Long Term Ecological Research (LTER) in the marine coastal environment: basic concepts and keystones from the plankton communities

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Abstract

Long-Term Ecological Research (LTER), which focuses on multidecadal observations, provides the correct approach and temporal context needed to avoid misjudgements in our attempts to understand and predict changes in marine ecosystems and to manage them. The LTER approach is particularly important when trend detection is a central issue, as in global change, and it is also critical for testing ecological theories on community dynamics, variability and resilience, enhancing our capacity of forecasting and of managing resources. Coastal marine ecosystems is among the most ecologically and socio-economically vital ecosystems in the planet; they are intrinsically highly variable, as a consequence of their connectivity to both land and open sea. Within these systems plankton is a primary driver of chemical and biological dynamics, directly affecting water quality, biogeochemical cycling and food supply to consumers. In marine costal ecosystems many regulatory processes fluctuate over multiple time scales and human disturbance is intense, making it a challenge the individuation of plankton "patterns". The study of coastal plankton communities, with a LTER perspective and with an across-system comparisons, appears crucial, in order to identify common patterns of variability and how they change with scales. In this paper we review the contribution to these issues coming from the Italian marine LTER sites, with emphasis on the researches carried out in the Northern Adriatic Sea.

1 Introduction

A typical psychological human trait is the so-called "change blindness" [1] that deals with the difficulties observers have in noticing large environmental changes, when they are not framed in the appropriate long-term recordings context. At the time scale of decades (or even less) human beings are inclined to perceive the world as static, typically underestimating the degree of change that does occur [2, 1]. From this inability to perceive slow changes and to interpret their cause-effect relationships, it stems that processes acting over years (namely: decades) are hidden and reside in what has been defined by Magnuson [3] as the "invisible present". The human knowledge of the natural world is strongly shaped and guided by the frequency, duration and geographic magnitude of our observations. The so called “Long-Term Ecological Research” (LTER), which is based on the analysis of multi-decadal observations, supplies the appropriate approach and temporal context that are needed to avoid misjudgements in our efforts to understand and predict changes in the world around us and to manage our environment. LTER may have different meanings, according to the resource being considered and to the phenomenon under investigation: it should, anyhow, be based on the time scale that enables signals of environmental change to be distinguished from background noise. LTER indeed should allow the recognition of the range of natural variability of ecological systems, providing baselines against which determining if a system has significantly changed. Therefore, ecological time series can be regarded as essential tools to detect meaningful shifts and assess whether changes are attributable to human or natural causes, thus enhancing our capacity of forecasting and of managing resources. Furthermore, LTER is a crucial tool to challenge paradigms and scientific dogmas of ecology, being critical for testing ecological theories on the way ecosystems or biological communities are organized and on community dynamics, variability and resilience. LTER is, indeed, intrinsically involved in what can be defined the “fundamental problem of ecology”, that is: the attempts to discover and define patterns, their causes and consequences, within and across ecosystems [4]. In this paper we aim to highlight the role and contribution of the LTER networks to the multifaceted and composite nature of marine LTER, considering the Italian marine LTER sites, with emphasis on the plankton communities and on the researches carried out in the Northern Adriatic Sea.

2 The LTER sites network

Although time-series observations are recognized to represent a critical element of ecology, they are also, paradoxically, among the easiest victims of funding shortage. The predominant picture of LTER research and monitoring shows that it frequently leans on the personal effort and dedication of individual scientists, with a frequent imbalance between the energy invested and the scientific result yield [5]. In the last decades, however, some programmes initiated a new era in time-series investigations [6]. The International LTER network (I-LTER) began in 1993, fostered by the United States LTER (US-LTER), and it was fuelled by the exigency of cooperation at local, regional and national levels through sharing and integrating data and findings, creating synergies on global projects and delivering scientifically-sound research to decision makers and public [7]. LTER sites consist of various reference ecosystems, research and monitoring facilities that set a network across the world. At the European level the LTER networking process started in 2004, in the framework of the network of excellence “AlterNet” and in compliance with the European strategy to overcome fragmentation in the field of environmental research and monitoring. LTER-Europe (E-LTER, [8]) could not rely on a steady long-term support from a central funding body and stakeholder, comparable to National Science Foundation for US-LTER, and it was essentially built on existing facilities with a strong LTER connotation. Thus, E-LTER developed into a complicated prospect of European environmental monitoring schemes, data bases,

Marine Environment	Transitional Environments	Lacustrine Environment	Terrestrial Environment
Northern Adriatic Sea	Po River Delta	Subalpine lakes	High altitude Apennines
Gulf of Naples	Lagoon of Venice	Lentic ecosystems of the Apennines	Forests of the Alps
Marine Ecosystems of Sardinia		Lacustrine Ecosystems of Sardinia	Forests of the Apennines
Marine Protected Area of Portofino		Himalayan Lakes (*)	Mediterranean Forests
Antarctica Research Stations (*)			Lowland Forests
			Mediterranean Island (Pianosa)
			Castelporziano Natural Park
			Western Alps
			Coastal dunes of central Italy

(*) Extra-territorial sites

Table 1: List of the twenty LTER-Italy Sites (updated at January 2011)

and institutions. In March 2010 E-LTER comprised 18 formal national LTER member networks [8]: Austria, Czech Republic, Finland, France, Germany, Hungary, Israel, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Switzerland, and the United Kingdom. Each country established a national network according to national peculiarities, as it concerns funding of research projects, institutions and infrastructures. However, a process of design, integration and harmonisation of the LTER research activities and facilities is successfully ongoing and comparable overviews are defined [8]. Although a number of similar organizations exists, LTER is the only one that has the whole set of the following attributes: i) it generates field data at different scales, in a wide array of ecosystems, with a marked trans-ecodomain and across ecosystems approach, ii) it dedicates itself to the provisioning, documentation and continuous use of long-term information and data on ecosystems with a time horizon of decades to centuries, iii) it contributes to better understanding the complexity of natural ecosystems and coupled socio-ecological systems, iv) it aims to the integration of LTER and Long-Term Ecological Monitoring (LTEM). Italy entered the ILTER network in 2006, at the end of a scientific and organizing process that started during the 1990s [9]. At the moment (2010), LTER-Italy consists of a group of 20 sites belonging to terrestrial, freshwater and marine ecosystems (Table 1).

3 LTER and plankton in marine coastal ecosystems

Marine coastal ecosystems are among the most ecologically and socio-economically vital sites on Earth. Given their global importance in terms of ecological diversity and economical value, and the potential impacts of men's activities (primarily: over-harvesting, pollution, and direct or indirect effects of climate change), their health is a matter of major concern, both for scientists and resource managers. The synergistic effects among climate change and other anthropogenic impacts, from one side, and among abiotic and biotic responses, from the other, require improvements to our definition of natural variability and to existing predictive framework [10]. Also the restoration of human impacted marine costal systems calls for LTER, as a tool supporting the formulation of clear and biologically sound hypotheses. The fundamental interdisciplinary nature of LTER, claiming for the actual share of methodologies, experiments, ecological data and findings, generates an intellectual and experimental partnership among disciplines and researchers that represents an essential requirement for knowledge driven environmental policy too. Coastal systems represent a hard challenge when facing the task of determining status and trends in water quality and ecological conditions. These systems are, by their very nature, highly variable, at different spatial and temporal scales, due to some unique attributes, e.g.: the shallowness, the strict benthic-pelagic coupling and the connectivity to both land and sea [11]. Indeed, human and natural perturbations often interact in these systems, over multiple time and space scales. The plankton communities are the bases of the food webs in marine systems and, therefore, the pathways and efficiencies of transfer of carbon and energy to upper trophic levels depend on the quantity and composition of the plankton community. Recent evidences suggest that plankton is a more sensitive indicator of environmental change than the abiotic variables themselves: the non linear response of biological communities may, indeed, amplify the environmental perturbations [12, 13]. Environmental perturbations may interfere with life histories and with the synchrony between trophic levels, leading to a trophic mismatch, with severe implications for energy flow to higher trophic level [14]. The definition of recurrent patterns and trends of plankton represents a standing task for the study of marine coastal environments. Indeed, the presence of many regulatory processes fluctuating over multiple timescales and the intense human disturbance in the nearshore coastal ecosystems across the world, makes uncertain even the existence of canonical plankton patterns [15]. Moreover, when interpreting the impacts of long-term changes on plankton communities, we must be aware that almost all plankton time series, across the world, are shorter than 50 years in duration [12], frequently spanning only the last 2-3 decades. The dynamics of phytoplankton, the dominant primary producers in most aquatic systems, have been recently reviewed by Cloern and Jassby

[11], showing that variability of coastal phytoplankton cannot be identified with a small set of common patterns. Whereas much of phytoplankton variability in the open oceans is generated by the annual cycles of solar radiation and atmospheric inputs, phytoplankton variability in coastal waters is related to many additional processes (e.g.: interactions with land, sea, atmosphere, sediments), with the main controlling processes varying both regionally and temporally. The intrinsically high variability of this community must be taken into account, also for environmental management purpose: actually, the phytoplankton is, at present, the only planktonic element included among the water quality indicator in the European Water Framework Directive (EC 2000). In this viewpoint, any effective use of the phytoplankton community as a biological quality element poses several constraints and implies a strong necessity of individuation and definition of adequate baselines against which evaluate local vs. large scale changes, as well as trends [16, 17, 18]. Multi-decadal studies are fundamental also for the definition of patterns and trends of the zooplankton communities. Zooplankton are critical for the functioning of aquatic food webs, being the major grazers and, therefore, providing the principal pathway for energy transfer from primary producers to consumers at higher trophic levels. Copepods, the most prominent zooplankton taxon, are the most abundant multicellular animals on the planet [19]; however, zooplankton communities are actually highly diverse, performing, therefore, a variety of ecosystem functions. The relations between climate change and other anthropogenic stressors with zooplankton [20], analyzed through a long-term perspective, show manifest changes in the distribution and phenology of zooplankton, in the timing of important life-cycle events, in the abundance and community structure.

4 The marine component of the lter-italy network

The institution of LTER-Italy, leaded by a Steering Committee, had a strong bottom-up nature and it can rely only on the different institutions' responsibilities and funding, and on the researchers' personal efforts and willingness. As for its governance structure (laid down by the LTER-Italy by-laws), LTER - Italy is made up by the responsibles of each LTER site, which constitutes the "National Site Representative Conference" and by a Coordinating Committee, whose members are elected by the site responsibles and are representative of the main institutions involved in LTER research.

In accordance with I-LTER and E-LTER, the driving aims of LTER-Italy are, first of all, to foster collaboration and coordination among LTER ecosystems, researchers and institution; then, to improve comparability and exchange of LTER data and findings; finally, to deliver information to policymakers and the public. LTER-Italy has a strong interdisciplinary nature, being made up by terrestrial, marine and freshwater ecosystems (Table 1). The links and feedbacks among terrestrial and aquatic ecosystems, when addressing global scale issues, such as climate change, are readily acknowledged but poorly investigated. The comparison across eco-domains is rarely achieved in ecological studies and conceptual and practical barriers among scientists working in the different domains have profound implication for addressing critical

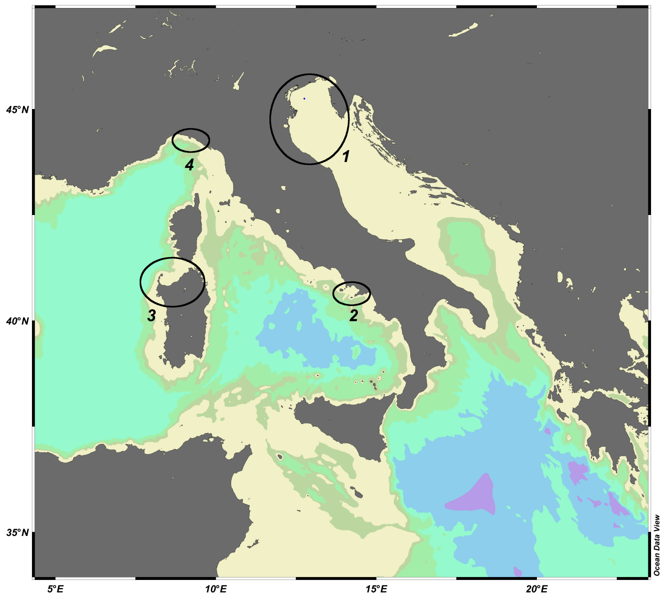

Figure 1: Location of the LTER-Italy marine sites and institutions responsible of each site: 1) Northern Adriatic sea - CNR ISMAR and OGS 2) Gulf of Naples – SZN A. Dohrn 3) NW Sardinia coast Univ. Sassari 4) Marine protected area of Portofino – Univ. Genova

ecological issues (e.g. biodiversity, climate change, invasive species), that are of basic importance also for conservation and management policies. Beside their obvious differences, marine and terrestrial systems may be seen to represent end-points of a continuum: the cross-sector collaboration among marine and terrestrial expertise, which is one of the most peculiar features of LTER-Italy, should represent a unique chance for approaching this insight.

Four out of the 20 LTER-Italy sites are coastal marine sites (the others being terrestrial and freshwater): the Northern Adriatic Sea, the Gulf of Naples, the Sardinia costal waters and the Portofino marine Protected Area (Fiure 1). These sites are under the responsibility of different institutions (Fiure 1). Despite the differences characterizing their history, these institutions share similar LTER philosophy, objectives and plans. The study of the plankton communities represents the main subject of common activities. The truly integration of the LTER observations on marine plankton at the national level, through the comparison of the plankton time series in each site, the individuation of shared hypotheses, the definition of common experimental protocols and activities, represents a difficult challenge, but also a vital necessity for a meaningful and fruitful evo-

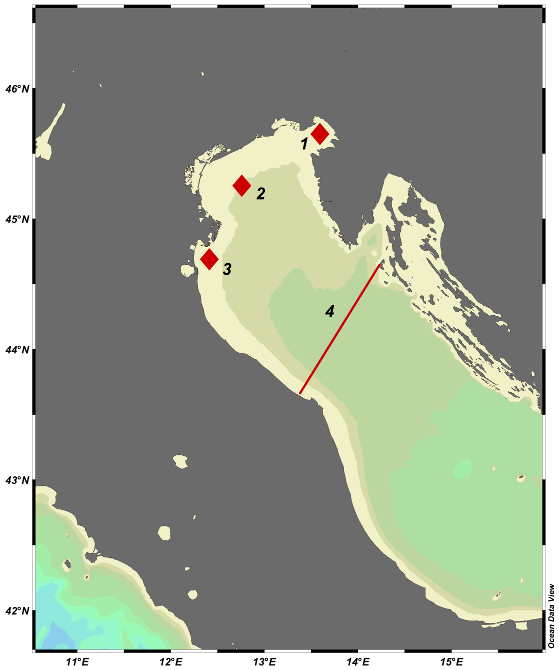

Figure 2: Stations of the Northern Adriatic LTER site and institutions responsible of each station 1) Gulf of Trieste, OGS Trieste-ISMAR Trieste 2) Gulf of Venice ISMAR Venezia 3)Po river Delta S1 ISMAR Bologna 4) Senigaglia-Susak transect, ISMAR Ancona

lution of LTER activities. The research focuses mainly on plankton patterns and scales of variability, on the identification of drivers and processes, and on the importance of species-specific attributes. A close collaboration with environmental monitoring programs and oceanographic observation networks is also fostered, with the goal of contributing to coastal resource management too, making the best use of the available information.

Some key issues represent the core of the research on plankton in the LTER-Italy marine sites: i) individuation the dominant scales of variability in plankton biomass and species composition, ii) identification of regime shifts or common trends and of the coherence of their occurrence in space and time, iii) recognition of evidence for external forcing (e.g.: basin scale oscillation, nutrient inputs, alien species, climate change) of variability and the differentiation between long-term signals from interannual noise, iv) search for consistent patterns among ecosystems in terms of relationships between environmental parameters, plankton biomass and changes in species composition.

The Northern Adriatic Sea (NAS) is one of the 4 LTER-Italy marine sites (Table 1). Three institutions (Figure 2), which hold a long tradition of ecological studies in this ecosystem, are jointly responsible for the 4 LTER research stations in the NAS. The NAS is the northernmost basin of the Mediterranean Sea and is one of the most productive Mediterranean areas. It is characterized by a shallow depth and by a dominant cyclonic circulation. The oceanographic and meteorological parameters show a marked seasonal and interannual variability. The remarkable river inputs (along the Italian coast), the istro-dalmatian current (bringing high salinity and oligotrophic waters from the southern basin), and the notable sea-level range (relatively to the Mediterranean area), represent major forcings of the system.

Of ecological relevance are also the urban and industrial inputs and the hydrodynamic exchange between the NAS and the lagoons, located along the Italian coast. The NAS is subjected to a marked anthropic impact (e.g.: nutrient inputs, coastal urbanization, fishing activity, tourism, maritime trade). In the past the basin has undergone eutrophication, and, more recently, has been subject to frequent episodes of large mucilage aggregates [21]. Many ecological researches have been carried out in the NAS, since the second half of the last century, by national and international institutions, most of them focusing on the ecology of plankton communities, also in relation to the main environmental emergencies (e.g.: eutrophication, mucilage aggregates, toxic algae). A huge amount of data and information are available for the NAS and its plankton communities, and in this chapter we synthesize some critical issues about these communities, within the national and international LTER context and principles.

First of all, the LTER activity on plankton has allowed identifying the main seasonal patterns of both phytoplankton [22, 23] and zooplankton taxa [24, 25]. Notwithstanding the elevated spatial and temporal variability, at different scales, of climatic and oceanographic factors that characterize the basins, a seasonal pattern does exist and a sort of "calendar of plankton" is known, at least for the areas that have been sampled with the highest consistency: it represents a baseline against which evaluate possible specific changes and future trends. In particular, as it regards phytoplankton communities, event though species group together in different ways over the year, the taxonomic composition of the dominant associations seems to be highly dependant on season, while environmental conditions can explain mainly the variability of total abundances and biomass [23, 26]. As a consequence, seasonal patterns in biological structure persist in spite of the large variations over time in environmental conditions.

Secondly, pluriannual trends have been identified in plankton communities in the NAS. An analysis of the chlorophyll variations in the years 1970 - 2007 at basin scale [27], demonstrates a tendency towards chlorophyll a reduction, which is particularly strong in the last decade and is mostly located in the eutrophic area under the influence of the Po River. This trend could not be related to temperature variations, but rather to a reduction in the Po nutrient inputs, which induced a general oligotrophication of the system. Also the analysis of the mesozooplankton series in the Gulf of Trieste (where is located the longest time series in Italy) for the pe-

riod 1970-2005 shows extensive changes in the copepod community around the end of the '80s. These include: i) a shift toward smaller species, ii) the appearance of a new species (*Diaixis pigmoea*), iii) the northward spreading of southern species and a general reduction of cold species, and iv) the changes in the phenology of most species. The main hypotheses for these variations include a large scale and abrupt change in the Mediterranean circulation at the end of the 1980s, and the 1°C warming in summer and fall that occurred over the 36 years sampled ([28], see also [29]).
Finally, we wish to stress that the patterns identified for the plankton variability and trends in the NAS, are partially shaped by the annual climatology at the basin scale, but also strongly guided by the area-specific relative importance of disturbance and nutrient enrichment. To this respect, the NAS can be seen as a paradigm of the difficulties that are retained in the LTER series: the choice of the appropriate data set, within the time series itself, and of study area, within the whole basin, are crucial for any descriptive and interpretative goals. The comparison among LTER series, within the NAS basin itself and across the other LTER sites, represents hence the step necessary to avoid misjudgments due to local drivers, and it is crucial for identifying the dominant processes and forcing factors, thus formulating clear and biologically-sound cause-effect hypotheses.

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