ASSESSMENT OF MARINE ECOSYSTEM SERVICES AT THE LATIN-AMERICAN ANTARES TIME-SERIES NETWORK

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EXECUTIVE SUMMARY

Marine ecosystem services (ES) such as fisheries' support and carbon sequestration undeniably contribute to human well-being and they are being affected by changes in the climate system. Human activities influence climate through the use of fossil fuels and reduce biodiversity by selectively extracting/exploiting species and drastically changing their habitats. Proper management of natural resource stocks and services and of human impacts on them is essential to promote human well-being. Defining proper management strategies requires monitoring the changes that are occurring in the environment and their impact on society. The Group of Earth Observations (GEO) coordinates international Earth observation programs, with the final goal of making the data easily available to decision makers. The ocean is still under-represented, however, even at this high inter-governmental level. Initiatives that have already been undertaken to protect natural ocean resources include the development of an ecosystem approach to fisheries management (Pauly, 2005) and the assessment of the state of health of the ocean (Halpern et al., 2012).

More specifically, the ocean offers many key ecosystem services and thus it can be regarded as a "global common" (Buck, 1998). Among them, phytoplankton (microscopic autotrophic organisms) provide essential services categorized as: *regulating* -since their role fixating atmospheric CO_2 and its eventual burial in deep waters represents a significant part of the global carbon cycle and hence influences climate trends-, and *supporting* -since through the photosynthesis process and nutrient cycling they support goods and services used by humans (including 50% of the oxygen we breathe). Making the necessary observations to monitor the state of phytoplankton and the oceanographic environment is difficult and expensive; hence marine time-series studies are relatively rare.

Here we propose to integrate data on phytoplankton and oceanographic variables regulating their growth collected at eight time-series stations around Latin America (Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Mexico and Venezuela), which constitute the Antares network (www.antares.ws). Historical *in situ* observations from each time-series station (starting in 1995 for the oldest and 2008 for the youngest) together with remote sensing information will be used to investigate the state and trend of changes in phytoplankton populations and the oceanographic environment. These studies will be complemented by modeling tasks aimed at understanding the functioning of the different local systems, including how they are connected at a regional scale. The Antares network integrates a variety of natural environments and socio-economic conditions among the eight participating Latin American countries. Thus, we propose a multidisciplinary approach to understand the impact that changes in the ocean may have especially in the regulating and supporting ecosystem services provided by phytoplankton and to investigate the connection of these ES with the human populations in the coastal areas of the Antares sites (primary stakeholders). As to the method, a channel for dialogue and information sharing with stakeholders will be created from the outset in order to identify key questions and information gaps. In this context a basic set of natural/socioeconomic vulnerability indicators and trends will be presented and discussed. As a second step, the project will define new methodologies and develop a set of socioecological variables and indicators to assess the phytoplankton ES and, subsequently, of environmental health. In addition, specific case studies will be developed to analyze possible changes in the natural (local and regional biogeochemical models to obtain information on changes in phytoplankton) and socioeconomic effects (e.g., fisheries, carbon uptake) of the identified trends. A strategy for effective communication of the knowledge co-constructed during the project will be developed to facilitate dialogue and awareness raising efforts with local decision makers as well as further outreach and research activities for the protection of these ocean ecosystem services for human well being.

BACKGROUND

It is known that more than 70% of the surface of the Earth is covered by the oceans, and that one third of the world's population lives close to coastal areas. In Chile, three-quarters of the population lives along a 500-km stretch of coastline between Valparaiso and Concepción. About 15 million people live in the Buenos Aires-La Plata-Montevideo coastal region. And the coastal area between Sao Paulo and Rio de Janeiro, Brazil, hosts over 30 million people. Each of these areas continues to grow in population. However, still the oceans remain seriously underrepresented in international fora concerning Earth observations aiming to contribute to the goals of sustainable development and challenges facing society due to global change. In this context we can pose the following questions: Why is the ocean and its production relevant for human society? How can we improve our knowledge about it? How can we make this information available to policy makers who take decisions on environmental management? The appearance of phytoplankton in the ocean, about 3 billion years ago, releasing oxygen into the atmosphere, facilitated the evolution of life on the planet. Actually, phytoplankton supports more than 95% of resident food webs and contributes with 50% of the global net primary production (Longhurst et al., 1995; Field et al. 1998). Therefore, phytoplankton has direct influences on the present and future of human society through: a) Food resources, since it constitutes the base of food webs leading to commercial fish populations, providing dietary proteins for more than 1.5 billion people; and b) Climate regulation, since the photosynthetic process plays a fundamental role in the modulation of the flow of carbon through the planetary system; on a millennial scale, about 80% of the anthropogenic release of CO_2 could be potentially removed by the ocean (Feely et al., 2001).

Phytoplankton cells are the most susceptible marine organisms to changes in the environment because of their short generation cycles and because they work as an interface between the environment and the rest of the marine biota (transforming simple elements as water, CO_2, and nutrients into organic matter with the energy provided by sunlight). These changes will be rapidly reflected in the phytoplankton composition (different species being adapted to different conditions); hence, phytoplankton can be considered sentinels of global warming (Hays et al., 2005). It has been suggested that climate change will induce the formation of shallower and more stable mixed layers (Behrenfeld *et al.*, 2006) that would limit the growth of large phytoplankton cells that need more nutrients to grow, whereas small cells recycle nutrients more efficiently within the upper mixed layer. This shift in populations has consequences in the total phytoplankton biomass and type of food available for upper trophic levels, including fish stocks, and in both the uptake of atmospheric CO_2 and the carbon export to the deep sea. Changes in the physical/chemical environment could also affect the timing and intensity of the spring phytoplankton blooms with consequences on the feeding of fish larvae and ultimately on the recruitment of fish stocks (Platt *et al.*, 2003). Determination of whether primary productivity is declining or escalating is critical because varying resources have cascading impacts on higher trophic levels, including commercial fisheries (Taylor et al., 2012) especially on continental margins. Dissenting interpretations of productivity trends have been obtained trough indirect methods (Behrenfeld et al. 2006; Boyce et al. 2010), statistical analysis of several variables at different time-series observations (Chavez et al., 2011), and direct monthly measurements since 1988 at two open ocean sites, the Hawaii Ocean Time-series (HOT; Corno et al., 2007) and Bermuda Atlantic Time-series Study (BATS; Lomas et al., 2010). Whether or not primary production is declining or rising is still on debate and would probably depend on the regions under evaluation. The way these changes are occurring will have a slow but profound global effect in the production of food, oxygen, and uptake of CO_2 (with implications in climate regulation).

Most stakeholders (as a matter of fact, in the context of organic carbon and oxygen production, the relevant stakeholder group should include all inhabitants of the planet) would nowadays recognize the (controversial) role of terrestrial environments (e.g. forests) as an important source of Ecosystem Services. However, few would know that half of the oxygen we breathe is produced by phytoplankton in the ocean. Ecosystem services are fundamental life-support processes upon which all organisms depend and refer to a wide range of conditions and processes through which natural ecosystems, and the species that are part of them, help sustain and fulfill human life (Daily et al., 1997). We are familiar with the economic value of fisheries for example, but there are many other ecosystem services, which do not have a value in the market, but are essential for human survival and their contribuition are not known to society.

Unlike economic services, ecosystem services are sometimes difficult to value since they are not traded in the market, but they meet key necessities of human life. According to Duffy (http://www.eoearth.org/article/Marine_ecosystem_services) the services provided by phytoplankton could be categorized as: *regulating services*, since its role fixating atmospheric CO_2 and its eventual deposition in deep waters represents a significant part of the global carbon cycle and hence influences climate trends; and *supporting services*, since through the photosynthesis process and nutrient cycling they support goods and services used by humans. The ocean is a complex interconnected system; for this reason, factors affecting biogeochemistry are trans-boundary processes, working at different scales of size, space and time. The only way to start putting the parts of the puzzle together and understand how the system is reacting to changes is by studying different aspects (from oceanic circulation to physiology and ecology of organisms) at different spatial scales (from molecular to satellite observations) through long-term (time-series) studies. These observations fuel the models from which a continuous dynamic, and predictive, picture can be drawn.

The Antares network (www.antares.ws) integrates the collaboration of different marine centers in Latin-America carrying out time-series studies on their coastal regions (Fig. 1). The approach of nucleating existing self-funded projects at each place makes possible to have access to relevant oceanographic data from different countries in Latin-America with continuity in time, since the absence of time-series data, especially in the southern hemisphere and developing countries, is evident (Rosenzweig et al., 2008). The network does not count with common funding. It is maintained by the good will of its members to share expertise and work in integrative projects. Maintaining long running oceanographic time-series in developing countries represents a tremendous challenge since the budgets of the institutes and funding agencies is lower, and the cost of obtaining instruments and supplies is higher than in developed countries.

The opportunities to obtain technical assistance and scholarships for students training is also much lower. Antares also has a satellite component that was developed through a project funded by the Inter American Institute for Change Research (SGP-II-026) “Coastal Ecosystems of the South American Region (CESAR): An integrated satellite data management and distribution system”. This system ran by the Institute for Marine Remote Sensing at the University of South Florida, consisted of an interactive database of the existing satellite images of sea surface temperature and ocean color since October 2004. This allowed the first integration of high-resolution satellite images of coastal areas around the Antares sites (at the beginning only in Argentina, Brazil, Chile and Venezuela), which has been used for scientific as well as management, and educational purposes. In the present project we propose to develop for all the Antares sites an improved version of this system already in place at the National Commission for the Knowledge and Use of Biodiversity (CONABIO) in Mexico, (http://www.biodiversidad.gob.mx/pais/mares/satmo) as well as sharing it with the Instituto Nacional de Pesquisas Espaciais (INPE) in Brazil.

Figure 1. Antares Network: Station location.

Even for traditional terrestrial ecosystem services, such as land use for agriculture and water provision, there are still challenges in developing a proper interface between science and policy makers, in terms of data intercomparability and translation into easy-to-interpret *indicators*, which can be used by decision makers (http://www.earthobservations.org; http://www.ihdp.unu.edu). In the case of most marine ecosystem services this interface between science and policy makers, is just starting. A recent study proposed the estimation of a single "ocean health index" (Halpern et al., 2012, http://www.oceanhealthindex.org), which has been computed for the exclusive economic zones of 133 countries around all continents. This index is built through a series of calculations and normalizations to reference values synthesizing 10 main items or goals considered necessary to have a healthy ocean system. For some of these items (from fisheries & aquaculture to aesthetic value) there are not enough data available to make a robust estimation, and the authors emphasize the urgent need to make more and better observations. Among the goals considered in that work, two would be pertinent to phytoplankton: biodiversity and carbon storage. Nevertheless, and comprehensible in such global estimation, some limits were given to what was considered within those categories. Thus, biodiversity does not include phytoplankton, and furthermore the reference value for a given species (the expected best number) was not set in consideration to its pristine abundance. In the case of carbon storage, only some coastline ecosystems, such as mangroves, salt-marshes, and coral reefs, were considered; with no account of phytoplankton production and its role in storing carbon in the ocean. As a background to any effort to develop and share scientific knowledge with decision makers and to co-develop with them on the relevant socioeconomic-natural links, variables and indicators of ocean health to account for phytoplankton, it is important to increase the general awareness of stakeholders of the importance of ecosystem services and the relevance of the ocean environment, and phytoplankton in particular. At the same time socio-economic aspects directly linked to the ecosystem services of phytoplankton related to 'coastal livelihood & economics' and fisheries (e.g. artisanal) will be considered. Although in a broad sense all people can be considered stakeholders, we will contact international and national organizations, governamental agencies with which some of the researchers are already interacting through existing (global, regional or national) networks to participate from the beginning in the construction of knowledge necessary to address the most relevant issues regarding support and regulating ecosystem services for society. One of these initiatives is the Regular Process for Global Reporting and Assessment of the State of the Marine Environment, including Socio-Economic Aspects, sponsored by the UN General Assembly, which aims to ellaborate the first World Ocean Assessment.

Antares counts already with valuable oceanographic data, from an area of the world ocean that has been poorly studied, and its goal is to continue and improve the *in situ* as well as remote sensing observations together with establishing a link between ES and the socio-economic impacts of the changes observed in nature on the local communities of the region. We expect that this proposal will allow the network to organize the existing data in a joint and regional database and to improve the observations by updating basic instruments and consumables in some of the stations. The dynamics of the possible changes in the phytoplankton populations and oceanographic conditions will be analyzed through local and regional models. These natural information will be used to assess ecosystem services and develop variables and indicators of environmental quality, thus connecting the scientific knowledge of the natural changes with the vulnerability of the human activities affected by potential changes in environmental quality due to natural or anthropic influence, and finally reinforce the educational component at Antares sites by incorporating students into thematic or transversal activities.

The integration of the network *in situ* data together with satellite and modeling results will be vital to interpret changes occurring at a regional scale in the context of global change. This natural information together with the socioeconomic information will be the basis of the co-construction of collective knowledge relevant for decision makers and stakeholders to improve awareness and governance on oceans at local and regional scales.

OBJECTIVES

General Objective

Study the trends in phytoplankton and associated ecosystem services in Latin-America (due to natural and/or man-made drivers) as well as their impacts on human livelihoods and socioeconomic activities.

Specific Objectives

1. Evaluate the main temporal trend in changes in phytoplankton biomass and composition at each region and the main environmental variables.
2. Identify and assess ecosystem services associated with phytoplankton and the influence of natural and man- made (climate change-local) drivers.
3. Characterize the linkages between trends in phytoplankton ecosystem services via economic activities such as fisheries, and key services as carbon uptake and nutrient cycling.
4. Generate integrated Socioeconomic and Natural Science assessment methods to better understand and communicate the dynamics of ecosystem services and their policy implications.

METHODOLOGY

Ecosystem Services and Socioeconomy

Protecting the environment and managing natural resources is essential to promote human well-being: we count on them to provide us with goods of market value as well as ecosystem services that are crucial for our survival. While the relevance of market-good providing resources is relatively easy to have the economic value, especially when resources are the direct source of market goods (e.g. fisheries and associated production/exports with market value), in the case of resources that mainly provide non-marketable ecosystem services (e.g. nutrient cycling) and whose role in the provision of market goods is rather indirect, their relevance to society proves harder to understand and assess.

In order to develop resource and environmental protection policies and management strategies it is necessary to monitor and assess the changes that are occurring in the environment due to the influence of anthropogenic and natural factors and, in turn, their impact on society (no matter whether they occur through direct or indirect channels). The ocean is still under-represented in such monitoring and assessment efforts. The initiatives undertaken so far to better understand and manage the interdependence between ocean resources, their ecosystem services and society include, for example, the development of an ecosystem approach to fisheries management (Pauly, 2005) and the assessment of the state of health of the ocean (Halpern et al., 2012). By contrast, the ecosystem services provided by phytoplankton and their importance to society are poorly understood. For all of the above, the project aims at analyzing the changes in phytoplankton popultations and their ecosystem services and how those changes have an impact on society.

The graph shown in Fig.2 below presents in a simple manner the main object of the project. It encompasses the whole socioecological system, and takes into account the impacts of global and local drivers on natural trends (phytoplankton populations and their ES). However, the project will only focus on some (unexplored) linkages between the natural and socioeconomic|c systems: the channels through which phytoplankton ES are related and contribute to the socioeconomic system and how global change is affecting them, all indicated by green arrows in the figure.

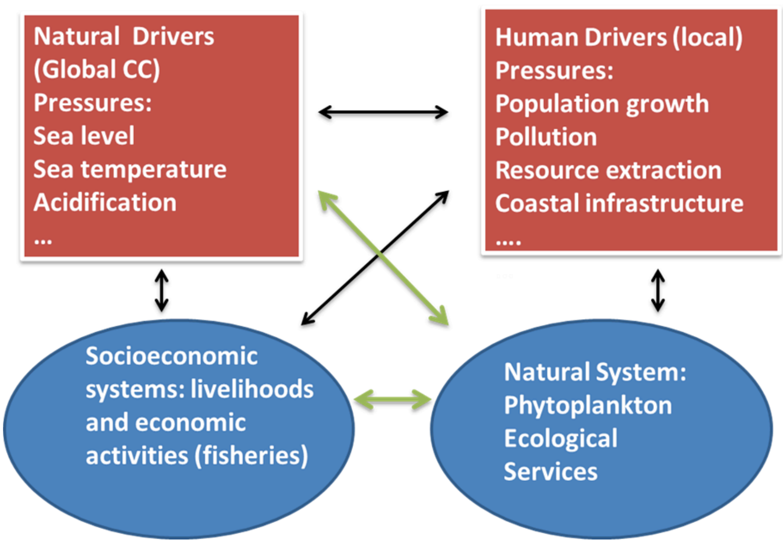

Figure 2. Focus of the project: Study the impacts of climate change and local drivers on phytoplankton and environmental services and their effects on society.

Exploring these relationships will be the main contribution of the project with regard to its multidisciplinary objective. Other important linkages will be recognized and taken into account but won´t be the focus of the analysis since they are being considered in other studies (e.g. the direct –two way- link between local and global change drivers, the direct impact of the latter on socioeconomic systems; the impact of socioeconomic systems on local drivers and pressures).

The graph developed in Fig.3 below despicts the project's roadmap, indicating the time sequence of steps and activities in its four phases and the main expected products. The phases, methods, activities and products are discussed below.

Phases

The project includes Four Phases. Each phase will be initiated by a workshop to discuss and define the workplan in detail – each phase is described according to the type of activities included:

- Phase 0 (Preparation): Project preparation.
- Phase 1 (Understand): Develop the scientific background, collect information, and set the scene for the scientific analysis and policy debate with key stakeholders.
- Phase 2 (Think): Critical review of the literature/information available and analysis of the information collected by project activities.
- Phase 3 (Act): Elaborate/discuss/communicate results, and to develop outreach activities and lessons.

Methods

To make progress towards the main project objective, in this unexplored field of study, the project needs to develop and apply many methodological disciplinary (Natural Science and Socioeconomic Analysis) and multi-disciplinary tools and approaches.

Firstly, considering the whole socioecologic system calls for a **specific methodological effort** to consider, discuss and develop assessment tools and concepts from Natural Science and from Socioeconomic Analysis that jointly serve the objective of providing clear and science based information relevant decision makers.

Secondly, the **identification of key policy and management questions** to be answered through the assessment will follow a collaborative or co-construction approach with the participation of key stakeholders in specific consultations and dialogue efforts in order to focus on their information and understanding gaps. The main stakeholders to be included are to a large extent part of existing national and international networks where many project Co-PIs already participate (e.g. at international scale, the United Nations World Ocean Assessment (www.worldoceanassessment.org), and the GEO Blue Planet (www.faroproject. org/blue_planet/announcement.html), and at national level, the Brazilian Biodiversity Adaptation and Mitigation Strategy – the Argentinean Third National Communication to the UNFCCC and the Adaptation and Vulnerability analysis).

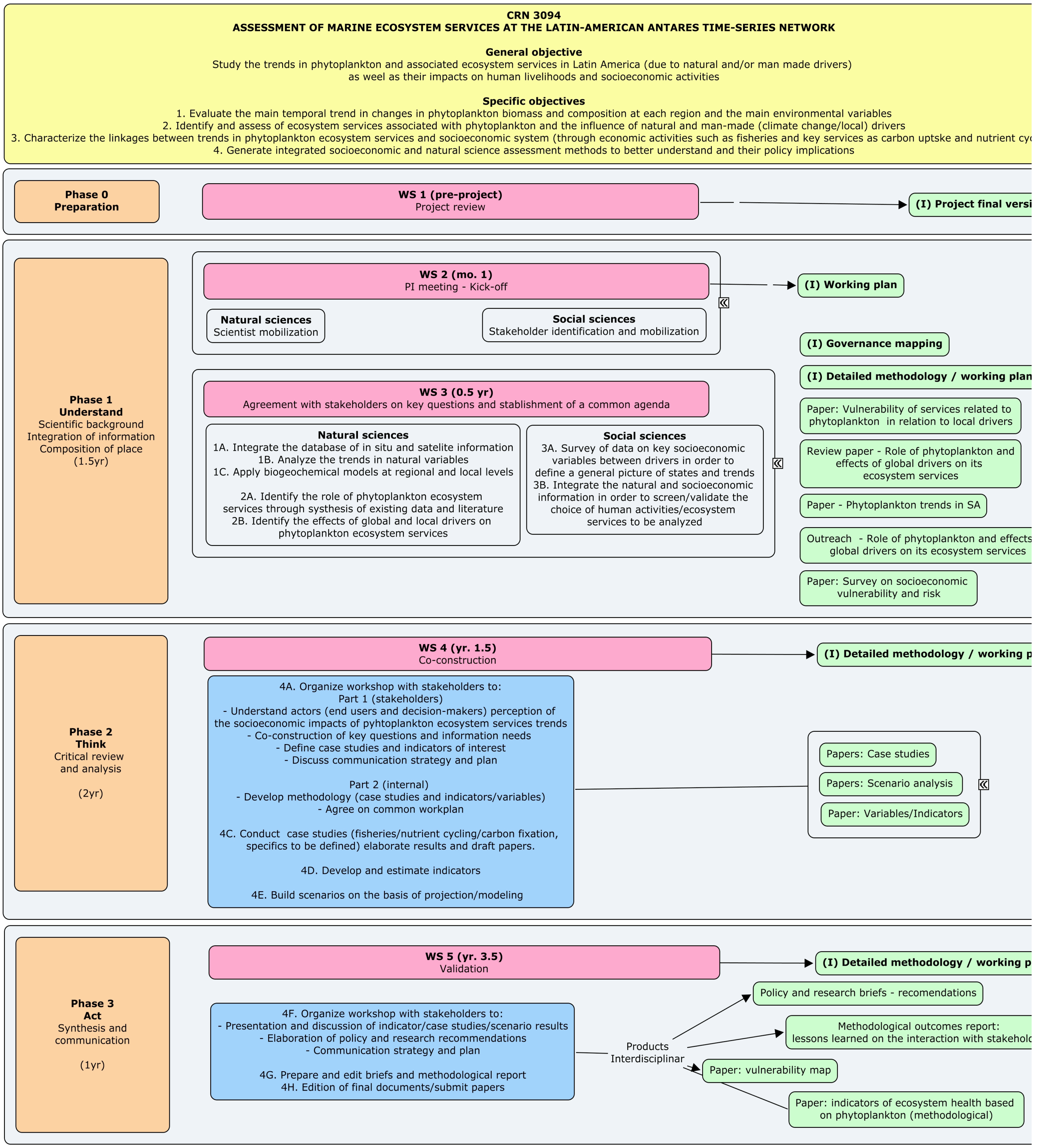

Figure 3. Project Roadmap.

Thirdly, to approach **ecosystem services**, the frameworks proposed by de Groot et al. (2002) and MEA (2005) will be used. The Groot et al (2002) typology allows the identification of structures and processes that produce a given service, while the MEA (2005) classification deals with the human benefits from each service and related human activities, thus justifying the importance of the service. Therefore, an integral analysis of the socioeconomic system and how they are directly or indirectly related to the marine ecosystem and phytoplankton related goods and services will be produced.

Fourthly, to a large extent, the **socioeconomic analysis** will be based on applying existing frameworks and data (vulnerability analysis, usual socioeconomic activity characterization and indicators) (CEPAL 2011 and 2012a,b,c; UNDP, 2010; IPCC, 2007). Socioeconomic data on employment, income, poverty, risk and on the relevance of economic activities such as artisanal and large scale fishing on regional GDP as well as natural data will be gathered and compiled. Data analysis along with case studies on economic sectors and key ecosystem services derived from phytoplankton will be developed to improve our understanding of the relationships between human livelihoods and activities and their dependence on phytoplankton ecosystem services (ES). Fisheries production, direct measurement of CO_2 fixation, employment, social variables –employment, income levels – and their trends will be considered.

Regarding **multi-disciplinary analysis**, a first effort will aim at providing a general overview of key natural and human activity trends related to the object of study (data on phytoplankton populations and ecosystem services and how socioeconomic systems relate to them). This analysis will be produced for all countries in the Antares Network. A second analysis will aim at the development of a **modeling approach to project scenarios** based on the trends identified in local and/or global changes, phytoplankton composition, their ES and their likely impacts on human activities. Both the oceanographic and socioeconomic data and especially the linkage between them, as depicted from existing literature and the project analytical and modeling efforts, will comprise the basis of a **first assessment of the regional situation and trends (including socioecological vulnerability)** and a first set of information and associated questions to be presented and discussed with stakeholders. A third analytical (and multi-disciplinary) effort will be aimed at **measuring "ocean and coastal health" through specific indicators/variables**. Following Halpern et al. (2012) a set of socioecological indicators/variables will be developed to assess phytoplankton and associated ES trends and their impacts on society with more detail, in a subset of countries (in first instance Argentina and Brazil). This study will be complemented with modeling efforts and case studies (fisheries' impacts, CO_2 reduction, and other direct ES) to better understand the links between ES and the socioeconomic system.

On this basis, a **communication strategy** for stakeholders will be discussed, designed and applied by the research team. A specific analysis of effective communication and presentation strategies and tools will be conducted during the project.

In these analytical efforts, as well as in the communication and outreach activities, the methodological and variable/model discussions and joint elaboration among the Natural Science and the Socioeconomic Co-PIs will be essential. Similar importance will have to conduct a critical review of the approaches and indicators/variables already developed and applied in other similar analytical and communication efforts, such as the Studies on the Economics of Ecosystems and Biodiversity –TEEB- (UNEP, 2009) and The United Nations Development Programme Biodiversity Report (UNDP, 2012).

In the methodological development and communication strategy, concepts from economic analysis will be considered, such as the notion of "natural capital" (Dasgupta, 2008). This concept can prove useful when discussing results from the health indicators, their trends and their implications to society. This approach is increasingly recognized in practical economic and multi disciplinary approaches to ecosystem protection challenges (see, e.g. WWF's project http://www.naturalcapitalproject.org/ and IISD's Natural Capital Approach, www.iisd.org/natres/agriculture/**capital**.asp). The distinction and relationship established by this approach regarding stocks and flows could help communicate more effectively the types and quantities of "services" provided by oceans and phytoplankton (varying levels of stocks provide varying flows as "interest from capital"), as well as their socioeconomic relevance.

Furthermore, it is important for the research team to build upon the concept of "socioecological health" akin to the notion of "sustainability" in order to define the objective of protecting a living resource and its sustainable flow of ES for human well-being.

Workshops will be designed to (i) establish dialogue, build capacity and inform decision makers about phytoplankton trends and the ecosystem services provided for society, especially the role of primary production; (ii) create a collaborative process to allow experience exchanges and discussion about oceanography, primary production, ecosystem services, trends due to future global or local environmental changes, knowledge gaps, and action to mitigate and/or adapt to future changes and to the technical diagnostics on human activities and stakeholders described above.

This interactive approach with stakeholders is the core of this proposal and is based on the availability of precise information on the natural environment, which will be detailed below.

Natural Science Methods

In situ data measurements

A list of the stations, variables and main methods used is shown in Table 1. Variables chosen in first place to be used in this project are those most relevant to assess changes in phytoplankton (biomass and structure) and in the main environmental factors influencing phytoplankton. The first two variables constitute core measurements across all Antares stations. The other four are not part of regular measurements at all sites (see Table 1).

Profiles of Sea **Temperature** will be measured at most stations using a CTD. The depth of the mixed layer will be estimated as that where the difference between the density (at that depth) and the surface density is > 0.05 Kg m^{-3} (Brainer & Gregg 1995).

Chlorophyll-a (surface): Samples from the surface will be taken and immediately filtered onto glass fiber filters (type GF/F ~ 0.7 µm retention capacity). The concentration of chlorophyll-a (Chla) will be analyzed from these filters for most using the fluorometric technique of Holm-Hansen et al. (1965).

Table 1. Variables measured at Antares stations.

	Cariaco	Ensenada	Ubatuba	EPEA	Cartagena	IMARPE	La Libertad / Manta	Concepción
Station PI	Y. Astor	E. Santamaría del Ángel	M.Kampel S. Gaeta	R. Negri V. Lutz	M. L.Páez Cañón	L. Escudero J. Ledesma	M. E. Tapia C. Naranjo	R. Escribano
Country	Venezuela	Mexico	Brazil	Argentina	Colombia	Peru	Ecuador	Chile
Geographic position	10.5° N, 64.7° W	31.2° N, 116.0° W	23.5° S, 45.1° W	38.5° S, 57.7° W	10.38°N, 76.01° W	12.1° S, 77.2° W	2.06° S, 81.08° W / 0.86° S, 80.81° W	36.5° S, 73.1° W
First sample date	Nov. 1995	May 2007	Dec. 2004	Feb. 2000	Jul. 2008	Feb. 1995	Feb. 2000	Jan. 2002
Cruise Periodicty	Monthly	Bimonthly	Montly	Monthly	Monthly	Quarterly	Monthly	Monthly
SST (1)	ºC	ºC	ºC	ºC	ºC	ºC	ºC	ºC
NO_3 Nitrate	µM	µM	µM	µM	mg.l^{-1}	µM	-	µM
Chlorophyll-a	mg.m^{-3}	mg.m^{-3}	mg.m^{-3}	mg.m^{-3}	mg.m^{-3}	mg.l^{-1}	mg.m^{-3}	mg.m^{-3}
Pigment Composition	µg.l^{-1} (2)	yes	-	starting in 2012	-	-	-	-
Secchi Disc	-	yes	yes	-	yes	-	yes	-
E_d (PAR, 0+) (3)	PRR-Biospherical	-	W. m^{-2}	µmolquanta . $m^{-2}s^{-1}$ (6)	-	-	-	-
E_0 (PAR, 0+) (4)	PRR-Biospherical	-	W. m^{-2}		-	-	-	-
Turbidity	-	-	-	-	NTU	-	-	-
Phytoplankton (5)	yes	Cells.ml^{-1}	yes	Cells.ml^{-1}	Cells.ml^{-1}	yes	-	-

(1) Sea Surface Tempetature. (2)Filters are sent to NASA to be analyzed by HPLC. (3) Downwelling solar irradiance. (4) Scalar solar irradiance. (5) Abundance and Composition. (6) PUV-Biospherical.

Irradiance measurements (surface and profile)**:** Irradiance (in the photosynthetically active part of the spectrum, PAR) incident at the sea surface (Io), as well as downwelling PAR in the water column ($I_d(z)$) will be measured using different radiometers. At some stations only Secchi disc measurements are available, which provide an indirect estimation of light penetration. The euphotic depth is considered as the depth at which irradiance equals 1% of Io.

Nutrients (nitrate): At first only surface nitrate concentrations are going to be used from the different stations. In most of them the measurements are performed using an autoanalyzer.

Phytoplankton composition by microscopy: Surface sea water samples will be fixed with neutralized formaldehyde solution and the cells will be identified and quantified by the sedimentation method (Edler & Elbrächter, 2010). The size of the main phytoplankton cells will be measured under the microscope to estimate the proportion of the different categories of '*Phy-Size*' (micro: > 20 μm; nano: 20-2 μm; pico: < 2 μm).

Phytoplankton composition by pigments: Pigments composition will be analyzed using the High Performance Liquid Chromatography (HPLC) technique following the method of (Van Heukelem & Thomas, 2001). Pigment indices (Vidussi et al., 2001), will be used to estimate the proportion of phytoplankton of different cell-sizes '*Phy-Size*' (micro: > 20 μm; nano: 20-2 μm; pico: < 2 μm).

Spatial resolution: The names and positions of the participating Antares time-series stations are given in Table 1 and are shown in Figure 1.

Temporal resolution: Data from the whole sampling period at each one of the time-series (starting from 1995 the oldest, and 2008 the youngest; see Table 1) will be used. Sampling is carried out at each institution by using their research vessels. The frequency of sampling at each station is also given in Table 1. Apart from the use of the historic dataset, new data collected during the period of the project will be included, and a strengthening of the sampling is proposed, incorporating some of the selected variables that are not regular measurements at all sites.

Satellite remote sensing data measurements

The project will continue to generate historical and near-real-time ocean products for region around the Antares stations from the MODIS-Aqua at 1 km spatial resolution.The use of information from other sensors, such as VIIRS (for which CONABIO already has the receiving antenna) is envisaged, as long as the data becomes available. The selection of variables is based on the relevance to assess changes in phytoplankton (biomass) and in the main environmental factors influencing phytoplankton. The following selected remote sensing products to be considered:

- **Sea Surface Temperature (SST)**; (Brown and Minnett 1999, Minnett et al. 2002).
- **Chlorophyll-*a* concentration (Chl-*a*)**; (O'Reilly et al. 2000).
- Light: **Photosynthetically Active Radiation (PAR)** (Frouin et al. 2003; Frouin and Murakami, 2007; Frouin and McPherson, 2012).

Apart from these main products relevant to assess changes in phytoplankton (biomass) and in the main environmental factors influencing phytoplankton, other products, which are complimentary for research, will be available (Total Suspended Matter concentration, Diffuse attenuation coefficient at 488nm, Phytoplankton chlorophyll Fluorescence emission Line Height, Colored Dissolved Organic Matter (CDOM)).

Some of these ocean products are already being processed by CONABIO. The idea is to work in generating new products and analysis of information, creating this capacity in INPE and CONABIO. An application will be developed that includes modules to extract observations from the satellite imagery including regional averages, transects, and time series. These remote sensing information will be used in the project to contribute to the analysis of variations in phytoplankton populations and oceanographic environment, and furtheromore for the modeling exercises and ultimately for the development of the indicators. On the other hand, this satellite information will be freely available in the Antares webpage for other communal uses. Products and applications will be accessible through portable devices and social media.

Altimeter **Sea Surface Height (SSH)**, will be used as ancillary satellite information in this project. SSH obtained by satellite radar altimetry is used to compute surface geostrophic velocities, and hence contributes to estimate ocean circulation and to assess climate change (e.g. Fu and Cazenave, 2001). However, data in the coastal zone are traditionally flagged as bad and left unused. In recent years, it has been shown that those coastal data can be successfully recovered and that coastal altimetry can be a legitimate component of coastal observing systems (Cipollini et al., 2012). Altimetry data sets are being produced by different centres (CTOH, PISTACH, COASTALT) using different corrections and re-tracking procedures to recover data close to the coast. Recent studies have shown that SSH at seasonal scales captures very accurately the coastal upwelling/downwelling wind-driven regimes in coastal areas of the Atlantic and Indian oceans (e.g. Saraceno et al, 2011, 2012; Strub et al, 2012). Here we propose to evaluate these products at the Antares stations to help understanding the environmental conditions for phytoplankton.

Modeling

Local: As a starting point, to set the appropriate approach, this modeling effort will be aimed at contributing to identify ecosystem indices at the EPEA station. This will be linked in a near future to an effort to develop a biogeochemical model for the Patagonian shelf in the framework of the Regional Ocean Modeling System (ROMS). We will use a 1D configuration of this model to examine the biophysical processes underlying productivity in the Argentinean coastal site EPEA. ROMS is a community-based model designed for regional applications (Shchepetkin and McWilliams, 2005). In addition, it provides the possibility to choose among several ecosystem schemes (NPZD models). The number of variables in the biological model (nutrients, different classes of phytoplankton and zooplankton, detritus pools) will have to be chosen to capture the main ecosystem dynamics of the biogeochemical domain. One-dimensional models have proven to be useful to identify the relative importance of physical and biological processes in regulating temporal variability in chlorophyll and phytoplankton biomass, at a low computational cost (Denman et al., 2006; Ji et al., 2006). The 12-years multi-parameter time-series available at EPEA makes this location unique in the southwestern American continental shelf to calibrate and validate the model. The biogeochemical model outputs will then be analyzed in conjunction with remote sensing data and relevant fisheries database available at INIDEP (Instituto Nacional de Investigación y Desarrollo Pesquero) to identify ecosystem indices. It is envisaged that based on this first study a similar approach could be developed for the other Antares stations.

Large-scale: Three-dimensional simulations using a coupled physical/biogeochemical ocean model will complement the local one-dimensional modeling effort. The ORCA2/LIM3/PISCES configuration of the Nucleus for European Modeling of the Ocean (NEMO, http://www.nemo-ocean.eu/About-NEMO) will be used. This global circulation model will be nested around Latin America to examine the local/regional ocean response to atmospheric phenomena in the context of the broader, basin-scale circulation. After spin-up from rest, the model will be integrated using the NCEP reanalysis data set, and the output for the last 50 years will be analyzed. Emission scenario experiments will also be performed to investigate the impact of future climate change. The focus will be on nano-phytoplankton, diatoms, and micro- and meso-zooplankton abundances, primary production rates, δPCO_2, and alkalinity. Seasonal and inter-annual variability in these predicted variables will be documented and contrasted for the ANTARES regions, analyzed as a function of various factors (e.g., mixed layer depth, nutrients, solar irradiance, horizontal advection), and related to climate change indices (Southern Oscillation Index, Southern Annular Mode Index, etc.).

EXPECTED RESULTS

(i) Strengthen the regional database on natural state and trends in oceanographic variables and phytoplankton populations and ES, with data from the participating Antares sites (Argentina, Brazil, Colombia, Chile, Ecuador, Mexico, Peru, Venezuela).

(ii) Gain a richer (socioecological) vision of vulnerability and develop more concrete indicators of the role of phytoplankton in ocean health and the socioeconomic system (through markets, support services for humans and biodiversity and ecological services).

(iii) Develop innovative approaches to assess and inform/communicate the key role of ocean services in some environmental problems could be provided, e.g. measuring greenhouse gas (GHG) emissions uptake and nutrient cycling (indicators/variables, case studies, scenarios, modeling)..

(iv) Develop and test concrete indicators of "ocean health" encompassing the whole socioecological system and projecting trends and future scenarios.

(v) Facilitate capacity building, dissemination and teaching on the project results and outputs, via the provision of:
- literature surveys on ecological services, and socioecological indicators of "ocean health" illustrating the role of phytoplankton services
- a methodological document gathering the experience of the project's multidisciplinary approach to assess socioecological vulnerability, conduct integrated assessments and lessons.

Without segmentation of data from different ecoregions from the outset, a wider perspective could be gained. Hotspots could be identified on the basis of different indicators regardless of their location, which allows for evaluating the regional scale of certain concerns, which may prove local, regional, national or transboundary. The varying geographic scale of different concerns (e.g. temperature increase, biodiversity loss) may be an important contribution from the project, for a subsequent discussion and analysis of governance and political recommendations.

The Antares web page will disseminate project results:
-Documents and briefs on the economic valuation of phytoplankton services.
-Documents and briefs on results form the biogeochemical modeling exercises as well as estimations of the ecosystem services indicators.
-Documents and briefs with the results of the national/international workshops with decisionmakers.

Regarding the expected results of possible trends in phytoplankton populations and environmental changes at the different Antares stations, a preliminary analysis (Santamaria del Angel et al., 2010) which took into account only some of the stations, showed that each of the analyzed sites is located in a different biogeochemical domain, and that some of the sites such as Cartagena, Ubatuba and EPEA show a trend of increase in satellite SST; while Ensenada showed an apparent increase in satellite chlorophyll. The overall match-up between *in situ* and MODIS chlorophyll concentrations (for all stations) had a high Pearson correlation of 0.76. A thorough match-up and trend analysis including all the Antares stations will be performed.

There is no precedent of integrating at a regional scale in Latin-America long-term information on phytoplankton and oceanographic data, and even more to provide this information in the context of its relevance to society. Since this study is based on a co-construction approach, we understand that some adjustments will be necessary during the implementation of the project.

POLICY RELEVANCE

The project will generate many policy relevant outputs and processes aimed at two main goals. Firstly, to raise awareness on the fact that guaranteeing a healthy oceanographic environment for phytoplankton is relevant to society (and where the relevant links lie). Secondly, to apply multidisciplinary methods to assess and communicate which are the ongoing trends in phytoplankton populations and their impact on the socioeconomic system (how climate change and local factors will have repercussions in the oceanographic environment and affect phytoplankton populations and their ecosystem services, thus affecting the food web and fisheries, CO_2 uptake and nutrient cycling). These types of 'life support' services are mostly taken for granted, but they are at the base supporting most other 'market valued' ecosystem products and services, so slight and slow changes in them may dramatically impact all services to human society.

Apart from gathering and making available all the data and derived information in the Antares network webpage, a special effort will be made to create a communication and dialogue channel with different levels of governmental agencies and other stakeholders, on the basis of the ongoing participation of many CoPIs in existing national and international networks (e.g. related to climate change strategies in Argentina, biodiversity challenges in Brazil, Blue Planet at international level with participation of many CoPIs). This will allow the project to incorporate policy relevant questions as well as create a space to convey to decision makers the importance to investigate the fundamental processes in the ocean which support other products and services and to understand and illustrate this importance with concrete data, assessments and case studies.

MULTIDISCIPLINARY AND MULTINATIONAL COLLABORATION

The level of collaboration among the different marine research institutions in Latin America is rather low, but among the Antares network has been an attempt to increase this level of collaboration among institutions that are already doing time-series observations. This proposal considers improving this level of collaboration by reinforcing the link already in existence between scientists from 9 countries (Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Mexico, Venezuela and USA) and promoting the exchange of information and expertise. The Antares network fostered by the IOCCG, POGO and the Nippon Foundation (http://dels-old.nas.edu/oceans/casestudies/antares_network.shtml) is already an established network with a website (http://www.antares.ws), and some of the time-series stations are already sharing current observations through different websites (http://imars.usf.edu/CAR/index.html; http://ocb.whoi.edu/index.html; http://cariaco.ws), evenmore, Antares has become the Latin-American branch of the 'Chlorophyll Globally Integrated Network'. One of the goals of this network is to promote improved collection, compatibility and management of the time-series observations and integrate these measurements for the understanding of ecosystem state in a way that can be useful for policy makers, ecosystem managers and society at large. The integration of these marine institutions in the common goals of this proposal would expand their local activities to a regional basis.

A first, and non-precedent, step will be made to link Natural Science information and results on phytoplankton ES with Socioeconomic Analysis. To this end a team including researchers (three CoPIs and three collaborators) with background in Sociology, Economics, Environmental Management and Anthropology, two CoPIs (a Biologist and an Environmental Engineer) experts in Ecosystem Services and Environmental Management and at least five students assisstants (mostly graduate students and including at least one post-doc), will be incorporated to carry out a socio-economic component from the beginning of the project. A collaborator with background in Anthropology will also collaborate with perception analysis and co-construction and a graduate student working in Economics and Climate Policies will help with the strategy of communication with stakeholders. It is expected that throughout the frequent communication via workshops and other media (mail, skype and telecoms) a strong interaction and mutual learning will be generated between the natural and social components. It is also expected that the interdisciplinary approach will be reflected in the outputs of the Project (as reflected in the expected products in Fig.3).

CONTRIBUTION OF EACH CO-PI

The Co-PIs, who are the principal investigators at each of the Antares stations: Kampel M. (Co-PI Ubatuba), Santamaria E. (Ensenada), Escribano R. (Concepción), Negri R. (EPEA), Lutz V. (Co-PI EPEA), Escudero L. (IMARPE), Ledesma J. (Co-PI IMARPE), Astor Y. (CARIACO), Cañon M.L. (Cartagena), Tous G. (Cartagena), Tapia M. (Libertad, Manta), Naranjo C. (Co-PI Libertad, Manta) will be responsible of the in situ component being carried out at their respective time-series.

The Co-PIs and collaborators who are experts in remote sensing: Cerdeira S., Kampel M., Santamaria E., Dogliotti A., Saraceno M., Palastanga V., Frouin, R., will be in charge of the satellite component.

The Co-PIs and collaborators who are experts in modeling: Frouin R., Saraceno M., Palastanga V., will be in charge of the modeling component.

The Co-PI expert in Socioeconomic analysis of environmental issues and collaborator expert in environmental economics: Chidiak, M.G. and Carciofi, I. will lead the socioeconomic team in Argentina with the assistance of four research assistants (graduate students) and a collaborator with training in Anthropology and Environmental Management will help with the perception analysis and co-construction to be developed in the workshops with decisionmakers.

The Co-PIs and collaborator experts in ecosystem services, ocean governance, ecological economics and environmental economics, respectively, Turra, A., Jacobi, P., Sinisgalli, P., Chidiak, M., and Carciofi I., will lead the integrated component of ecosystem services and socioeconomics with the interaction of all Natural Science Co-PIs.

The Co-PIs and collaborators experts in pigments: Millan-Nuñez R. and Rodrigues, S.V., will be in charged of the pigment analysis and interpretation of data (pigment indices).

An extended list of Collaborators are essential for the development of this proposal (see attached list); among them Drs. Shubha Sathyendranath and Trevor Platt, promoters of Antares, ChloroGIN, as well as international organizations (e.g., POGO, IOCCG), are going to participate as advisors.

CAPACITY BUILDING

Capacity building has been an important component of the Antares network, since the training of young students and researchers in the field of oceanography is pertinent everywhere, and even more in developing countries. The share of expertise among members of the network, including advisors from Canada and USA has been manifested through two international training courses (see www.antares.ws/training) carried out in Brazil 2006 and 2009. Three workshops were also held (http://www.antares.ws/?p=workshop.html) including the foundational one in Argentina (2003), a second one in Venezuela (2005), and a third one in UK (2006) which gave as an outcome the formation of the ChloroGIN network, as well as an intercalibration exercise on the method to measure chlorophyll-a by fluorometry (http://www.antares.ws/?p=Publications.html). Several publications and thesis work were carried out at each of the time-series (http://www.antares.ws/?p=Publications.html).

In this project we expect to strengthen the interaction among all participants. At least three workshops are foreseen, including a first organizational one in the first quarter after initiation of the project. At least one training course (attached to a WS, and seeking complementary funds) will be organized. Especial attention will be put in making a link between natural and social sciences. The idea will be to make a dedicated multidisciplinary training course where students from the different disciplines (natural and social fields) will be stimulated to interact in developing common 'study cases'.

Policy makers are going to be individualized and contacted through the socio-economic and ecosystem services components, and a series of meetings to explain the importance and outcomes of the project will be planned after the third year. Outreach will include the dissemination of the on-going results through an educative section to be developed in the Antares webpage. Open public seminars are going to be organized at each of the major cities close to the Antares sites, as well as especial classes offered at local public schools.

RELATED WORK

The Antares network has been since its inception related to international programs, since it was first fostered by the 'International Ocean-Colour Coordinating Group (IOCCG)' (http://www.ioccg.org) and the 'Partnership for the Observation of the Global Oceans (POGO)' (http://ocean-partners.org). It was sponsored for two training courses by the Nippon Foundation (http://www.nippon-foundation.or.jp/en/) and POGO, and it is at the moment part of a project of the 'NF-POGO Alumni Network for Oceans (NANO)' for Latin-America (http://www.nf-pogo-alumni.org/Latin+American+Regional+Project). It served as a seed for the creation of a global network 'Chlorophyll Globally Integrated Network (ChloroGIN)' (http://www.chlorogin.org). Antares as the Latin-American branch of ChloroGIN is part of the 'Group of Earth Observation (GEO)' task SB-01 'Oceans and Society: Blue Planet' (http://www.earthobservations.org/geoss_imp.php). Therefore, the results obtained throughout this project will be made available to these programs. Furthermore, it is envisaged a connection of this project to the 'Integrated Marine Biogeochemistry and Ecosystem research (IMBER)' (http://www.imber.info) and to the 'International Human Dimensions Programme on Global Environmental Change (IHDP)' (http://www.ihdp.unu.edu).

WORK PLAN AND TIMETABLE

During the first six months of the project a workshop or Co-PI meeting will be organized in order to discuss and agree on the full workplan and organizational details for the project.

The project envisages many workshop activities, aimed at interaction among Co-PIs as well as at networking and interaction with decision-makers aiming at co-construction of key policy questions and information gaps, and the discussion of science results and their implications.

As to data management and coordination efforts, a student, from the field of informatics, will be hired part-time to work as data-manager to organize the format of the local databases, advising the person in charge at each station, and making them intercompatible and linked within the Antares webpage. Two other part-time students will help coordinating networking activities and workshops, frequent skype and telecoms meetings among Co-PIs, and at least one training course.

Work plan

In what follows, the activities are presented in relation to each specific objective of the project.

Natural Science Component

The detailed project activities aimed at specific objective 1 are included in the following list:

1.Data collection and dataset organization

In situ activities to be performed at each of the time-series-stations for the whole sampling period (historical and new data):

1.1 The selected data sets (first historical) will be organized in a standardized format database.
1.2 Sampling and data analyses will be carried on at all Antares stations.
1.3 Phytoplankton composition, using microscopic information, will be categorized by size-classes '*Phy-Size*' (micro > 20 μm; nano 2 – 20 μm; pico < 2 μm).
1.4 In the case of stations where pigments composition, but not microscopic data, is available, pigment indices will be computed to infer '*Phy-Size*'.
1.5 In the case of stations where pigments composition in conjunction with phytoplankton structure by microscopy are available, a validation of *Phy-Size* results provided by pigment indices will be performed, to estimate the error in assigning size-classes by pigments.
1.6 The mixed layer depth (Zm) will be computed from temperature profiles.
1.7 The euphotic depth (Ze) will be computed from the downwelling PAR profile.
1.8 A description of the variability, annual and inter-annual, will be performed for the following properties: SST, Chla, Io, NO_3, Zm, Ze, *Phy-Size*.
1.9 Statistical analyses of inter-annual anomalies and main trends of change of these properties will be performed. *[These results will also be interpreted in light of the remote sensing analyses 2.4]

2. Satellite remote sensing analyses to be performed for areas surrounding the time-series-stations:

2.1 Re-establishment and improvement of the remote sensing data processing and distribution system which was in place since October 2004 from now on for all Antares sites. This will incorporate in a systematic way new data from MODIS-Aqua for sea surface temperature, chlorophyll-a concentration, and photosynthetically active radiation; as well as other products (total suspended matter concentration, diffuse attenuation coefficient, phytoplankton chlorophyll fluorescence emission line height, colored dissolved organic matter index).
2.2 Development of a system to offer elaborated remote sensing information such as time series from a given point, or transects between two points; in a user friendly way to retrieve.
2.3 A validation of satellite SST, Chla and PAR with the matching *in situ* data from the constructed database from all stations (activity 1.1) will be performed.

2.4 Statistical analyses to investigate inter-annual anomalies and main trends of change in the studied remote sensing data will be carried out. *[These results will also be interpreted in light of the in situ analyses 1.9]

3. Modeling

3.1 Possible connections of the main oceanographic conditions at the local selected sites with the main ocean basins and ocean-atmospheric phenomena at local and large scale (e.g., wind-driven upwelling/downwelling) will be investigated. SSH will be used to explore relationships with other variables and investigate wind-driven upwelling and downwelling conditions.

3.2 To set the initial and boundary conditions of the biogeochemical model at Antares station EPEA, we will use a 1D configuration of ROMS including only physical processes. The model outputs will be compared with the hydrographic (T, S) *in situ* data in this region.

3.3 To start a simple biogeochemical module with Nitrogen as limiting factor will be used. The multi parameter time series at station EPEA will be used to select the ecosystem model parameters. The possibility of adding additional nutrients (Si) and more complex biogeochemical processes to the biogeochemical module will be evaluated.

3.4 Numerical experiments with a regional physical-biological model that encompasses the offshore sides contiguous to the coastal ANTARES sites will be performed. The connections between local/regional biological variability and physical variables, including basin-scale phenomena will be investigated.

3.5 A global ocean circulation model around Latin America will be nested; and model simulations will be run to characterize bio-physical variability during the last 50 years in the ANTARES regions.

3.6 Links with climate change indices (SOI, SAMI, PDO, AMO, etc.) will be examined; and model-predicted ecosystem response and feedbacks to future IPCC emission scenarios will be analyzed.

4. Ecosystem Services and Socioeconomic Analysis: Activities to be undertaken in the framework of each specific objective

As seen in Fig.3 the main activities to be developed in relation to each specific objective are:

4.1 Objective 2: Integrate the data base of in situ and satellite information, analyze trends in the natural variables and apply biogeochemical models at regional and local levels.

4.2 Objective 3: Identify the role of phytoplankton ecosystem services through synthesis of existing data and literature and develop new analysis to identify the effects of global and local drivers on phytoplankton ecosystem services.

4.3 Objective 4:

a- Survey of data on key socioeconomic variables and drivers in order to define a general picture of state and trends.

b- Integrate the natural and socioeconomic information in order to screen/discuss (co-construct) with decision-makers.

c-Organize a workshop with stakeholders (WS 3) to

- Understand actors (end users and decision-makers) perception of the socioeconomic impacts of phytoplankton ecosystem services trends
- Co-construction of key questions and information needs

d-Organize a workshop with stakeholders (WS4, part I) to

- Present initial picture of trends of socioeconomic and natural data on phytoplankton ES
- Define case studies and indicators of interest
- Discuss communication strategy and plan

e-Organize an internal workshop (WS4, Part- II) to:

- Agree on common work-plan
- Define details of methodology (case studies and indicators/variables)

f-Conduct case studies (fisheries/nutrient cycling/carbon fixation, specifics to be defined) elaborate results and draft papers.
g-Develop socioecological vulnerability indicators and results.
h-Build scenarios on the basis of projection/modeling
i-Organize a workshop (WS5) with stakeholders aiming at:

- Presentation and discussion of indicator/case study/scenario results
- Elaboration of policy and research recommendations
- Start with communication strategy and plan

j-Preparation and edit briefs and methodological report
k-Edition of final documents /submission of papers

TIMETABLE

As described in Fig.3, the project activities have been organized in 4 phases.

- **Phase 0** (pre project) was dedicated to redefining the proposal in its current form (which was possible thanks to the organization of a discussion workshop in Buenos Aires: WS1).
- The initiation of **Phase 1** (focus: setting scientific background, data gathering and defining policy relevant questions, with a duration of 1.5 yr) will be marked by an organizational meeting (WS2 in month 1 or during the first quarter of year 1) to adjust activities and project time-line. This phase will also include another workshop (WS3 in the third quarter of year 1) to establish dialogue with decisionmakers and to refine the relevant questions with a co-construction approach. This phase will produce the literature surveys on ES, a mapping of Ocean Governance as well as the basic data for Natural Science and Socioeconomic and ES analysis, and basic results from analysis of socioeconomic variables and trends and natural trends in phytoplankton ES in the region.
- **Phase 2** (focus: critical review and analysis, with a duration of 2 years) will also start with a workshop (WS4) to present preliminary results from the project on vulnerability analysis to decisionmakers and to define relevant case studies and to discuss implications and communication strategies. WS4 will comprise two parts: Part I (with stakeholders) and Part II (internal) to refine methodology and agree on the details of variables/indicators to assess ocean health (phytoplankton ES), case studies (ES, valuation, and implications for fisheries/artisanal fishing) and integrated natural and socioeconomic analysis and scenario analysis. On this basis, case studies on ES and fisheries as well as integrated assessment of ES from a natural and socioeconomic perspective and projected scenarios will be developed. The results include papers and documents on methodology, case studies, scenario analysis and draft paper on indicators/variables of ocean health.
- **Phase 3** (focus: synthesis and communication, with a duration of 0.5 year) will start with a validation workshop (WS5 by mid third year) where the results from case studies, indicators/variables of ocean health (phytoplankton ES), integrated assessment of ES and scenario analysis will be presented and discussed with stakeholders. This workshop will also aim at developing the policy implications of the scientific results. Phase 3 will produce a methodological document from the project, a paper on socioecological vulnerability results, a paper on ecosystem health indicators/variables focused on phytoplankton.

Frequent interaction among PI and Co-PIs is expected through scheduled Skype meetings (at least 1 every 2 months). Data managing, mantainance and development of the Antares webpage will be carried out throughout the project. Efforts of dissemination of the results of the project and creation of links with international programs will involve all participants in the whole period of the project.

A reasonable a priori schedule of specific activities follows:

- Activity 1.1 will be accomplished by the first half of the second year; though the data-base will be continue to be fed with new data throughout the project. Activities 1.2 to 1.7 will continue throughout (i.e., maintenance of time-series). Activities 1.8 and 1.9 will be accomplished by the beginning of the third year.
- Activities 2.1 and 2.2 will be accomplished by the beginning of the second year, and will keep functioning throughout. Activities 2.3 and 2.4 will be accomplished at the beginning of the third year.
- Activity 3.1 will be accomplished by the beginning of the third year. Activities 3.2 and 3.3 will be accomplished by the second semester of the third year. Activity 3.4 will take place throughout the first three years; while activities 3.5 and 3.6 will take place mainly in year 4.
- Activities 4.1 and 4.2 will be carried out mostly during Phase 1, although some results from activities in 4.2 will be available during Phase 2. Activities in 4.3 a,b,c will take place during Phase 1 (by year 1,5)., Activities 4.3d-h will be carried out in Phase 2. Activities in 4.3 i-k will be carried out in the final year (Phase 3).

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