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NEREA, the Naples Ecological REsearch for Augmented observatories: Towards an end-to-end transdisciplinary approach for the study of marine ecosystems

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Abstract – Here we present the concept of NEREA, the Naples Ecological REsearch for Augmented observatories, an integrated observatory with a modular, adaptive structure, characterised by two main modules, NEREA-mob and NEREA-fix. NEREA-mob is conceived as monthly sampling at a coastal station in the Gulf of Naples where the whole water column is sampled for end-to-end (from microbes to fish) biological parameters coupling traditional with "omic" approaches (metagenomics, metatranscriptomics and metabolomics). NEREA-fix will be deployed in 2020 in the Dohrn canyon at ca. 600 m, and will integrate a seabed platform and a mooring line equipped with a set of different chemical-physical and bio-ecological sensors. Ecological information from the two modules will be integrated by ad-hoc additional samplings in key moments and experimental activities aimed at contextualizing the sites at a larger scale. NEREA therefore aims at representing a first step towards the establishment of a network of augmented observatories, end-to-end approaches under the multidisciplinary framework required for ocean health assessment.

I. INTRODUCTION

Marine ecosystems drive global biogeochemical cycles and fuel a large part of the Earth's food webs. The huge biological complexity characterizing marine communities makes the development of well-resolved, and ecologically robust models, particularly challenging. Marine communities span over several order of magnitude in size and include all kingdoms of life. Approaching their complexity requires a deeper and adaptive integration between data-acquisition tools and data-analysis, covering traditional observations (i.e., physical, chemical and biological) and innovative approaches including, among others, in-flow imaging and omics (meta-barcoding, -genomics, -transcriptomics, -metabolomics) over wide space and time scales. The data collected require complex processing by advanced computational approaches, such as niche and network modelling, as well as artificial intelligence algorithms, thus extending a vision already introduced in plankton investigations [1, 2]. In addition, marine ecosystems are increasingly submitted to different anthropogenic stressors that can act synergistically and alter their diversity and functioning. Addressing such pressing threats requires an integrative approach encompassing all marine sciences and all level of biological organizations from genes to ecosystems. Under this vision, the integration of different sampling approaches combining fixed and mobile observatories has been already established under different initiative, such as the Ocean Observing Initiative (OOI, USA), the Ocean Network Canada (ONC) or the EMSO (European Multidisciplinary Seafloor and water column Observatory network), among others. However, although all these initiatives are transforming the research of the oceans, by establishing a network of interactive, globally distributed sensors with real-time data acquisition, augmenting existing marine observatories with novel ecological sensing and data processing technologies and know-how, is necessary to track human threats spreading within marine ecosystems. Coastal and deep-sea ecosystems are strictly connected through upwelling, downwelling, currents and other wind-driven processes. Submarine canyons are active corridors for transport of materials and organisms from the land into deep waters, *via* oceanographic drivers or *via* exceptional meteorological events such as cascading. These canyons are hotspots of biodiversity, nursery areas and juvenile shelters [3]. Here, we present the concept of NEREA, a pilot-project which will integrate data from fixed (NEREA-fix) and mobile (NEREA-mob) observatories, and that will encompass sensing technologies and direct sampling in both shallow-water and deep-sea ecosystems. The sensing technology in the NEREA observatory will be compliant with the Sensor Web Enablement standards [4] and based on this, intelligent services will be studied and developed for an adaptive management of the data collection.

II. METHODS

NEREA is based in the Gulf of Naples (GoN), an extremely interesting area from different aspects. It is a roughly 15-km long gulf located along the south-western coast of Italy (Fig. 1, top), bordered by the Naples and Pozzuoli urban areas and Mount Vesuvius. It is closed by Capri , Procida and Ischia islands. The Naples metropolitan area accounts for ca. 4.5 million inhabitants and the entire population is distributed along a very narrow area along the coast. The presence of illegal dumping (including toxic discharges) and untreated sewage, along with the presence of wide contaminated areas, intense maritime transportation, maritime infrastructures (ports), and other direct and indirect anthropogenic stressors [5-8] have determined a progressive loss of marine habitats [9]. The water mass structure of the GoN is predominantly linked to the main circulation of the southern and mid-Tyrrhenian Sea, with influences from local factors, such as the wind stress and the river runoff. The two main water masses flowing in the GoN are the Modified Atlantic Water (MAW) that occupies the upper 50–100 m and the Levantine Intermediate Water (LIW) located below ~200–300 m [10]. Depending on the season, other water masses can be recognized within the GoN, such as the Tyrrhenian Intermediate Water (TIW), formed during winter mixing at depths down to ~150 m, and the Tyrrhenian Surface Water (TSW), found above 75 m as the result of summer warming and freshening of the TIW [11].

In the area, a Long-Term Ecological Research station (LTER), i.e. Mare Chiara (MC), is located (LTER-MC) ca. 2 nm off Naples coast (Fig. 1, top), at 80 m depth. LTER-MC has been sampled for plankton and other parameters since 1984 and its data set represents one of the few plankton time series available in the Mediterranean Sea, and one of the longest [12].

The main submarine feature of the GoN is the Dohrn Canyon, a bifurcate structure (see Fig. 1, bottom) that indents perpendicular to the coastline the continental shelf 12 nm off Naples, beginning at ca. 250 m and sharply declining down to ca. 1300 m in the Tyrrhenian plain [13]. There, the NEREA data are collected by NEREA-fix (a stand-alone observatory) and NEREA-mob.

Within NEREA-mob (the monthly periodic sampling) data from the LTER-MC will be integrated with those from oceanographic

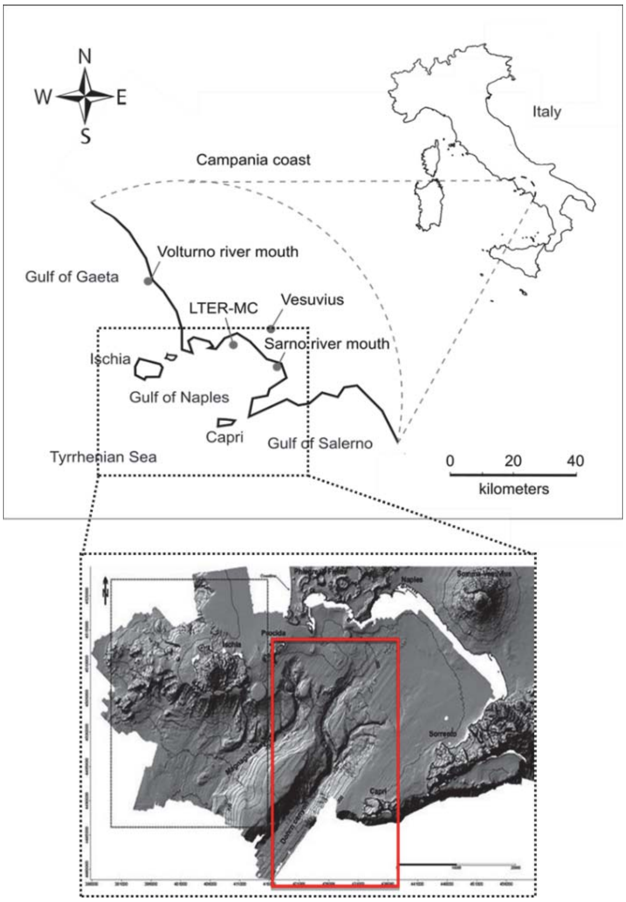

Fig. 1. Map of the study area (top) with the Gulf of Naples and the LTER-MC station in front of Naples along with the Multibeam sonar image of the canyon Dohrn (bottom, within the red rectangle) where NEREA-fix will be deployed.

transects in a triangle limited by MC, the River Sarno mouth (max sampling depth = - 15 m) and a deep station located in the Dohrn Canyon (max sampling depth = - 750 m). Plankton samples are being collected for meta-barcoding, -genomics, -transcriptomics, -metabolomics, plus analyses of trace metals, of turbulence profiles, *in situ* flow-cytometry, and visual census of microbes. Collection of samples of environmental DNA (eDNA) is going to be implemented. Both protocols from Tara Oceans program and new, ad-hoc sampling protocols are being implemented and applied [14].

NEREA-fix consist of a stand-alone Mooring Line (ML) and a Seabed Platform (SP) connected to a surface buoy (Fig. 2), and it will be deployed by spring 2020, within the Dohrn canyon at ca. 600 m. The surface buoy will be equipped with solar panels to power the instrumentation located on the SP, data logger connected to the SP, GSM modem for data transmission, GPS for position control. On the surface buoy, a weather station for the acquisition of the following parameters, will be palced: Wind Direction and Speed, Air Temperature, Atmospheric Pressure, Relative Humidity, Rainfall and Solar Irradiance;

The ML will be equipped with an ADCP for current direction and velocity measurements and a sediment trap, positioned close to the bottom.

The SP will allow automatic long-term measurements of oceanographic (physical and chemical) parameters and optoacoustic time-lapse imaging, it will allocate:

- the junction box (OBSEA-like; www.obsea.es), cable-connected to the surface buoy allowing the data transmission;
- multi-sensor asset measuring Depth/Pressure, Temperature, Salinity, CO_2 , O_2 and pH;
- Chlorophyll, turbidity and CDOM fluorescence sensors;
- HD video and acoustic camera for fauna;
- PAR sensor for monochromatic blue light measurements in dysphotic environments (to mimic bioluminescence).

Data science methodologies for modelling, understanding, monitoring and forecasting environmental relevant phenomena will be developed based on the integrated data collected. For this reason, NEREA is conceived to host specific modules for data management and bioinformatics (NEREA-dat), functional genomics (NEREA-lab), and modelling

(NEREA-mod), this latter being a module in which ecological and physical data are to be integrated into circulation models. In particular, supervised and unsupervised machine learning approaches based on evolutionary computing, random forests, neural-network and spectral clustering [15,16], will be developed for content-based optoacoustic recognition and classification of the macro and megafauna, as well as for the multivariate analyses and modelling of time-series combining environmental, biological, biogeochemical and metabarcoding data.

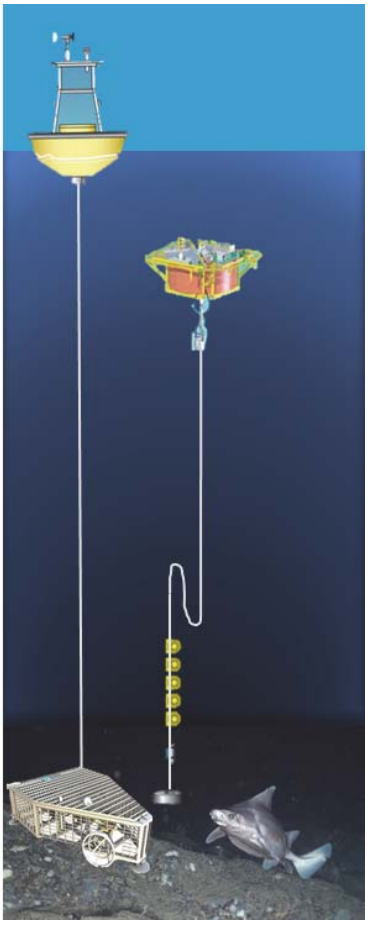

Fig.2. Scheme of the NEREA-fix, with the seabed platform (OBSEA-model) and the mooring line.

III. RESULTS AND DISCUSSION

The NEREA ecological research and monitoring scheme is conceived to assess biodiversity as a whole, along with ecological processes occurring within communities, providing improved data on ecosystem functioning and health status [17]. At present, preliminary data are available only for NEREA-mob, which started on February 12th 2019. The combined, quasi-synoptic sampling at LTER-MC and Canyon Dohrn stations (March 2019) highlighted a flux of krill (*Euphausia* spp.) from the deeper waters of the GoN to its inner side. Conversely, quasi-synoptic sampling along the transect Sarno river-mouth – Dohrn Canyon (May 2019) evidenced the extension of the river-plume, which fuelled a diverse community of dinoflagellates, including potentially toxic species. These observed trends will be soon tested and sampling integrated by seabed optoacoustic imaging across a range of fauna sizes (i.e. from macro-zooplankton to megafauna). Such information will be then directly related to multiparametric environmental information obtained *via* the simultaneous collection of geochemical and oceanographic data from SP and ML [18]. In parallel, integration of advanced genomic approaches for *in situ* sequencing of samples will enhance networked ecological monitoring beyond what could be achieved using imaging approaches alone. Eco-genomic sensors can autonomously collect biological samples and perform molecular analyses [18], an approach applicable for the characterization of marine community composition as a whole, regardless of the faunal size classes involved [18]. High-throughput sequencing technologies will allow the processing of huge volumes of environmental DNA, enabling the metabarcoding of species for their traceability [e.g. 19].

IV. CONCLUSIONS

Considering the growing human pressure on marine ecosystems, 'Ocean Health' (OH) assessment should be (i) well routed on scientific tools quantitatively characterizing target key elements of the ocean's status, including biological, physical, economic and social ones, and (ii) devoted to guide decision-makers towards the sustainable use of marine resources. A network of augmented observatories coupling plankton and benthos, using an end-to-end approach (from microbes to large marine mammals) under a multidisciplinary context, (encompassing the simultaneous measurement of biogeochemical and oceanographic variables), will enable to effectively assess OH. These data should support knowledge-based management toward the achievement of SDG14. The NEREA initiative is a new technology-based, analytical platform for such an OH-oriented assessment, integrating existing cutting-edge technologies and implementing near future ones (i.e. omics and eDNA).

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