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

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

WP3 – Design of the Ecological Observing System in the Adriatic Sea (ECOAdS)

3.3 – Identification of key oceanographic processes and performance indicators for Natura 2000 marine site

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CONTENT

1. INTRODUCTION

1.1 Activity 3.3 and deliverable 3.3.1

This deliverable is the result of the Activity 3.3 - "Identification of key oceanographic processes and performance indicators for Natura 2000 marine sites". It was prepared by OGS with the contribution of CNR, and inputs from SHORELINE, UNIVE and PIDNIC.

In accordance with what is reported in the application form, this deliverable aims at developing a conceptual model to connect ecological and oceanographic observations with performance indicators, proper for answering specific management questions on environmental quality, conservation and biodiversity of Natura 2000 (N2K) sites. That will include:

1) Identification of target species and of the ecological and oceanographic variables that may affect their life cycle.

2) Identification of key ecological process and of the ecological and oceanographic variables that may affect them.

3) Individuation of the main connections, synergies and gaps among different directives (MSFD, WFD and HBD), through harmonising and interconnecting of their main indicators.

4) Identification of goals, management objectives and performance indicators that are required for attaining proper conservation status of N2K sites.

1.2 Work outline

The present deliverable is divided into several sections. In the first part (paragraph 2) a clear definition of all the terms used in the conceptual model is provided, such as target species, ecological processes, performance indicators, ecological and oceanographic monitoring systems, management goals and objectives. This is crucial to make understandable each element of the conceptual model and the links among them. Some of the definitions were recalled from the previous deliverables of the ECOSS Project,

in particular the definition of ecological processes from deliverable 4.3.1[1] and of the ecosystem services from deliverable 3.4.1[2]. CNR contributed to define the performance indicators and to contextualize a comparative analysis of the main European Union (EU) directives to support the conceptualization of the model relating it to a legal framework.

In paragraph 3, we presented the generic conceptual model linking the ECOlogical observing system in the Adriatic Sea (ECOAdS) to the management objectives and goals and to the target species and ecological processes, which are the object of conservation. A detailed description of the concept behind its development and application, specifically for ECOSS needs, is provided. Each element, its spatial organization and connection with other elements of the model are also explained in detail and graphically represented.

Successively, for each N2K site selected as case study within ECOSS, we identified the target species (paragraph 4.1), the ecological processes (paragraph 4.2) and the environmental variables that may affect them, by using the outcomes of deliverables 4.2.1[3] and 4.3.1. Other deliverables (3.2.1[4], 4.1.1[5], 4.1.2[6]) were also consulted to get additional information on the conservation status of each species, their threats and the most important variables. Information provided by deliverable 3.1.1[7] was used to highlight the monitoring programmes in the project area that already collect some ecological data useful for assessing the status of target species and ecological processes. Thanks to this work, in paragraph 4.3, we outline a list of potential management goals and objectives for each N2K case study, based on their ecological characteristics.

With the contribution of CNR, we then carried out a comparative analysis of the main connections, synergies and gaps among different European environmental directives, harmonizing their main

[1] D4.3.1 Review of the knowledge of the ecological processes in the selected Natura 2000 sites.
[2] D3.4.1 Report on the ecosystem services to be used for monitoring ecological processes within the Natura 2000 sites.
[3] D4.2.1 Review of the knowledge of the target species at the selected Natura 2000 sites.
[4] D3.2.1 Report on environmental monitoring, protection strategies and management issues in marine area of the Natura 2000 ecological network.
[5] D4.1.1 Report on the characterization of the selected Natura 2000 sites.
[6] D4.1.2 Report on the relationships between ecosystem-level management goals with ecological variables and oceanographic processes and the performance indicators.
[7] D3.1.1 Report on the assessment of existing ecological monitoring programs and observing systems.

indicators (paragraph 4.4). Finally, taking into account the target species/habitats and the related ecological variables in the N2K case studies, for each management objective we defined one or more performance indicators that may help N2K management bodies to assess the effectiveness of their conservation measures.

2. DEFINITIONS

This paragraph provides the definitions of the keywords used in the generic conceptual model aiming at linking ecological observing systems with performance indicators and management objectives of the N2K sites selected as case studies within the ECOSS project. The definitions are not meant solely for the purpose of understanding the concepts behind the model, but also as a framework for all the ECOSS activities. Some of these definitions are given here for the first time, and they have been, whenever possible, taken from published scientific literature. Other definitions are taken from the ECOSS deliverables that were already approved.

2.1 Target species

Target species are all rare, threatened or endemic animals and plants targeted for conservation under the Habitats Directive (HD, 92/43/EEC) and Birds Directive (BD, 2009/147/EC). Their protection or re-establishment represents the primary management goal of the N2K network. The HD protects over 1200 target species – often collectively referred to as 'species of European importance'. The Bird Directive covers all bird species that are naturally present in the EU (about 500 species). A list of target species present inside N2K sites, compiled before their establishment, is reported in the Standard Data Forms (SDF) available at https://natura2000.eea.europa.eu/. A periodical assessment of the status of target species is required to evaluate the effectiveness of the N2K sites. Here, we will adopt this definition, also in agreement with the ECOSS deliverable 4.2.1, where a list of target species of each N2K site within the ECOSS project is reported.

2.2 Ecological processes

The definition of ecological processes adopted here was provided in the ECOSS deliverable D.4.3.1. Ecological processes were identified as intrinsic ecosystem characteristics that sustain biodiversity. A

number of biological, physical, and chemical processes, such as primary production and nutrient cycle sustain the ecological systems and allow production and transfer of matter between organisms and the physical environment (EPA 1999; Millennium Ecosystem Assessment 2005). For instance, Bennett et al (2009) identified different categories of ecological processes, such as climate and hydrological processes, natural disturbances events that change habitats and nutrients availability, or movement and interaction of organisms that influence the structure of communities and populations (for further details, see deliverable D.4.3.1). Monitoring and conservation of ecological processes, as well as target species, is crucially important in the ECOSS project, since they influence the assessment of the performance indicators of the conservation status in N2K sites. Nevertheless, the imperative to protect ecological processes is seldom translated systematically into explicit conservation goals or actions (e.g. Klein et al 2009). In the present deliverable, we will consider both target species and ecological processes as important for the conservation of the N2K sites and they will be included in the conceptual model.

2.3 Ecosystem services

The ECOSS deliverable D3.4.1 has defined the Ecosystem Services (ESS) as the contributions of ecosystem structure and function to human well-being (Burkhard et al 2012), resulting from the interaction with the social components (Reyers et al 2013; Rova & Pranovi 2017). ESS can be organized into four main categories, following the TEEB (2010) classification: i) regulating services, that are the benefits obtained from the regulation of ecosystem processes and influence climate, water flow, erosion, soil fertility and air and water quality; ii) provisioning services, that are the products obtained from the ecosystems; iii) cultural services, providing recreational, aesthetic, and spiritual benefits; iv) and habitat/maintenance services representing the capacity of ecosystems to provide living space for resident and migratory species, such as soil formation, photosynthesis, nutrient cycling and genetic diversity.

2.4 Physical ocean processes

Ocean processes are physical phenomena occurring in the world oceans and seas, which regulate trend, transport and flux of water, substances and organisms in the marine system. Water circulation around the oceans has direct impacts on climate, on nutrient availability and on the distribution and spread of

species. Examples of ocean processes include waves, current patterns, swell, tides, upwelling and downwelling (Carr et al 2011). Changes in ocean processes also produce modifications of the associated measurable variables, such as water temperature, light penetration, salinity and current velocity.

2.5 Global changes

In the last decades, human activities have caused global changes at different spatial and temporal scales. Multiple ecological levels are altered by global changes: from individuals to species, from communities to ecosystems and ecological processes, although the entity of such a change may vary according to local factors and the involved components. The rising of carbon dioxide (CO_2) is one of the most critical problems causing climate change (Pörtner et al 2014). Effects of climate change on the marine environment include increasing sea water temperature, rising sea level, acidification, increased ocean stratification, decreased sea-ice extent, and hypoxia (Diaz & Rosenberg 2008; Rhein et al 2013; Pörtner et al 2014; Howes et al 2015). The effects of such changes are diversified and often species-specific, ranging from regression and distribution shifts to widespread extinction (Brierley & Kingsford 2009). In particular, increasing seawater temperatures and water acidification are considered as the main direct and severe consequences of climate change in the marine environment (Bindoff et al 2007; Doney et al 2011). Warm-water species are being displaced towards higher latitudes and are experiencing changes in the size and productivity of their habitats (Parravicini et al 2015). Heatwaves are modifying the seasonality of biological processes, altering food webs with unpredictable costs for fish production and services provided by coastal ecosystems (Edwards & Richardson 2004; Cochrane et al 2009). Reef-building corals are also extremely vulnerable to warming, experiencing mass mortality through bleaching (Hoegh-Guldberg 1999). In addition, ocean warming is expected to act synergistically with acidification to push corals into conditions that are unfavourable (Gattuso et al 2015). Water acidification affects mainly organisms with calcium carbonate shells and skeletons by reducing calcification and the rates of repair, and by weakening calcified structures (Gattuso et al 2011). Exceeding limits of tolerance of species to warming and acidification can also have primary effects on growth, body size, behaviour, stress-response mechanisms, feeding, and reproductive success (Pörtner et al 2014; Zunino et al 2017).

Climate change does not act in isolation. Additional local pressures on marine ecosystems include overfishing, destructive fishing methods, coastal development, rising aquaculture production, chemical

pollution, intense use of fertilizers and invasive species (Halpern et al 2008). Ecosystem regression and loss due to these stressors is increasing, particularly in coastal systems, where it has been estimated that 89% of oyster reefs, 50% of salt marshes, 35% of mangroves, 30% of coral reefs, and 29% of seagrasses is already lost or degraded (Jackson 2010; Barbier 2012). Although the evolutionary potential for species to cope with global changes is uncertain, effects are likely to become increasingly important, given that climate change is expected to accelerate over the next decades (Doney et al 2011; Peters et al 2013; Molinos et al 2016). Thus, the synergistic effects of these multiple stressors on marine ecosystems should be considered as a whole, not as independent issues (Doney 2010). Developing adaptive management would allow to cope with the unknowable risks of global change and promote biodiversity conservation on the long-term. The establishment of marine protected areas (MPA) may also help reducing multiple local stressors on marine environment; however climate impacts should be also taken into account in order to avoid investments in areas that would not survive the next decades. Increase size and reduce the edge effect of MPAs, protect critical areas for species reproduction and development, increase connectivity among MPAs and adopt an ecosystem-based management are only some of the potential strategies that decision-makers may adopt to build resilience and redundancy in MPA network and limit the effects of global impacts on marine ecosystems (McLeod et al 2009).

2.6 Performance indicators

The term ‘‘indicator’’ is used often in ecology and environmental planning, with many different meanings, definitions and purposes and in various contexts so that there is no one-fits-all definition (Heink et al 2010). Among the many definitions of indicators (see Organisation for Economic Co-operation and Development, OECD; European Environment Agency, EEA, and many others), to which we refer in ECOSS, one of the broadest and all-encompassing (Heink et al 2010) is: ‘‘An indicator in ecology and environmental planning is a component or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals”.

Indeed, this definition integrates the different characteristics that an indicator should have: (i) be measurable, in a way to allow the measurement of the environmental phenomena; (ii) have at least one reference value (as a starting or final point), to allow the comparison of diverse environmental conditions and the observation of their changes in space and time; (iii) be understandable and clearly

associated to the aim it was selected for; and (iv) be sensitive to changes of the target it describes, to allow the evaluation of the level of achievement of environmental goals or to guide their establishment.

Indicators should be also considered as "boundary objects" (Star & Griesemer 1989) at the interface between science and policy, useful to communicate scientific information to policy makers and non-experts (Heink et al 2010). Indeed, by playing a crucial role for effective and coherent policymaking, they provide selected, aggregated and interpreted information with three major purposes (Stanners et al 2007): (i) deliver information on environmental problems, in order to support policymakers to evaluate their urgency (this is especially important for new and emerging issues); (ii) support policy development and priority-setting, by highlighting key factors in the cause-effect chain that affect environmental pressures and that policy can target; (iii) measure policy progress and evaluate the effectiveness of policy responses. Because indicators are multiple and can be adopted to describe diverse phenomena at diverse environmental and management complexity levels (Turnhout et al 2007), there is the need to diversify them for setting up a coherent indicators' selection for effective monitoring programs.

EEA (2002) divided the environmental indicators in four typologies depending on the target they should describe and the use for which they are selected:

• Type A: **descriptive indicators** of what is happening to the environment or human health, e.g. emissions and concentrations of pollutants.

• Type B: **performance indicators** linked to a reference value or policy target, illustrating how far the conditions are far from a desired level.

• Type C: **efficiency indicators** illustrating the efficiency of production and consumption processes, e.g. energy consumption per unit of output.

• Type D: **total welfare indicators**, which aggregate together economic, social and environmental dimensions to illustrate whether, overall, welfare is increasing.

The ECOSS project, through the establishment of ECOAdS, aims at supporting the realization of an *ad-hoc* monitoring approach able to describe the environmental state of N2K sites in the Adriatic Sea and to identify humans' derived pressures acting on them, and at helping the implementation of N2K network

by informing the present and future conservation and management goals and sustaining the achievement of EU Nature directives' objectives. For this reason, as a starting point, we focused our attention on two typologies of indicators fundamental for the settlement of a harmonised suite of monitoring indicators: Type A, descriptive indicators to describe the environmental state and its change in space and time; and Type B, performance indicators to describe and inform the management aspects.

The selection of the descriptive indicators is a process that mainly depends on the characteristic of the monitored natural component at the level of each biological organization (species, community, habitat, ecosystem), since they must be representative and able to describe its state. In the case of N2K sites, these would be ecological variables mainly in the form of target species and habitats, as well as oceanographic variables that play a key role within oceanographic processes fundamental for species and habitats life. Descriptive indicators' selection is also the key to be able to individuate possible pressures acting on a specific species, population, habitat or ecosystem leading to any variations from its original state. The performance indicators are clear attributes and consequences of management and are fundamental for tracking effectively the progress towards goals and evaluate the effects of management actions (Bundy et al 2019). Indeed, they are necessary to supervise the achievement of any management and governance objectives, which are usually described by one or more performance indicators that mainly correspond to the outcome-based results of management actions (Ehler 2003). The performance indicators may refer, for instance, to: the effective reduction of habitat loss and a higher water quality after management actions to limit the source of impact and pollution on the environment; the biodiversity recovery in a pre-impacted natural area after restoration actions; the increase of reproduction rate within the population of a threatened species after limiting its harvesting. Eventually, different descriptive indicators relate to one performance indicator, which describe the level of achievement of at least part of a defined management and conservation goal.

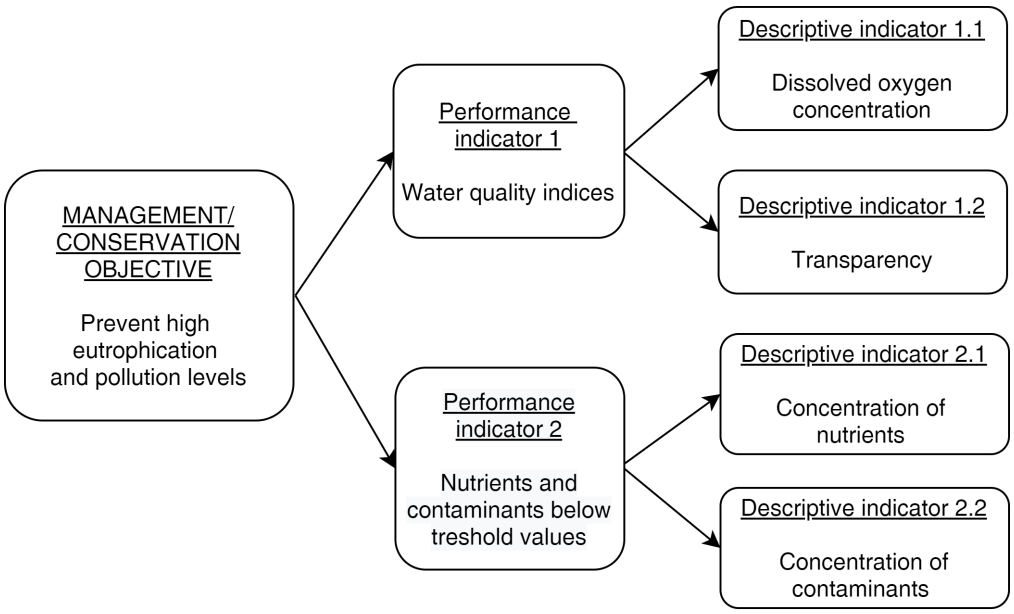

Fig. 1 Example of the relationships between management and conservation objective, performance indicators, and descriptive indicators or measurable variables.

In this deliverable we focus our attention on the indicators already defined in relevant policy instruments: the HD and BD, the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC). This first analysis, which will be further developed in the deliverable 4.4.1, entails a comparison among the four directives in any of their relevant aspects, even beyond the indicator one, and it is the starting point for the creation of a coherent and harmonised set of indicators to boost the monitoring and implementation of N2K network (see paragraph 4.4).

2.7 Ecological monitoring and ecological variables

Ecological monitoring is the process of periodical observations conducted at different spatial and temporal scales, giving information on environmental status (Vos et al 2000; Vaughan et al 2001). Monitoring programmes can be particularly important since they give information on the status of ecological processes and target species in selected areas by using descriptive indicators (or variables).

ECOSS deliverable 3.1.1 reported information on ecological monitoring programmes either performed in the past or currently still in place in the project area by the partner institutions, and the available level of knowledge with emphasis on the connections with the main EU Directives on environmental protection. Some examples include: bathing water quality monitoring, monitoring of seagrasses, macroalgae and coralligenous, ecosystem services assessment, fishing area mapping, and assessment of the quality of shellfish waters. Each monitoring presents a pool of investigated variables, in accordance with the most important European Directives, such as: population size and structure, habitat characterization, diversity indices, species composition, distribution, density and coverage. In the N2K sites selected as case studies in ECOSS, the descriptive indicators are the ecological variables, and oceanographic variables (see below), that give information on the state of target species and ecological processes, and on the level of natural and anthropogenic pressures that might affect them.

2.8 Oceanographic observing system and oceanographic variables

An oceanographic observing system is a network of instruments designed to monitor the state of the sea and helping in predicting how coastal environments will respond to anthropogenic alterations (Carr et al 2011; Crise et al., 2018). In ECOSS deliverable 3.1.1, a detailed compilation of the oceanographic observing programmes conducted in the past and still ongoing in the Adriatic Sea and managed by ECOSS partners is reported. Several types of instruments characterize the system: buoys, pylons, wavemeters, fixed platforms, fluvial currentometers, radar HF, and satellites. The observing system includes also the EU Copernicus Marine Service that provides forecasts, near-real time products and multi-year reanalysis, either from observations (satellite or in-situ) or from modelling products. The observing system collects periodically data of different oceanographic variables: physical parameters such as water temperature, salinity, water transparency, conductivity, fluorescence, current direction; chemical parameters as dissolved oxygen, pH, dissolved macronutrient concentration; meteorological parameters; and some biological parameters: chlorophyll a, phyto- and zooplankton abundance and biomass. Data collected by the oceanographic system within the frame of ECOAdS may help to detect changes in ocean processes, to define the performance indicators, and to foresee possible impacts on the ecosystems of each N2K site. Incorporating existing observing programmes into protected area monitoring designs is crucial to improve their effectiveness.

2.9 Protected area management goals and objectives

A management goal of a protected area is a long-term objective that describes or envisages the expected conservation state that protected area policies want to achieve and maintain. It generally takes the form of a broad statement and its purpose is to give a coherent direction to the management plan and objectives (Thomas & Middleton 2003). The statement should be clear and help understand people the reasons of the MPA establishment and the management actions. It should not change over time in order to give continuity to the conservation measures. The goals can be described as a set of economic, social, and environmental aspirations and could set targets or standards in several areas as ecosystem functioning, biodiversity conservation, local community participation, sustainability (Pomeroy et al 2004).

Management objectives, sometimes called purposes, are the specific statements that follow the main goal and set out the conditions that management aims to achieve. They are statements of the desired short-term 'outcomes' rather than how to achieve them. The objectives help managers with planning, measuring progress, and evaluating success (Thomas & Middleton 2003). They should relate to the key values of the protected areas (i.e. important species or ecosystems) or to major areas of management activity (e.g. tourism, education). Typically, objectives would be formulated to cover different aspects such as habitat and species protection, education, tourism management, protected area services, research and monitoring, social and cultural features. For each goal a series of specific, programmatic objectives should be listed and they must be met to accomplish the management plan successfully. A good objective should be specific, measurable, achievable, realistic and time-limited. They should be assessed at intervals to see if they need revision (Thomas & Middleton 2003; Pomeroy et al 2004; Wells & Mangubhai 2004).

In the application form and in the previous deliverables of the ECOSS project, the term 'management questions' was used instead of 'management objectives'. After careful consideration and discussion with the other ECOSS partners, we have decided to use the term 'management objectives' here and in the next deliverables, since this term is more widely used in MPA management science to indicate the desired outcomes of the management.

2.10 Public/management authority

In this deliverable we define as public/management authority, any public institution, private company, NGO, organization or association responsible to manage a protected area and, specifically in ECOSS, the N2K sites used as case studies. For each N2K site, the responsible management authority is reported in the SDF, section 1.6 "RESPONDENT(S)", which Member States (MS) transmit to the Commission in accordance with 97/266/EC Commission Decision of 18 December 1996 (Official Journal L 107, 24/04/1997).

In Italy, according to the Decree of the Republic President (DRP) n° 357/97, Regions and Autonomous Provinces are in charge of the implementation of all conservation measures to protect and monitor the N2K sites within six years from the adoption of the EC lists of Sites of Community Importance and six months from their establishment. Therefore, Regions and Autonomous Provinces are firstly responsible to assess if the existing conservation measures are appropriate and, if not, to put in place further measures (e.g. management plans). However, Regions and Autonomous Provinces can also adopt a specific legislation on N2K site management and delegate other authorities (Provinces, Municipalities, local communities, management bodies of protected areas) the assessment of the existing conservation measures, the implementation of management plans or any other action that should be carried out in order to guarantee N2K site protection (Ministero dell'Ambiente e della Tutela del Territorio, 2005). The designated authorities can be different depending on the site location and the type of action.

In case a N2K site falls within another protected natural area, the managing authority of the protected area identifies conservation measures as part of its own regulation and planning instruments (Calvario et al 2016). If the N2K site falls partially within another protected natural area, DRP 357/1997 specifies that "for the portion falling outside the perimeter of the protected natural area, the Region or autonomous Province shall adopt, after consultation with the relevant local bodies and the managing body of the protected area, all opportune conservation measures and management norms" (Calvario et al 2016). Thus, the adoption and approval of the conservation measures, always requires the involvement of the Regions/Autonomous Provinces, in collaboration with the State and local authorities. Finally, Regions, Autonomous Provinces and the managing body of the protected area can agree that the management of the N2K site, both the portion within the perimeter of the already existing protected

area and the portion outside it, is entrusted to the managing body of the protected area (Calvario et al 2016).

Regions and Autonomous Provinces are also obliged to yearly assess the conservation state of biodiversity in each N2K site and, based on the scientific results, they can propose new N2K sites, and modification of their borders or of the information contained in the SDF. The Italian Ministry of Environment submits the proposal to the European Commission (EC), and after approval, the Ministry implements changes by decree.

In Croatia, according to the Nature Protection Act and OG 80/2019, N2K sites are managed by Public Institutions (PI). A single PI may manage numerous sites. If a N2K site is also protected in the category of the national or nature park, or is within a park, bordering it or in larger territory overlapping with a park, park's PI is responsible for management. If a N2K site is protected in another category, County PI is responsible for management. If a N2K site is situated on the territory of more than one county – County PIs are managing it together. Management plans are mandatory for N2K sites and are adopted by PIs. Management plan for marine N2K sites, which are partly or entirely outside of Croatian territorial waters, but within sea borders under national jurisdiction, will be delivered by the Ministry responsible for nature conservation. Governance of protected areas can be also (partially) delegated. e.g. to NGOs (Ministry of Environment and Energy, and Croatian Agency for Environment and Nature, 2018).

2.11 Conservation measures

Article six of the HD requires that 'for special areas of conservation, Member States, shall establish the necessary conservation measures involving, if need be, appropriate management plans specifically designed for the sites or integrated into other development plans, and appropriate statutory, administrative or contractual measures […].' The HD also identifies 'the conservation measures as a series of measures required to maintain or restore the natural habitats and the populations of species of wild fauna and flora at a favourable status […]'.

Thus, conservation measures adopted in N2K sites can be identified as management plans or any appropriate statutory, administrative or contractual measures, defined by the law of each MS, that are finalized to regulate activities, uses and collection of organisms in the protected sites, and maintain

biodiversity. Management plans are not strictly required, according to the HD, if other mandatory conservation measures are already in place in the N2K site and result appropriate to protect target species and habitats, as required by the HD and BD. Nonetheless, management plans are strongly suggested and should establish both spatial and management measures for the conservation of species and habitats in need of protection and to the sustainable use of natural resources.

The effect of these measures has to be periodically monitored, by using performance indicators, with the aim to assess the management effectiveness and, in case, arrange adequate changes.

2.12 Stakeholders

A possible definition of stakeholder is 'any individual, group or organization who affects, or is affected by the situation being studied' (Grimble & Wellard 1997). Stakeholders can share a common interest, are usually active and interact with each other; nevertheless, they can be diverse, acting and interacting at different levels (e.g. from policy makers to local artisans) depending on the context. For the purpose of this deliverable, we define as stakeholders all those people who have an interest in the N2K site or its natural resources. We also recognize some groups of stakeholders as reported in RAC/SPA and IUCN-Med (2013): government (policy-makers, State/Regional/Municipal institutions); civil society (NGOs, universities, research institutes, local organizations); private sector (fisheries, touristic operators, coastal developers); and general public. All these groups of stakeholders could be involved in the management process of the protected area, but it is worth mentioning that their selection and the way they are involved in the process depends on the specific context of each MPA. Before starting any participatory process, management bodies should carry out a comprehensive stakeholder analysis and mapping, using some criteria that help in identifying stakeholders (Pomeroy & Douvere 2008). Such criteria may include:

- Existing legal or customary rights to the land or natural resources included in the protected area;
- Degree of economic, social and cultural dependence on the resources of the protected area;
- Present or potential impact of the activities of the stakeholders on the resource base;
- Equity in the access to the resources and the distribution of benefits from their use.

2.13 Human activities

For the aim of this deliverable, here we identify as human activities all those activities that depend on the ocean and coastal ecosystems for goods and services and that interact and affect the marine habitats and species of the N2K sites. Usually, such interactions have a direct or indirect effect on the environment (Lotze et al 2006). Ocean-based activities alter habitats, change species composition, sometimes favouring the proliferation of invasive species, and impact the water quality. Land-based activities increase chemical agents, debris and nutrients release into the sea, which may cause eutrophication and water contamination. However, the intensity of impact on the marine communities differs according to the human activities and to the spatial/temporal scales under consideration (Halpern et al 2008). A list of possible human activities related to the marine environment is reported in Table 2 of Annex III of the Marine Strategy Framework Directive (MSFD, 2008/56/EC). In order to adopt adequate regulation and ecosystem-based management measures (Costa et al 2016), a detailed analysis of all human activities and stakeholders present in the N2K sites and their interaction with the ecological components, should be performed.

2.14 EU Directives

One of the objectives of this deliverable is the identification of the main connections, synergies and gaps among different Directives focused on nature protection, through harmonising and interconnecting of their main indicators. The legal instruments here considered are: the Habitats Directive (HD, 92/43/EEC), the Birds Directive (BD, 79/409/EEC), the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC). We considered exclusively Directives focused on coastal and marine conservation, despite both the HD and BD are applied to both terrestrial and aquatic environments, to answer to the request of the ECOSS project, which is focused on the marine environment. A detailed description of and comparison between these Directives is reported in the paragraph 4.4.

In Italy, the HD and BD have been transposed by the Government with the Framework Law on Protected Areas (394/1991) and with the Framework Law 157/1992, respectively. Both laws were enacted with the DRP 357/1997, modified with the DRP 120/2003. The WFD was transposed with the legislative decree of 3 April 2006, n. 152. Specifically, Art. 64 divided the national territory into 8 River Basin Districts (map:

https://www.minambiente.it/direttive/recepimento-della-direttiva-italia) and assigned to District Authorities the responsibility to draft management plans for each district. However, only with the law 13/2009 ('Special measures on water resources and environment protection'), the River Basin Authorities had the power to develop the management plan, working together with the regional representatives (for more details: Balzarolo et al 2011; www.minambiente.it/direttive/direttive-acque). The MSFD was transposed with the legislative decree 190/2010. The Italian Ministry of Environment, Land and Sea (IMELS) is the responsible Authority for the implementation of the Directive. IMELS has charged a Technical Committee for the definition of the marine strategy documents (Art. 5), while the Italian National Institute for Environmental Protection and Research (ISPRA) offers the scientific-technical support (website: www.strategiamarina.isprambiente.it).

Croatia has partially met HD and BD through the Nature Protection Act and its additional emendations (OG 80/2013, 15/2018, 14/2019, 127/2019), while the WFD was transposed through the Water Act (OG 66/2019). There are two River Basin Districts: the Danube River Basin and the Adriatic Sea Basin. At national scale, a single management plan was developed by the Croatian Waters (CW) in June 2013 for both districts. CW is responsible for river maintenance and flood protection, drainage system maintenance, management of public water, water use and water protection. CW also externalizes some activities, such as monitoring to scientists and environmental impact companies (for more details: Zaharia et al 2018). At present, Croatia adopted and reported the second generation of River Basin Management Plan (RBMP) under the WFD and the EC assessed the status and the development since the adoption of the first RBMP, including suggested actions in the 2017 EIR. The country transposed the MSFD through the 'Regulation establishing the framework for action of the Republic of Croatia in protection of marine environment' (OG 136/2011) and the 'Regulation on preparation and implementation of documents under the Marine Environment and Coastal Area Management Strategy' (OG 112/2014, 39/2017, 112/2018). Within the framework of the Strategy development, and based on its preparatory documents defining the Initial Assessment, Good Environmental Status (GEnS) and Goals related to achieving GEnS in marine environment, the Croatian Government adopted two important documents: 'System for marine environment surveillance and monitoring' (OG 153/2014) and 'Programme of Measures for the Protection and Management of the Marine Environment and Coastal Zone of the Republic of Croatia' (OG 97/2017). The competent authority for implementing the

Regulation is the Ministry of Environmental Protection and Energy, which is at the same time also the coordinator for collaboration with other competent bodies (Luttenberger & Slišković 2020; website of the Ministry of Environment: mzoe.gov.hr/o-ministarstvu-1065/djelokrug-4925/vode-i-more/strategija-upravljanja-morskim-okolisem-i-obalnim-podrucjem-1441/1441).

2.15 ECOAdS

The Adriatic Sea is under the joint impact of multiple stressors (e.g. climate change, pollution, fishery, mariculture, tourism, maritime traffic, coastal development, alien species invasions), requiring for a joint, systemic and integrated management of coastal and marine resources. Challenges related to the health and function of the marine ecosystem need an innovative integration of ecological and oceanographic research with conservation programmes, across a wide range of temporal and spatial scales.

ECOSS project overall objective is the establishment of an ECOlogical observing system in the Adriatic Sea (ECOAdS), shared between Italy and Croatia, and eventually extended to other Adriatic countries, able to integrate the ecological and oceanographic research and monitoring with the N2K conservation strategies. The realization of the ECOAdS is an invaluable tool for the implementation of EU Environmental Directives, for defining GEnS under the MSFD, for improving the management and expansion of marine N2K sites, and for implementing the 2020 target of the EU biodiversity strategy. The creation of marine ecological observatories, able to maintain long-term ecological observations, is also required by the EUSAIR Action Plan. ECOAdS will tightly connect, in a permanent and stable partnership, different actors in the science-society-policy context, within each Country and across the two Countries, through a joint partnership for the monitoring of ecosystem, biodiversity, and resources to support their management. ECOAdS will be built on the facilities, infrastructures and long-term ecological monitoring and observing systems already existing in the Adriatic Sea. The N2K sites considered in ECOSS will be used as case studies for the establishment of the ecological observatory ECOAdS. The development of case studies on selected N2K sites, will allow testing the usefulness and the relevance of the ecological observing system to support significant management questions in biodiversity conservation. In particular, data on ecological and oceanographic processes and variables collected in ECOAdS will be useful to get information on the status of performance indicators adequately identified to assess the conservation effectiveness of N2K sites in the project area. The results will affect

the marine N2K sites only with soft intangible measures, since they will identify performance indicators and will give indications on improving the management and possible expansion of the protected sites.

Following the principles of open science, data collected within the frame of ECOAdS will be made, whenever possible, available publicly through an online platform, to any private and public users which might be interested in using them. The sustainability and maintenance of ECOAdS on the side of the involved countries and regions, will be guaranteed after the end of the project by the ongoing national monitoring programmes for the implementation of the EU Directives. On this point, a specific roadmap document within the Activity 3.5 will be produced in the next months to define the long-term strategy for the development and maintenance of the ECOAdS.

3. GENERIC CONCEPTUAL MODEL

3.1 Introduction to conceptual models

Conceptual models are schematic representations of the reality and are created to visualize a more complex process or system in a simpler way. They tell the story of "how the system works" and are descriptions of the general relationships among essential elements of the system (Fischenich 2008). The most common types of conceptual models are those that have a narrative, tabular, matrix, or a schematic form (Gucciardo et al 2004). Narrative conceptual models generally use mathematical and symbolic formulas or word descriptions or combinations of both. This kind of models does not use any visual presentation of important linkages. Tabular or matrix conceptual models are tables or two-dimensional arrays of elements in some form of a row-column structure, but they may be difficult to comprehend due to the high amount of information. Schematic conceptual models reduce the system to key elements and relationships, are intuitive, but may result too simple to model complex ecosystems or interactions. They can generally be classified as picture models or box-arrow models, which may be state transition, hierarchical, or input-output (Fischenich 2008; Gucciardo et al 2004).

Well-developed conceptual models effectively communicate which elements are essential to understand the problem and which are outside the control of the modeller. Regardless of the kind of model format, they should be relevant to the problem and appropriate to the examined spatial and

temporal scales. Good models also have a tolerable balance between oversimplification and excessive complexity. Conceptual models can be useful to different aspects. They can synthesize scientific understanding of a system and guide next studies, provide a "mental picture" from which to develop alternatives, bring all the planning work accomplished so far into a visual scheme, help in emphasising an underlying problem, provide a basis for identify causes and effects, reveal missing information, highlight the key element of a system and how they are connected, identify appropriate monitoring indicators and metrics, and serve as a good communication tool to build understanding and consensus among stakeholders (Fischenich 2008; Di Gennaro et al 2012). Some examples of practical application to different projects are reported in Fischenich (2008) and Margoluis et al (2009).

Conceptual models are particularly useful tools in guiding MPA management. They are the frameworks on which the management plan of protected areas is built. Through a flow diagram, they connect objectives, inputs, outputs and outcomes, and provide a visual depiction of what results a program will produce and how. Bringing different steps of the planning process together helps to link all the elements and provides a roadmap of information to support the next actions. Conceptual models lay out the basic information needed to structure the plan, such as the target species and habitats, the source of impacts, the services provided by the ecosystems, the specific human-use activities and how they alter the environmental ecology. This information then will provide the basis for implementing management strategies.

Conceptual models are also useful in the framework of adaptive management since they serve as a "memory" of the work done to implement the management plans, they help interpret results of monitoring programs and explore alternative ways and the foreseen responses. Hypotheses about uncertain relationships between elements may be tested and the model can be revised. Indicators for this process may be bio-physical, socio-economic or of governance, focused on communities, populations or species (Fischenich 2008; Pomeroy et al 2004).

However, conceptual models have also some limits. They are not the truth (i.e. they are simplified depictions of reality), they are not definitive, since they provide a flexible framework that evolves as understanding of the problem increases, and neither are comprehensive since they focus only upon some elements of the system to analyse.

3.2 Set up of the conceptual model for ECOSS

The generic conceptual model here presented, specifically created to answer to the request of the ECOSS project, consists of a schematic conceptual model (box-arrow model) that displays and simplify the most important socio-ecological elements related to the management of N2K sites and their connections. In particular, it highlights the role of ECOAdS in collecting ecological and oceanographic variables that feed performance indicators, which in turn allow assessing if management objectives are being achieved in N2K marine sites. Even if the model is focused on MPA management, we want to stress that it has not been developed to plan all conservation actions needed to control impacts and achieve goals in MPAs. Many other solutions already exist in this context, such as the ISEA diagram (www.progettoisea.it) by MIRADI software (www.miradi.org), whose application is mandatory for all Italian MPAs.

To create the model we used the software Cmaps v 6.04 (https://cmap.ihmc.us/), which allows constructing, sharing and modifying online knowledge models represented as concept maps. We followed a step-wise process for formulating the conceptual model, as described in Grant et al (1997). We first stated the model objectives and the system of interest. Then, we identified the critical model elements within the system of interest and articulated the relationships among the elements. Finally, we represented the conceptual model graphically and described the expected pattern of model behaviour.

The idea behind the creation of this model was to connect the ecological/oceanographic observing systems with the management of N2K network. In fact, the main goal of ECOSS project is to integrate ecological and oceanographic research with N2K conservation strategies, in order to implement EU Environmental Directives and improve the management of ecosystems in marine N2K sites. The formulation of the model required a deep understanding of all the key elements related to the management of protected areas. Every aspect of the N2K management was identified and broken down into different parts, connected according to their relationships. However, we tried to keep as simple as possible the model by avoiding an overcrowded scheme and include too many relationships among the elements. Thus, only the most important elements and relationships are shown (Figure 1). We split elements in social, ecological and oceanographic elements. Social elements (yellow boxes in Figure 1) are characterized by all those elements concerning the governance domain of N2K management: EU Directives targeted by ECOSS (i.e. HD, BD, WFD, MSFD), the public/management authority of the N2K

sites, the management goals, objectives, conservation strategies, the stakeholders involved in the N2K sites and human activities. The ecological elements (green boxes) identified are: target species and ecological processes for which N2K sites were designated, the ecosystem services, the ecological monitoring programmes and the ecological variables they measure. Oceanographic elements (blue boxes) include: global changes, ocean processes, oceanographic observing system and the monitored oceanographic variables. Performance indicators constitute a cross-cutting element (orange box), since they can be obtained from single ecological or single oceanographic variables, combinations of multiple ecological or multiple oceanographic variables, or even combinations of one or several ecological variables with one or several oceanographic variables. The monitoring programmes, the variables and the performance indicators are then all included in the ECOAdS box (red box in Figure 1).

All the elements are strictly connected one other and the change of one determines changes in many others. Starting from the top of the model (Figure 1), we outlined that the EU Environmental Directives ask management bodies to define the conservation measures and management goals of N2K sites. At the same time, the EU Directives also demand the effectiveness of these measures to be assessed and this can be done by adopting performance indicators. Goals can be then split in more management objectives that in turn influence the choice of conservation measures. Since in MPAs the socio-economic component is relevant, management bodies generally engage stakeholders to discuss limitation of the activities in the N2K sites and agree on the conservation measures. In fact, human activities in the N2K sites can directly affect species and ecological processes targeted for conservation. In case anthropogenic pressures induce changes in natural resources, effects can reduce functions and services provided by ecosystems. For a far more complete model centred on the ecosystem services developed in ECOSS, we refer to the one proposed in deliverable 3.4.1. Natural processes and events can also affect target species and ecological processes. For instance, global changes and ocean processes are two of the main drivers of change for biodiversity and ecosystem functioning. In this context, ECOAdS plays a crucial role since, through ecological and oceanographic monitoring programmes, it collects data on environmental variables related to target species and to both ecological and ocean processes. Descriptive variables, which depict the status of the system, are then used to obtain performance indicators that, at the end, track the progress towards goals and evaluate the effects of management actions.

Graphically, the conceptual model consists of several boxes containing the elements related to the management of N2K sites. There is no distinction in terms of size of the boxes, while the colour defines the kind of elements related to the N2K management. The spatial arrangement of the boxes in the model follows a hierarchical organization: boxes at the top and at the bottom of the model refer to global aspects such as EU Directives, wide-scale monitoring programmes and ecosystem services, while in the centre of the model, the elements are related to local aspects of the N2K sites, such as goals, objectives, target species and ecological processes. Arrows indicate the relationships among the elements. They can go in one direction from one box to another or can be bi-directional in case elements are expected to influence each other. Dotted lines indicate data flow, while continuous lines indicate a causal relationship between two boxes based on the direction of the arrow. Terms upon arrows specify the type of relationship linking two boxes (Figure 1). While the conceptual model was built around the need to manage N2K sites, i.e. with the box 'MPA Management Goal' as an entry point, different users may use different entry points according to their needs: a stakeholder may start at the Stakeholder box, a public authority at the Public/Management authority box, and so on.

Furthermore, the conceptual model is not meant as a blueprint for the implementation of the technological and informatics solutions of ECOAdS. ECOAdS box occupies a preeminent position in the conceptual model in order to make clear the way in which ECOAdS will be integrated in the management workflow of the N2K sites. Its implementation as an online portal where a user can have access to information and links to the existing monitoring programmes, observing systems and publicly available databases, would need a different, spatially and temporally constrained query system, which is outside the scope of the conceptual model developed in this activity. This general conceptual model can be applied to any N2K case study. For a correct application, the first step is the identification of the specific elements of the boxes: species, habitats, ecosystem services, the management body, specific human uses and stakeholders and the relevant ecological and oceanographic processes. A practical application of this general model to the N2K case studies within ECOSS will be presented in the deliverables 4.2.2[8] and 4.3.2[9].

[8] D4.2.2 Report on the application of the conceptual model linking oceanographic processes, performance indicators and management questions for target species.
[9] D.4.3.2 Report on the application of the models linking oceanographic processes and management questions.

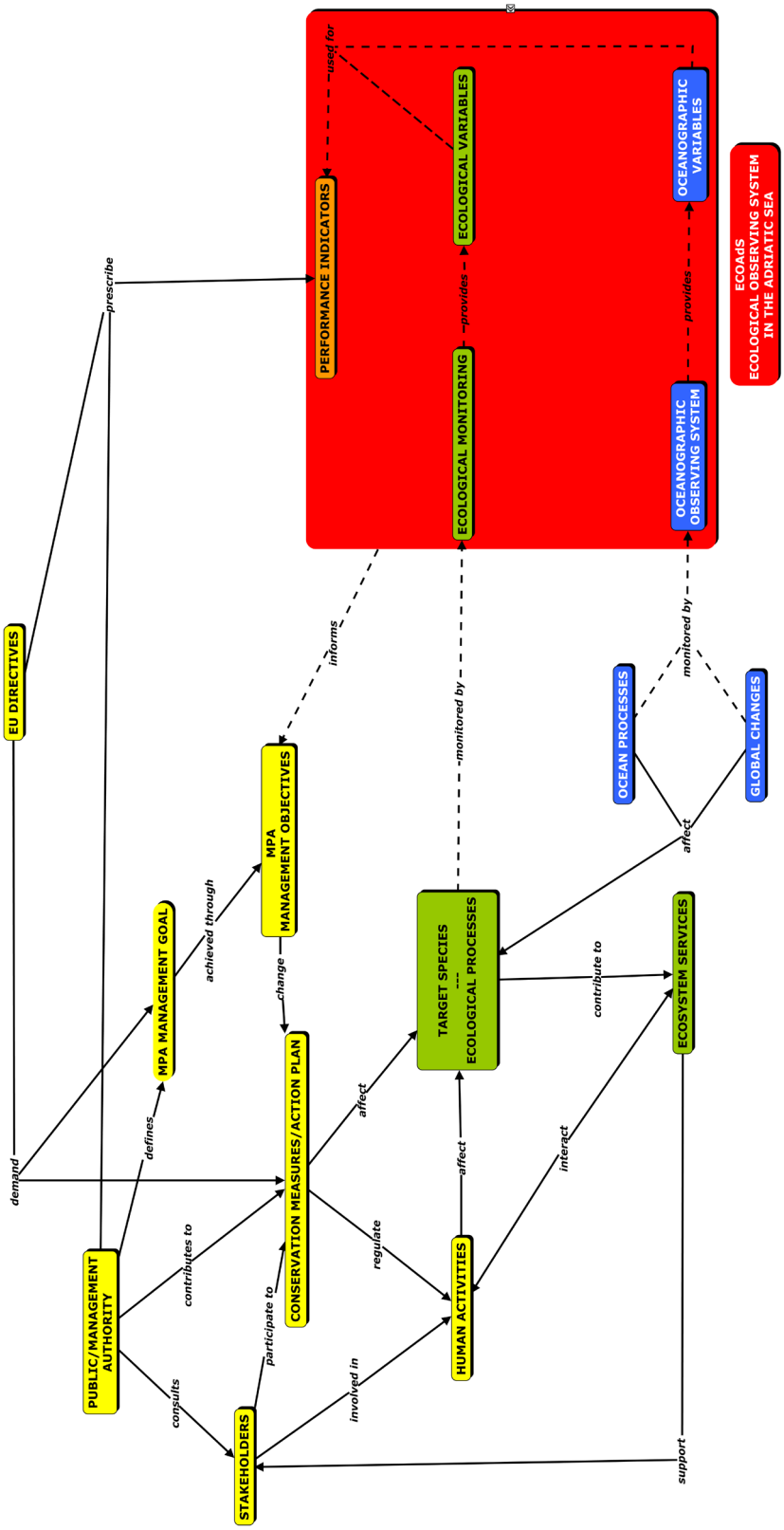

Figure 1. Generic conceptual model linking ECOAdS with MPA management and EU Directives.

4. INDIVIDUATIONS OF ELEMENTS FOR THE CONCEPTUAL MODELS OF THE N2K CASE STUDIES

4.1 Identification of target species and of the ecological and oceanographic variables that may affect their life cycle

Target species of the N2K sites, selected as case studies within the ECOSS project, were derived by the deliverable 4.2.1, the SDF of the N2K sites and by expert opinion. Oceanographic/ecological variables that potentially affect target species were identified by using information in the deliverables 4.1.1, 4.1.2 and 4.2.1, the criteria listed in the HD, BD, WFD and MSFD (see paragraph 4.4) and the available scientific literature on Google Scholar. A complete summary is shown in Tables 1-4, together with the source of literature divided in specific studies carried out in the N2K sites and general studies related to the identified target species (note that the literature may not be exhaustive). In Tables 1-4 we have also reported the ecological monitoring programmes and observing systems in the project area that already assess some of these variables inside the N2K sites or in the surrounding area, as described in the deliverable 3.1.1. It is worth noting that the list of ecological variables we suggest to monitor for each target species and N2K site, is not meant to be definitive: management bodies can adapt monitoring programmes based on what has already been done, their available resources (time, equipment, facilities, funding, people), and new threats that may arise.

The considered N2K sites are: Malostonski zaljev (HR4000015), Cres-Lošinj (HR3000161), Viški akvatorij (HR3000469), Trezze San Pietro e Bardelli (IT3330009), Tegnùe di Chioggia (IT3250047), Delta del Po: tratto terminale e delta veneto (IT3270017) and Delta del Po (IT3270023). Since some of these sites share similar ecological/geographical features, they were treated together and thus a total of 4 case studies were analysed (see also deliverable 4.1.2):

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

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

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

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

The N2K sites of Cres – Lošinj and Viški akvatorij in Croatia are two of the most important feeding and breeding areas for the common bottlenose dolphin (*Tursiops truncatus*) in the Eastern Adriatic Sea and they were both established to protect this species (the only one listed in their respective SDFs) (Table 1). Research on *T. truncatus* started in 1987 in Cres – Lošinj and has been ongoing since then (deliverable 4.1.1). Until 2004 field work was conducted in summer seasons only, while since 2005 it is performed all year round. The field work is mostly concentrated within the Cres-Lošinj site with significant parts of surrounding areas also covered, albeit with less intensity. Based on the results of the monitoring programs, the Cres-Lošinj N2K site is inhabited by approximately 224 common bottlenose dolphins, which show long-term residency to this area (deliverable 4.2.1). In the Viški akvatorij N2K site, research on the common bottlenose dolphin started in 2007 and has been conducted during summer seasons. The research effort is highest within the site, while surrounding areas are covered with less intensity. Based on the results of the monitoring programs between 2007 and 2018, the population can be considered stable (about 261 individuals) (deliverable 4.2.1). Possible threats for *T. truncatus* in these sites are: shipping lanes, ports, marine constructions, water pollution, fishing, marine litter, noise pollution, and recreational activity (e.g. nautical sports).

The Malostonski zaljev N2K site protects two target habitats listed in the Annex I of the HD: 'Reefs' (1170) and 'Large shallow inlets and bays' (1160). There is no target species listed in the SDF. Protection of the ecological conditions of the bay indirectly guarantees the conservation of traditional shellfish farming that represents an important income for the area in terms of production and tourism (deliverable 3.2.1). However, important target species were also identified by expert opinion in the deliverables 4.2.1 and 3.2.1 and during the ECOSS first meeting (Bologna, 11-12/02/2020): *Fucus virsoides, Cymodocea nodosa, Posidonia oceanica, Pinna nobilis, Alosa fallax* and species forming coralligenous assemblages on rocky substratum (Table 2). These species can suffer different impacts. Alteration of physical parameters due to climate change has well-known effects on most of benthic species, in particular for cold-water species, such as *F. virsoides* (Kremer & Munda 1982), or for those involved in calcification processes (i.e. coralligenous species) (Zunino et al 2019). Direct human impacts such as trampling on *F. virsoides* or anchoring on *C. nodosa* and *P. nobilis*, can also affect their survival

(Montefalcone et al 2008, Vázquez-Lui et al 2015). Other potential threats for these target species in the Bay of Mali Ston may be the loss of physical habitats, the reduction of water quality due to high nutrient loads, pollutant loads, and high sedimentation rates (Carić & Jasprica 1997; Benović 2008; Kremer & Munda 1982; Kljaković-Gašpić et al 2007; Deudero et al 2015). Finally, *P. nobilis* is experiencing massive population reduction in the whole Mediterranean due to the parasite *Haplosporidium pinnae* (Catanese 2020).

Trezze San Pietro e Bardelli and Tegnùe di Chioggia have been established to protect the same habitat type: the mesophotic biogenic reefs of the Northern Adriatic Sea. They also share the same ecological/oceanographic processes and are potentially subject to the same impacts, even if they are more than 40 nm distant (Falace et al 2015). In the SDF of both sites, many benthic species are listed. All together they contribute to form coralligenous-like concretions and shape these biogenic reefs (Ballesteros 2006; Falace et al 2015). Thus, target benthic species for these two sites were here grouped together under the name “Coralligenous community” (Table 3). These reefs have great importance for several pelagic and demersal species, both as spawning areas and nurseries, and as refuge for adult specimens (Ingrosso et al 2018). Bio-concretions observed on these rocky outcrops are formed by aggregation of many organisms that compete for space and light: sponges, Corallinaceous red algae (mainly *Lithophyllum incrustans* and *Lithothamnion calcareum)*, tube worms (e.g. *Serpula* spp.), molluscs (e.g. *Arca noae, Gastrochaena dubia, Chama gryphoides; Lithophaga lithophaga*), bryozoans, brown algae, boring sponges, anthozoans (e.g. *Cladocora caespitosa*) (Ponti et al 2011; Falace et al 2015). On sediments close to the reefs, the noble pen shell (*P. nobilis)*, listed in the Annex IV of the HD, can be also observed. Some individuals of *Caretta caretta, T. truncatus*, *A. fallax* and seabirds (*Larus melanocephalus; Phalacrocorax aristotelis; Puffinus yelkouan*) have been reported inside the N2K borders, but there is no specific information on their spatial/temporal density and distribution (Table 3). Possible threats that may affect mesophotic biogenic reefs include: nutrient load and pollution from the mainland, scuba diving disturbance, illegal fishing, burial due to bottom trawling performed in neighbouring areas, and increased sea water temperature and acidification due to climate change.

The two Delta del Po N2K sites are geographically overlapping and compose a single river-delta-sea system with the same species. The majority of the species are exclusively related to freshwater and terrestrial habitats. For the aim of this project and based on expert opinion, only species strongly

dependent on the marine environment, where they can be observed regularly or during some stages of their life cycle, are listed here. In particular, different migratory and sedentary seabirds (*Sterna albifrons; Sterna hirundo; Sterna sandvicensis; Sterna nilotica; Sterna caspia; Larus ridibundus; Larus genei; Larus melanocephalus; Phalacrocorax aristotelis*) all listed in the Annexes I and II of the BD, can be observed in colonies in lagoons, coastal dunes, and on sea water surface during different seasons while feeding, resting or nesting (Table 4). They are subject to different threats in the two N2K sites: anthropic disturbance, habitat degradation, loss of nesting sites, hunting, interaction with fishing activities, water pollution, and predation by terrestrial predators and the yellow-legged gull (Ente Regionale Parco Delta del Po 2010). Species of particular value are also some anadromous fish (*A. fallax, Acipenser naccarii, Petromyzon marinus*) that migrate from sea to the upper part of the rivers for reproduction. They are all included in the Annex II of the HD. The Adriatic sturgeon (*A. naccarii*) is a priority species since it is endemic in the Adriatic Sea, and its natural population has drastically decreased (Meadows & Coll 2013) (Table 4). Currently, several conservation attempts are trying to restore this species, also in the Po Delta, and improve its genetic pool (Caramori et al 2007); however the restoration activities have been focused only on the rivers of the N2K sites, without taking into account the marine environment that it is not included in the protected areas, but where the species can also live. The main threats that affect these species are: migratory route obstructions, habitat degradation, water pollution, competition with invasive species and (illegal) fishing. Other marine species that were reported in the Po Delta are three seagrasses (*C. nodosa*, *Zostera noltii* and *Zostera marina*). However, limited information is available on their distribution, abundance and conservation status in the N2K sites (Ente Regionale Parco Delta del Po 2010) (Table 4). Seagrass monitoring programmes in the Po Delta are strictly urgent to avoid possible impacts due to different threats such as dredging, aquaculture, anchoring, eutrophication, herbicides, invasive species, maintenance works that increase burial and turbidity, changes in salinity and temperature.

The potential variables here identified to explain the status of the target species are in many cases similar for all N2K sites (Tables 1-4). The most important variables are those that give information on population structure of target species. Population structure can be defined in two different ways. Ecologists usually consider the composition of a population according to age, sex, abundance of individuals, while geneticists consider the genetic variation within and between populations (Rockwood

2015). Both views are correct and linked since the size, density, mortality and growth rates, and the amount of larvae production, influence the propensity of individuals to disperse, the genetic flow exchange, and the possibility to colonize new areas. Genetic diversity may give clues on the connectivity between populations, the possibility to evolve in response to changing environmental variables and on their potential destiny, such as diverging into separate species or going extinct (Rockwood 2015). This is critical in term of conservation and restoration since it affects the choice of protection actions that should be undertaken. If possible, all kind of variables related to population structure should be collected, among them: density, abundance, age, sex, size, biomass, percentage cover, birth-growth-mortality rates, spatial distribution and movements, settlement and recruitment rate/success, genetic information and, for some species (e.g. invertebrates, algae, fish), larval production and dispersal and spawning rate.

Other variables that should be always measured are those that give information on chemical-physical habitat alteration and climate change: temperature, salinity, pH, dissolved oxygen, water level, current velocity and direction, turbidity, wave exposure, nutrient and contaminant concentration in water and sediments, type of sediments/substratum, sedimentation rate. Variations in values of some of these variables can be particularly important for the ecology of some species, while totally irrelevant for others. For instance, wave exposure and sedimentation may affect *C. nodosa* and *P. nobilis* (Infantes et al 2011; Coppa et al 2013), but not seabirds. Water parameters, such as salinity or nutrients, have a great effect on anadromous fish or sessile species (McKenzie et al 2001; Piazzi et al 2011), but they do not have any known effects on dolphins. Contrarily, temperature has been observed having an impact of different magnitude on several traits of numerous marine organisms (Poloczanska et al 2013), including some of the target species here identified.

A different pool of variables, but equally important for assessing the status of target species, are those that quantify the level of pressure and potential impact derived from the human activities. Also in this case, the presence and distribution of anthropogenic pressures potentially affecting the species depend on the presence of human activities, their frequency and spatial footprint, their overlap with species distribution and their capacity to interfere with species ecology and behaviour. In the N2K case studies, for instance, professional fishing can directly reduce population of target species by decreasing prey availability for seabirds, dolphins and fish (Piroddi et al 2011), or cause behaviour changes and increase the interaction of individuals with fishing activities for feeding (Bearzi et al 2010). Recreational activities

are also expected to determine an impact on species, for instance by trampling on benthic species (e.g. *F. virsoides,* coralligenous) (Di Franco et al 2009), disturbing birds at nesting sites (Carney & Sydeman 1999), increasing marine debris or noise pollution, as observed in Cres – Lošinj (Rako et al 2013).
Habitat alteration can also affect some species that strongly depend on habitat features. Dams, weirs and other barriers along rivers represent obstructions that hamper migration of species, as already happened for *A. naccarii* (Meadows & Coll 2013). Further, maintenance works in river channels and on the coast reduce the number of optimal sites for reproduction of birds and fish (Ente Regionale Parco Delta del Po 2010).
Finally, indirect effects of climate change and human activities are the main drivers of the spreading of invasive species (Rahel & Olden 2008) and limitation of resources that induce competition between species (Connell et al 2013).

Table 1. Target species for Cres –Lošinj and Viški akvatorij N2K sites and potential oceanographic and ecological variables that may affect them.

CASE STUDY	**Cres –Lošinj and Viški akvatorij**
Target species	*Tursiops truncatus*
Oceanographic/Ecological variables	Contaminant concentration in water; density; abundance; sex; age; biometric measures; birth-growth and mortality rate; recruitment rate; spatial distribution and dispersal; emigration/immigration rate; genetic diversity; contaminant concentration in tissues; prey abundance and distribution; interaction with fishing activities and fish farms (site fidelity, group dynamics, and seasonal and yearly occurrence); mortality rate from incidental by-catch or incidents with boats; type, number and proximity of vessels to dolphins; spatial distribution, temporal extent, and levels of noise pollution by traffic boats;

	composition, amount and spatial distribution of litter and micro-litter in water, on seabed and coastline; the amount of litter and micro-litter ingested, the number of individuals which are adversely affected due to litter; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	Bearzi et al 1997; 2009; Rako et al 2012, 2013; Pleslić et al 2015; Fortuna et al 2018; Pleslić et al. 2019
Other source literature	Constantine et al 2004; Bearzi et al 2010; Schwacke et al 2010; López 2011; Piroddi et al 2011; Baulch and Perry 2014; López and Methion 2017
Monitoring programmes/observing systems	Adriatic Dolphin Project; Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Interreg project AdriSmartFish; High-frequency oceanographic radars

Table 2. Target species for Malostonski zaljev N2K site and potential oceanographic and ecological variables that may affect them.

CASE STUDY	**Malostonski zaljev**
Target species	*Fucus virsoides*
Oceanographic/Ecological variables	Air and water temperature; salinity; PAR; type of substratum; wind exposure; current velocity and direction; nutrient and contaminant concentration in water and sediments; relative exposure index (REI); biomass; cover; density; abundance; growth-mortality rates; photosynthetic activity; net primary productivity; spatial distribution; spawning rate; spawning stock biomass; heavy metal and organic

	pollutant concentration in tissues; biometric and phenological measures; genetic diversity; settlement and recruitment rate; associated organisms; presence/abundance/percentage cover of invasive species; density and abundance of herbivores; effect of trampling; area covered by and structure of the suitable habitats; cover of opportunistic species; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	
Other source literature	Munda 1977; Kremer and Munda 1982; Orlando-Bonaca et al 2013; Falace et al 2018
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia
Target species	Seagrasses *(Cymodocea nodosa, Posidonia oceanica)*
Oceanographic/Ecological variables	Temperature; salinity; PAR; wave exposure; depth; current velocity and direction; sediment type; sedimentation rate; nutrient and contaminant concentration in water and sediments; organic matter in sediments; biomass; cover; growth rate; leaf elongation rate; net primary productivity; erosion-recolonization rate; spatial distribution; patch size; heavy metal and organic pollutant concentration in tissues; biometric

	and phenological measures; genetic diversity; associated organisms; habitat characterization; presence/abundance/percentage cover of invasive species; density and abundance of herbivores; area cover destructed by anchoring-trawling; biomass of epiphytes; intensity and spatial and temporal variation of physical disturbance; spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of each habitat type adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	Špan and Antolić 1981
Other source literature	Duarte and Jensen 1990; Pérez and Romero 1992; Marba and Duarte 1994; Sànchez et al 1999; Alberto et al 2005; Cabaco et al 2010; Infantes et al 2011; Pérez-Ruzafa et al 2012; Orlando-Bonaca et al 2015; Chefaui et al 2016
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Mali Ston Bay Marine Culture Survey
Target species	*Pinna nobilis*
Oceanographic/Ecological variables	Current velocity and direction; wave exposure; temperature; pH; dissolved oxygen; salinity; chl-a; nutrient and contaminant concentration in water and sediments; organic matter in sediments; biometric measures; density; age; birth-growth-mortality rates; spatial distribution; genetic diversity; spawning rate; heavy metal and organic

	pollutant concentration; settlement and recruitment rate/success; shell burial level and orientation; habitat characterization; associated organisms; mortality rate due to *Haplosporidium pinnae;* mortality rate due to anchoring-fishing-diving; interaction with other species; presence/abundance/ cover of invasive species; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance
Source literature referred to the N2K site	
Other source literature	Coppa et al 2010, 2013; Rabaoui et al 2011; Davenport et al 2011; Hendriks et al 2013; Sureda et al 2013; Basso et al 2015; Deudero et al 2015; Natalotto et al 2015; Vázquez-Lui et al 2015; Catanese et al 2018; Wesselmann et al 2018; Catanese 2020
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Sea and bivalve shellfish quality monitoring plan; Mali Ston Bay Marine Culture Survey
Target species	*Alosa fallax*
Oceanographic/Ecological variables	Salinity; water temperature; dissolved oxygen; current velocity and direction; flow rate; contaminant concentration in water; density; abundance; biomass; biometric measures; age; birth-growth

	and mortality rate; spawning rate and stock biomass; recruitment rate; timing and duration of the estuarine phase; spatial distribution and movements; genetic diversity; contaminant concentration in tissues; competition with other species; number and type of barriers to migration; fishing mortality rate; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	
Other source literature	Aprahamian et al 2003; Doherty et al 2004; Maitland and Lyle 2005; Maes et al 2008; Lochet et al 2009; Jolly et al 2011; Bao et al 2015; La Mesa et al 2015
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Interreg project AdriSmartFish; Mali Ston Bay Marine Culture Survey
Target species	Coralligenous community
Oceanographic/Ecological variables	Current velocity and direction; temperature; pH; dissolved oxygen; salinity; depth; slope; geographic orientation respect to currents; turbidity; percentage cover of sediment; sedimentation rate; habitat characterization; rugosity (structural complexity); presence/quantity of mucilage and number of events; nutrient and contaminant concentration in water and sediments;

	percentage cover of benthic species; biomass; density; abundance; biometric and phenological measures; presence and size of erect Anthozoa; percentage of necrotic tissues; texture of the calcareous matrix; spatial distribution; community structure; number of taxa per functional group; dissimilarity between species; presence/abundance/percentage cover of invasive species; number/percentage cover of damaged organisms/substrate; composition, amount and spatial distribution of litter and micro-litter on the seabed; abundance of opportunistic species; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	
Other source literature	Balata et al 2005; Ballesteros 2006; Gibson et al 2006; Ponti et al 2011; Curiel et al 2012; Piazzi et al 2012; Martin et al 2014; Falace et al 2015; Ingrosso et al 2018
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Interreg project AdriSmartFish; Sea and bivalve shellfish quality monitoring plan; Mali Ston Bay Marine Culture Survey

Table 3. Target species for Trezze San Pietro e Bardelli and Tegnùe di Chioggia N2K sites and potential oceanographic and ecological variables that may affect them.

CASE STUDY	**Trezze San Pietro e Bardelli and Tegnùe di Chioggia**
Target species	*Alosa fallax*
Oceanographic/Ecological variables	Salinity; water temperature; dissolved oxygen; contaminant concentration in water; density; abundance; biomass; biometric measures; age; growth and mortality rate; spatial distribution and movements; genetic diversity; contaminant concentration in tissues; competition with other species; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance
Source literature referred to the N2K site	
Other source literature	Aprahamian et al 2003; Doherty et al 2004; Maitland and Lyle 2005; Maes et al 2008; Lochet et al 2009; Jolly et al 2011; Bao et al 2015; La Mesa et al 2015
Monitoring programmes/observing systems	LTER-Italy; Regional Water Protection Plan- Monitoring of FVG marine waters; Interreg project AdriSmartFish
Target species	*Caretta caretta*
Oceanographic/Ecological variables	Contaminant concentration in water;

	biometric measures; sex; age; genetic information; gut content; signs of injuries; presence of epibiotics; contaminant concentration in tissues; composition, amount and spatial distribution of litter and micro-litter in water, on seabed and coastline; the amount of litter and micro-litter ingested, the number of individuals which are adversely affected due to litter; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	Melli et al 2017; Fortuna et al 2018
Other source literature	Tomas et al 2002; Carreras et al 2007; Casale et al 2009; García-Fernández et al 2009; Lauriano et al 2011; Clusa et al 2014
Monitoring programmes/observing systems	LTER-Italy; Monitoring of sea turtles in the Adriatic Sea; Regional Water Protection Plan – Monitoring of FVG marine waters
Target species	*Tursiops truncatus*
Oceanographic/Ecological variables	Contaminant concentration in water; density; abundance; sex; age; biometric measures; birth-growth and mortality rate; recruitment rate; spatial distribution and dispersal; emigration/immigration rate; genetic diversity; contaminant concentration in tissues; prey abundance and distribution; spatial distribution, temporal extent, and levels of noise pollution by traffic boats; type, number and proximity of vessels to dolphins; composition, amount and spatial distribution of litter and micro-litter in water, on seabed and coastline; the amount of litter and micro-litter ingested, the number of individuals which are adversely affected due to litter; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats

Source literature referred to the N2K site	Melli et al 2017; Fortuna et al 2018
Other source literature	Bearzi et al 1997, 2009, 2010; Constantine et al 2004; Bearzi et al 2009; Schwacke et al 2010; López 2011; Piroddi et al 2011; Rako et al 2012, 2013; Baulch and Perry 2014; Pleslić et al 2015; López and Methion 2017; Pleslić et al 2019
Monitoring programmes/observing systems	LTER-Italy; Regional Water Protection Plan – Monitoring of FVG marine waters; Interreg project AdriSmartFish
Target species	*Pinna nobilis*
Oceanographic/Ecological variables	Current velocity and direction; wave exposure; temperature; pH; dissolved oxygen; salinity; chl-a; nutrient and contaminant concentration in water and sediments; organic matter in sediments; biometric measures; density; age; birth-growth-mortality rates; settlement and recruitment rate/success; spawning stock biomass; spawning rate; spatial distribution; genetic diversity; heavy metal and organic pollutant concentration in tissues; shell burial level and orientation; habitat characterization; associated organisms; mortality rate due to *Haplosporidium pinnae*; mortality rate due to anchoring-fishing-diving; presence/abundance/ cover of invasive species; interaction with other species; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats

Source literature referred to the N2K site	Melli et al 2017; Moschino et al 2019
Other source literature	Coppa et al 2010, 2013; Rabaoui et al 2011; Davenport et al 2011; Hendriks et al 2013; Sureda et al 2013; Basso et al 2015; Deudero et al 2015; Natalotto et al 2015; Vázquez-Lui et al 2015; Catanese et al 2018; Wesselmann et al 2018; Catanese 2020
Monitoring programmes/observing systems	LTER-Italy; Coralligenous monitoring by UNITS, TRECORALA, PRIN ReefReseArcH projects; Regional Water Protection Plan - Monitoring of FVG marine waters; Visual census of the seafloor by ROV; Visual census of *P. nobilis* by Shoreline Soc. Coop.
Target species	Coralligenous community
Oceanographic/Ecological variables	Current velocity and direction; temperature; pH; dissolved oxygen; depth; slope; geographic orientation respect to currents; salinity; turbidity; reef geomorphology; percentage cover of sediment; sedimentation rate; nutrient and contaminant concentration in water and sediments; rugosity (structural complexity); habitat characterization; presence/quantity of mucilage and number of events; percentage cover of benthic species; biomass; density; abundance; biometric and phenological measures; presence and size of erect Anthozoa; percentage of necrotic tissues; texture of the calcareous matrix; community structure; spatial distribution; number of taxa per functional group; dissimilarity between species; presence/abundance/percentage cover of invasive species; number/percentage cover of damaged organisms/substrate; abundance of opportunistic species; composition, amount and spatial distribution of litter and micro-litter on the seabed; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration

	of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	Casellato and Stefanon 2008; Ponti et al 2011; Curiel et al 2012; Falace et al 2015 and references therein; Melli et al 2017; Moschino et al 2019
Other source literature	Balata et al 2005; Ballesteros 2006; Gibson et al 2006; Piazzi et al 2012; Martin et al 2014; Ingrosso et al 2018
Monitoring programmes/observing systems	LTER-Italy; Coralligenous monitoring by UNITS, TRECORALA, PRIN ReefReseArcH projects; Regional Water Protection Plan - Monitoring of FVG marine waters; Visual census of the seafloor by ROV; Seagrasses and macroalgae monitoring UNITS and FVG Region; Interreg project AdriSmartFish
Target species	Seabirds (*Larus melanocephalus*; *Phalacrocorax aristotelis; Puffinus yelkouan)*
Oceanographic/Ecological variables	Density; abundance; genetic diversity; biometric measures; age; spatial distribution and dispersal; contaminant concentration in water and in tissues; competition with other species; prey abundance and distribution; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; composition, amount and spatial distribution of litter and micro-litter in water, on seabed and coastline; the amount of litter and micro-litter ingested, the number of individuals which are adversely affected due to litter; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	
Other source literature	Tasker et al 2000; Shumway et al 2003; Burger and Gochfeld 2004;

	Fukami et al 2006; Genovart et al 2013; Wilcox et al 2015
Monitoring programmes/observing systems	LTER-Italy; Regional Water Protection Plan - Monitoring of FVG marine waters; Interreg project AdriSmartFish

Table 4. Target species for Delta del Po: tratto terminale e delta veneto and Delta del Po N2K sites and potential oceanographic and ecological variables that may affect them.

CASE STUDY	**Delta del Po: tratto terminale e delta Veneto and Delta del Po**
Target species	*Acipenser naccarii*
Oceanographic/Ecological variables	Salinity; air and water temperature; dissolved oxygen; turbidity; depth; current velocity and direction; water flow rate; amount of precipitation; sediment type; nutrient and contaminant concentration in water; density; abundance; biomass; biometric measures; age; birth-growth and mortality rate; spawning rate; spawning stock biomass; recruitment rate; genetic diversity; spatial distribution and movements; contaminant concentration in tissues; number of suitable sites for reproduction; competition with other species including invasive species; estimate of illegal fishing mortality rate; mortality rate from incidental by-catch; number and type of barriers to migration; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; area covered by and structure of the suitable habitats; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on

	the health of individuals and the condition of habitats
Source literature referred to the N2K site	Bressa et al 1996; Caramori et al 2007; Ente Regionale Parco Delta del Po 2010; Lanzoni et al 2010; Lassalle et al 2010; Meadows and Coll 2013
Other source literature	Randall et al 1992; Cataldi et al 1998; McKenzie et al 2001; Martinez-Alvarez et al 2002; Ludwig et al 2003; Boscari et al 2014
Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; ARPAE Emilia-Romagna, monitoring program; Monitoring network of the Po Delta lagoons (ARPAV); Interreg project AdriSmartFish; S1-GB dynamic pylon
Target species	*Alosa fallax*
Oceanographic/Ecological variables	Salinity; water temperature; dissolved oxygen; current velocity and direction; water flow rate; contaminant concentration in water; density; abundance; biomass; biometric measures; age; birth-growth and mortality rate; spawning rate; spawning stock biomass; recruitment rate; timing and duration of the estuarine phase; spatial distribution and movements; genetic diversity; contaminant concentration in tissues; competition with other species; number and type of barriers to migration; fishing mortality rate; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the	Vitali et al 1982; Serventi et al 1990; Lanzoni et al 2010; Ente Regionale Parco Delta del Po 2010; La Mesa et al 2015

N2K site	
Other source literature	Aprahamian et al 2003; Doherty et al 2004; Maitland and Lyle 2005; Maes et al 2008; Lochet et al 2009; Jolly et al 2011; Bao et al 2015
Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; ARPAE Emilia-Romagna, monitoring program; Monitoring network of the Po Delta lagoons (ARPAV); Interreg project AdriSmartFish; S1-GB dynamic pylon
Target species	*Petromyzon marinus*
Oceanographic/Ecological variables	Salinity; water temperature; dissolved oxygen; current velocity and direction; water flow rates; type of substrate; contaminant concentration in water; density; abundance; biomass; biometric measures; age; birth-growth and mortality rate; spawning rate; spawning stock biomass; recruitment rate; spatial distribution and movements; contaminant concentration in tissues; competition with other species; number and type of barriers to migration; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; number of resting sites and features; mortality rate from incidental by-catch; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats
Source literature referred to the N2K site	Ente Regionale Parco Delta del Po 2010; Lanzoni et al 2010
Other source literature	Hagen et al 1985; Andrade et al 2007; Silva et al 2019

Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; ARPAE Emilia-Romagna, monitoring program; Monitoring network of the Po Delta lagoons (ARPAV); Interreg project AdriSmartFish; S1-GB dynamic pylon
Target species	Seabirds (*Sterna albifrons; Sterna hirundo; Sterna sandvicensis; Sterna nilotica; Sterna caspia; Larus ridibundus; Larus genei; Larus melanocephalus; Phalacrocorax aristotelis)*
Oceanographic/Ecological variables	Water level; number, frequency and period of the year of extreme events; density; abundance; birth-growth and mortality rate; recruitment rate; genetic diversity; biometric measures; age; spatial distribution and dispersal; contaminant concentration in water and tissues; number and distribution of nesting sites and breeding pairs; predators abundance/density; competition with other species; number of feeding sites; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; prey abundance and distribution; events of human disturbance; mortality rate from incidental by-catch or incidents with nets/fences; composition, amount and spatial distribution of litter and micro-litter in water and coastline; the amount of litter and micro-litter ingested; the number of individuals which are adversely affected due to litter; interaction with fishing activities and fish farms (site fidelity, group dynamics, and seasonal and yearly occurrence); spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance

Source literature referred to the N2K site	Boldreghini et al 1988; 1992; Fasola et al 1989; Fasola and Canova 1996; Valle and Scarton 1999; Tavecchia et al 2005; Ente Regionale Parco Delta del Po 2010; Verza 2015; Scarton et al 2018
Other source literature	Tasker et al 2000; Shumway et al 2003; Burger and Gochfeld 2004; Brichetti and Foschi 2006; Fukami et al 2006; Genovart et al 2013; Wilcox et al 2015
Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; ARPAE Emilia-Romagna, monitoring program; Monitoring network of the Po Delta lagoons (ARPAV); Interreg project AdriSmartFish; S1-GB dynamic pylon
Target species	Seagrasses (*Nanozostera noltii, Zostera marina; Cymodocea nodosa*)
Oceanographic/Ecological variables	Temperature; salinity; PAR; wave exposure; depth; current velocity and direction; sediment type; sedimentation rate; nutrient and contaminant concentration in water and sediments; organic matter in sediments; biomass; cover; growth rate; leaf elongation rate; net primary productivity; erosion-recolonization rate; spatial distribution; patch size; heavy metal and organic pollutant concentration in tissues; biometric and phenological measures; genetic diversity; associated organisms; habitat characterization; presence/abundance/cover of invasive species; density and abundance of herbivores; area cover destructed by anchoring-trawling; biomass of epiphytes; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the suitable habitat adversely affected due to alteration of hydrographical conditions; spatial extent and duration of significant acute pollution events; effects of significant acute pollution events on the health of individuals and the condition of habitats

Source literature referred to the N2K site	Sfriso et al 2009; Ente Regionale Parco Delta del Po 2010; Trombin et al 2012; Verza and Cattozzo 2015
Other source literature	Olesen and Sand-Jensen 1994; Peralta et al 2002; Plus et al 2003; Moore and Short 2007; Elhers et al 2007; Cabaco et al 2010; Infantes et al 2011; Han et al 2012; La Nafie et al 2012; Perez-Ruzafa et al 2012; Orlando-Bonaca et al 2015; Chefaui et al 2016
Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; Monitoring network of the Po Delta lagoons (ARPAV); ARPAE Emilia-Romagna, monitoring program; S1-GB dynamic pylon

4.2 Identification of key ecological process and of the ecological and oceanographic variables that may affect them

Information on key ecological processes of the N2K sites within ECOSS project was obtained from the deliverable 4.3.1, based on Bennett et al (2009). Oceanographic/ecological variables influencing ecological processes of the N2K sites were identified by using information in the deliverables 4.1.1, 4.1.2 and 4.3.1, the criteria listed in the HD, BD, WFD and MSFD (see paragraph 4.4) and the available scientific literature on Google Scholar. A complete summary is shown in Tables 5-8, together with the source literature divided in specific studies carried out in the N2K sites and general studies related to the identified ecological processes (note that the literature may not be exhaustive). In Tables 5-8 we have also reported the ecological monitoring programmes and observing systems in the project area that already assess some of these variables inside the N2K sites or in the surrounding area, as described in the deliverable 3.1.1. As for target species, the list of proposed variables linked to the ecological processes can be modified by the monitoring body according to the management needs.

The main ecological processes identified in the N2K sites are: climate processes, hydrological processes, interactions between organisms, movement of organisms, spatial/temporal variation in primary

productivity, natural disturbance regime and formation of biophysical habitats. Most of these processes can be observed in many of the N2K sites. In the next paragraphs, we described in detail how these ecological processes are affecting the N2K sites and which variables can help in detecting their changes.

Climate change is considered one of the main causes of habitat modification and loss along 85% of the world's coastline (Airoldi & Beck 2007). Several ecological processes directly related to climate change (hereinafter referred as "Climate processes") are acting on the marine environment (Henson et al 2017; Breitburg et al 2018), such as rising sea level and temperature, ocean acidification and deoxygenation. MPAs cannot stop global alterations, but can mitigate future impacts on ecosystems by adopting management measures that increase resiliency and resistance to these threats (Micheli et al 2012). In this context, monitoring programmes are essential to reveal how coastal ecosystems are responding to the changing ocean conditions and evaluate the effectiveness of conservation measures. Variables that could help to assess potential or ongoing changes due to climate processes include water/air temperature; pH; dissolved oxygen; frequency and amount of rainfall; mean sea level and tidal range. Climate processes are presumably affecting all the selected N2K sites, but detailed information on their effects on target species and habitats are limited for most of the sites.

Hydrological processes are also important ecological processes that shape estuarine habitats of the Po Delta, the benthic communities of Trezze San Pietro and Bardelli and Tegnùe di Chioggia, the ecological features of Malostonski bay. The Po Delta is characterized by a complex system of fluvial branches covering 30,000 km^2 and sustaining a rich biodiversity. The main hydrographic process in this area is the water circulation affected by the river flow, sea tides, and alluvial deposits. Water circulation in the Po Delta is also highly changed by sluices, dykes, flooding defences and other human interventions. In addition, in the last years, the distance upstream of the salt wedge is increased due to climate change and subsidence events (Maicu et al 2019). The salt wedge is now 20 km inland from the coast and is expected to cause severe consequences to agriculture and freshwater species (Ente Regionale Parco Delta del Po 2010). Thus, water circulation from the river and sea tides is critical for the maintenance of the estuarine habitats and should be constantly monitored and managed. The mesophotic biogenic reefs of Trezze San Pietro and Bardelli and Tegnùe di Chioggia are also affected by hydrological processes linked to the Po River and other minor rivers in the Northern Adriatic Sea (Ponti et al 2011; Falace et al 2015). The main oceanographic feature in this area is the bottom topography characterized

by low depths (<25 m), especially along the northern and western coast due to the sedimentation from the river estuaries (Isonzo-Soča, Tagliamento, Brenta, Adige, Po) (Gordini et al 2012). Strong river runoff and the associated seasonal and interannual variability in temperature, salinity and sediments, regulate the presence of species. Opportunistic species characterize reefs closest to the coast, which are affected by stronger currents, river inputs and sediment resuspension, while sensitive species forming coralligenous-like assemblages are located offshore (Falace et al 2015). Ecological conditions in Malostonski zaljev are largely influenced by the waters flowing from the mainland, by surface and groundwater runoffs and currents from the open sea. The effect of the Neretva River is more pronounced in the outer and middle part of the bay, while strong underwater freshwater springs have a significant impact on the inner part of the bay (deliverable 3.2.1; Benović 2008). Among the main variables that can be measured to control for hydrological process alterations, we identified: salinity; water level; current velocity and direction; magnitude, seasonality, rate of water flow; wave height; turbidity; sedimentation rate; thickness and distance upstream of the salt wedge and number of flood events.

Hydrological processes are strictly linked to the spatial-temporal variability in primary productivity. Nutrient inputs from rivers modify local patterns of primary productivity, influencing phytoplankton, benthic macrophytes and seaweeds (Carić & Jasprica 1997). In return, also biomass and species composition of their consumers (i.e. zooplankton and benthic herbivores) are modified (Cardona et al 2013). This process can be particularly relevant in the complex system of the Po Delta, where a high nutrient load is associated to the fertilizers used in agriculture, soil leaching, flooding and poor water circulation (Gaglio et al 2017). Such conditions may then cause algal blooms and anoxic events, often deadly for water fauna (Facca et al 2014). Primary productivity is also a key ecological process in Malostonski bay, considered a natural moderately eutrophic site due to the nutrient inputs from the Neretva River. A large number of filtering organisms inhabit this area, including commercially important shellfish, which depend on phytoplankton abundance (Čalić et al 2013). Recent papers have shown that nutrient load is one of the main drivers that control benthic species distribution on the mesophotic biogenic reefs of the Northern Adriatic Sea, favouring stress-tolerant species (Ponti et al 2011; Falace et al 2015). Thus, even Trezze San Pietro and Bardelli and Tegnùe di Chioggia are affected by changes in nutrient loads and primary productivity. In order to assess this ecological process in the N2K sites, we

suggest to collect periodically data of the following variables: turbidity; dissolved oxygen; nutrient concentration in water and sediments; chlorophyll-a; harmful algal bloom frequency, intensity and species composition; seasonal and annual variability in species composition, abundance and photosynthetic efficiency of phytoplankton; zooplankton biomass and composition.

Interactions between species (e.g. predation, herbivory, competition, parasitism, mutualisms) is an ecological process that alters the structure of communities, influencing and modulating other processes such as nutrient cycling and organisms' distribution (Bennett et al 2009). In particular positive interactions (e.g. mutualism, commensalism and facilitation) can be as important as, or even more important than competition and predation in regulating ecosystem structure and function (Halpern et al 2007). Interactions between native-exotic species can be also crucial. Recent studies have demonstrated that the success of invading species may be enhanced by positive interactions with native species, for example during restoration actions. Thus, intervention strategies targeting biological invasions should always take into account these relationships (Bulleri et al 2008 and references therein). Interactions between species often determine movement of organisms, another important ecological process in nature conservancy. Organisms spatially disperse due to several reasons: habitat alteration, resources limitation, competition with exotic species or with native species that experience population outbreaks (Bowler & Benton 2005). The dispersal of an individual has consequences not only for individual fitness, but also for population dynamics, genetics, and help explaining spatial pattern of species distribution at small and large scales (Benedetti-Cecchi 2001). Due to this link between dispersal and population dynamics, understanding its causes and consequences is vital to predict how populations will respond to habitat fragmentation, climate change and the invasion of alien species (Araújo & Luoto 2007).
Deliverable 4.3.1 has recognised these processes as preponderant in Parco Delta del Po, Trezze San Pietro and Bardelli and Tegnùe di Chioggia and in Cres – Lošinj and Viški akvatorij.
In the Po Delta, many colonial species interact, such as gulls and terns, due to similar habitat preferences, obtaining mutual advantages in terms of defence from predators and exchange of information for food acquisition (Rodgers 1987). On the other hand, colonial birds may compete for resources, and colonies may attract predators (Valle & Scarton 1999). Similarly, the Adriatic sturgeon population has been impacted by the presence of invasive fish and above all by the construction of dams that reduce upstream movements needed for food and reproduction (Caramori et al 2007).

On biogenic reefs of Trezze San Pietro and Bardelli and Tegnùe di Chioggia, space competition is the most recognised factor that shape species composition and distribution. Indeed, the largest part of the living biomass in coralligenous assemblages consists of algae and suspension feeders, often made of calcareous skeletons, which suggests that grazing and predation are not as important as in other environments, even if herbivorous and carnivorous organisms are not totally absent (Ballesteros 2006). Many organisms invest in production of allelochemicals that act as a defence against consumers or mediate the interactions between species regarding the occupation of space. Others choose the way of epibiosis since most of the space is occupied and larvae usually have to settle on living organisms, but mutualism and commensalism were also observed (Ballesteros 2006). Dispersal is also an essential process that affects stability, resilience and recovery of marine populations, in particular for species standing on isolated outcrops disseminated on a sandy bottom. Dispersal for sessile species, and to a less extent for pelagic ones, is strongly dependent on water circulation patterns, as well as on biotic features such as parental larval production, pelagic larval duration, the swimming capacity of larvae, substratum requirement, and settlement and recruitment dynamics (Cowen & Sponaugle 2009). However, genetic information and dispersal behaviour of many species inhabiting these habitats are lacking, thus further data are needed to understand if and how these reefs are connected and put in place adequate protection measures.

Interactions between individuals can be also important and determine the spatial distribution and demographic structure within populations. Studies conducted in Cres – Lošinj demonstrated that variations in home range patterns among the resident dolphins are primarily related to differences in gender and how they respond to external stressors, in particular to the noise produced by nautical tourism (Rako et al 2017). Females use significantly wider areas, especially during the nursing periods, probably due to habitat features and differences in energetic requirements. Contrarily males have the smallest home range sizes, indication that at least Cres-Lošinj waters are affected by the creation of strong and highly territorial alliances (Rako et al 2017). Conversely, in the Central Adriatic Sea, associations between females tend to be stronger (Holcer 2012). Similar patterns could also be observed in Viški akvatorij N2K site, but more studies are needed.

Variables that should be measured to have information on interactions and movement of organisms may be: cover/abundance and composition of benthic species; fish community composition and abundance; interspecific interaction frequency and dominance; percentage cover/abundance of invasive

species; spatial distribution and movement of species; emigration/immigration rates; genetic diversity; larval production and dispersal; settlement and recruitment rate; migratory route obstructions (particularly in the Po Delta).

Processes of biophysical habitat formation can be the result of species interactions. This is particularly visible in Trezze San Pietro and Bardelli and Tegnùe di Chioggia where the whole build-up of coralligenous frameworks is regulated by the interactions between encrusting coralline seaweeds, sessile invertebrate builders, and boring organisms (e.g. sea urchins, excavating sponges, molluscs and polychaetes) (Ballesteros 2006). Bioerosion and bioconstruction rates should be primarily measured to assess habitat formation in these N2K sites, together with other variables previously cited to assess other ecological processes, such as abundance/coverage and biomass of species, spatial distribution, nutrient load, pH and light availability. Recently, the Habitat 1180 – 'Submarine structures made by leaking gases' has been identified in Tegnuè di Chioggia and included in the SDF of this site. This habitat overlaps with the already protected Habitat 1170 – 'Reefs', shares the same species and the methanogenic processes contribute to the habitat formation for the target species.
In the Po Delta, the complex fluvial system is the main driver of habitat creation. Coastal dunes, wetlands, lagoons, fishing ponds, sandbars and river islands are all generated by continuous processes of erosion, flooding and supply of sediments and debris by the river flow (Cencini 1998). These hydrological processes interact with the biotic components to further shape the estuarine habitats and create hygrophilous forests, reeds, swamps with floating vegetation, belts of psammophilous and halophilous vegetation where numerous species find refuge and appropriate sites for nesting (Valle & Scarton 1999; Verza 2015). Such habitats also sustain local economy by providing opportunities for fish farming, fishing and touristic visits (Ente Regionale Parco Delta del Po 2010). Habitat formation and modification in the Po Delta is an unceasing process and several variables can be measured to monitor which areas are subjected to erosion and which ones to sediment deposition/vegetation growth: current velocity and direction; magnitude, seasonality, rate of river flow; sedimentation rate; erosion rate; water level; number of flood events; vegetation cover and composition.

Finally, we want to stress that in this paragraph we identified the potential ecological processes and the relative variables in each N2K site, however none of the selected sites have yet a management plan and/or a management authority. This reduces the available knowledge of the existing ecological

processes on these N2K sites and an accurate identification of the associated environmental variables to monitor. In addition, information on the effects of human activities on ecological process in each N2K site is scarce.

Table 5. Ecological processes in Cres –Lošinj and Viški akvatorij N2K sites and the related ecological variables.

CASE STUDY	Cres –Lošinj and Viški akvatorij
Ecological processes	- Climate processes; - Interactions between organisms; - Movements of organisms
Oceanographic/Ecological variables	Temperature; dissolved oxygen; emigration/immigration rates; genetic diversity; spatial dispersal of dolphins; ethogram of dolphins; fish community composition, biomass, size and age structure and abundance; fish catches/effort; intra and interspecific interaction frequency and patterns; frequency of interaction with fishing activities; intensity and spatial and temporal variation of physical disturbance; spatial extent of the suitable habitat which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance
Source literature referred to the N2K site	Degobbis et al 2000; Bearzi et al 2009; McQuatters-Gollop et al 2009; Coll et al 2010; Giani et al 2012; Rako et al 2012; Pleslić et al 2015; Rako et al 2017; Pleslić et al 2019
Other source literature	Bennett et al 2009; Carnabuci et al 2016; Poloczanska et al 2016
Monitoring programmes/observing systems	Adriatic Dolphin Project; 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; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Interreg project AdriSmartFish; High-frequency oceanographic radars

Table 6. Ecological processes in Malostonski zaljev N2K site and the related ecological variables.

CASE STUDY	Malostonski zaljev
Ecological processes	- Climate processes; - Space/time variability in primary productivity; - Hydrological processes
Oceanographic/Ecological variables	Salinity; temperature; turbidity; pH; dissolved oxygen; chl-a; nutrient concentration in water and sediments; sedimentation rate; magnitude, seasonality, rate of river flow; current velocity and direction; amount of precipitation; primary productivity; number and type of barriers to migration; number of flood events; seasonal and annual variability in species composition, abundance, biomass and photosynthetic efficiency of phytoplankton; frequency and intensity of phytoplankton bloom; zooplankton biomass and composition; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; composition, distributional range and pattern, abundance, biomass, size and age structure of benthic organism populations; community structure; composition, abundance, biomass, size and age structure, distributional range and pattern of fish populations; species composition, cover, depth distribution of macrophytes; percentage cover/abundance of invasive species; abundance of opportunistic species; intensity and spatial and temporal variation of physical disturbance; spatial extent of the habitats which are adversely affected, through change in the biotic and abiotic structure and functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the habitats adversely affected due to alteration of hydrographical conditions
Source literature referred to the N2K site	Benović 2008; Carić and Jasprica 1997; Degobbis et al 2000; Jasprica and Car 2003; Jasprica et al 2007; Kljaković-Gašpić et al 2007; McQuatters-Gollop et al 2009; Giani et al 2012; Čalić et al 2013; Lušić et al 2019

Other source literature	Bunn and Arthington 2002; Kimmerer 2002; Ballesteros 2006; Bennett et al 2009; Poloczanska et al 2016
Monitoring programmes/observing systems	Monitoring of parameters needed for evaluation of the state of descriptors according to Adriatic Monitoring Plan enabling fulfilment of obligations of the Republic of Croatia according to MSFD; Systematic research of water quality in transitional and coastal waters of the Republic of Croatia; Interreg project AdriSmartFish

Table 7. Ecological processes in Trezze San Pietro e Bardelli and Tegnùe di Chioggia N2K sites and the related ecological variables.

CASE STUDY	**Trezze San Pietro e Bardelli and Tegnùe di Chioggia**
Ecological processes	- Climate processes; - Hydrological processes; - Space/time variability in primary productivity; - Interactions between organisms; - Movements of organisms; - Formation of biophysical habitats
Oceanographic/Ecological variables	Salinity; water temperature; turbidity; dissolved oxygen; pH; chl-a; primary productivity; nutrient concentration; current velocity and direction; magnitude, seasonality, rate of river flow; sedimentation rate; seasonal and annual variability in species composition, abundance and photosynthetic efficiency of phytoplankton; frequency and intensity of phytoplankton bloom; zooplankton biomass and composition; abundance of opportunistic species; composition, distributional range and pattern, abundance, biomass, size and age structure of benthic organism populations; community structure; bioerosion and bioconstruction rates; percentage cover/abundance of invasive species; genetic diversity of assemblages; spatial distribution and movement of species; larval production and dispersal; settlement and recruitment rate; interspecific interaction frequency and dominance; trophic guild

	species diversity; abundance across trophic guilds; trophic guild size distribution; trophic guild productivity; intensity and spatial and temporal variation of physical disturbance; spatial extent of the habitat type which is adversely affected, through change in the biotic and abiotic structure and functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the habitat type adversely affected due to alteration of hydrographical conditions
Source literature referred to the N2K site	Degobbis et al 2000; McQuatters-Gollop et al 2009; Giani et al 2012; Falace et al 2015 and references therein; Albano et al 2018; Ingrosso et al 2018
Other source literature	Gibson et al 2002; Hellberg et al 2002; Kinlan and Gaines 2003; Paul and Puglisi 2004; Ballesteros 2006; Bennett et al 2009; Selkoe et al 2011, 2016; Poloczanska et al 2016
Monitoring programmes/observing systems	LTER-Italy; Coralligenous monitoring by UNITS, TRECORALA, PRIN ReefReseArcH projects; Regional Water Protection Plan - Monitoring of FVG marine waters; Visual census of the seafloor by ROV; Seagrasses and macroalgae monitoring UNITS and FVG Region; Interreg project AdriSmartFish

Table 8. Ecological processes in Delta del Po: tratto terminale e delta veneto and Delta del Po N2K sites and the related ecological variables.

CASE STUDY	**Delta del Po: tratto terminale e delta veneto and Delta del Po**
Ecological processes	- Climate processes; - Space/time variability in primary productivity; - Hydrological processes; - Interactions between organisms; - Movements of organisms; - Natural disturbance regimes; - Formation of biophysical habitats

Oceanographic/Ecological variables	Temperature; salinity; dissolved oxygen; pH; turbidity; nutrient concentration in water and sediments; amount of precipitation; mean sea level; tidal range; thickness and distance upstream of the salt wedge; current velocity and direction; magnitude, seasonality, rate of river flow; soil leaching and erosion rate; sedimentation rate; number and type of barriers to migration; number of flood events; chl-a; primary productivity; organic matter in sediments; seasonal and annual variability in species composition, abundance and photosynthetic efficiency of phytoplankton; frequency and intensity of phytoplankton bloom; zooplankton biomass and composition; frequency, intensity, duration, spatial extent and species composition of harmful algal blooms; abundance of opportunistic species; presence/abundance/percentage cover of invasive species; composition, distributional range and pattern, abundance, biomass, size and age structure of benthic organism populations; interspecific interaction frequency and dominance; spatial distribution and movement of species; community structure; composition, abundance, biomass, size and age structure, distributional range and pattern of fish populations; species composition, cover, depth distribution of macrophytes; trophic guild species diversity; abundance across trophic guilds; trophic guild size distribution; trophic guild productivity; intensity and spatial and temporal variation of physical disturbance; spatial extent of the habitats which are adversely affected, through change in the biotic and abiotic structure and functions by physical disturbance; spatial and temporal variation of hydrographical conditions; spatial extent of the habitats adversely affected due to alteration of hydrographical conditions
Source literature referred to the N2K site	Degobbis et al 2000; McQuatters-Gollop et al 2009; Simeoni and Corbau 2009; Ente Regionale Parco Delta del Po 2010; Giani et al 2012; Facca et al 2014; Giosan et al 2014; Gaglio et al 2017; Albano et al 2018; Cibic et al 2019; Maicu et al 2019
Other source literature	Bunn and Arthington 2002; Kimmerer 2002; Kinlan and Gaines 2003; Palmer et al 2008; Bennett et al 2009

Monitoring programmes/observing systems	LTER-Italy; Integrated monitoring programme of transitional water bodies in according to legislative decree n. 152/2006; ARPAE Emilia-Romagna, monitoring program; Interreg project AdriSmartFish; S1-GB dynamic pylon

4.3 Identification of the management goals and objectives in each N2K site

The management goals and objectives here reported for each N2K site (Table 9) were partially taken from the ECOSS deliverable 4.1.2 and re-elaborated with the information provided by deliverables 3.2.1, 4.1.1, 4.2.1, 4.3.1 and by the partners during the ECOSS first meeting (Bologna, 11-12/02/2020). Management objectives for Parco Delta del Po N2K sites were also derived from the management plan, that has not yet been approved (Ente Regionale Parco Delta del Po 2010). For the aim of this project, only biophysical objectives, related to the ecological components, were considered, while socio-economic and governance objectives were not included.

Specifically, the long-term management goals of the N2K case studies were outlined according to the requirements of the HD and BD that aim at conserving the species and habitats of protection in a favourable state. In fact, Art. 1 of the HD explicitly refers to the Favourable Conservation Status (FCS), as well as to restore and support the recovery of already degraded populations and habitats. In addition, it defines a Site of Community Importance as "a site which, in the biogeographical region or regions to which is belongs, contributes significantly to the maintenance or restoration at a favourable conservation status of a natural habitat type in Annex I or of a species in Annex II and may also contribute significantly to the coherence of Natura 2000 referred to in Article 3 , and/or contributes significantly to the maintenance of biological diversity within the biogeographic region or regions concerned". Thus, the goals we have defined for N2K sites (Table 9) reflect such a definition and were focused on target species/habitats and ecological processes protected by these sites (Tables 1-8).
To achieve these goals, specific and measurable objectives must be linked to them and defined in terms of what outputs and outcomes are being sought. Target species and ecological processes identified in

the paragraph 4.1 and 4.2 represent the priority targets around which the objectives of the N2K sites have to be constructed. Another important step is to understand the threats or impacts to those target species in order to set effective objectives that can address them. Here, we have recalled and summarized the human activities and potential pressures to biodiversity in each N2K site reported in the deliverables 3.2.1, 4.1.1, 4.1.2 and 4.3.1 and in the Table 1-8 associated to the ecological/oceanographic variables:

- **Cres-Lošinj and Viški akvatorij**

Noise and disturbance from nautical tourism; aquaculture and commercial fishing; scuba-diving; spear-fishing; land-based pollution; coastal development; marine macro-pollution (i.e. plastic bags, Styrofoam); climate change.

- **Malostonski zaljev**

Eutrophication due to nutrient load from Neretva River and springs; coastal development and human activities; commercial fishing; scuba-diving; nautical tourism; pollution from mainland; shellfish farming; waste material mainly from aquaculture; poaching of *Lithophaga lithophaga*; climate change.

- **Tegnùe di Chioggia and Trezze San Pietro e Bardelli**

High nutrient load and sediments from rivers; scuba-diving; illegal recreational and commercial fishing; water pollution from mainland; marine debris; climate change.

- **Delta del Po: tratto terminale e delta Veneto and Delta del Po**

Maintenance works in channels; soil leaching and erosion; changes in water circulation, flow and sedimentation rates; human induced changes in hydraulic conditions; rising of the salt wedge; sea level rise; climate change; invasive species; discharges and pollution; aquaculture; commercial and recreational fishing; destruction of native habitats of target species; tourism and other recreational activities; shipping lanes, ports, marine constructions; noise pollution; beach nourishment; estuarine and coastal dredging; trampling; use of fertilizers in agriculture

Most of these threats originate from human activities, thus they can be addressed by establishing management objectives and related regulatory actions. Except for climate change, all these threats can be managed directly by the management bodies of N2K sites. The management objectives we have formulated are specifically focused on a single species, when pressures in N2K sites are expected to affect only a target species, or are more general, embracing communities or ecosystems, in case pressures are more widespread in the protected areas and expected to influence multiple species and processes (Table 9).

Management objectives are statements of the desired short-term 'outcomes' rather than how to achieve them (Pomeroy et al 2004). Thus, the objectives we have identified do not want to indicate how management bodies should manage threats and pressures in the N2K case studies. The next step would be to develop specific strategies and actions linked to each objective in order to effectively achieve that objective and lastly the main goal. It is important to examine the goals and objectives regularly to determine if they are appropriate or need to be revised to make them more clearly defined, measurable, and useful for future management purposes. Clearly stated goals and measurable objectives are the base to identify and select performance indicators that are most appropriate to assess conservation measures in the MPAs (see next paragraph) (Thomas & Middleton 2003; Pomeroy et al 2004).

Table 9. Management goals and objectives for each N2K site selected as case study within ECOSS project.

CASE STUDY	GOAL	MANAGEMENT OBJECTIVES
Cres-Lošinj and Viški akvatorij	Preservation of the common bottlenose dolphin (*Tursiops truncatus*) population at a favourable status	• Protect and increase the population of *T. truncatus* • Prevent over-exploitation of prey of *T. truncatus* • Preserve incoming/outgoing genetic flow for *T. truncatus*

		• Maintain a good seawater quality • Decrease/regulate interactions between human activities and *T. truncatus* individuals
Malostonski zaljev	Preservation of target habitats ('Shallow inlets and bays' and 'Reefs') at a favourable status	• Prevent high eutrophication and pollution levels in the bay • Assess distribution and conservation status of the identified target benthic species • Maintain/restore the current status of target species populations • Preserve coralligenous community diversity • Preserve bioconstruction process • Prevent illegal fishing of *Lithophaga lithophaga* • Reduce impact of aquaculture and tourism on target benthic species • Reduce impact of invasive species
Tegnùe di Chioggia and Trezze San Pietro e Bardelli	Conservation of mesophotic biogenic reef communities at a favourable status	• Maintain/restore the current status of target species populations • Preserve coralligenous community diversity and gene pool • Preserve bioconstruction process • Minimize nutrient load and pollution from coast • Reduce human activities inside and next to the N2K sites

		• Assess the presence and impact of invasive species • Reduce impact of marine debris on benthic species
Delta del Po: tratto terminale e delta Veneto and Delta del Po	Conservation of target habitats and species at a favourable status in the Po Delta	• Improve water circulation and quality • Reduce impact of invasive species • Monitor and limit fishing • Create/restore optimal habitats for target species (nesting/resting/feeding sites) • Maintain/restore the current status of target species populations • Increase genetic diversity of the Adriatic sturgeon • Decrease tourism-induced disturbance at nesting bird sites • Control of the yellow-legged gull population and terrestrial predators of target birds' eggs • Minimize the impact of artificial structures on target species (e.g. electrical cables on birds) • Assess distribution and status of aquatic macrophytes • Minimize the impact of aquaculture and maintenance works on the coast and river channels • Reduce the impact of shipping lanes, ports, marine

		constructions, noise pollution • Prevent soil leaching, erosion and discharges

4.4 Individuation of the main connections, synergies and gaps among different directives (HD, BD, WFD and MSFD), with considerations related to their indicators

With this comparative analysis, we aim at identifying the main synergies among the legal instruments focused on nature protection, namely HD and BD, WFD and MSFD. We contextualize the comparative analysis considering exclusively coastal and marine conservation objectives and targets, despite both the HD and BD are applied to both terrestrial and aquatic environments, to answer to the request of the ECOSS project, which is focused on the marine environment. The assessment is mainly based on official documentation - such as Commission directives, reports and guidelines - by selecting aspects relevant to drive the emergence of the synergies and favourable to the achievement of the conservation objectives entailed within the directives. These aspects are the following (Table 10):

i) Conservation objectives and targets

ii) Approaches adopted to foster conservation initiatives

iii) Spatial application

iv) Reporting period that guides the evaluation of conservation objectives and targets achievement and of conservation measures effectiveness

v) Criteria and indicators adopted to evaluate conservation objectives and targets achievement, and for monitoring, if any

vi) Indications related to the monitoring strategies, if any

vii) Considerations related to the human uses, to the human-derived pressures, and to the ecosystem services delivered by the marine environment.

Our aim is also to recognize potential conflicts and inconsistencies among the directives, as well as their

main relevant weaknesses, to contribute supporting their improvement and overcoming possible limitations to achieve conservation goals.
We finally consider possible links and interactions with: (i) the EU Action Plan 2017 for Nature directives, which informs the need of implementing the Natura 2000 network, (ii) the Common Fishery Policy (CFP), and the (iii) Maritime Spatial Planning Directive (MSPD).

4.4.1 Directives comparison

Since the Convention on Biological Diversity (CBD), opened for signature at 1992 (Rio de Janeiro Earth Summit) and entered into force on December 1993, several initiatives and legal commitments have been established to pursue its objectives, which in short are: (i) the conservation of biological diversity, (ii) the sustainable use of the components of biological diversity, and (iii) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. Thanks to this convention, all the MS recognized as a priority the *in situ* conservation of habitats and species. This was the starting point of biodiversity conservation initiatives around the world. From that moment until today, the EC translated the CBD objectives in several legal instruments.

Habitats and Birds Directives

The HD was among the first ones to be enacted. This directive aims at "promoting the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, making a contribution to the sustainable development". The main strategy to achieve such goal is the establishment of a coherent ecological network of protected sites, defined as Special Areas of Conservation (SACs), which is the European ecological network named N2K, to conserve species and habitats identified as of priority for conservation in Europe. This network includes also the sites designated under the BD, established well before the CBD, and that introduced the idea of a protected areas network, through the designation of Special Protection Areas (SPAs). The BD was first drafted in 1979 and amended several times. In this report, we refer to the last amended version, which is 2009/157/EC. The aim of this directive is to protect wild birds, including seabirds, which naturally occur in European territory mainly presenting a migratory nature. Both the HD and BD recognize the predominant need of ensuring the ecological connectivity that characterize the life history of different

bird species and other migratory animals. Ecological connectivity has been defined as “the degree to which landscapes and seascapes allow species to move freely and ecological processes to function unimpeded” (UNEP 2019). Most animals and plants, indeed, during their life-cycle can depend on more than one habitat. For this reason they need to freely move from land to sea and vice versa, and to span through the whole marine environment to accomplish their vital functions, such as feeding and breeding, in synergy with all the natural ecological processes (e.g. production and consumption of food and oxygen). Mainly for this reason, HD and BD incorporate their respective objectives in the N2K network.

The two directives entail both a proactive and a reactive approach, since they do aim at conserving the species and habitats of protection in a favourable state, the HD explicitly referring to the FCS, as well as to restore and support the recovery of already degraded populations and habitats. The “conservation status of a natural habitat means the sum of the influences acting on a natural habitat and its typical species that may affect its long-term natural distribution, structure and functions as well as the long-term survival of its typical species within the territory referred to in Article 2”.

The conservation status of a species in the HD (Article 1(i)) will be taken as “favourable” when:

- population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats;
- the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future;
- there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

The conservation status of a habitat in the HD (Article 1(e)) will be taken as “favourable” when:

- its natural range and the areas it covers within that range are stable or increasing;
- the specific structure and functions which are necessary for its long-term maintenance exist and are likely to continue to exist for the foreseeable future;
- the conservation status of its typical species is favourable.

Management plans to address the achievement of Nature directives' objectives are not mandatory, nonetheless are strongly suggested and should establish both spatial and management measures for the conservation of species and habitats in need of protection (e.g. huntable bird species considered in unfavourable status), and to the sustainable use of natural resources. They both work mainly at the national level since each MS must propose potential N2K sites, even though forms of transnational cooperation are highly recommended to concretely entail ecological connectivity aspects in the wide N2K framework (Art. 18 Par. 2 of HD, and not (4) of BD), especially for the aim of protecting migratory and highly mobile species. The HD and BD identify and list several species and habitats in need of protection, which represent specific conservation targets. The EC published a Guidance Document on "Hunting under the Birds Directive" with the aim of giving clear guidance, based on scientific knowledge, to MS regarding the management of birds hunting in their territories.

Based on the last N2K barometer (December 2019), more than 3150 marine N2K sites have been designated under H&BD, covering almost 10% of the total EU marine area, i.e. over 550,000 km^2 (EEA, 2019). The sites are spread from the coast to the offshore because both the directives act on all MS territories. For this reason, the sites can include a mix of habitats and species being composed by terrestrial, freshwater and marine ecosystems, even crossing the land-sea interface. From the Committee Meeting held on 23/10/2000 the HD considers 9 main biogeographical regions (Alpine, Atlantic, Black Sea, Boreal, Continental, Macaronesian, Mediterranean, Pannonian, and Steppic), searching for habitats and species representative of each. The BD, instead, presents a broader approach considering the European territories as a whole, trying to fully respect the nature of migratory birds.

The HD and BD define a reporting period (6 and 3 years, respectively) within which the MS must deliver a document, describing the state of the species and habitats under protection and the effectiveness of the conservation measures set up by the management plan, if this is present. The need of reporting the state of the conservation targets implies the need of carrying out monitoring activities and updating the existing management plans. Indeed, Art. 11 of HD states that MS "shall undertake surveillance of the conservation status of the natural habitats and species". The EC also calls for the monitoring activities carried out under the BD to support effective management of all the activities that may affect bird populations, as well as to detect changes in their conservation status (EC 2008). Finally, they both refers to the human dimension from the perspective of the sustainable development, recognizing that nature

delivers key services for the socio-economic development of local communities.

Water Framework Directive

The WFD was not conceived as an instrument for the designation of areas for conservation, but mainly for addressing the ecological quality of water. The WFD, indeed, considers water as a common and fundamental good, a heritage, recognizing that water sources are under increasing pressure for the growing demand and for the increasing human-derived impacts, which contribute to the water environment deterioration.

WFD establishes a framework for Community action in the field of water policy for the protection and sustainable management of inland surface waters, transitional waters, coastal waters, and groundwater (Art. 1a); Art. 2 N°. 18; Art. 4 par. 1 a) ii) and iii); Annex 5 N°. 1.2 table 1.2). It protects the whole body of waters on which its jurisdictional action extends, up to 1 nautical mile (nm) from the coastline, dividing it within river basin districts that are adopted as main management units and managed by competent authorities through the adoption of RBMPs.

Central to the WFD is the achievement of the Good Ecological Status (GEcS) defined as “the values of the biological quality elements for the surface water body type which show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions”. The achievement of this quality target was primarily scheduled by 2015, with possible delay until 2021. By addressing the ecological status of the whole aquatic environment thus considering the structure and functioning of aquatic ecosystems, differently from the H&BD, the WFD adopts a pioneering approach, going beyond the protection of single species and habitats. Moreover, the ecological concept behind WFD (and, later, MSFD) consists in comparing the current state of an area with that which would be expected under minimal or sustainable human use and, in case of degradation, intervening to bring it back to the desired good status (Mee et al 2008). In the WFD the Quality Status (QS) of a water body can be determined based on the evaluation of Biological Quality Elements (BQE), for example phytoplankton, macroalgae, macro-invertebrates and fish (the latter only in transitional waters), which are supported by chemical, physico-chemical quality elements (e.g. transparency, thermal and oxygen conditions, salinity and nutrients). The evaluation of

these latter aims at supporting the achievement of the second target of the directive, which is the Good Chemical Status (GCS). The approach adopted by WFD can be defined as a "deconstructing structural approach" (Borja et al 2010), since (i) it separates the ecosystems into several quality elements and districts, then (ii) it compares their structure individually and, finally, (iii) it combines them to assess the overall conditions

Although not specifically designated for conservation, the WFD shows anyway some relevant connections with nature conservation issues. Primarily, it aims at improving the habitat quality and the diversity of species in surface waters, by the criteria of GEcS and GCS, and at preventing the deterioration of the environment. It mentions also the protection of terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems, clearly referring to the management objectives for N2K sites (Annex IV part A and Annex V N°. 1.3.5). The objectives of WFD, HD and BD are therefore closely related. The interplay of WFD and Nature directives is of high practical relevance, because monitoring activities and measures according to WFD can take place within N2K sites. In addition, Art. 6 of WFD states that MS "shall ensure the establishment of a register or registers of all areas lying within each river basin district designated as requiring special protection under specific Community legislation...", such as the HD and BD, "...for the protection of their surface water and groundwater or for the conservation of habitats and species directly depending on water".

Marine Strategy Framework Directive

The MSFD represents the most updated and comprehensive policy instrument that addresses the protection and conservation of the marine environment in its entirety. Indeed, it creates a framework that aims at "maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive". While protecting and conserving the marine environment, it promotes its sustainable use recognizing it as "a precious heritage that must be protected, preserved and, where practicable, restored". The MSFD aims at achieving the GEnS by 2020 for all MS. GEnS is defined as "the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations". The GEnS shall be determined at the level of the marine

region or subregion, as referred to in Art. 4, on the basis of eleven qualitative descriptors, reported in Annex I:

- Descriptor 1. Biodiversity is maintained
- Descriptor 2. Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3. The population of commercial fish species is healthy
- Descriptor 4. Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5. Eutrophication is minimised
- Descriptor 6. The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8. Concentrations of contaminants give no effects
- Descriptor 9. Contaminants in seafood are below safe levels
- Descriptor 10. Marine litter does not cause harm
- Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

The MSFD enlarges its action range with respect to the WFD, since it extends its spatial application to the whole marine environment, meaning “waters, the seabed and subsoil on the seaward side of the baseline from which the extent of territorial waters is measured extending to the outmost reach of the area where a Member State has and/or exercises jurisdictional rights” (Art. 3). The marine waters are divided into marine regions and subregions where MS shall implement their obligations under this Directive.

Despite this spatial division, the approach adopted by the MSFD has been defined as “holistic and functional” (Borja et al 2010), since marine regions are not defined on the basis of geopolitical boundaries, and because it considers functional objectives related to the ecosystems, concentrating on the 11 descriptors that together ensure the whole ecosystem integrity and entail ecological connectivity aspects.

As the other above-described directives, the MSFD applies a proactive and reactive approach, since it

considers restoration and recovery among the range of actions that needs to be implemented to pursue conservation objectives. The directive calls also for the integration of the precautionary approach and of the ecosystem-based one into the management of all human activities, recognizing the importance of ensuring the delivery of ecosystem services, on which socio-economic development strongly relies. Finally, the MSFD presents a highly integrated and transnational approach reflecting the transboundary nature of the marine environment. Indeed, it promotes the integration of environmental considerations into all relevant policy areas delivering the environmental pillar of the future maritime policy for EU, and highlights the need to ensure cooperation among MS, as well as with third countries when needed, by taking advantage of the existing Regional Sea Convention when possible.

The MSFD clearly recognizes the important contribution that the establishment of MPAs, including N2K sites and areas designated under international or regional agreements to which the EC or MS concerned are Parties, delivers to the achievement of GEnS. For this reason, the MSFD promotes the designation of MPAs as fundamental tools for marine conservation, with the aim of contributing, together with the N2K network, to the achievement of the CBD conservation targets.

4.4.2 Monitoring activity and related indicators

As there is no one-fits-all definition of indicators, there is no uniqueness from the directives in considering and defining them to guide the monitoring plans. In fact, the directives lack homogeneity in the adoption of terminology and none of them refer to descriptive or performance indicators, as shown below.

By declaring the need of establishing and enforcing appropriate management plans to pursue the protection of species and habitats of priority for conservation, the HD and BD entail the need of setting up monitoring activities. Indeed, the HD and BD require every 6 and 3 years, respectively, the reporting related to the state of the target species and habitats present in each N2K site, and of the implementation of the management measures taken by MS. The directives also support research activities addressed towards the identification of suitable areas for the establishment of N2K sites and the building of a coherent ecological network. They do consider the human activities and related impacts on the habitats and species of priority for protection, even though they do not list them specifically. Both directives clearly state that any type of activities that can degrade, deteriorate and

disturb the protected species populations and habitats must be strictly avoided, if not for human health reasons (HD, Article 12; BD, Art. 9). The BD specifically calls for scientific research to assess possible threats and negative effects to birds (e.g. noise, maritime traffic, light pollution), as well as to evaluate the effectiveness of the management and conservation measures put in place in the protected sites (Art. 10, Annex V). Deliberate and incidental captures of target species are forbidden and monitoring strategies addressing such activities must be established. However, both Directives, especially the HD, consider that in most of the N2K sites local communities strongly rely on the natural resources delivered by the environment where they live for their socio-economic development. For this reason, H&B directives aim at finding a balance between the presence of humans and their uses and nature protection needs.

The HD, referring to monitoring, specifies parameters instead of descriptive indicators to evaluate the achievement of the FCS of habitats and species. These comprise quantitative (range, area, population size) as well as qualitative (structure and functions) criteria plus a forecast for the future ('future prospects' parameter) (EC 2016). The combination of these criteria and the monitoring parameters are intended to reflect the status of the species or habitats (FCS), which, even though not defined in the directive, can be regarded as performance indicator.

The DG Environment (2017) released specific guidelines for MS for reporting the state of N2K sites that guide the gathering of the necessary information for the assessment of sites' state. However, it does not deliver specific guidelines to foster the monitoring of target species and habitats to MS, which are mainly let free to manage their own activities based on their context and possibilities. It has to be highlighted that where management plans are not set, the reporting is not carried out, nor are the monitoring activities.

The BD indicates some monitoring parameters**,** as the HD, and it does not explicitly give specific guidelines for the definition of performance indicators. Anyway, for those bird species that enter in the Annexes of the HD, the same rules and indications are valid as for all HD target species.

The WFD foresees a reporting period of 6 years and, differently from the Nature directives, provides specific guidelines for monitoring. Indeed, in Art. 8 it presents very detailed monitoring requirements for

both surface and groundwater and, in Annex V, it lists several steps to carry out for effective monitoring: design of surveillance, operational and investigative monitoring, frequency of monitoring, additional monitoring requirements for protected areas, standards for monitoring of quality elements (BQE). In fact, the WFD adopts quality elements instead of descriptive indicators. The GEcS and the GCS are used as environmental indicators of system performance, since they show the distance between the current state and the desired one of the defined quality elements that are subjected to monitoring. For each quality element (biological, hydro-morphological, and physico-chemical) the value of high, good, moderate, poor, bad quality is assessed, following normative definition, to quantify the ecological status. Pollution is the major source of impact affecting the water bodies and generated by human activities (Annex II, N°. 2.5.). Article 5 of the directive asks for a systematic "review of the impact of human activity on the status of surface waters and groundwater". However, similarly to the Nature directives, it does not specifically list the human activities and related pressures to be considered and managed.

The MSFD deliver monitoring in even a more structured way than WFD. Indeed, it declares the need of developing "criteria and methodological standards to ensure consistency and to allow for comparison between marine regions or subregions of the extent to which GEnS is being achieved. These should be developed with the involvement of all interested parties". To make this possible, the directive recognizes the need of establishing environmental targets and monitoring programmes, which should be built upon relevant provisions for assessment and monitoring laid down by EC legislation, such as the WFD, and including the Nature directives (Art. 11). Thus, the MSFD considers and integrates the existence of other monitoring and management programmes and foresees, when possible, synergies among them. It also suggests to avoid unnecessary discordances that can emerge, for instance in coastal waters, where the WFD already applies, by aligning the adopted criteria to those established and used under WFD.

As the WFD, the MSFD set what we might consider as an overall performance indicator, the Good Environmental Status (GEnS), which can be valued as good or not good on the basis of several biotic and abiotic parameters that must be included in the monitoring programmes. As described above, the GEnS is determined on the basis of eleven qualitative descriptors (Annex I). The EC, in 2017, laid down the

criteria and methodological standards to give common guidelines to MS to monitor advances towards the achievement of GEnS through the EU 2017/848. In this document, the Commission indicated criteria**,** instead of descriptive indicators, related to each descriptor, which should be monitored for the achievement of the set environmental performance.

Another document was delivered concurrently, the EU 2017/845, written to better guide the MS during the second cycle of implementation of their marine strategies. MS should take into account pressures or impacts of human activities in each marine region or subregion, having regard to the indicative lists set out in Table 2a and 2b of Annex III (Art. 9). In this case, the human derived pressures and impacts are specifically listed and possible related parameters indicated. Table 2a and 2b of Annex III are reported below.

MDSFD: Table 2a of Annex III (EU 2017/845). Anthropogenic pressures on the marine environment.

Theme	Pressure	Possible parameters
Biological	Input or spread of non-indigenous species	Intensity of, and spatial and temporal variation in, the pressure in the marine environment and, where relevant, at source
	Input of microbial pathogens	
	Input of genetically modified species and translocation of native species	
	Loss of, or change to, natural biological communities due to cultivation of animal or plant species	
	Disturbance of species (e.g. where they breed, rest and feed) due to human presence	

	Extraction of, or mortality/injury to, wild species (by commercial and recreational fishing and other activities)	
Physical	Physical disturbance to seabed (temporary or reversible)	
	Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)	
	Changes to hydrological conditions	
Substances, litter and energy	Input of nutrients — diffuse sources, point sources, atmospheric deposition	
	Input of organic matter — diffuse sources and point sources	
	Input of other substances (e.g. synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events	
	Input of litter (solid waste matter, including micro-sized litter)	
	Input of anthropogenic sound (impulsive,	

	continuous)	
	Input of other forms of energy (including electromagnetic fields, light and heat)	
	Input of water — point sources (e.g. brine)	

MSFD: Table 2b of Annex III (EU 2017/845). Uses and human activities in or affecting the marine environment.

Theme	Activity
Physical restructuring of rivers, coastline or seabed (water management)	Land claim
	Canalisation and other watercourse modifications
	Coastal defence and flood protection
	Offshore structures (other than for oil/gas/renewables)
	Restructuring of seabed morphology, including dredging and depositing of materials

Extraction of non-living resources	Extraction of minerals (rock, metal ores, gravel, sand, shell)
	Extraction of oil and gas, including infrastructure
	Extraction of salt
	Extraction of water
Production of energy	Renewable energy generation (wind, wave and tidal power), including infrastructure
	Non-renewable energy generation
	Transmission of electricity and communications (cables)
Extraction of living resources	Fish and shellfish harvesting (professional, recreational)
	Fish and shellfish processing
	Marine plant harvesting
	Hunting and collecting for other purposes
Cultivation of living resources	Aquaculture — marine, including infrastructure

	Aquaculture — freshwater
	Agriculture
	Forestry
Transport	Transport infrastructure
	Transport — shipping
	Transport — air
	Transport — land
Urban and industrial uses	Urban uses
	Industrial uses
	Waste treatment and disposal
Tourism and leisure	Tourism and leisure infrastructure
	Tourism and leisure activities

Security/defence	Military operations
Education and research	Research, survey and educational activities

Below, we report five tables (10-14), with the aim of summarizing for each directive the principal aspects related to their jurisdictional framework (Table 10) and the suggested descriptive indicators to be monitored for the achievement of their performance indicators and environmental objectives (Tables 11-14). We use the term descriptive indicators to adopt a common term for what is called criteria in the MSFD, quality elements in the WFD, and parameters in the H&BD. Because the MSFD is the most recent and adopts the most holistic and functional approach, including the ecological connectivity aspects, we consider it as the most advanced and comprehensive. For this reason, we compare its descriptive indicators (criteria) with those of the other directives to find possible correspondences and to make a first attempt of indicators' harmonisation. We emphasize that the MSFD criteria do not cover all the quality elements of the WFD and all the parameters of H&BD. This is mainly due to the distinct characteristics of each directive that, as shown in Table 10, were conceived for addressing different conservation and monitoring targets, despite being forged for the common achievement of a better quality of the environment and of its natural components.

Table 10. Principal aspects related to the jurisdictional framework focused on environmental protection and the establishment of Protected Areas for the conservation of natural aquatic/marine ecosystems. The most relevant jurisdictional instruments in the framework of the ECOSS Project are compared. HD = Habitats Directive; BD = Birds Directive; WFD = Water Framework Directive; MSFD = Marine Strategy Framework Directive.

Comparison aspects	HD (92/43/EEC)	BD (2009/157/EC)	WFD	MSFD (2008)	References

			(2000/60/EC)		
General objectives and target of protection	- Maintenance of biodiversity, taking account of economic, social, cultural and regional requirements, and making a contribution to the sustainable development - Protection of selected species and habitats identified as of priority for protection. - Achievement or restoration of the Favourable Conservation Status (FCS	- Maintain natural birds populations in the wild state to ecological-scientific-cultural adequate levels. Protection of selected species and habitats identified as of priority for protection. - The preservation, maintenance or restoration of a sufficient birds diversity and area of habitats	-Maintain and improve the quality of the aquatic environment in the Community. - Achievement of Good Ecological Status (GEcS) of all waters by 2015, or 2021. -Achievement of the Good Chemical State (GCS) of all waters by 2015, or 2021	- Protection and conservation of the marine environment and promotion of the sustainable use of the seas and conserving marine ecosystems. - Achievement and maintenance of Good Environmental Status (GEnS) in the marine waters by 2020.	-Directives -EEAC, 2018

Approach to conservation	-Spatial and management measures mainly. -Proactive and reactive: it considers restoration and recovery actions. -They work more at national level even though regional cooperation is highly recommended. -List of species and habitats to protect and monitor already defined.	-Spatial and management measures mainly. -Proactive and reactive: it considers restoration and recovery actions. -They work more at national level even though regional cooperation is highly recommended. -List of bird species and habitats to protect and monitor already defined.	-Ecological state including ecosystem functioning -Deconstructing, structural approach (see text), based on 5 biological quality elements (BQE) plus hydromorphological and physicochemical quality elements -Proactive and reactive: it considers restoration	-Holistic, functional approach. -Proactive and reactive: it considers restoration and recovery actions. -Ecosystem-based. -Highly transnational (needs to work through regional programmes). -Consideration of socio-economic aspects. -It explicitly includes ecological connectivity	- Directives -Borja et al. 2010 -FAQ final 2012-07-27

Spatial application	-Broad. -5 main biogeographic regions. -Transitional, coastal and territorial waters, including EEZ where declared.	-Broad. -European territory and not biogeographic regions. -Transitional, coastal and territorial waters, including EEZ where declared.	- Rivers, lakes, transitional and coastal waters up to 1 nm from the coastline. -River basin districts as management units for river basins	-Broad. -4 marine regions that include sub-regions. -Coastal and territorial waters, including EEZ where declared.	-Directives
Reporting period	-Reporting every 6 years on the implementation of national provisions taken under the directive	-Reporting every 3 years on the implementation of national provisions taken under the directive	-Monitoring and reporting every 6 years.	-Monitoring and reporting every 6 years.	-FAQ final 2012-07-27 -Directives

Criteria and Performance indicator	-Criteria for site selection both for a given natural habitat and species, Annex III - Achievement or restoration of the Favourable Conservation Status (FCS, Favourable, unfavourable - inadequate, unfavourable - bad, unknown) and associated criteria for both habitats and species.	-Not indicated explicitly in the directive. For selection of N2K sites for birds protection, the criteria are the same indicated in the HD - Achievement or restoration of the Favourable Conservation Status (FCS, Favourable, unfavourable - inadequate, unfavourable - bad, unknown) and associated criteria for both habitats and species.	- Good Ecological Status (GEcS) - Good Chemical State of all waters -High, good, moderate, poor, bad quality of the ecological status defined by normative	- Good Environmental Status (GEnS) - 11 descriptors -Good or not good	-Directives
Indication for monitoring	- Required monitoring but not explicit indication	- Required monitoring but not explicit indication	- Detailed monitoring requirements (e.g. types of monitoring, quality elements to be monitored, monitoring	- Detailed monitoring requirements - Established criteria and methodological standards on GEnS	-Directives - EU 2017/848

			frequency)	and specifications and standardised methods for monitoring and assessment	
Human activities, derived pressures, and ecosystem services (ES)	- Mainly hunting, illegal killing, trapping and trade of species - In its objectives the directive entail considerations of economic, social, cultural and regional aspects rooted in the use of natural resources, making a contribution to the sustainable development. Not explicit reference to ES.	- Mainly hunting, illegal killing, trapping and trade of birds - Long-term protection and management of natural resources as an integral part of the heritage of the peoples of Europe. - Control natural resources and governs their use on the basis of the measures necessary for the maintenance and adjustment of the natural balances between species as far as is reasonably possible. Not explicit	-Member States should ensure a review of the impact of human activity on the status of surface waters and on groundwater -Mainly focuses on pollution sources and to reduce the discharge and emission of pollutants and hazardous substances -Clear reference to water provisioning as fundamental service to human	- The strategy addresses all human activities that have an impact on the marine environment. - Human-derived pressures and impacts to monitor and manage specified and described - Reference to the adoption of an ecosystem-based approach and to the importance of the marine environment for the services and benefits it delivers	-Directives https://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm - EU 2017/848

		reference to ES.		it humans	

Table 11. Descriptive indicators (criteria) of the MSFD with related criteria codes (EU 2017/848).

Criteria Code	Descriptive indicators: Criteria MSFD
D1C1	Mortality rate from incidental by-catch
D1C2	Population abundance
D1C3	Population demographic characteristics
D1C4	Population distributional range and pattern
D1C5	Habitat for the species
D1C6	Pelagic habitat condition
D2C1	Newly-introduced NIS
D2C2	Established NIS
D2C3	Adverse effects of NIS
D3C1	Fishing mortality rate (F)
D3C2	Spawning stock biomass (SSB)
D3C3	Population age/size distribution
D4C1	Trophic guild species diversity
D4C2	Abundance across trophic guilds
D4C3	Trophic guild size distribution

D4C4	Trophic guild productivity
D5C1	Nutrient concentrations
D5C2	Chlorophyll a concentrations
D5C3	The number, spatial extent and duration of harmful algal bloom events
D5C4	The photic limit (transparency)
D5C5	The concentration of dissolved oxygen
D5C6	The abundance of opportunistic macroalgae
D5C7	The species composition and relative abundance or depth distribution of macrophyte communities
D5C8	The species composition and relative abundance of macrofaunal communities
D6C1	Spatial extent and distribution of physical loss (permanent change)
D6C2	Spatial extent and distribution of physical disturbance pressures
D6C3	Spatial extent of each habitat type which is adversely affected, through change in its biotic and abiotic structure and its functions by physical disturbance
D6C4	Benthic habitat extent (loss)
D6C5	Benthic habitat condition (extent of adverse effects including alteration to its biotic and abiotic structures and its functions)
D7C1	Spatial extent and distribution of permanent alteration of hydrographical conditions to the seabed and water column

D7C2	Spatial extent of each benthic habitat type adversely affected due to permanent alteration of hydrographical conditions.
D8C1	Concentrations of contaminants
D8C2	Health of species and the condition of habitats
D8C3	Spatial extent and duration of significant acute pollution events
D8C4	Effects of significant acute pollution events on the health of species and on the condition of habitats
D9C1	The level of contaminants in edible tissues of seafood
D10C1	The composition, amount and spatial distribution of litter on the coastline, in the surface layer of the water column, and on the seabed
D10C2	The composition, amount and spatial distribution of micro-litter on the coastline, in the surface layer of the water column, and in seabed sediment
D10C3	The amount of litter and micro-litter ingested by marine animals
D10C4	The number of individuals of each species which are adversely affected due to litter, such as by entanglement, other types of injury or mortality, or health effects.
D11C1	Spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources
D11C2	Spatial distribution, temporal extent, and levels of anthropogenic continuous low-frequency sound

Table 12. Descriptive indicators (Quality elements) of the WFD (Annex V) and associated criteria code of the MSFD. Notice that not all quality elements correspond to a MSFD criteria.

Descriptive indicators: Biological quality elements (BQE) chemical, physico-chemical quality elements WFD	**MSFD (Criteria Code) related**
Composition of aquatic flora (macrophyte) Abundance of aquatic flora (macrophyte) Presence of sensitive taxa of flora (macrophyte)	D5C7
Abundance of phytobenthos Composition of phytobenthos Presence of sensitive taxa of phytobenthos	-
Abundance of phytoplankton Composition of phytoplankton Bloom frequency of phytoplankton Bloom intensity of phytoplankton Biomass of phytoplankton	D2C2, D4C4, D5C2, D10C1, D10C2, D10C3
Composition of benthic invertebrate fauna Abundance of benthic invertebrate fauna Presence of sensitive taxa of invertebrate fauna	D6C5

Diversity of invertebrate fauna	-
Composition of fish fauna Abundance of fish fauna Age structure of fish fauna Life cycle of fish fauna Presence of sensitive taxa of fish	D3C2, D3C3, D1C2, D1C4, D1C5, D1C6, D1C3
Historical flow	-
Modelled flow	-
Real time flow	-
Water table height	-
Surface water discharge	-
Number and type of barriers	-
Provision for passage of aquatic organisms	-
River cross section	-
Flow	-
Cross sections	-
Particle size	-

Presence of Catchment Water Drainage Location of Catchment Water Drainage Length of the riparian zone Width of the riparian zone Species composition of the riparian zone Continuity of the riparian zone Ground cover of the riparian zone	- - - - - - -
Temperature	D1C6, D5C4, D7C1
Dissolved oxygen	D5C5
Electrical conductivity	D5C4, D7C1, D1C6
pH	D1C6
Alcalinity	-
Acid Neutralizing Capacity (ANC)	-
Total phosphorus	D5C1, D1C6
Soluble reactive phosphorus	D5C1, D1C6
Total nitrogen	D5C1, D1C6

Nitrate + nitrite	-
Ammonium	-
Suspended solids	-
Turbidity	D1C6, D5C4, D7C1
Pollution by all priority substances identified as being discharged into the body of water Pollution by other substances identified as being discharged in significant quantities into the body of water	D8C3
Composition of other aquatic flora (macrophyte) Abundance of other aquatic flora (macrophyte)	D5C7
Mixing patterns Circulation patterns	D1C6, D7C1
Inflow Outflow Lake surface Lake volume Lake depth Water content of the lake bed Particle size of the lake bed	- - - - - - -

Elemental composition of the lake bed Sedimentation age of the lake bed Sedimentation rate of the lake bed Length of the lake shore Species composition of the riparian zone	- - - - -
Vegetation cover	D5C7
Bank features	-
Secchi depth	D5C4, D7C1, D1C6
Colour Total Organic Carbon (TOC)	- -
Composition of invertebrate fauna Abundance of invertebrate fauna Presence/absence of invertebrate fauna	D6C5
Bioaccumulation Bioassay	- -
Freshwater inputs Residence time	D7C1
Exchange	-

Wave exposure Basin shape	- -
Particle size of the bed Organic content of the bed	D6C5
Vegetation composition of the tidal zone Vegetation cover of the tidal zone Diversity of phytoplankton	- - -
Diversity of other aquatic flora (Macrophyte)	D5C7
Presence of sensitive taxa of macroalgae	D5C6
Depth cover of macroalgae Distribution cover of macroalgae	- -
Diversity of angiosperms Abundance of angiosperms Presence of sensitive taxa of angiosperms Depth cover of angiosperms Distribution cover of angiosperms	D5C7
Biomass of invertebrate fauna	D6C5
Tide speed	-

Tide direction	-
Wave speed Wave direction	D1C6, D7C1
Freshwater flow	D7C1
Hydrological budget Topography Particle size of the coastal bed Solid rock of the coastal bed General characteristics of the coastal bed Particle size of the intertidal zone Solid rock of the intertidal zone	- - - - - - -

Table 13. Descriptive indicators (parameters) of the HD (EU 2012) and associated criteria code of the MSFD. Notice that not all parameters correspond to a MSFD criteria.

Descriptive indicators: Parameters HD	**MSFD (Criteria Code) related**
Natural range of natural habitat types of community interest Area covered by natural habitat types of community interest	D1C5

Specific structure of natural habitat types of community interest	
Necessary functions of natural habitat types of community interest	-
Status of conservation of species in natural habitat types of community interest	D8C2
Population dynamics of animal and plant species of community interest	D1C2, D1C3, D1C4
Natural range of animal and plant species of community interest	D1C4
Presence of habitat for animal and plant species of community interest	D1C5
Population dynamics of animal and plant species of community interest in need of strict protection	D1C2, D1C3, D1C4
Natural range of animal and plant species of community interest in need of strict protection	D1C4
Presence of (sufficiently large) habitat of animal and plant species of community interest in need of strict protection	D1C5
Incidental capture and killing of animals of community interest in need of strict protection	D10C4
Presence of (sufficiently large) habitat of animal and plant species of community interest whose taking in the wild and exploitation may be subject to management measures	D1C5

Table 14. Descriptive indicators (parameters) of the BD (EU 2012) and associated criteria code of the MSFD. Notice that not all parameters correspond to a MSFD criteria.

Descriptive indicators: Parameters BD	MSFD (Criterial Code) related
Trends and variations in population for the species birds in the Annex I Trends and variations in population for species in danger of extinction Trends and variations in population for vulnerable species Trends and variations in population for species considered rare Trends and variations in population for other species requiring particular attention Trends and variations in population for migratory species not listed in the Annex I	D1C2, D1C3, D1C4
National lists of species in danger of extinction Listing and ecological description of areas important to migratory species Listing population levels of migratory species as shown by ringing Role of certain species as indicators of pollution	-
Adverse effect of chemical pollution on population levels of bird species	D8C4

From Tables 11-14 it is possible to notice that there is not a complete and specific correspondence between the listed descriptive indicators, the MSFD criteria against the quality elements and parameters of WFD and H&BD. Indeed, they are aggregated differently: the MSFD criteria are articulated upon the 11 descriptors, which identify specific environmental performances (descriptors 1-4) explicitly considering also the human-induced pressures sphere (descriptors 5-11). Interestingly, the MSFD is the only directive that considers species interactions through descriptor 4, related to the food-web and the elements from which this is composed. Indeed, criteria related to D4 find almost no correspondence with the descriptive indicators of the other directives.

The WFD presents a rich set of specific quality elements related to the water bodies' characteristics, including also inland (e.g. lakes and rivers) and transitional water ecosystems (e.g. lagoons), which are not covered by MSFD. One other noticeable characteristic of the WFD is that it specifically addresses only some target communities, i.e.: macrophytes, phytobenthos, phytoplankton, benthic invertebrates, and fish. It does not include pelagic population beyond phytoplankton and fish components (e.g. cephalopods, reptiles and marine mammals). However, some WFD quality elements finds a pretty good correspondence with different MSFD criteria, as for example those related to the phytoplankton component that can be linked with different criteria, related to D2, 4, 5 and 10. Also several WFD chemical and physical indicators find good correspondence (e.g. all elements related to the hydrographical conditions) with MSFD, even though the terminology and the level of specificity of the indicators are distinct.

Regarding the H&BD, it is possible to observe a major correspondence of their parameters with criteria related to MSFD Descriptor 1 "Biodiversity is maintained". For instance both the directives find correspondence with three criteria related to D1: D1C2 population abundance, D1C3 demographic characteristics and D1C4 distributional range and pattern. The correspondent parameters in HD is "population dynamics of animal and plant species", while in BD is "trends and variations in population for species". Both Nature directives do not consider the set of chemical and physical indicators that are included in the other two, being mainly focalized on target species and habitats preservation. However, the state of several of such indicators (e.g. water turbidity and temperature) is obviously fundamental for the good state of all species and habitats of priority for conservation. This consideration highlights

the need of develop synergies between the monitoring programs of WFD and MSFD and the monitoring of the conservation state of N2K sites, as we will detail in the next paragraph.

4.4.3 Synergies, complementarities, heterogeneities and gaps: a synthesis

All the compared directives share a common goal that coincides with the protection of the aquatic environment and the preservation and sustainable management of the resources it provides to humans. The achievement of a good quality ecological and environmental state is central. If the HD and BD focus their conservation objectives on target species and habitats, the WFD and, even more the MSFD, expand their action by including functional aspects and considering the ecosystems as a conservation unit. Thus, all these directives can be considered as complementary to each other, since all together provide an overall normative context for conservation priority objectives at different spatial and ecological levels. Explicitly or implicitly, the ecosystem-based approach is commonly adopted and the human dimension is always present, since all the directives aim at contributing to the sustainability objectives, highlighting the tight interconnections between nature and humans.

Complementarity is also present when considering the spatial scale of application of the directives. The HD and BD, by supporting the implementation of the N2K network, are more focused on the *in situ* protection, while the WFD and MSFD, with their widest frameworks, address a broader scale and, through the achievement of their objectives, extend their conservation strategies also beyond the establishment of areas dedicated to conservation. In addition, the WFD and the MSFD apply within different jurisdictional boundaries, the WFD being focused on internal and coastal waters (up to 1 nm) and the MSFD extending from the coast to offshore areas. If appropriately coordinated, these two instruments can cover the entire water territories supporting the implementation of N2K network also in offshore waters, not leaving gaps amidst aquatic domains. The reporting periods of the four directives mainly overlap. This aspect can be of great benefit for the aim of coordinating the assessment of the state of the marine environment. The provided information entailed within all reporting periods should provide a complete and comprehensive knowledge framework to inform management and conservation strategies, also at the level of the N2K sites.

The descriptive and performance indicators, as intended in the ECOSS project (see above), are defined differently by these directives, and there is heterogeneity in the terminology used that may create

confusion to MS and N2K sites' managers that need to define and setting up coherent monitoring strategies. As such, we highlight the need of terminology harmonisation and, with this deliverable, we made a first step to define links and common definitions. In addition, descriptive indicators differ among directives as each jurisdictional instrument addresses specific conservation targets despite their overall shared objectives. The HD and BD address the conservation of target species and habitats, well defined in their Annexes. Thus, the performance indicators relate to the conservation status of these targets, considering the status, the dynamic, the structure and the natural range of specific species populations and habitats, which are described by parameters. The WFD focuses on the GEcS of the aquatic environment adopting specific quality elements to describe it, which do not focus on single species and habitat, but rather on certain organisms groups and on environmental parameters. Thus, the environment is considered in its entirety, and the quality elements are used to describe it. This holistic approach is underpinned by the MSFD with its GEnS, which is articulated in descriptors and associated criteria used for describing the achievement of the set environmental target and which addresses both species and habitats of priority for protection, but from the ecosystem functioning perspective, not leaving behind the other marine components, and recognizing the need of achieving the good status of the entire marine environment to ensure its functioning. Such an approach should be beneficial for the H&BD to advance on the implementation and extension of the N2K network, especially considering the need of integrating ecological connectivity aspects in the network to make it more effective and coherent. Actually, the collaboration between the two directives and the contribution that the MSFD can deliver in identifying new areas for marine conservation, may help overcoming the Nature directives limitations. Despite the different emphasis, the measures implemented under the H&BD can make an important contribution to achieving the wider objectives of MSFD and vice versa. Conservation measures under the H&BD should be part of any programme of measures to meet the requirements of MSFD and therefore help delivery more integrated policy and planning.

Although the HD does not look at all species occurring in a waterbody (i.e. the aquatic community as a whole), being mainly focused on the conservation status of selected species and habitats, there are some quality elements defined by the WFD and some criteria defined by the MSFD that - if jointly monitored - can be shared and beneficial, in particular for those monitoring activities that require the same methodological approach. Especially for those N2K sites that lack management plans and where,

consequently, monitoring activities are absent, WFD and MSFD monitoring programmes can be crucial to investigate their environmental state, also considering that all the target species and habitats listed in the HD are object of monitoring under the MSFD. Wherever possible joint monitoring programmes should be arranged in order to save resources and time, avoid the risk of overlapping and duplicate the monitoring efforts and of neglecting some marine areas, especially at the interfaces (e.g. land-sea, coastal-offshore waters) and allow an assessment based on a shared dataset. This is particularly relevant in a transboundary context.

As already mentioned, the human dimension is a common aspect considered by the four directives, since they all address the need of ensuring the sustainable management of natural resources, by balancing the societal economic needs and the conservation priorities. Natural goods and services are mentioned, more or less explicitly, in all these jurisdictional instruments, and the need of preserving and managing them is recognized as critical. While the HD, the BD, and the WFD mention the human activities only generically, the MSFD makes an ad hoc analysis of the human-derived pressures and impacts that can negatively affect the marine environment, highlighting the need of addressing all of them through ecosystem-based management measures. Taking advantage of this analysis and of the monitoring and research efforts supported by MSFD addressing the effect that human uses can have on both species and habitats, the N2K network managers can be informed on the priority management measures that should be taken for improving N2K sites effectiveness.

The comparative analysis of the four directives allows also evidencing some gaps, related to different aspects of their implementation. In particular, the application of HD and BD varies between EU countries, which are left a considerable degree of freedom to set up their own conservation strategy. This hampers the possibility of setting up a coherent regional-based ecological network of N2K sites. In addition, management plans related to N2K sites are not mandatory and they are often lacking: this greatly affects the conservation effectiveness, since adequate monitoring activities are not set up, thus leaving the sites often unmanaged and unmonitored, without the possibility to assess the achievement of the conservation objectives they were set for. Furthermore, Nature directives may anyway fail in achieving their aims, if they focus only on specific habitats and species, overlooking the overall environmental complexity and connectivity.

As for the WFD, the deconstructing and structural approach relies on river basin districts and considers separately the constituting parts of the environment (the BQE) losing the functional aspects of the ecosystems. Such an approach may weaken the possibility of thoroughly assessing the ecological status of the aquatic environment, by not adequately addressing the whole ecosystem picture. This is something that the MSFD avoids by developing a fully holistic and ecosystem-based approach. However, the MSFD, as the WFD, does not give any indication to MS on threshold values or baselines to be considered when assessing the level of GEnS, leaving MS free to establish their own values. Difficulties in establishing current extent and quality of habitats and populations and in setting acceptable limits to degradation against unknown levels of natural variation for many key habitats and species may strongly affect the efficiency of MS of implementing the directive and may lead to incoherency among MS assessment results.

4.4.4 Synergies with other jurisdictional instruments

On December 2017 the EC decided to develop an action plan (COM(2017) 198 final) to improve the implementation of Nature directives and the related N2K network, trying to accelerate the achievement of EU 2020 goal linked with the protection of biodiversity and nature. The plan highlights diverse priorities to be taken into consideration when implementing Nature directives. Among these, the ones that can be greatly supported by the synergies among the directives are: (i) Priority A - Improving guidance and knowledge and ensuring better coherence with broader socio-economic objectives; (ii) Priority B - Building political ownership and strengthening compliance. Priority A foresees among its actions the number 3: “Improve knowledge, including through enhanced and more efficient monitoring, and ensure public online access to data necessary for implementing the Directives (e.g. satellite imagery from the Copernicus programme)”. Monitoring programmes entailed within MSFD and WFD are greatly beneficial for the implementation of such action, potentially covering the monitoring needs also in those N2K sites where no management and monitoring plan is put in place. Priority B, instead, include the action 4: “Complete the Natura 2000 network, especially filling gaps for the marine environment, and put in place the necessary conservation measures for all sites”. As this action highlights, there is the strong need of acquiring a better understanding of the marine environment and how it functions, by filling gaps and informing management and conservation measures focused on it. The monitoring programmes guided by the WFD and MSFD are key to lead to the achievement of such understanding at

the scale of the N2K network, in order to support the implementation of a real coherent ecological network appropriately managed for the will of protect the marine environment.

Relevant synergies exist also between the Common Fishery Policy (CFP, EU 2013) and the here considered directives. Indeed, the aim of the CFP is to conserve the marine biological resources and to manage the fisheries targeting them: for this reason, it considers biologically sensitive areas as areas where fishing activities must be prohibited. This policy refers also the recreational fishery and aquaculture, recognizing that also these can have an impact on the marine environment and asks for an adequate management. This is an important aspect considering that diverse N2K sites, including some of the 4 case studies of the ECOSS Project, host or may host both these activities, which must be managed in a way not to impact the protected species and habitats. Indeed, Parco Delta del Po, Cres Lošinj and Malostonski zaljev sites, among their services, provide seafood from aquaculture, and together with the other ECOSS N2K sites, namely Viški akvatorij, may provide opportunity in terms of recreational fishery activity for the good presence of fish as it is indicated in Table 23 of Deliverable 3.4.1. In addition, the CFP refers to existing obligations regarding special protection areas, special areas of conservation and marine protected areas imposed by the Nature directives and by the MSFD, thus obliging MS to adopt measures in line with them. This policy requires an appropriated multiannual plan for fishery management that should include conservation objectives and quantifiable indicators for periodic monitoring and assessment of progress in achieving its targets (Art. 9 and 10). Relevant synergies between the CFP and the implementation of the N2K network are evident, considering the ecology of many marine species that may present distinct foraging, breeding and spawning sites and/or a highly migratory nature. To protect them, the *in situ* approach, related to the single protected site, may not be enough and a broader approach to conservation through the application of sustainability fishery measures is essential. The monitoring programmes planned under CFP can therefore be beneficial to inform conservation initiatives and the efficacy of N2K sites in protecting nursery habitats of species of commercial value.

Finally, it is fundamental to highlight the connections among the Nature directives, MSFD, WFD and the Maritime Spatial Planning Directive (MSPD, EC 2014). This directive imposes to MS to develop and enforce a maritime spatial plan in their own territorial waters, to boost Blue Growth objectives considering the multisectoral reality of the maritime economy. The MSPD is not focused on achieving

conservation objectives, but clearly states that to promote the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources, it is fundamental to ensure healthy marine ecosystems and the maintenance of the delivery of their multiple services, by applying an ecosystem-based approach (Art. 5). MSPD recognizes such an approach as imperative and it is committed to ensure collaboration in achieving the aims of Nature directives and of the MSFD, by ensuring that the collective pressure of all activities is kept within levels compatible with the achievement of good environmental status. Indeed, the MSPD, in Article 8, considers - among the relevant human activities - the nature and species conservation sites and protected areas, revealing the concrete interest of the Commission to support marine conservation objectives and the strong synergy among MSPD, Nature directives and MSFD. This means that, by designing their marine plans, MS should integrate considerations on conservation priorities dedicating space for conservation areas, N2K sites included. The MSPD does not asks specifically for environmental monitoring programmes, but states that MS shall organise the use of the best available data, also regarding the marine environment (Art. 10). Thus, this directive needs the information derived by the monitoring programmes carried out under the framework of the WFD and MSFD. Despite the MSPD is not a monitoring instrument, by incorporation conservation priorities and sustainability objectives, it proves to be a fundamental instrument to support marine environment protection from the multiple human-derived pressures, and for the establishment of future marine areas for conservation.

4.4.5 Identification of specific performance indicators for the N2K case studies

Performance indicators are intended to help managers improve the management of N2K sites by determining whether management objectives are being achieved. To do that performance indicators should closely track the objective that it is intended to measure, have to be developed on the specific features of the single species/habitats object of conservation and be able to detect any changes in the environmental status (Pomeroy et al 2004). They can have as a reference the initial condition of the system (e.g. the community structure before MPA establishment) or can be based on a future conservation target. There is no predefined unique list of indicators, and for each N2K site, relevant indicators must be adapted. However, the number of indicators monitored should be as low as possible to optimize costs.

Here we reported some performance indicators that management bodies of the N2K case studies within

ECOSS project may apply to assess the achievement of the identified management objectives. We considered both state and pressure indicators. Performance indicators were identified also taking into account, whenever possible, the requirements of the HD, BD, WFD and MSFD, even if none of them specifically refer to performance indicators. The performance indicators here identified are particularly in agreement with the eleven qualitative descriptors of the MSFD aimed to determine the GEnS (see paragraph 4.4.1). For instance, D1 can be investigated by different performance indicators such as: surface area of optimal habitats, habitat structure, abundance/cover of species, population/community structure, and recruitment success. HD and BD also find correspondence in this descriptor, since they do aim at conserving the species and habitats of protection in a favourable state. Descriptor 2, focused on non-indigenous species, is monitored by collecting data on cover and abundance of invasive species, as well as on the interactions with native ones. Performance indicators that give information on population structure (e.g. fishing mortality, abundance, size, age, spawning stock biomass) of commercial fish species may answer to Descriptor 3. Descriptor 5 and 8, also related to the requirements of the WFD, can be monitored by water quality indicators such as water quality indices, physico-chemical water parameters below the Threshold Limit Value, cover of benthic species (invertebrates, macrophytes, phytobenthos). Then each of these performance indicators can be based on different quality levels (high, good, moderate, poor, bad quality), following the WFD, to quantify the ecological status quality of water (GEcS and GCS). Descriptor 7, focused on alteration of hydrographical conditions, is particularly important in the Po Delta N2K sites, where some performance indicators were identified on this issue (amount of lagoon-sea water exchange, distance upstream of the salt wedge, sedimentation rate, mean erosion rate).

The HD, BD and MSFD also highlight the need to ensuring the ecological connectivity. This aspect was considered by identifying performance indicators that assess genetic diversity or the presence of migratory passages. Also the potential impact of human activities that can degrade, deteriorate and disturb the protected species as defined by all the directives, is considered by using indicators such as fishing effort, number of boat anchoring, number of visitors, etc.

Table 15. Link between the management objectives of each case study and performance indicators.

Case study	Management objectives	Performance indicators
Cres-Lošinj and Viški akvatorij	Protect or increase the population of *T. truncatus*	- Abundance and population structure - Recruitment success
	Prevent over-exploitation of prey of *T. truncatus*	- Fishing mortality - Spawning stock biomass of fish - Fishing effort
	Preserve incoming/outgoing genetic flow for *T. truncatus*	- Genetic diversity within population
	Maintenance of a good seawater quality	- Water quality indices - Water parameters below the Threshold Limit Value
	Decrease/regulate interactions between *T. truncatus* individuals and human activities	- Number of touristic vessels inside MPA in a year - Mortality rate from incidental by-catch or incidents with speed boats - Frequency of interactions with fishing boats/aquaculture cages
Malostonski zaljev	Prevent high eutrophication and pollution levels in the bay	- Water quality indices - Nutrients and contaminants below the Threshold Limit Value
	Assess distribution and conservation status of the identified target benthic species	- Cover of benthic species - Benthic habitat structure
	Maintain or restore the current status of target species populations	- Abundance and population structure - Recruitment success
	Preserve coralligenous community diversity	- Community structure and composition

		- Diversity indices - Sensitivity level of species - Genetic diversity within populations
	Preserve bioconstruction process	- Cover of bioconstructor species and bioeroders - Structural complexity - Bioerosion and bioconstruction rate
	Prevent illegal fishing of *Lithophaga lithophaga*	- Surface area of destructed benthic habitat - Number of reported offences in a year
	Reduce impact of aquaculture and tourism on target benthic species	- Number of visitors in MPA within a year - Number of boat anchoring on the sea bottom - Water quality indices - Surface area occupied by aquaculture
	Reduce impact of invasive species	- Cover/abundance of invasive species vs native ones
Trezze San Pietro e Bardelli and Tegnùe di Chioggia	Maintain or restore the current status of target species populations	- Abundance and population structure - Recruitment success
	Preserve coralligenous community diversity and gene pool	- Community structure and composition - Sensitivity level of species - Diversity indices - Genetic diversity within populations
	Preserve bioconstruction process	- Cover of bioconstructor species and bioeroders - Structural complexity

		- Bioerosion and bioconstruction rate
	Minimize nutrient load and pollution from coast	- Water quality indices - Nutrients and contaminants below the Threshold Limit Value
	Reduce human activities inside and next to the N2K sites	- Number of vessels, divers inside MPA - Fishing effort next to MPA
	Assess the presence and impact of invasive species	- Cover/abundance of invasive species vs native ones
	Reduce impact of marine debris on benthic species	- Amount and composition of litter ingested by marine animals (gut analysis) - Total amount of marine litter collected or observed
Delta del Po: tratto terminale e delta Veneto and Delta del Po	Improve water circulation and quality	- Water quality indices - Distance upstream of the salt wedge - Amount of lagoon–sea water exchange - Presence of passages for migratory fish
	Reduce impact of invasive species	- Cover/abundance of invasive species vs native ones
	Monitor and limit fishing	- Fishing mortality - Spawning stock biomass of fish
	Creation/restoration of optimal habitats for target species (nesting/resting/feeding sites)	- Significant increase in surface area of optimal habitats - Birth rates of target species
	Maintain or restore the current status of target species populations	- Abundance and population structure - Recruitment success

	Increase genetic diversity of the Adriatic sturgeon	- Genetic diversity within population
	Decrease tourism-induced disturbance at nesting bird sites	- Number of visitors during the nesting season
	Control of the yellow-legged gull population and terrestrial predators of target birds' eggs	- Abundance and population structure of the predators - Predation rate on target species
	Minimize the impact of artificial structures on target species (e.g. electrical cables on birds)	- Mortality rate of target species due to artificial structures
	Assess distribution and status of aquatic macrophytes	- Surface area covered by seagrasses - Size of continuous patches
	Minimize the impact of aquaculture and maintenance works on the coast and river channels	- Water quality indices - Sedimentation rate and levels of turbidity - Decrease of physical disturbance and loss of optimal habitats for target species
	Reduce the impact of shipping lanes, ports, marine constructions, noise pollution	- Levels of underwater noise pollution - Water quality indices - Number of boats in channels and basins - Number of boat anchoring on benthic species
	Prevent soil leaching, erosion and discharges	- Mean erosion rate - Water quality indices

5. CONCLUSIONS

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

However, this report highlighted a widespread lack of information on the ecological processes and the conservation status of target species in the considered N2K sites, mainly due to the lack of management plans and management bodies. In addition, ecological data are often not available or have been collected only occasionally in the past. The outcomes that ECOSS will produce and the creation of ECOAdS will likely help in improving the existing monitoring programmes and the exchange of data between different data producers and data users. In order to achieve a wide coverage of the monitored area and focus on specific ecological factors, we suggest including some sampling stations inside the N2K sites and standardizing the monitored variables. Based on the descriptive indicators we have identified for each target species and ecological process in the N2K sites, a possible common pool of variables to monitor at all sites could include: depth; salinity; air and water temperature; dissolved oxygen; pH; PAR; current velocity and direction; chl-a; contaminant and nutrient concentration in water and sediment; population structure of target species; habitat structure; community structure and composition; biomass and spatial distribution of species; cover or abundance of invasive species; spawning stock biomass; harmful algal blooms frequency, intensity and species composition; abundance of marine debris and type; human pressures, including average number of visitors per day, fishing effort,

fishing mortality rate, aquaculture impact, discharges, marine traffic. Almost all of these descriptors are listed in the four directives here investigated even if with different terminology.

The comparative analysis among the environmental directives (HD, BD, WFD and MSFD) in all their relevant aspects, showed some inconsistencies among them and weaknesses. In fact, though the goal of the directives is the protection of the aquatic environment and the preservation and sustainable management of the resources, they lack in homogeneity in the adoption of terminology and none of them refer to specific indicators. Some gaps also exist since the application of the directives is left to each MS, the management plans are not mandatory, and the ecosystem management approach is not always considered. Nevertheless, the directives are complementary to each other on multiple aspects: the conservation priority objectives extend across different spatial and ecological levels, they are applied within different jurisdictional boundaries, and the different parameters can be jointly monitored to have a more complete picture of the environmental status. This analysis is only a first step for the creation of a coherent and harmonised set of indicators to increase the monitoring and implementation of N2K network; a detailed study will be then developed in deliverable 4.4.1[10].

The list of management objectives and the related performance indicators we have outlined for each N2K site do not want to be strict, but represent a starting point for putting in place a real management of the N2K sites here analysed and for developing appropriate management plans. In particular, each MPA is likely to have a different set of indicators, selected and prioritized according to the objectives, the types of changes wanted, and available human, technical and financial resources.

Management bodies, governments and funding agencies are increasingly demanding information on MPA management effectiveness in order to assess whether results are commensurate with their efforts and resources and are in line with policy and management goals. The conceptual model here developed can help in visualizing the links among the ecological and social components that characterize MPAs and, through ECOAdS, in showing possible unsuccessful conservation strategies in respect to the planned outcomes. The model can be potentially applied to different MPAs, both at Adriatic and

[10] D4.4.1 Report on the interactions, synergies and gaps among the WFD, MSFD and H&BD for an effective management of the marine ecosystem.

Mediterranean scale. An example of the practical application of the conceptual model to the N2K case studies within ECOSS will be presented in the deliverables 4.2.2 and 4.3.2.

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