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Pacific Ocean observation programs: Gaps in ecological time series

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ABSTRACT

How well do existing ocean observation programs monitor the oceans through space and time? A meta-analysis of ocean observation programs in the Pacific Ocean was carried out to determine where and how key parameters defining the physics, chemistry, and biology of the oceans were measured. The analysis indicates that although the chemistry and physics of the Pacific Ocean are reasonably well monitored, ecological monitoring remains largely ad hoc, patchy, unsystematic, and inconsistent. The California Cooperative Oceanic Fisheries Investigations (CalCOFI), for example, is the only Pacific Ocean program in which the zooplankton and micronekton are resolved to species with consistent time series of greater than 20 years duration. Several studies now indicate massive changes to nearshore, mesopelagic and other fish communities of the southern California Current but available time series do not allow these potential changes to be examined more widely. Firm commitment from the global community to sustained, representative, quantitative marine observations at the species level is required to adequately assess the ecological status of the oceans.

1. Introduction

Bishop Berkeley is reputed to have asked, “If a tree falls in the forest and there is no one around to hear it, did it make a sound?” However, if a fallen tree is encountered in the forest, one can be confident that once it stood upright and even surmise from where it fell. Photographs of a forest taken from the same vantage years apart allow growth, death and other forms of change in the forest to be evaluated, even without observations of each tree fall.

Observing and understanding change in the ocean present greater challenges. How is it known if a species declines or increases? Sub-surface ecological observations remain difficult and costly and therefore relatively scarce. Isolated observations or “snapshots” of local conditions, unlike photographs of the forest, often prove to be of little value in assessing change, because the ocean is a dynamic environment. The abundance of its ever-shifting, patchily-distributed populations may vary daily, seasonally, inter-annually, and from decade to decade in relation to naturally varying conditions, as well as in response to human influences. Isolated observations may therefore be aliased and of little value in evaluating change. The consistent systematic time series of observations that are required to evaluate change across this range of time scales and to distinguish natural variability from secular climate change must be maintained for a very long time, well beyond the time scale of any single government's tenure in office or scientist's career: a very long time, indeed, on the human scale. It is no wonder that such time series are scarce.

Despite the inherent difficulties of achieving long-term ocean time series, they are nonetheless essential, given that the oceans are not at equilibrium, as once believed, but rather continuously varying in response to a poorly-understood array of natural and anthropogenic pressures. Multi-decadal ocean time series are a *sine qua non* to distinguish natural variability from secular trends induced by climate change and other anthropogenic stressors. Ocean time series are therefore also fundamental to effective ocean management, since without these, the need for management may be missed and the effectiveness of management measures, such as instituting marine protected areas (MPAs), cannot be evaluated.

The United Nations (UN) is conducting its first World Ocean Assessment (WOA) to be completed in 2014, a process intended to parallel the periodic reporting of the UN Intergovernmental Panel on Climate Change. The need for a periodic WOA is clear, given the large number of anthropogenic stressors to which the ocean environment is subjected: overfishing, the impacts of marine industries from fishing and mariculture to mining and energy development, eutrophication due to nutrient runoff, pollution, invasive species, coastal development, warming, acidification, and deoxygenation. The impacts of these stressors are generally poorly understood in isolation from each other, much less in concert with the potential for synergistic interactions. Without time series, it is impossible even to know that there is change in marine ecosystems. And because there are a number of more or

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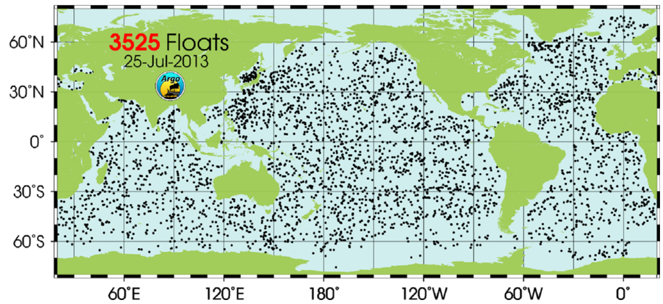

Fig. 1. The distribution of the 3525 Argo floats that currently profile the temperature and salinity of the world oceans from the surface to 2000 m depth. Source: Argo web-site, http://www.argo.ucsd.edu/.

less distinct biogeographic provinces or large marine ecosystems (LMEs) within the global ocean [41,30], a system of *representative*, consistently sampled ocean observation programs is required to achieve an effective global ocean assessment.

Recent decades have seen dramatic advances in observation systems for the physics and chemistry of the global ocean, with further improvements on the horizon, based on advances in sensor technology. Satellites now provide global coverage of sea surface temperature, altimetry, and chlorophyll *a* (chl), which is commonly used as an index for phytoplankton abundance. The Argo float program, operational since the early 2000s, today has approximately 3600 floats deployed to sample ocean temperature and salinity to 2000 m depth (Fig. 1). Dissolved oxygen measurements are currently being obtained from a limited number of floats, with plans to add sensors to measure chl, nutrients, and pH. The Argo program monitors the open ocean, and the physical state of the coastal ocean is monitored by the Global Ocean Observing System (GOOS) coastal program.

However, observing the physical state of the ocean is the low-hanging fruit. Measurements of temperature and salinity (and chl) are well-standardized and can be readily and consistently measured to a high level of precision. On the other hand, as a former GOOS director once observed, the critical lack of ecological ocean time series remains an "embarrassing gap" more than 25 years after GOOS was formed [2]. The only possible exception to this gloomy overview is fishery time series. Fishery statistics based on catch and effort have been maintained in parts of the world for on the order of 100 years. However, fishery statistics are generally limited to commercially-exploited species and are influenced by changes in market conditions, technological change, and the effects of over-exploitation itself; fishery-independent time series are generally more limited in duration as well as in the number of species and regions covered.

Several recent issues highlight the need for improved ecological time series for the ocean. These involve ecological groups – gelatinous zooplankton and midwater fishes – that are immensely important in pelagic ecosystems but that have been poorly monitored to date. As a result, potential changes in these groups remain controversial and uncertain, although these groups may be responding to anthropogenic influences and changes in these groups could have profound implications for global marine ecosystems.

The first issue is the uncertainty whether jellies are increasing globally in response to overfishing, eutrophication, and deoxygenation, particularly in degraded coastal ecosystems. Blooms of gelatinous plankton (jellyfishes and salps) have been widely observed in recent years, with implications for marine industries, including fisheries and power plants, and potentially signaling a regime shift in the structure of marine food webs (reviewed in Refs. [34,35,8,19]). However, lack of adequate time series has led a number of leading experts to conclude that it is not possible at present to distinguish natural cycles from a secular increase in their abundance [11]. Indeed, there are no existing quantitative time series in the Pacific Ocean for gelatinous zooplankton [11].

A second issue is the potential impact of deoxygenation on mesopelagic fishes in regions with oxygen minimum zones. Koslow et al. (2011) [25] reported a 63% decline in a broad assemblage of mesopelagic fishes in the California Current (CC), apparently linked to declining oxygen concentrations at midwater depths (200–400 m). Declining oxygen is now reported over much of the global ocean [20] apparently a consequence of global climate change, and global climate models predict continued deoxygenation of the deep ocean as increased warming and stratification of the upper mixed layer leads to decreased ventilation of the deep ocean [39,40]. Mesopelagic fishes are dominant zooplankton consumers in the global oceans; as such, they are key vectors for the transfer of energy to higher trophic levels and for the sequestration of carbon into the deep ocean [13,22]. A significant decline in their abundance could have profound consequences for global marine food webs and biogeochemistry. However, at this time there do not appear to be time series to examine changes in the midwater micronekton in other regions with well-developed oxygen minimum zones [24].

This study examines the availability of ecological time series for pelagic ecosystems in the Pacific Ocean based on a meta-analysis of ocean observation programs. The study concludes with a modest proposal to enhance ecological time series for the global ocean.

2. Methods

This study comprises a meta-analysis of sustained Pacific Ocean observation programs leading to ocean time series based on parameters measured consistently over time in the same geographic region. Short-term projects, surveys, cruises, and expeditions were therefore not considered. The analysis is also restricted to non-proprietary programs and data sets, so military or industrial data sets to which there is no public access were not considered, along with geological data sets (for example, seafloor mapping) that are not, properly speaking, time series observations. For each program, we noted the start and end dates of the program, geographic location (latitude and longitude) of routine data collection, sampling frequency, sampling months and the physical, chemical and biological variables measured, although the focus of the study is on biological observations and time series. Information was obtained from web sites and the scientific literature.

For each variable, sampling methodology and depth range of sampling were noted. Methodology included the oceanographic instrument used for collection at sea (including the net types and mesh sizes) and the method of analysis. For programs with biological time series, the taxonomic resolution or grouping was noted. For zooplankton samples in particular, there is a variety of methods for sample analysis: bulk biomass measurement (displacement volume, settled volume, or wet or dry mass), analysis to functional groups, or species-level enumeration. For surveys of fishes, sampling methods range from sampling with a variety of nets, ichthyoplankton sampling (sampling the fishes during the planktonic phase in their early life history), and acoustic-trawl surveys. The availability of long ($\geq$20 years) and short ($<$20 years) time series for zooplankton (both bulk biomass and species-level resolution) and micronekton were mapped using online mapping software, HamsterMap (http://www.hamstermap.com).

3. Results

Pacific Ocean biological observation programs were found in Australia, Canada, Chile, Japan, Korea, Russia, Mexico, Panama, Peru,