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Sustained Observation of Marine Biodiversity and Ecosystems

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At a time of unprecedented global change it is essential to distinguish short-term and local scale variability ("noise") from the low-amplitude longer wavelength signal of climate-driven change. Moreover, global responses to climate need to be separated from regional and local scale impacts and their interactions better understood to enable effective management of marine ecosystems. In this short editorial, we make the case for sustaining long-term and broad-scale observations of the oceans and coastal waters. First we consider the value of long-term observations drawing on work in the Western English Channel [1,2]; before considering the challenges of sustaining time series and cautioning that such observations are at risk in any period of financial constraints for public sector research funding. We conclude by discussing their relevance to policy and marine management. This editorial is written primarily from an ecological and inshore perspective reflecting the experience of the lead author but the general issues discussed apply equally to work in the open ocean.

Value of Long-Term and Broadside Observations

Empirical observations of the physics, chemistry and biology of the oceans and coastal seas have been made since the last quarter of the 19th Century, given impetus by the major oceanographic expeditions (e.g. *Porcupine* - 1868-1869, *Challenger* - 1872-1876, *Hirondelle I* and *II* - 1886-1922, *Princesse Alice I* and *II* - 1886-1922, *National* - 1889 and *Valdivia* - 1898-1899) as well as the establishment of a network of coastal Marine Stations such as those in France (*Station de Biologie Marine et Marinarium de Concarneau* - 1859, *Station Biologique de Roscoff* - 1872, *Observatoire Océanologique de Banyuls* - 1881, *Villefranche-sur-mer Oceanological Observatory* - 1882); Italy (at Naples, *Stazione Zoologica Anton Dohrn* - 1872); Sweden (*Kristineberg Marine Research Station* - 1877); Great Britain (*The Plymouth Laboratory of the Marine Biological Association* - 1888, *Port Erin Marine Laboratory* - 1892, *Marine Biological Station Millport* - 1894); USA (*Woods Hole Marine Biological Laboratory* - 1888) and Germany (*Biological Institute Helgoland* - 1892). The International Investigations of the early 1900s led by the International Council for the Exploration of the Seas (ICES) was an early and important attempt to integrate and network the efforts of multiple nations. In the UK the Marine Biological Association of the United Kingdom (MBA) led the work from its Laboratories at Lowestoft and Plymouth. The work in the English Channel initiated a long-running, but much interrupted time-series. Wars, funding cuts, institutional re-organisation and changes in research priorities all took their toll at various times over the last century.

The Plymouth time-series (initially led by the MBA until 1987, with additional parameters measured by Plymouth Marine Laboratory (PML) (1987-2007), consolidated as the Western Channel Observatory www.westernchannelobservatory.org.uk in 2007, has made some major contributions to marine science over the last 100 years. One of the strengths of the Western English Channel time-series is its comprehensive nature covering physical, chemical measurements and observations of various biological compartments (phytoplankton, zooplankton, fish, benthos, intertidal assemblages) [1-6] of the ecosystem and its grid nature with two to three main stations E1, L5, L4 [2] on an inshore-offshore axis with both stratified and mixed water bodies. Observations in the Western English Channel have shown how climate fluctuations can drive whole nearshore and coastal ecosystems [3,4,7-10]. These were apparent long before the recent spell of rapid warming since the late 1980s [1,2] and were coined "the Russell Cycle" by Cushing and Dickson [11]. Thus they provide a true fluctuating baseline of colder (early part of 20th Century, 1962-1987) and warmer (1930s to 1960) periods against which to judge subsequent rapid climate-driven change since the late 1980s. Recent examination of the long-term data suggests that the Russell Cycle may reflect the Atlantic Multidecadal Oscillation (AMO) [12]. Early ideas about the relative importance of top-down control versus bottom-up forcing stemmed from this work [13]. More recently the time-series has been used to show the response of whole bottom; fish assemblages to climate change [14], enabling the separation of climate change and fishing impacts [15]. There have been major switches in pelagic fish: from herrings in cold periods to pilchards (also called sardines) in warmer periods, which historical analysis showed stretched back to the Middle Ages [16]. Interestingly there was not a major return to herring in the cold period of the 1960s to late 1980s; perhaps because of overexploitation of herring in much of Europe restricting source populations [1]. These changes in fish were also accompanied by changes in the zooplankton with shifts between typical of northern offshore assemblages to those typical of warmer and more inshore waters, thereby suggesting a broad change in the ecosystem rather than the influence of overfishing [4]. Periodic re-surveys have shown the influence of fishing disturbance on benthic assemblages with a shift from larger organisms such as bivalves to smaller polychaetes from the 1950s [7,17] compared to the 2000s [18].

Changes offshore have been mirrored by those in the intertidal zone [19,20]. Many marine invertebrates have extensive larval periods spent in inshore waters and subsequent recruitment success can reflect

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nearshore conditions. Because of the rich history of experimental ecology on rocky shores, processes are well understood. Frameworks have been developed to better predict the impacts of future species range changes on community structure and functioning [21]. Furthermore, the coupling of this knowledge of process with statistical treatment of 40-year data sets [5,22] has enabled predictive modelling [23]. This work has shown how the northern cold-water species of barnacle (*Semibalanus balanoides*) will be replaced by southern warm-water species (*Chthamalus* spp.) under various future climate scenarios as warmer weather releases the slower growing southern species from competition due to mortality during recruitment. No doubt similar processes will be occurring in less tractable offshore species as climate change modulates biological interactions.

Challenges with Long Term Data Collection

One of the major challenges of maintaining time-series from a technical perspective is internal consistency of methodology, especially in the face of technological change and development of new techniques. This is particularly the case with chemical measurements such as nutrients. Joint et al. [24] demonstrated real deficiencies in the measurement of nutrients in the 1920s and 1930s compared to current practise (although well audited methodologies allow for some recalibration and cross-calibration). This means some interpretations of shifts in ecosystem functioning [4] have to be viewed with caution as differences in nutrients were likely to have been due to changes in methodology.

Some measurements such as temperature and salinity are very simple and whilst there may be improvements in precision they are still sufficiently accurate to enable comparisons over century-long time scales. There should also be a caution that sea surface temperature measured by satellites, whilst incredibly valuable, must be complemented by shipboard, drifter or buoy-gathered data. In particular routine bottom seawater temperatures are invaluable. For example, Sims et al. [25] showed that timing of squid migrations were correlated with sea bottom temperatures.

Fortunately, plankton and fishing nets have changed little over the last 130 years. Providing deployment, mesh size and towing speeds are consistent, both quantitative and qualitative comparisons can be made. It is important, however, that standard operating procedures are followed and that there are lead scientists acting as champions of the data sets for long periods.

The MBA time-series had two key figures: Russell from the 1920s to the 1970s and Southward from the 1950s to the late 1980s. Moreover, Southward's involvement with Hawkins and others was essential for restart of the time-series in the 1990s and 2000s. Many other laboratory staff were involved over the years (e.g. Garstang, Steven - fish; Boalch - phytoplankton and primary production measurements; and Corbyn - zooplankton) as well as expert support staff (Mattacola and well trained ships crews). In some cases catch logs maintained by non-scientist crews of research vessels have led to interesting publications on phenology [25,26]. The Dove time-series collected by the University of Newcastle (NE England), owed much to Buchanan, Evans and latterly Frid [27-31]. The Port Erin Marine Laboratory hydrography and nutrient time-series was built by Slinn [27,32]. Wulf was the stalwart and steward of the Helgoland time-series [30] now taken on by Wiltshire [33]. With internal consistency and training and baton-passing to new generations of staff, such time-series can be maintained - but this is not always easy. They are particularly vulnerable to retirement (voluntary and forced) and departure of key staff or the inability to develop new champions.

The other major vulnerability is that time-series are often viewed in some quarters as being merely monitoring exercises, and not addressing hypothesis-testing research. Certainly, the work by Southward in Plymouth did test hypotheses about the underlying role of climatic fluctuations in driving change. Moreover, sustained observing of temporal patterns often generates hypotheses for subsequent testing by shorter-term targeted cruises or experiments in the field or laboratory. Most importantly, long-term and broad-scale data can be used to calibrate and validate modelling exercises [23,34].

The biggest challenge is getting and maintaining "long thin" funding and ensuring continuity to sustain observing. Low-cost programmes using ships of opportunity have been the platform for both physical and biological observing programmes - in the latter case the Continuous Plankton Recorder (CPR) Survey operated by the Sir Alister Hardy Foundation for Ocean Science. This survey was closed down by the UK's Natural Environment Research Council (NERC) in the late 1980s, but immediately rescued as a charitable foundation. Pleasingly, it now receives core NERC support and the data gathered has led to some exceptional papers informing our knowledge of the responses of marine ecosystems to climate change [35-38].

Sustained observations are often strongest when networked at regional, national, super-national (i.e. the EU) and internationally. This enables both long-term and broad-scale coverage and congruence of trends to be detected and measured. In the UK the Marine Environmental Change Network (MECN - www.mba.ac.uk/mecn) enabled the re-start of time-series and has latterly enabled analysis of multiple data sets [39] to critically evaluate whether the regime shifts have occurred or not. Similar efforts have been pursued by the LargeNet programme resulting from the European MARBEF Network of Excellence (www.marbef.org/projects/largenet/index.php) [40].

Policy Relevance

Long-term data are essential for informing a precautionary approach in managing fisheries as overfishing and climate change usually interact to the detriment of cold water species. There is however, the potential for new fisheries to develop when warm-water species expand pole-wards [41,42]. Low biomass stocks that have been fished down can be less resilient to climate change. Phenological mismatches due to climate change can lead to recruitment failure [30,38,43]. Understanding undergoing long-term change can reduce uncertainty in managing fish stocks [41].

Long-term data are essential to understand both regional and local-scale eutrophication, particularly in separating broader oceanographic drivers from processes internal to the catchment of enclosed seas [32,44]. Often a combination of particular hydrographic conditions such as warm sunny weather enhancing stratification and higher nutrients due to eutrophication lead to blooms of harmful algal species [45,46]. Long-term data can be used to quantify whether the frequency of such events has increased or not.

Coming inshore, condition monitoring of areas of conservation interest (e.g. Special Areas of Conservation (SACs)) requires separation of local impacts from broader change. For example, has a species decreased in abundance due to climate driven change (impossible to manage) or to some local impact such as habitat loss or degradation which is manageable, and therefore reversible?

Much national and international marine policy is formulated with the long-term objective of having "clean, healthy, safe productive and biologically diverse oceans and seas" and with specific targets for with which to measure status [47]. Without long-term data there is no way of charting progress [48] towards these objectives or knowing which management and adaptation measures are appropriate for implementation. For example, in European marine waters the Marine Strategy Framework Directive has been adopted with the goal being to meet 'Good Environmental Status' by 2020. The specific target for biodiversity is that 'Biological diversity is maintained'. However, the second part of its target states 'The quality and occurrence of habitats and the distribution and abundance of species are *in line with prevailing physiographic, geographic and climate conditions*'. The need to understand natural variability as measured by long-term observations is therefore vital as these 'prevailing conditions' will be subject to much variability at large spatial and temporal scales.

In the UK, the Marine Climate Change Impact Partnership (MCCIP), is a good example of a programme that has drawn heavily on long-term studies in its work engaging with policy makers to inform adaptative response and management (as well as communicating with the general public) [49].

Concluding Comments

Long-term data sets are invaluable but yet vulnerable; especially in the current funding regime. Often their value is only appreciated when the time-series ceases. They can, however be easily re-started as demonstrated by the Western English Channel time-series and despite gaps, still provide extremely valuable data. A major challenge for the marine science community is to sustain observing, building on the foresight of those early pioneers of oceanography and marine biology of the late 19th century. There is a danger that the current emphasis on sharing and re-using data has diverted attention from the need to maintain long-term data-sets. Sustained observing, suitably networked provides the basic data to enable forecast and hopefully prediction of the future status of the ocean.

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