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# Challenges for Marine Ecological Observatories to Promote Effective GMS of Natura 2000 Network

## The Case Study of ECOAdS in the Adriatic Sea

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### Abstract

The Natura 2000 (N2K) network is a key conservation instrument in Europe, despite its many limitations concerning the efficacy in covering and adequately safeguarding the marine environment, mainly due to missing coordinated Governance and Management Systems (GMS). In this study, we present and discuss the main benefits, which could be provided by Marine Ecological Observatories (MEOs) to support N2K marine network implementation and related GMS. The conceptual design of the ecological observatory ECOAdS, under development in the framework of the Interreg Italy-Croatia project ECOSS, is described. ECOAdS, which focuses on marine N2K sites under jurisdiction of Italy and Croatia, is a first operative pilot proposal of MEO for the Adriatic Sea. It represents an opportunity to build a common knowledge and monitoring framework and shared data management practices at the transnational level, overcoming the N2K site fragmentation. The main challenges that ECOAdS should face in its implementation are discussed, with emphasis on the integration of the marine connectivity aspects and on the adoption of adaptive and participative GMS to address the main conservation issues in the area.

**Keywords:** Adriatic Sea, Natura 2000 network, GMS, marine ecological observatories

## 1 Natura 2000 for Marine Conservation: How far are we from a Real Network?

The Natura 2000 (N2K) network of protected areas, both at land and at sea, is the main biodiversity conservation instrument in Europe, at the foundation of the EU commitment to the international Convention on Biological Diversity (CBD) and its Aichi Targets, and of the EU Biodiversity Strategy. The CBD Aichi Target 11 calls for the designation of a number of areas for marine conservation able to cover at least 10% of the marine waters by 2020. The N2K network represents the main driving forces contributing to the achievement of such a target in Europe. The network's legally binding basis are the Habitats [1] and Birds [2] directives, which set the same rules and obligations for all EU, even though the application of the legislation varies by countries, which are left with a considerable degree of freedom to set up their own conservation strategy. The Birds Directive (BD) defines Special Protection Areas (SPAs) for major migratory and threatened bird species and in its annexes lists 60 birds' species linked

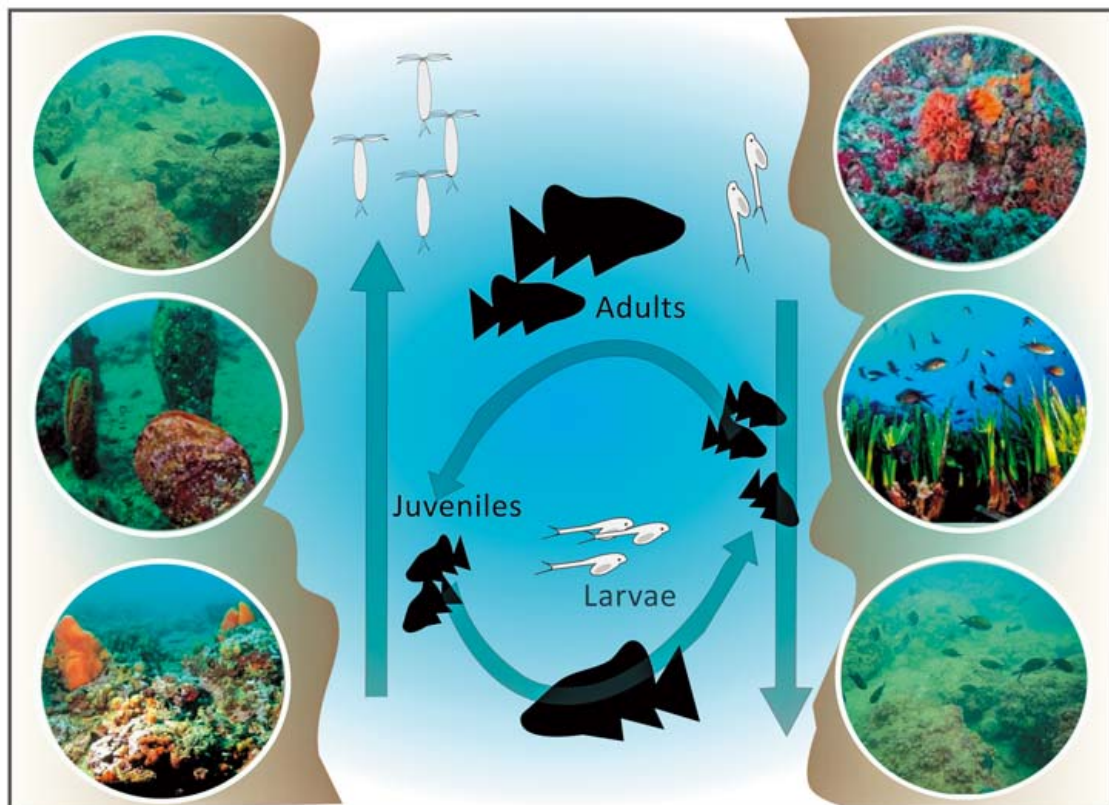
to marine sites protection; the Habitats Directive (HD) defines Special Areas of Conservation (SACs) and lists 9 marine habitats and 16 marine species in need of protection. The network encompasses a multiplicity of protection levels, from strictly protected reserves to others where human activities are allowed and regulated and the protection of species or of habitats is combined with the management of the natural resources [1] [3].

The total number of marine protected areas in EU seas has more than doubled in the last six years, primarily due to the expansion of the N2K network. Based on the last N2K barometer (December 2019), more than 3150 marine N2K sites have been designated, covering almost 10% of the total EU marine area, corresponding to over 550,000 km<sup>2</sup> [4] [5].

Despite the contribution of the marine N2K network, the CBD conservation goals are still far from being fully achieved, while the worldwide marine conservation target has been proposed to increase up to 30% by 2030 [6]. To achieve this target, Europe must enlarge the number of marine areas devoted to conservation, also in the N2K network. However, numerous are the present limitations concerning the marine N2K sites' efficacy in covering and safeguarding adequately the marine environment [7] [8], preventing the establishment of an effective protection network. The selection of marine N2K sites lacks a systematic procedure, which could clearly and effectively address marine conservation needs. Most frequently, marine sites are the results of an extension of the terrestrial ones to the adjacent marine environments, often without assessing whether the priority marine species and habitats are the ones to be protected. N2K marine sites cover mainly coastal and shallow waters [9], leaving offshore and deep habitats almost completely under-represented. The prevalent small size of the sites limits their capacity of covering effectively habitats and areal dispersion of species or their populations, as well as the efficacy of sufficiently managing possible threats affecting protection targets, as these threats sources can be located in adjacent areas. For all the above reasons, N2K sites deliver limited protection to many threatened species. Moreover, many of these species are not even listed in the annexes of the HD and BD directives, which need to be updated [10]. On top, factors affecting N2K conservation efficiency are also: the rarefaction and fragmentation of ecological research and data availability mainly due to the different approaches adopted for their collection; the lack of transnational strategies, especially for the protection of highly mobile marine species that cross the geopolitical boundaries during their life; the limited attention to socio-economic and socio-ecological issues. About 40% of the N2K sites having a marine coverage higher than 10%, lack management plans and related conservation measures.

Ecological connectivity, which is one of the most relevant conservation issues, has been largely ignored during the design phase of the N2K network, even though it is one of the main objectives of HD (mentioned in Articles 3 and 10). Ecological connectivity is defined by UNEP [11] as “the degree to which landscapes and seascapes allow species to move freely and ecological processes to function unimpeded”. This concept derived from the fact that, during their life-cycle, most animals and plants are largely dependent on more than one habitat and might need to freely move from land to sea and vice versa, as well as in the entire marine environment to accomplish their vital functions (e.g. feeding and breeding), in synergy with all the natural ecological processes (e.g.

production and consumption of food and oxygen) (Fig. 1). Connectivity becomes even more important in the marine environment where processes are highly interlinked, the complex life histories of most species have evolved adapting to the marine habitats, and many species are widespread [11]. Since single protected areas cannot conserve marine ecological connectivity, a network of ecologically coherent marine protected areas is a promising alternative. An effective network should be structured in a way to choose the right sites to protect, able to really preserve ecological connectivity [12] [13].



**Fig. 1.** Sketch showing species connectivity with the seascape.

The lack of a coordinated governance of N2K network, at both European and national levels, has so far strongly limited the capacity of N2K to foster each of the above listed limitations and to achieve ecosystem wide conservation measures through the establishment of management plans [14]. Governance systems can be defined as “the interactions among structures, processes and traditions that determine how power and responsibilities are exercised, how decisions are taken, and how citizens or other stakeholders have their say” [15]. N2K governance model, as for most protected areas, has still a marked traditional top-down approach, where national authorities are committed to the implementation of the conservation sites and to the coordination of their goals and may delegate the responsibilities to lower level hierarchies (e.g. regions, parks, municipalities). The actors involved in such a model should engage a wide variety of stakeholders to find solutions to possible conflicts of interest and to build strong collaboration to pursue effectively conservation goals [16].

The direct participation of citizens and stakeholders to N2K governance systems are fundamental to support decision-making processes, from the early stages of the N2K

sites establishment through their implementation, creating a stable partnership among all involved parties, and conquering their willingness to act collaboratively. In reality, the governance and management systems (GMS) of sites under protection rarely involve the local stakeholders and people in decision making and taking through participatory processes [17] [18]. The transformation of N2K into a real network requires an effective and robust GMS, based on the best ecological knowledge of the marine environment and on the local realities, in order to be able to deal with the fast ecological and socio-economic changes. GMS should rely on the ecosystem-based approach, which has been promoted by institutions worldwide as the best way to assess and harmonize science-based knowledge, environmental-related policies, stakeholder needs and the wider societal aspects [19] [20]. Most N2K sites are local realities that aim at finding a balance between the presence of humans and their uses and nature protection needs. The adoption of an ecosystem-based approach underpins connectivity among ecosystems, as well as among humans and nature, thus becoming a necessary approach to be incorporated into N2K GMS.

The successful implementation of the N2K network as well as their GMS requires being adaptive, founded on well-designed and dynamic research and monitoring strategies, able to assess the effectiveness of protection network. This implies that agencies and managers should hold the institutional capability and tools to carry out suitable monitoring, evaluate and report the derived results, and adapt properly their conservation strategy to respond to changes both within and outside the network.

This study explores the potential of Marine Ecological Observatories (MEOs) in favoring the overcoming of the above-described issues. MEOs, by promoting harmonization mechanisms, transnational information flow, and knowledge co-production at regional level to inform N2K GMS, can support N2K network implementation and the application of an ecosystem-based approach to its management. In the following sections, we identify and address the main challenges MEOs might face to deliver their benefits to N2K GMS. Moreover, we detail and scale up these concepts in the context of the Adriatic Sea, where an ecological observing system is under design and development in the framework of the Interreg Italy-Croatia project ECOSS (Observing System in the Adriatic Sea: oceanographic observations for biodiversity) [21].

## **2 GMS and the Fragmentation of Marine Conservation: the Role of Marine Ecological Observatories**

Marine Observatories (MOs) are globally widespread: they consist mainly of observing, monitoring and experimenting infrastructures conceived to monitor oceanographic variables and to assess the state and modifications of coastal and offshore sea in response to anthropogenic alterations and to the changing global climate [22]. Oceanographic processes, which are mostly addressed in the MOs, are obviously entangled with the ecological ones, across a range of spatial and temporal scales. Therefore, a proper integration between oceanographic and ecological research and monitoring is key to build the knowledge needed to assess the performance of protected areas and the impact of on-going environmental and human-induced changes on conservation strategies [13]. This holistic view should be incorporated into MOs,

leading to the development of Marine Ecological Observatories (MEOs), able to arrange and maintain harmonized and coherent long-term observations linking oceanographic and ecological monitoring with the effectiveness of the protected areas [23]. In order to achieve long-term operational sustainability, MEOs should develop a proper governance structure, which includes, e.g., an advisory board, the establishment of shared regulations among the different players (e.g., managers, researchers and users), and an established framework of research activities oriented to answer and inform conservation management issues and hypotheses. In addition to playing a primary role in monitoring and coordinating different observers and existing or new data streams, MEOs should be designed to generate knowledge related to the dynamics between the human dimension and the natural systems. This typology of observatories should be able to involve researchers, policy makers and members of the civil society, and to collect a variety of knowledge and viewpoints to favor innovation and development in information planning and management at a proper spatial scale. Only in this way, MEOs can offer real support for conservation strategic planning, setting goals, performance standards and monitoring [24]. Although several examples of potential partnerships among marine protected areas monitoring activities and MOs are known worldwide [13], coherent and operative MEOs do not exist yet nowadays. We propose here essential attributes that MEOs should incorporate in their own governance systems and observation framework, to tackle the main issues evidenced in Chapter 1 for an effective N2K network implementation (Fig. 2).

(i) *An agreed conceptual framework* for the harmonization of monitoring schemes, data acquisition and analysis at trans-regional and national levels. At the core of MEOs are environmental observations, which are gathered with various instruments and strategies at different spatial and temporal scales, and which should be integrated into the N2K monitoring schemes in order to properly assess the effectiveness of conservation [13]. The framework should be based on assessed criteria and selected environmental monitoring indicators, recognized for being adequate to describe globally the state of the marine environment, also coherently with the EU legislative requirements.

(ii) *Data platforms to deliver oceanographic and ecological information and knowledge, fully adopting the open science approach.* Central to the development of MEOs, to inform properly GMS of N2K, is the adoption of the open science approach, which creates the conditions for the exchange of knowledge among scientists, decision-makers and citizens. Open science practices in ecology has become increasingly necessary for responding to conservation issues and for addressing environmental changes, by removing the cultural, institutional and technological barriers through the establishment of open information flows. MEOs should provide ways of making knowledge more readily available and comprehensible to different types of users, enhancing the transformation of a typical top-down flow of information into a multi-players dialogue [25].

(iii) *Tight cooperation among the fragmented multi-level governance systems and responsible managing authorities of N2K sites.* The present EU status still reflects a fragmented approach in the conservation and management of N2K sites within the wider context of marine environment. Data and information gathered and made available through MEOs should inform different policies and strategies, dealing with marine conservation, planning and management at both EU and global level. MEOs

should represent platforms to harmonize and create synergies among all these different jurisdictional instruments in particular the Habitats Directive HD [1], the Birds Directive BD [2], the Marine Strategy Framework Directive MSFD [26], the and the Maritime Spatial Planning Directive MSPD [27]. In addition, all EU countries, driven by legal commitment (MSPD), are now developing their own marine spatial plans, and, never like today, it is important to inform this process in order to properly find space for new areas devoted to marine conservation. MEOs should support a systematic conservation planning to individuate coherently marine areas of priority for conservation, N2K sites included, to be integrated within the broader MSPD framework [28], and to favor ecosystem-based approach implementation. MEOs could also help to reach the United Nations Sustainable Development Goals (SDGs), in particular the UN SDG 14 “Life below water” that specifically requires strategies, infrastructures and investments for observing and monitoring the marine environment [29].

*(iv) Local ecological knowledge and priorities for the effective involvement of stakeholders and the civil society within the mechanism of knowledge co-production.* In the context of the marine N2K network, MEOs should function as knowledge cogeneration platforms from which different users could take advantage and effectively contribute to inform N2K GMS. MEOs would recognize the role of multiple knowledge sources to deal with uncertainties derived by knowledge gaps, by entailing local and traditional knowledge and directly engaging local communities that should become part of the observatory system itself and support the GMS [25] [30]. Contemporarily, MEOs should help GMS of N2K sites to apply concretely an ecosystem-based approach to pose people in the condition both to be able to recognize their deep interconnection with nature, and to approach the existing knowledge related to the marine environment.

### **3 MEOs Potential to Enhance GMS and N2000 Strategy in the Long-term: the Pilot Study of ECOAdS in the Adriatic Sea**

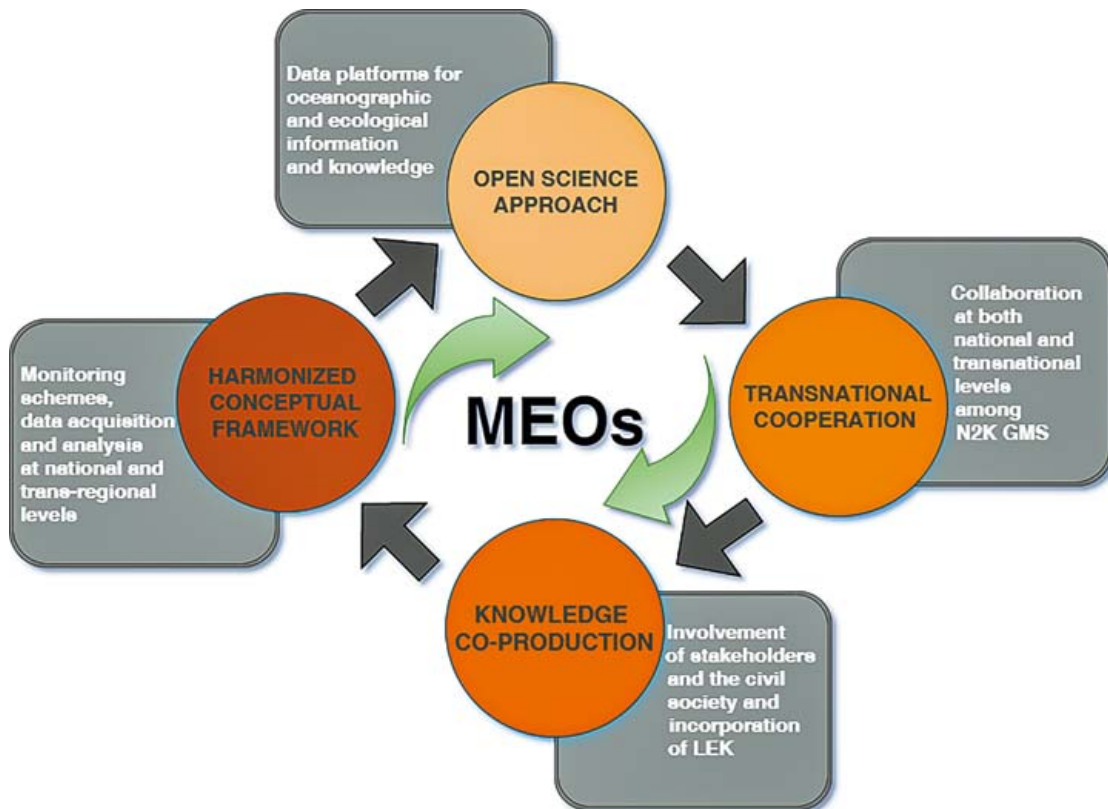
The Adriatic Sea is a significant geographical zone for the establishment of a MEO, due to the concomitant presence of high degree of biodiversity, sensitive habitats and ecosystems, numerous ongoing monitoring and research activities, as well as heavy and diversified human pressures and economic interests, based on the marine resources of the area.

The design and implementation of such an observatory, named ECOAdS (ECOLOGical observing system in the Adriatic Sea), is one of the main goals of the Interreg Italy-Croatia project ECOSS, a collaboration between 10 organizations from Italy and Croatia which will run from January 2019 to June 2021. The ECOSS project aims at integrating in ECOAdS the existing ecological and oceanographic research monitoring with N2K conservation strategies in the Adriatic Sea, focusing on the area under the jurisdiction of Italy and Croatia, thus providing a contribution to improve the conservation status of habitats and species of the N2K marine sites. This contribution will be of benefit especially for those sites that lack management and monitoring plans, therefore not being operationally implemented with respect to their conservation objectives.

ECOSS project foresees a design phase of ECOAdS, where the four main challenges evidenced for MEOs (Fig. 2) will be addressed, taking into account the specific features



of the area of the Adriatic Sea on which the project activities are focused. The design will be followed by an implementation phase where six specific N2K sites (Fig. 3), currently managed by the ECOSS partners, will be taken as case studies to pragmatically test the establishment of ECOAdS. Finally, a roadmap outlining the long-term strategy for the governance and maintenance of the ECOAdS will be produced, extrapolating the lessons learned also to other N2K sites in the Adriatic.



**Fig. 2.** The essential attributes of MEOs to tackle the main issues for an effective N2K network implementation. N2K = Natura 2000; GMS = governance and management systems; LEK = local ecological knowledge.

### 3.1 ECOAdS: the MEO Case Study in the Adriatic Sea, shared between Italy and Croatia

The Adriatic Sea region, as defined by the MSFD, comprises 368 marine N2K sites mainly covering the nearshore zone (0-1 Nautical Miles) and without offshore sites beyond the 12 NM [31]. On the base of the spatial measurement assessed through the use of data from November 2017 of MAPAMED dataset, the Adriatic counts 44 Italian and 245 Croatian sites wholly or partially marine, which cover respectively ca. 1694 km<sup>2</sup> (ca. 1.2%) and 5998 km<sup>2</sup> (ca. 4%) of the basin.

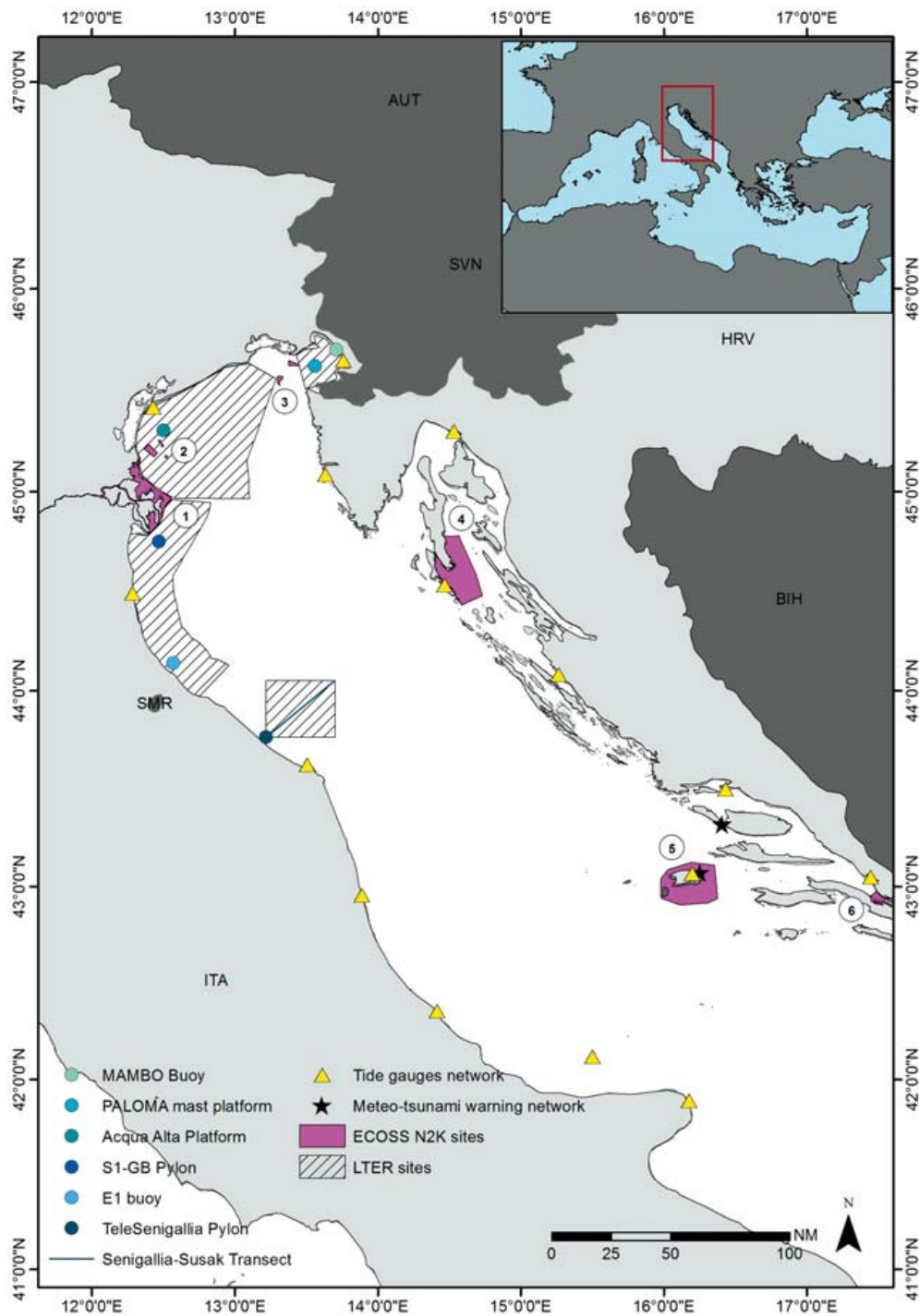
As reported in Chapter 1, the EC does not provide systematic guidelines on the management of N2K, but only general indications. In Italy, the Decree of the President of the Republic No. 1997/357 states that the regions must identify and establish conservation measures, and that they can also define and implement management plans.

In Croatia, the administration of protected areas and of the corresponding N2K sites is in general a responsibility of the managing authorities of counties and municipalities. However, many sites in both countries are not managed and monitored by established plans and strategies [32]. For instance, management plans are missing for five out of the six N2K sites considered in ECOSS: only the Po River Delta has produced its own management plan, which, however, is not yet in force.

Nonetheless, the Adriatic Sea hosts a number of well-established monitoring programs, acting at different spatial scales, from national to county/region level, and fixed-point observing systems (i.e. pylons, buoys, tide gauges, oceanographic platforms). These latter provide multidisciplinary and automated monitoring of coastal and offshore marine environments, with high temporal resolution, for a series of marine and atmospheric variables [33] [34] [35]. In general, ongoing monitoring observations are mainly linked to the fulfilment of the obligations established by the various EU Directives (mainly WFD and MSFD) or to specific programs and initiatives, such as the Italian Long-Term Ecological Research network, LTER-Italy. They address a wide variety of environmental issues, spanning from the assessment of the quality of transitional, coastal and marine waters to the monitoring of target species (e.g. dolphins and sea turtles) and other biotic components (e.g. plankton, macroalgae, coralligenous assemblages). It must be mentioned that neither of these initiatives are shared between the two countries, nor their focus is on N2K sites. In the case of ECOAdS, we considered the fixed-point observing systems, located in the pilot study area and of which ECOSS partners are managers and/or direct scientific advisors (Fig. 3).

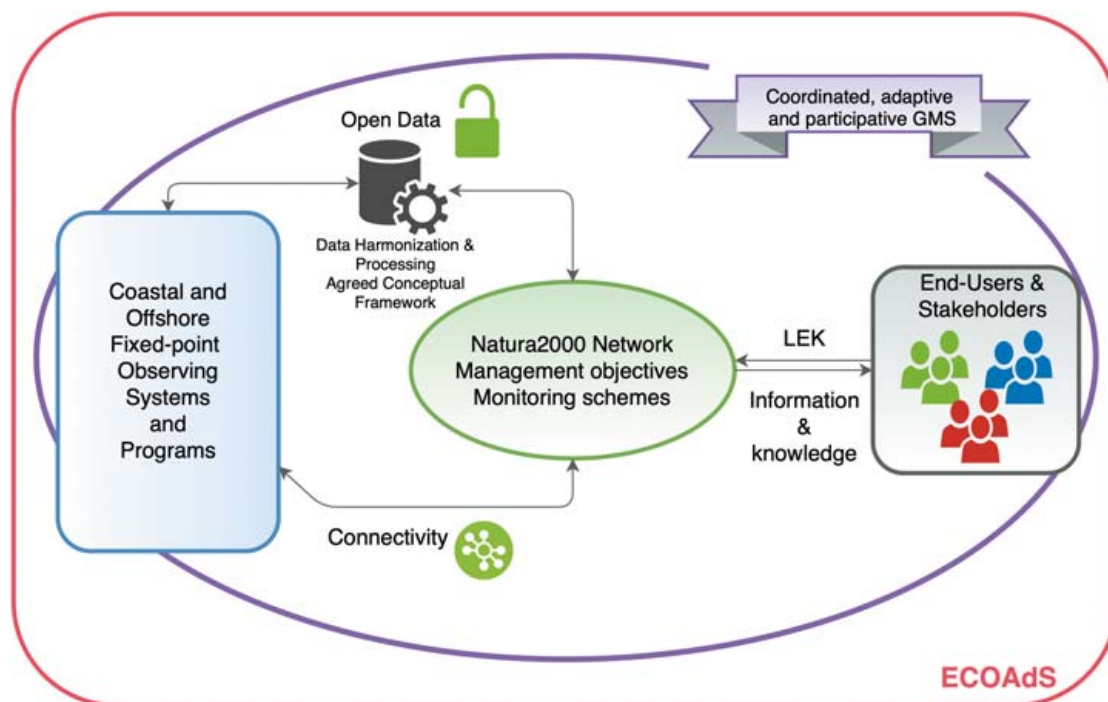
As part of the design of ECOAdS, which aims at entailing all these monitoring initiatives, ECOSS recognizes that these existing observing platforms and monitoring schemes operate at various scales, with different aims and maturity levels, lacking an adequate coordination among them, which should connect the local, the regional, up to the whole Adriatic basin scale, in an integrated and coherent observatory.

In the design of a long-term sustainable and successful observatory, ECOAdS needs to be harmonized and incorporated into a suitable and clear governance structure, which could effectively support a shared understanding of the state of the marine environment and the connections among oceanographic and ecological observations with conservation issues.



**Fig. 3.** ECOAdS N2K sites and fixed point observing systems managed by ECOSS project's partners. N2K sites: 1. Po river delta (IT3270017 and IT3270023), 2. Tegnùe di Chioggia (IT3250047), 3. Trezze San Pietro e Bardelli (IT3330009), 4. Cres-Lošinj (HR3000161), 5. Vis (HR3000469), 6. Mali Ston (HR4000015). Data Sources: ECOSS N2K sites [21], RITMARE [33], MAPAMED [36], Meteo-tsunami network [37], Tide gauges network [38], LTER-Italy sites [39].

The four main challenges faced by MEOs to support effectively GMS of N2K network, individuated in Chapter 2, will be addressed for ECOAdS, drafting a roadmap for its implementation. Figure 4 resumes the four essential attributes that will be incorporated by ECOAdS.



**Fig. 4.** Schematic view of the essential attributes of ECOAdS to support effective GMS of Natura 2000 in adopting an ecosystem-based approach and in implementing the network. (LEK=Local Ecological Knowledge).

### 3.1.1 Adoption of an agreed conceptual framework

Firstly, ECOAdS will develop and adopt a conceptual framework for the harmonization of existing oceanographic and ecological observations, monitoring schemes, data acquisition and analysis at national and trans-regional levels, in order to allow answering to the main N2K management issues. This will be mainly achieved through the selection of suitable performance indicators, recognized for being adequate to describe globally the state of the marine environment coherently with the EU legislative requirements, and to be monitored at adequate temporal and spatial scales. Besides, it will integrate different but complementary conceptual schemes of environmental variables, for identifying drivers of biodiversity changes, such as the Ecosystem Integrity framework, adopted by the LTER communities [40], the Essential Biodiversity Variables (EBVs) [41], developed by the Group on Earth Observations-Biodiversity Observation Network GEO-BON, and the Essential Ocean Variables (EOVs) [42], implemented by the Global Ocean Observing System GOOS. The obtained harmonized monitoring scheme entailed in ECOAdS will be shared at both national and trans-regional level in order to support common approaches of data

acquisition and data management practices, which has to be compliant with both the Essential Variables frameworks and the EU legislations [43].

### **3.1.2 Adoption of the open science approach**

Observations have no meaning without open data policies and effective data management, which make information and knowledge accessible for different kinds of users. Data management procedures based on the “FAIR” principles, which states that data must be “Findable, Accessible, Interoperable, and Reusable”, are indeed the base of open access to data and represent a crucial step towards open science [44]. In the present complex data management landscape, it is required to develop streamlined and modern data management, which could simplify, automate, and make the flow of data more efficient. Taking into account the experiences already available in the area [45] [46] [47] and the different level of maturity in respect to open science, ECOAdS will develop further techniques to better disseminate the results to the potential end-users (e.g. local, regional and national public authorities, managers of protected areas and N2K sites, education and research organizations). The aim is the implementation of an easily accessible data portal giving, whenever possible, open access to the observations collected by fixed-points systems and monitoring programs.

### **3.1.3 Cooperation among the fragmented multi-level governance systems**

By embracing existing and coming observatory systems and monitoring programs in the Adriatic region, which cover different spatial scales, from the most limited sites scale to the largest basin scale, ECOAdS will require a nested structure. This will enable the collection of all relevant environmental data and information representatives of each N2K site, simultaneously capturing the wide regional ecological dimension that drives connectivity aspects related to networks of protected sites. Such structures will be the key to support conservation objectives, which need to be achieved at the country and regional level, although conservation measures need to be implemented at the N2K site level [48]. In this way, ECOAdS will concretely support and guide the GMS of N2K sites in establishing, if absent, or in implementing, if already present, coherent management and monitoring plans of both existing and future N2K sites.

ECOAdS top-down strategy foresees the acquisition of relevance in the environmental governance arena as fundamental decision-support tool for conservation, by engaging governance representatives and management authorities at the level of the N2K sites in the co-production of knowledge to support N2K GMS at both local and basin scales. ECOAdS will be addressed to favor an informational governance of N2K sites, where the information represents the key to boost adaptation strategies and ecosystem-based approaches in GMS [25] [49]. It will function as a cooperation bridge between Italy and Croatia, overcoming local and national boundaries, representing the opportunity of removing geopolitical limitations to build a regional-based marine knowledge framework.

By serving both these countries, ECOAdS may potentially benefit from regional financial mechanisms to ensure long-lasting activities. In this context, the EU Strategy for the Adriatic and Ionian Region (EUSAIR), acting at macro-regional level to promote economic and social prosperity and growth in the region [50], might play a decisive role. In particular “Environmental quality”, which is one of the four pillars of

EUSAIR, addresses the environmental and conservation needs in the area with a special focus on the marine environment, to answer to both EU directives and Biodiversity Strategy.

Besides, ECOAdS could rely on, contribute to, and benefit from various Environmental Research Infrastructures (RIs), EU and global networks, supported by EU and national funds. Actually most of the ongoing research and monitoring activities in the Adriatic area are already connected to many environmental RIs (e.g. eLTER RI, Danubius RI, LifeWatch ERIC, EMBRC ERIC, ICOS ERIC, JERICO), and to other EU and global observatory networks (e.g. Copernicus, FixO3 and EMODnet). These initiatives could become relevant for the long-term maintenance and financial sustainability of ECOAdS. A joint collaboration is required and is arising among the different marine RIs [51], and ECOAdS could represent the opportunity to boost such collaboration in the Adriatic Sea, by representing and developing a co-located system with shared research and monitoring tasks allowing modular and multi-purpose uses. Long-term financial sustainability is actually a crucial issue for ECOAdS as well as for other MEOs. Although this issue is not addressed by ECOSS, it should be taken into account in the construction of the ECOAdS roadmap, aiming to achieve its full effectiveness and long-term maintenance. Financial sustainability should be facilitated also by the creation of efficient collaborations, transparent data sharing, and the maximum effort to minimize the duplication of activities [52].

### **3.1.4 Knowledge co-production**

Human presence plays an important role and influence in the success of the N2K network, thus making it necessary to combine the social and ecological dimension and to integrate the priorities in the political agenda [53].

ECOAdS will entail a bottom-up approach by posing itself in the interface between scientists and non-experts, engaging the civil society benefiting from N2K sites to incorporate local ecological knowledge (LEK), as well as involving the younger generation of scientists through participatory processes. In this way, ECOAdS will collect local needs and support the adoption of its proposed holistic approach into future research and monitoring practices. The transfer of environmental knowledge will not be unidirectional, from scientists to non-experts, but rather it will turn in a multi-actors dialogue including different competencies. End-users and stakeholders engagement is at the heart of building and sustaining an observatory: it stimulates the increase in the ocean observing capacities, facilitates sharing of infrastructure, promotes best practices, builds capacity, fosters diversity, and develops innovative technologies and approaches [49]. Several experiences coming from both terrestrial and marine sites highlighted the added value gathered when citizen science mechanisms are set up in monitoring approaches, through the adoption of voluntary sighting activities, questionnaires, interviews and interactive open access portals [54] [55] [56]. Although the citizen science approach is not yet a common practice in the implementation of the N2K network, there is empirical evidence of their usefulness for the enrichment of environmental monitoring databases and information frameworks [57].

ECOAdS, in this context of sharing knowledge and information, will favor the meeting among individuals, organizations, and agencies at multiple governance levels, as well as between these actors and the marine environment, thus supporting the

operationalization of an ecosystem-based approach. The synergy between experts, the civil society and N2K GMS, would support governance and management authorities in taking responsibility and right actions, and in reinforcing their willingness toward effective implementation of N2K sites and networks in the Adriatic at multiple spatial scales and governance levels, willingness that has been observed to be often scarce [58].

## 4 Conclusions

This study reports the main limitations that curtail the efficacy of Natura 2000 (N2K) network, the main biodiversity conservation instrument in Europe. Missing systematic procedures to identify priority sites for conservation including offshore and deep habitats, inappropriate size of N2K to protect highly mobile species and to manage human pressures with large footprint, paucity of available ecological research and data, lack of coordinated transnational strategies, and limited attention to socio-economic and socio-ecological issues emerged as key constraints for N2K network implementation. Most of all, the lack of management plans and related conservation measures put in place in N2K sites strengthen these limitations.

Despite the recognized role that ecological connectivity plays in the marine environment, supporting all ecological processes that enable marine life to exist, related aspects have been largely ignored in the N2K network design until today. This weakens even more the conservation efficiency of the network, which is undermined also by the absence of a coordinated governance, at both national and regional scales.

The N2K governance model, presenting a marked traditional top-down approach, fails to involve citizens and stakeholders in its governance and management systems (GMS), leaving behind a key component to build a successful partnership for N2K conservation and sustainable management.

In this study we highlight the need of incorporating an ecosystem-based approach within the GMS of N2K to concretely include connectivity among ecosystems, as well as among humans and nature. A GMS of N2K network needs to be adaptive, founded on well-designed and dynamic research and monitoring strategies. Moreover, agencies and managers need the institutional capability and tools to carry out suitable monitoring, evaluate and report the derived results, and act to adapt properly their conservation strategy.

This paper reports the main benefits that the design and establishment of Marine Ecological Observatories (MEOs) can deliver, to support N2K marine network implementation and related GMS, coping with existing issues and favoring priorities' achievement. Moreover, the essential attributes that MEOs should include and support to become decision-support tools for the responsible authorities and agencies and to favor the overcoming of the identified issues that hinder N2K implementation and efficacy are outlined. These are: (i) an agreed conceptual framework for the harmonization of monitoring schemes, data acquisition and analysis at trans-regional and national levels; (ii) data platforms to deliver oceanographic and ecological information and knowledge, fully adopting the open science approach; (iii) tight cooperation among the fragmented multi-level GMS and responsible managing

authorities of N2K sites; (iv) local ecological knowledge and priorities integration for the effective involvement of stakeholders and the civil society within the mechanism of knowledge co-production.

The ecological observatory ECOAdS, which is the main outcome of the Interreg Italy-Croatia project ECOSS, is here presented as a first proposal of MEO acting in the Adriatic Sea. Supported by the transnational collaboration of Italy and Croatia, ECOAdS can function as a decision-support instrument useful to help the setting up of adequate N2K monitoring strategies able to entail marine connectivity aspects and to inform adaptive GMS at the Adriatic scale.

To bridge the dialogue between multi-level GMS at cross-border scale, ECOAdS foresees a harmonized set of ecological monitoring indicators by adopting a nested approach to depict the state of the Adriatic Sea, coherent with the FAIR principles: “Findable, Accessible, Interoperable, and Reusable”. ECOAdS, by triggering participatory processes with multiple actors and in a multidisciplinary context, poses itself at the interface between authorities, experts, and the local communities inhabiting N2K sites, favoring a co-production of knowledge to implement the network and making the partnership of GMS with the civil society integral part of the observatory. Overall, ECOAdS can represent an opportunity to build a common knowledge and monitoring framework at a transnational level to overcome the N2K sites fragmentation, incorporating marine connectivity aspects and supporting transnational cooperation for planning and managing the Adriatic Sea conservation and the sustainable use of its resources. In the hope that the role of ECOAdS in supporting the transnational sharing of knowledge and in informing N2K Adriatic network and conservation strategies will be recognized, we suggest that regional collaboration scheme at the Adriatic level, such as EUSAIR, become starting platforms to support ECOAdS long-lasting activities.

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