Catalan Sea (Coll et al. 2008). The increase in catch and biomass during the 1970s could also be due to the increasing fishing effort, changing target species (e.g. towards invertebrate species), and/or to an increase of nutrient enrichment in the area. The eutrophication in the NAd began in the 20th century, reached a maximum in the late 1970s, and levels were still high during the early 1990s (Sangiorgi & Donders 2004).

Anyway, the Adriatic Sea is one of the Mediterranean areas with a relatively high availability of data. For example, Coll et al. (2010a) affirmed that the scientific trawl biomasses considered in their work, were mainly demersal and thus not adequate to capture changes in pelagic species. Data were mainly focused on fish species and a few commercial invertebrate species, so those data were not sufficient for analyzing changes in the lower trophic level organisms. On the contrary, the same data were valuable for analyzing changes in the demersal fish community (Coll et al. 2010a).

Another interesting result found by Coll et al. (2010) was the decrease of cetaceans as keystone group in the ecosystem, which has also been observed in other marine ecosystems (e.g. California upwelling and Catalan Sea; Libralato et al. 2006; Coll et al. 2009). This could be related to the decreasing population of these organisms in the Adriatic Sea (Bearzi et al. 2004). Also, the importance of the phytoplankton has changed. Coll et al. (2010a) showed the higher importance of phytoplankton in the mid-1990s in comparison to the mid-1970s, indicating that the ecosystem likely became more sensitive to changes in primary production and environmental forcing. In fact, the Adriatic Sea primary production is partially limited (Bosc et al. 2004) and is under the influence of local enrichment by river runoff or changes in current circulation and in salinity that produce temporal upwelling areas associated with higher productivity (Agostini & Bakun 2002). As discussed by Hughes et al. (2005), overexploitation and simplification of food webs decrease the resilience of marine ecosystems and increase their vulnerability to environmental change. This may also be the case for the Adriatic Sea (Coll et al. 2010a).

In addition, also changes in the structure and functioning of the Northern and Central Adriatic Sea ecosystems occurred. Time series considered by Coll et al. (2010a) showed a general decrease in biomass. Moreover, the mean trophic level of the community (mTL_{co}) suggests that the ecosystem progressed from low abundance of large slow-growing organisms towards higher importance of small and fast-growing organisms.

In general, results from Coll et al. (2010a) highlighted changes in ecosystem functioning during the 1990s: decreasing nutrient inputs due to changes in environmental policy may have influenced the decline in biomass and catches during this period (although eutrophication was still high during the 1990s; Sangiorgi & Donders 2004), in parallel with a continuous increase in fishing effort. Trophic spectra calculated from catch and data also showed this impoverishment of ecosystem biomass.

Overall, fishing impacts have increased in the Adriatic Sea over the last 30 years, while the ecosystem has progressed towards an altered and depleted state. There is a relationship between these changes and a fishing effort increase in the ecosystem, in addition to changes in the environment (Coll et al. 2010a). This supports the Adriatic Sea being ranked as one of the ecosystems most impacted by fishing, accounting for current states and recent trends (Coll et al. 2010b and references therein).

5. KEY ECOLOGICAL PROCESSES AT NATURA 2000 SITE SCALE: A MANAGEMENT POINT OF VIEW

In order to manage Natura 2000 sites and develop new and better conservation strategies, it is necessary to adopt an approach focused on the management and try to downscale the ecological processes seen in Table 1, at local scale. This means to consider elements that are measurable and evaluable through monitoring programs, to reach a whole knowledge of the sites and of the processes involved.

For each of the above-mentioned *challenges* (and the ecological processes linked to), we defined a set of possible measures and methods to describe and evaluate them (Table 3-5). We identified these

methods on the basis of information found in peer-reviewed literature (see authors and papers above-mentioned).

Table 3. Proposal of a monitoring program for “Eutrophication”

<i>Proposal of a monitoring program for “Eutrophication”</i>	
Main management challenges and ecological processes link to	1) Eutrophication (Space/time variability in primary productivity, Climatic processes, Hydrological processes) (RAC/SPA 2005; Bužančić et al. 2016)
Subject of monitoring	- DO (dissolved oxygen) - dissolved inorganic nutrients (DIN-nitrogen and DIP-phosphorus, SiSi-silica) - Chlorophyll <i>a</i> - Phytoplankton abundance and community composition
Frequency of monitoring	Monthly (seasonal cycle)
Other related elements to monitor	Physical-chemical parameters: - salinity - temperature - other nutrients (organic nutrient)
Standard monitoring program (proposal)	→ <i>Coastal/island N2K sites</i> 3(4) transects: - 1 near human activities, i.e. dock, harbor, boatyard, urban center, mussel farm, aquaculture, sewer pipe etc. - 1 near river outlet or freshwater input source (when present) - 1 far from human activities or presence (the farthest place possible) - 1 optional in a middle place depending on the space availability in the site 3 equidistant stations for each transect, according to a gradient near shore-off shore, of total length of 100m 3 sampling points for each station, at different depths depending on the site 3 replications for each sampling point → <i>Offshore N2K sites</i> 1 area of 100 m ² in which include 3 transects like above
Other indicators (Jensen et al. 2015 and references therein)	

<i>Proposal of a monitoring program for "Eutrophication"</i>	
<p>Macrobenthic assemblages have been used as an indicator of eutrophication in coral reefs and other coastal and estuarine benthic ecosystems. Other successful indicators include tissue C:N:P ratios and nitrogen stable isotopes ($\delta^{15}N$) in macroalgae, gastropods (rather long-term responding), and epilithic biofilms (rather short-term responding)</p> <p>In benthic ecosystems, the sediment-water interface is sensitive to eutrophication due to the settling and decomposition of the increased biomass of primary producers in the water column. Lehtoranta et al. (2009) proposed eutrophication thresholds for this organic carbon input to coastal ecosystems, which result in a shift in microbial sedimentary processes leading to anoxic conditions and a shift from iron reduction to sulfate reduction, thereby increasing the efflux of P from the sediment. This alters the biogeochemical cycling of P and may have wider ecological implications (Lehtoranta et al. 2009)</p> <p>Hyland et al. (2005) found that total organic carbon (TOC) concentrations in sediments in a range of temperate coastal ecosystems were a good indicator for benthic health based on benthic species richness</p>	

Table 4. Proposal of a monitoring program for "Maintenance/resilience of species and habitats and nonindigenous species (NIS)"

<i>Proposal of a monitoring program for "Maintenance/resilience of species and habitats and nonindigenous species (NIS)"</i>	
Main management challenges and ecological processes link to	2) Maintenance/resilience of species and habitats and nonindigenous species (NIS) (Interactions between organisms, Movements of organisms) (Giani et al. 2012 and references therein)
Subject of monitoring	<ul style="list-style-type: none"> - Submerged Macrophyte composition (soft-bottom areas) - Algal vegetation composition (rocky coasts) - Benthic macrofauna composition - Macroepifauna composition - Fish community composition and abundance - NIS
Frequency of monitoring	Seasonal
Other related elements to monitor	<ul style="list-style-type: none"> - Turbidity - Sea urchin population (abundance and distribution)
Standard monitoring program (proposal)	<ul style="list-style-type: none"> - Visual census: 3 transects of 100 m length, if possible, in the same area of monitoring program for "Eutrophication", through scuba diving sessions - Photographic quadrat samples - Scratching sampling - Oceanographic buoys (turbidity)

Table 5. Proposal of a monitoring program for “Marine resources: food web changes”

<i>Proposal of a monitoring program for “Marine resources: food web changes”</i>	
Main management challenges and ecological processes link to	3) Marine resources: food web changes (Climatic processes, Space/time variability in primary production, Hydrological processes, Formation of biophysical habitats, Interactions between organisms, Movements of organisms) (Coll et al. 2010a and references therein)
Subject of monitoring	- Fishing effort - Cetaceans monitoring - Fishing community
Frequency of monitoring	Seasonal
Other related elements to monitor	<u>Abiotic parameters:</u> - Sea surface water temperature (annual and winter mean °C) - Po River runoff (annual mean, hm ³ yr ⁻¹) (SINAPSI project, Italian Ministry for research [MIUR]) - North Atlantic Oscillation (NAO) Index (www.cgd.ucar.edu), both annual and winter values - Mediterranean Oscillation Index (MOI) <u>Human factors:</u> - Human Development Index (HDI; UNDP: http://hdr.undp.org/en/statistics/data/) - Nominal fishing effort.
Standard monitoring program (proposal)	Index application (scientific trawl surveys, fisheries data): mTLc The mean trophic level of the catch (mTLc) reflects the fishing strategy in terms of selected food-web components, and was defined as the weighted average TL of harvested species mTLco The mean trophic level of the community reflects the structure of the community and was defined as the weighted average trophic levels (TL) of all species Both indicators generally decrease with increased fishing impact due to a reduction in the number of large predators and a relative increase in lower TL organisms
Other indicators (Coll et al. 2010 and references therein; Pomeroy et al. 2005; Christensen & Walters 2004) The fishing-in-balance (FIB) index assesses whether catch rates are in balance with ecosystem trophic production due to catch at a given TL being related to assimilation efficiency of the ECOSYSTEM. A positive FIB value indicates that the fishery has expanded, or that bottom-up effects are occurring, so there is more catch than expected. The FIB index falls below zero when discarding occurs and discarding is not considered in the analysis, or when the fishing impact is so high that the ecosystem function is impaired Primary production required to sustain the catch. The PPR typically measured as t km ⁻² yr ⁻¹ , is obtained by back-calculating the flows, and is expressed in primary production and detritus equivalents for all pathways from the exploited	

Proposal of a monitoring program for “Marine resources: food web changes”

species down to the primary producers and detritus. This index can be expressed per unit of catch relative to primary production and detritus of the ecosystem (%PPR)

The loss-in-production index (L index) quantifies the theoretical depletion of secondary production due to fishing in an exploited ecosystem and increases with fishing impacts (Libralato et al. 2008). This index was proposed as a proxy to characterize the effects of fishing on the ecosystem, and to estimate the probability that the ecosystem is being fished in a sustainable manner. The L index can be used to estimate the probability that the ecosystem is being sustainably fished (P_{sust})

The modified Kempton’s index of biodiversity (Q' index), or modified biomass diversity index, measures the relative index of biomass diversity based on the calculations proposed by Kempton’s index expressing species diversity. This index represents the slope of the cumulative species abundance curve between the 10th and 90th percentile, but since it is applied using functional groups and biomasses, the functional groups are considered equivalent to ‘species’, and their biomass the number of individuals. This indicator is expected to decrease with increasing fishing impacts

How is your MPA doing? (Pomeroy et al. 2005) offers a process and methods to evaluate the effectiveness of MPAs for the purposes of adaptive management. The evaluation is based on indicators that measure the effectiveness of management actions in attaining goals and objectives that are specific to MPAs, the marine environment and coastal communities. It presents a flexible approach that can be used in many types of MPAs.

Ecopath with Ecosim (EwE) combines software for ecosystem trophic mass balance (biomass and flow) analysis (Ecopath) with a dynamic modeling capability (Ecosim) for exploring past and future impacts of fishing and environmental disturbances (Christensen & Walters 2004).

As regard to monitoring programs, we have proposed some elements to discuss to better reach the final objective of establishing ECOdAS. This proposal does not want to be a rigid and pre-established scheme, but something on which discuss among the project partners.

Finally, we reported each ecological process (see Table 1) that distinguishes each Natura 2000 site-case study according to its geographical position, physical characteristics, tourism and human pressure and, above all, species or habitats that characterize the site and for which the site itself has been established (Table 6). For each Natura 2000 site-case study, the parameters to be considered in monitoring are specified. The items listed in the “Human activities” category come from expert judgement. During the First Meeting of ECOS project (11th and 12th February 2020, Bologna), the partners representing the managing body of the selected Natura 2000 sites, worked together to identify the human activities that could influence each site.

Table 6 (A-D). Ecological processes and other characteristics for each Natura 2000 site-case study.

(A)

N2K site	HR3000161 Cres – Lošinj - HR3000469 Viški akvatorij
Target species/habitat	Dolphins (<i>Tursiops truncatus</i>)
Ecological processes	<ul style="list-style-type: none"> - Interactions between organisms - Movements of organisms - Space/time variability in primary productivity
Components to consider	<ul style="list-style-type: none"> - Fish community structure - Food web structure - Population connectivity
Human activities	<ul style="list-style-type: none"> - Fishery - Tourism (noise) - Land-based pollution - Scuba divers - Spearfishing

(B)

N2K site	HR4000015 Malostonski zaljev
Target species/habitat	1160- Large shallow inlets and bays 1170-Reefs <i>Pinna nobilis</i> , <i>Lithophaga lithophaga</i> , <i>Cymodocea nodosa</i>
Ecological processes	<ul style="list-style-type: none"> - Climatic processes - Space/time variability in primary productivity - Hydrological processes
Components to consider	<ul style="list-style-type: none"> - Temperature (seasonality) - Nutrients load and distribution - Salinity (influence of Neretva freshwater)
Human activities	<ul style="list-style-type: none"> - Land-based activities and related sewage - Fishery - Scuba diving - Oyster farming - Fish farming - Tourism (nautical) - Illegal fishing of <i>L. lithophaga</i>

(C)

N2K site	IT3330009 Trezze San Pietro e Bardelli - IT3250047 Tegnùe di Chioggia
Target species/habitat	1110- Sandbanks which are slightly covered by sea water all the time 1170-Reefs <i>Alosa fallax</i> , <i>Caretta caretta</i> , <i>Tursiops truncatus</i> , <i>Cladocora caespitosa</i> , <i>Geodia cydonium</i> , <i>Maerl (Lithothamnion philippii, Lithothamnion minervae)</i> , <i>Lithophaga lithophaga</i> , <i>Pinna nobilis</i> (the last 5 not in the SDF but important at a site and basin scale)
Ecological processes	- Interactions between organisms - Movements of organisms - Formation of biophysical habitats - Climatic processes
Components to consider	- Fish community structure - Food web structure - Bioerosion and bioconstruction rates - Patterns of dispersal and recruitment of species - Population connectivity
Human activities	- Fishery - Spearfishing - Smothering by fine sediment

(D)

N2K site	IT3270017 Delta del Po: tratto terminale e delta veneto - IT3270023 Delta del Po
Target species/habitat	<i>Alosa fallax</i> , <i>Acipenser naccarii</i>
Ecological processes	- Climatic processes - Space/time variability in primary productivity - Hydrological processes - interactions between organisms - Movements of organisms - Natural disturbance regimes
Components to consider	- Nutrients load and distribution - Fish community structure - Salinity (Po Delta freshwater/Sea exchanges) - Flood events (Po Delta freshwater/Sea exchanges)
Human activities	- Fishery - Maintenance works in the channels

Unfortunately, very little is known about this topic in each case study area. Information are fragmented and divided among the existing monitoring programs (and not always available) and is missing a full overview on each site. So, the lack of a management plan in each Natura 2000 site has an impact also on the level of knowledge of the sites themselves.

6. MAIN ECOSYSTEM SERVICES PROVIDED FROM NATURA 2000 SITES

In this section, we discuss briefly about ecosystem services (ESs). It is important to know that this is only a preliminary ES reporting because an in-depth ES analysis will be specifically developed in deliverable 3.4.1 (lead by University Ca' Foscari of Venice) of the project. ES classification used in this section refers to TEEB, Ecological and Economic Foundations (2010), adapted to marine/coastal ecosystem following Bohnke-Henrichs et al. (2013).

From a management point of view, the establishment and implementation of effective Natura 2000 sites addressed to the preservation of the marine environment in a healthy condition, provide relevant benefits for humans. As already said, these benefits are called ecosystem services and they supply both naturalistic and recreational worth.

We identified, for each Natura 2000 site, some of the main ESs, as reported below (Table 7). We started from the question: what kind of habitat is present in each site, and which are the provided ESs? In general, what is the main peculiarity of each site?

As one can see, there are many ES related even to just one aspect of each site. Beyond the priceless naturalistic and biodiversity value represented by Natura 2000 sites, it is also important to recognize the recreational value, given the growing tourist demand for coastal and maritime areas.

In accordance to our judgement, the ES highlighted in (Table 7) are the most relevant services provided by the selected Natura 2000 sites.

Table 7. Main ecological processes and their relevance in each Natura 2000 site-case study. Ecosystem services classification used: TEEB, Ecological and Economic Foundations (2010), adapted to marine/coastal ecosystem following Bohnke-Henrichs et al. (2013)

N2K site	Peculiarity	ES provided	Relevance
HR3000161 Cres – Lošinj - HR3000469 Viški akvatorij	Marine phanerogams meadows (<i>Posidonia oceanica</i>) Bottlenose dolphin (<i>Tursiops truncatus</i>) population	<p><u>Regulating services</u></p> <ul style="list-style-type: none"> - Contribution to the maintenance of a favorable global climate through the sequestration of climate-influencing substances (e.g. carbon sequestration) - Contribution to the maintenance of natural healthy population dynamics to support ecosystem resilience through maintaining food web structure and flows <p><u>Habitat/maintenance services</u></p> <ul style="list-style-type: none"> - Contribution to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation (e.g. nursery function) - Contribution to the maintenance of viable gene pools <p><u>Cultural services</u></p> <ul style="list-style-type: none"> - Provision of opportunities for tourist recreation linked with marine/coastal ecosystems (visiting, bathing, diving) 	<p><i>P. oceanica</i> is a Mediterranean endemic marine phanerogam. It is a habitat forming species because of its function as breeding and nursery area. Its presence contributes to increase biodiversity in the whole Adriatic Sea</p> <p><i>T. truncatus</i> is listed in Annexes II and IV of Habitat Directive. As cetacean, it's strictly protected in the EU</p>
HR4000015 Malostonski zaljev	Moderate natural eutrophicated system	<p><u>Provisioning services</u></p> <ul style="list-style-type: none"> - Seafood from aquaculture <p><u>Cultural services</u></p> <ul style="list-style-type: none"> - Provision of opportunities for tourist recreation linked with marine/coastal ecosystems (visiting, bathing, diving) 	Starting from evidences that the Adriatic Sea is going toward an oligotrophication process, this area acquires even more importance, especially in relation with human activities like mussel farming

N2K site	Peculiarity	ES provided	Relevance
		- Contribution of marine/coastal ecosystems to education, research, etc.	
IT3330009 Trezze San Pietro e Bardelli - IT3250047 Tegnùe di Chioggia	Bioconstruction	<u>Habitat/maintenance services</u> - Contribution to migratory species' populations through the provision of essential habitat for reproduction and juvenile maturation (e.g. nursery function) <u>Cultural services</u> - Provision of opportunities for tourist recreation linked with marine/coastal ecosystems (visiting, bathing, diving) - Provision of opportunities for recreational/sport fishing in marine/coastal ecosystems - Contribution of marine/coastal ecosystems to education, research, etc.	Trezze and Tegnùe represent a hotspot of biodiversity in the Northern Adriatic Sea due to their hard-rocky bottom that emerge from a muddy seabed. On and near these outcrops, there are sessile and epibenthic organisms, coral algae, as well as benthic and demersal fishes. They are also used as breeding and nursery area
IT3270017 Delta del Po: tratto terminale e delta veneto - IT3270023 Delta del Po	Brackish area/Freshwater input	<u>Provisioning services</u> - Fish and seafood extracted through artisanal fishery activities - Seafood from aquaculture <u>Regulation services</u> - Contribution to the maintenance of localized current structures <u>Cultural services</u> - Provision of opportunities for tourist recreation linked with marine/coastal ecosystems (visiting, bathing, diving)	Po River is the main contributor of freshwater in the Northern Adriatic Sea. The contribution of nutrients in the basin depends on its load. So, it's important to maintain and preserve at this role of balance

N2K site	Peculiarity	ES provided	Relevance
		- Provision of opportunities for recreational/sport fishing in marine/coastal ecosystems	

7. CONCLUSIONS

The result of this review showed that there is a widespread lack of information, mainly due to the lack of a management plan in the considered Natura 2000 sites. There is little information on the ecological processes, together with the little availability of data (most institutions that conduce monitoring programs do not open their data to the public). However, there is a real possibility of improving existing monitoring programs in order to achieve a wide coverage of the monitored area and focus on specific ecological factors to be monitored.

Finally, as scientific community, we are aware that a good environment is able to provide fundamental ES. ES are the direct and indirect contributions of ecosystems to human well-being and they support directly or indirectly our survival and quality of life. Climate regulation, provision services (fishing, mussel farming, seaweed farming, aquaculture etc.) but also cultural services (as the scientific, educational and entertainment values of natural locations) are a basic component of our life. In order to guarantee these services for us and for the future, assessing the links among ecosystem processes, functions and services also enables us to identify threats to the effectiveness of marine ecosystems of delivering ES due to unsustainable management practices (Banerjee et al. 2012).

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