Summary of the Italian BioGeoSCAPES planning workshop

The Italian BioGeoSCAPES planning workshop was held at Stazione Zoologica Anton Dohrn, in Napoli, on September 26th, 2023. The meeting was organized by Serena Leone (Stazione Zoologica Anton Dohrn) and Mario Sprovieri (Istituto di Scienze Marine - CNR) and held in mixed mode, *via* Zoom and in person. Twenty-seven participants, representing different institutions, attended the discussion. The meeting had the aim of spreading the Mission and Vision of BioGeoSCAPES, as defined in the scoping meeting in Woods Hole (2018), gathering a community of Italian scientists that could elaborate the national contribution to the international program. To this extent, an interactive discussion took place, focusing on the four questions proposed also to other national communities:

1. The preliminary BioGeoSCAPES Mission statement is: "To improve our understanding of the functioning and regulation of ocean metabolism and its interaction with nutrient cycling within the context of a hierarchical seascape perspective". How could this be improved?

The Italian community represented at the meeting did not have major comments on the Mission statement in its present formulation, agreeing that it captures one wide scope of BioGeoSCAPES. However, it was highlighted that an effort should be made to better highlight that '*ocean metabolism*' goes beyond elemental cycling, which is not only a driver but also a product of biological activity. The latter is what should ultimately be understood in terms of mutual exchange of matter and information among organisms in the "*context of a hierarchical seascape perspective*".

2. How would your nation best contribute to BioGeoSCAPES efforts? – e.g. fieldwork, laboratory work, modeling, intercalibration efforts, project coordination, data management, bioinformatics

Several expertises are available within the Italian BioGeoSCAPES community, as well as infrastructures and ongoing projects that may contribute to the realization of the BioGeoSCAPES Vision. These include:

Fieldwork and Oceanographic cruises:

This is certainly an essential component, however dependent on national ship allocation and approved grants. All data collected in the framework of EU AtlantECO project (coordinated by Daniele Iudicone, SZN) will be available after the agreed embargo periods and will cover most of the Atlantic basin. For some areas these will include most of what can be presently assessed using classical methods, -omics and bioptics.

Italy has a long lasting activity of biogeochemical studies in the Southern Ocean, mostly in the Ross Sea, coastal areas as well as some work on sympagic communities.

OGS is responsible for managing the R/V Laura Bassi that every year circumnavigates the globe on its way to Antarctica and back. This transect could represent an unprecedented opportunity to sample a wide range of environments. However, significant work is required to make this happen.

Argo Italy at OGS deploys physical and biogeochemical profiling floats in the Mediterranean Sea and Southern Ocean. Data from these floats describe the context (current state and variability) in which BGS observations could be embedded.

There is a great interest and a very qualified contribution (Donato Giovannelli and Angela Cordone, University of Napoli) on the link between trace elements and microbiota in the present and during the evolution. While most of the sampling is carried out in extreme environments, not necessarily marine, the question is very much linked to BGS themes.

Within the Mediterranean Ship-based Hydrographic Investigations Program (Med-SHIP) initiative, a trans-Mediterranean cruise is planned for the year 2025 with the participation of groups from OGS (Trieste) (physics, Vanessa Cardin, and biogeochemistry, Giuseppe Civitarese). The scope is more on the

physical and biogeochemical descriptors, with emphasis on the Carbonate System, but by the time of the cruise it could be possible to add observations better suited for BGS.
Another cruise is planned for this fall on board of the CNR Gaia blue ship in the Ionian Sea. The focus will be more on the deep sea, but also questions of interest for BGS, e.g., horizontal connectivity among communities, impact of coastal inputs on the high sea and processing by microbiota, will be analyzed. Other basin-specific questions will be detailed below.
Within the TREC expedition (EMBL), Ulisse Cardini (SZN) is contributing with protocols for the analysis of O2/Ar, N2/Ar, as well as DMS analyses in water samples along all European coastlines, aiming at resolving the influence of land runoff on key coastal biogeochemical processes.
As part of the EU BIOcean5D project consortium, several researchers are contributing to a 2-years effort to unveil (sub)mesoscale processes shaping coastal marine biodiversity along land-sea gradients, combining remote sensing, physics of the seascape, planktonic and benthic ecosystem functional properties, ecosystem productivity and N2 fixation (13C and 15N labeling experiments), GHG fluxes, as well as omics-based biodiversity patterns (Ulisse Cardini, Francesca Margiotta and others, SZN as well as other Italian Research Institutes).

Historical time series and augmented Observatories:

In terms of *in-situ* observations the fundamental information deriving from historical time series, especially in the more recent advanced format of augmented observatories, has been strongly stressed. The Italian community has a few of these observatories, among which the most continuous and rich of information are the LTER-Marechiara (MC) and LTER-Lacco Ameno (LA) of Stazione Zoologica Anton Dohrn. They provide data on taxonomic, chemical and physical parameters in two sites, a coastal station in the Gulf of Naples for the water column and another in the Ischia Island for benthic communities, over ca. 40 years.
For over two years now, the MC observatory has been augmented by the activities within the NEREA project. This augmented observatory extended periodic observations to more than one station with a monthly periodicity, and has been designed to merge periodic observations with process-oriented sampling. NEREA is already implementing the BioGeoSCAPES vision and features and will serve as a background reference for other *in-situ* observations, as well lab and modeling activities. So far, NEREA has produced two years of metagenomic, transcriptomic, and barcoding data paired with chemical and phyto- and zooplankton taxonomic identifications, all already available. For one year, samples dedicated to the chemical -omics (meta- proteomics and metabolomics) have also been collected.
Other fixed observatories of interest are Mambo-C1 and E2M3A, in the Northern Adriatic and in the Southern Adriatic, respectively, where repeated multidisciplinary observations are carried out by OGS.

Laboratory work:

Based on the *in situ* observations, numerous strains of phytoplankton species are established to refine biodiversity and study their phylogenetics, reference transcriptomes and -genomes (Mariella Ferrante, Wiebe Kooistra et al. at SZN). The extensive strain collections and associated metadata have paved the way to laboratory experiments in controlled conditions by groups interested in phytoplankton genomics and physiology targeting life strategies, reproduction, chemical communication, sensing, photobiology, circadian rhythms, and nitrogen transporters. This research, in turn, helps bridging observations at sea and -omic data. Processes regulating microalgal growth are currently investigated in the framework of the -omics datasets generated within BioGeoSCAPES (Mariella Ferrante, Monia Russo et al at SZN and Alessandra Rogato, at IBBR-CNR, both in Napoli).
The physiology and the metabolic rates of the microbial communities is also investigated in connection to various chemical substrates and at various depths in multiwell plates (Marco Melita, IRSA-CNR, Rome).

Mesozooplankton biology is investigated with a focus on swimming and mating behavior or in the context of chemical ecology, especially for what concerns diatom-copepod interactions (Ylenia Carotenuto, SZN).
Finally, symbiotic relationships and superorganismal organization, as well as their emergent properties for ecosystem biogeochemistry, are studied through the use of stable isotope labeling experiments, prevalently in benthic systems (Ulisse Cardini, SZN)

Modeling capabilities:
This activity encompasses several Institutions (OGS, Trieste; CNR-ISMAR, various laboratories at SZN, Napoli) and covers a wide range of scales and processes. A biogeochemical model for the whole Mediterranean basin is operationally run on behalf of the EU Copernicus initiative by OGS. More regional models nested with basin-wide models have been implemented by SZN. Earth system models of intermediate complexity, with trait based approaches are developed at CNR-ISMAR to address the controls of global scale biogeochemistry over centennial timescales (Angela Landolfi, CNR-ISMAR). Food web models with network approaches, *e.g.*, Ecopath, have been developed in collaboration between OGS (Simone Libralato) and SZN (Domenico D'Alelio, Ferenc Jordan and Maurizio Ribera d'Alcalà). Mechanistic IBM models have also been developed to address questions such as persistence and turnover of plankton communities in the North Atlantic (Paul Fremont, formerly at Genoscope France and Daniele Iudicone, SZN) as well as the impact of sexual reproduction events in diatom population dynamics. Part of the modeling activity is operational, *e.g.*, within Copernicus but, in prevalence, is intertwined with in-situ and laboratory activities as an additional tool for hypothesis testing.

Sensors development:
New paper-based sensors can be developed for targeted chemical and/or biochemical measurements, employing technologies inspired to the “frugal science” philosophy (Stefano Cinti, UNINA).

3. What science questions are most important to your nation within the broad scope of BioGeoSCAPES on a 10-year timeframe?

A significant part of the Italian BioGeoSCAPES community is currently focused on three aspects of the ecological dynamics of the Mediterranean basin:
1) A better assessment of the circulation models of the basin and their drivers, especially because of the relevant changes observed in the last three decades;
2) How the Med ecosystem is changing due to the relatively higher impact of anthropogenic activities and climate variation in relation to the global ocean;
3) The extent to which the quite specific nutrient fluxes and stocks shape the pelagic communities.

The studies carried on in specific areas (e.g., The Gulf of Naples, the Adriatic sea), besides characterizing long-term trends, are more and more focused (see above) on understanding the dynamics of plankton communities, their biodiversity and the interactions within them, building on the background information provided by classical physical and biological oceanographic approaches and the -omics. The BioGeoSCAPES theme of ocean metabolism is tightly connected to these efforts since one of the questions is on the link between community composition, its resilience or time course, species degeneracy and elemental cycling.

Several relevant questions have emerged from the collective discussion, and in particular:

- *The Mediterranean sea undergoes changes at a faster pace compared to other basins, from which it differs physically and biologically. What are the most relevant parameters that should be considered to compare these systems? Do global changes alter the hierarchy of metabolic processes? What peculiarities can be studied to interpret specific phenomena linked to global changes in a predictive key?*
- *Which baselines should be defined to frame the metabolic changes deriving from global changes? How could we evaluate the effects of the formation of ecological micro-niches?*
- *Could we use the data generated in the framework of BioGeoSCAPES to assess the adaptive capabilities of eukaryotic organisms on the scale of the individual cellular compartments?*
- *Can we use the data on environmental variants and nutrient availability to understand population dynamics at the strain level? Can we extract a correlation between taxonomy and functional redundancy?*
- *Can we identify specific metabolic markers to define new functional trades and develop more reliable biogeochemical models? Could these be used to develop new (bio)sensors?*
- *Can we integrate these models with studies on the land/sea axis, also in light of the effects of global changes on terrestrial habitats?*
- *How can we incorporate the impact of viruses together with micronutrient limitation on phytoplankton population dynamics?*
- *Since symbionts have higher metabolic rates compared to their free living counterparts, has their role been underestimated to date? How can we quantify it?*
- *Oceanography has a traditional focus on the great basins. What is the contribution of coastal waters to the oceanic budget of nutrients? What is the impact of the influx of DOM from the rivers on the marine ecosystem? How does this contribute to carbon cycling and CO_2 production? How does the benthos contribute to the main processes?*
- *How does plankton succession work and how much is it influenced by global changes?*
- *What is the mechanism of fluid-mediated interactions? What is the contribution of sporadic interactions? How could we measure them? What are the implications for metabolisms function?*
- *How can we distinguish between anthropic and climate-related effects in coastal areas?*
- *How can we integrate observations inherent to phenomena that take place on such different time scales?*
- *What contribution can be envisioned from the development of novel AI models?*

The answers to these questions will be sought by forming new collaboration networks, initially among the Italian BioGeoSCAPES community. External collaborations will be needed to generate much of the -omics data required for the fulfillment of the program.

4. Are there any impediments that the international community could seek to mitigate via training or collaboration?

The discussion among the Italian BioGeoSCAPES community highlighted some structural challenges, among which the lack or limited availability of -omics facilities, both in terms of NA- and chemical omics. This could be solved by establishing stronger collaborations with biomedical research facilities, as well as outsourcing these analyses to international collaborators. In addition, many researchers perceive a lack of established bioinformatics pipelines. Only a few Italian universities have well established bioinformatics training paths, and stronger collaborations with other countries could help train a new generation of specialized researchers, to increase the presence of this discipline on the Italian territory.

Participants

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