



Need for monitoring and maintaining sustainable marine ecosystem services

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Increases in human population and their resource use have drastically intensified pressures on marine ecosystem services. The oceans have partly managed to buffer these multiple pressures, but every single area of the oceans is now affected to some degree by human activities. Chemical properties, biogeochemical cycles and food-webs have been altered with consequences for all marine living organisms. Knowledge on these pressures and associated responses mainly originate from analyses of a few long-term monitoring time series as well as spatially scattered data from various sources. Although the interpretation of these data can be improved by models, there is still a fundamental lack of information and knowledge if scientists are to predict more accurately the effects of human activities. Scientists provide expert advices to society about marine system governance, but such advices should rest on a solid base of observations. Nevertheless, many monitoring programs around the world are currently facing financial reduction. Marine ecosystem services are already overexploited in some areas and sustainable use of these services can only be devised on a solid scientific basis, which requires more observations than presently available.

Keywords: biodiversity, ecosystem trends, eutrophication, food-webs, global change, ocean acidification, ocean governance, overfishing

INTRODUCTION

The last 10,000 years, known as the Holocene, have been a relatively stable period in earth's climate history (Petit et al., 1999), but recently human activities have become the main driver of environmental change at the local as well as global scale (Rockström et al., 2009). Humans have significantly altered the biogeochemical cycles on earth (Vitousek et al., 1997); something thought impossible just a few decades ago. Burning of fossil fuels, deforestation, mining, and other activities have increased the concentration of CO₂ in the atmosphere and ocean, elevating the greenhouse effect with rising temperatures as consequence. So far, the oceans have managed to store three times as much heat as the atmosphere (Levitus et al., 2001) and absorb about one third of the human-induced CO₂ emitted into the atmosphere (Steffen et al., 2007). However, recent studies suggest that the ocean's buffer capacity might decrease with further warming (Gruber et al., 2004).

Industrial nitrogen fixation and phosphate mining as well as fossil fuel burning have mobilized nitrogen and phosphorus (Vitousek et al., 1997). Humans have almost doubled the supply of nitrogen from the atmosphere to land, leading to an increased release of the greenhouse gas N₂O (Gruber and Galloway, 2008). Phosphate demands for agriculture have increased phosphorus inputs to the biosphere by factor of almost four (Falkowski et al., 2000). Nutrients applied to land as fertilizers are partly lost to the aquatic environment, eventually the ocean, where they stimulate production of organic matter, a process known as eutrophication (Nixon, 1995). One of the most deleterious effects of

eutrophication is the development of hypoxia (Carstensen et al., 2014), having strong ramifications on nutrient biogeochemical processes (Diaz and Rosenberg, 2008; Conley et al., 2009).

Human demand on fish has significantly reduced populations of marine top predators (Pauly et al., 1998), altering the flow of energy through food-webs and eventually leading to ecosystem collapses (Jackson et al., 2001). Fisheries landings have increased by more than 50% from 1970 to 2005 (Duarte et al., 2009) and the number of unsustainable fisheries is growing (Vitousek et al., 1997). In addition to reducing the overall population of marine top predators, overfishing has also selected toward smaller populations by removing the largest individuals (Jackson et al., 2001). It is possible that overfishing may exacerbate effects of eutrophication through trophic cascades, disrupting the normal flow of energy through marine food-webs (Scheffer et al., 2005). Another facet of altered energy flows is the global loss of biodiversity caused by overfishing, pollution, and habitat destruction reducing ocean ecosystem services (Worm et al., 2006).

Human pressures on marine ecosystems have increased recently to an extent where every area of the oceans is affected to some degree, although the human footprint is largest in the coastal zones with a high population density (Halpern et al., 2008). The multiple pressures of human activities have eroded the capacity of marine ecosystems to provide services benefiting humans. The oceans no longer constitute an infinite reservoir of natural resources that humans can exploit unconcerned. Therefore, science has an important role in identifying problems as well as their solutions, and conveying this knowledge

broadly to the public and particularly, decision makers (Levin et al., 2009).

ASSESSING HUMAN IMPACTS ON MARINE ECOSYSTEMS

Our knowledge on human impacts on marine ecosystems has mainly been driven by observations supported by models for extrapolation. However, there is a significant lack of data on human pressures and marine effects, particularly in the open ocean. Data are often scattered in time and space, because they mostly arise from various research cruises and ships-of-opportunity; uncoordinated activities not aimed at assessing changes over time. Therefore, models are needed to integrate these data (e.g., Boyce et al., 2010; Halpern et al., 2012), but for many components of ocean health such models do not exist or they are so coarse that the reliability of the output may be disputable (Mackas, 2010; McQuatters-Gollop et al., 2010; Rykaczewski and Dunne, 2011).

Remote sensing data from satellites overcome the problem of spatial and temporal sampling heterogeneity and can be used for assessing changes in sea surface temperature and ocean color from which proxies for phytoplankton biomass and productivity can be derived (Behrenfeld et al., 2006), but they also have their limitations. Remote sensing applies to the upper surface layer only, and satellites cannot assess processes taking place at deeper depths. Algorithms for processing remote sensing data have mainly been developed for the open ocean, and the algorithms produce biases in shallower coastal waters. The proxy information obtained from satellite imagery provides only a small fraction of information needed to assess human impact on marine ecosystems.

Autonomous sensors typically placed on fixed buoys or floatable undulating devices such as Argo floats complement remote sensing by providing subsurface information on salinity, temperature, oxygen, and bio-optical properties (Roemmich et al., 2009). For instance, Argo float data with the support of global climate models revealed that the deep ocean (>300 m) was taking up more heat during the recent surface-temperature hiatus period (Meehl et al., 2011). At present, only the most basic physical-chemical variables are measured using these autonomous devices, since other measurements of interest (e.g., nutrient concentrations) typically require more regular maintenance, increasing the operating costs substantially.

Monitoring programs providing more consistent time series across a wide range of different physical, chemical and biological variables are found in certain coastal areas, e.g., the Chesapeake Bay and the Baltic Sea. These were typically initiated in the 1970s and 1980s, when pollution effects became clearly visible, to assess the efficiency of management actions to alleviate human pressure on overstressed marine ecosystems (Carstensen et al., 2006). In addition to assessing physical-chemical status, different organism groups from phytoplankton to top predators in the marine ecosystems were monitored. These monitoring programs have contributed substantially to our present understanding of trophic interactions in coastal areas and the disturbance of these imposed by human activities.

Understanding of long-term variations in ocean waters has so far been based on a few observatories, some of these organized

within the Long Term Ecological Research (LTER) Network (www.lternet.edu). Long-term decreases in pH and aragonite saturation from the Hawaiian Ocean Time-series (HOT) and Bermuda Atlantic Time Series (BATS) have highlighted another problem associated with increased emission of CO₂, namely ocean acidification (Doney et al., 2009), which may alter ocean biogeochemistry (Beman et al., 2011). Long-term time series in coastal waters have revealed that pH is governed by changes in inputs from land rather than CO₂ in the atmosphere (Duarte et al., 2013). The Continuous Plankton Recorder (CPR) survey has been in operation since 1931 and has provided valuable insights into how climate oscillations affect plankton communities (Edwards et al., 2009). Since 1949 the California Cooperative Oceanic Fisheries Investigations (CalFOCI) program has investigated distributions of phytoplankton, zooplankton and fish distributions off Southern California and showed how changes in the Pacific Decadal Oscillation (PDO) can precipitate sudden shifts in these distributions (McGowan et al., 2003). Nevertheless, despite the value of these unique time series there is a need to establish and maintain ocean time series of high research quality, particularly in subtropical and tropical waters that are severely understudied at present.

DIRECTIONS FOR THE FUTURE

“We know more about the surface of the Moon and about Mars than we do about the deep sea floor, despite the fact that we have yet to extract a gram of food, a breath of oxygen or a drop of water from those bodies.” This statement by Dr. Paul Snelgrove clearly articulates the need for improving our understanding of how marine ecosystems function, particularly as they provide essential ecosystem services to humans and because expanding human activities are putting these services under threat.

Our current understanding of marine ecosystem responses to human activities is limited by the availability of data, particularly long-term time series of physical and chemical conditions as well as biological properties. Moreover, efforts should be made to improve the accessibility and comparability of existing time series. Further development of models integrating monitoring data is needed to better assess changes over time and predict future trends, but models cannot stand alone without data. The lack of data is partly technical, as current measurement techniques may not necessarily provide the needed information, and partly financial, as costs of ocean sampling are indeed excessively expensive. Technological developments are expected to contribute more accurate, precise and cost-effective measurements over time. However, many marine monitoring programs are facing budget reductions, which have led to discontinuation of monitoring stations and abandoning sampling of biological components as well as decreasing monitoring frequencies. A possible consequence is loss of invested capital for establishing such long-term time series, simply because their value has to be written down. There is a growing discrepancy between the need for better understanding of human impact on marine ecosystems and the basis for addressing these scientific questions.

Ducklow et al. (2009) have identified seven key elements that will help science address critical issues on marine ecosystem

services in times when human pressures on these are intensifying: (1) maintain existing monitoring programs and expand these with additional biological components, (2) establish new monitoring programs in under-sampled regions, (3) increase the use of remote sensing and autonomous monitoring devices, (4) establish targeted research program (process studies) in connection to long-term monitoring sites, (5) improve the integration of monitoring activities with ships-of-opportunity, (6) modify current funding for ecological research to balance consistent long-term research and short-term targeted studies, and (7) improve data access and synthesis using models. If these are recommendations are pursued we may eventually know more about our oceans than the surface of the Moon and Mars. The growing human imprint on marine ecosystems may, if left unmonitored and unattended, result in significant losses of ecosystem services that are crucial to support a globally growing population.

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