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Theme Session on the North Atlantic Components of Global Programmes: Lessons to ICES-GLOBEC from WOCE/JGOFS (O)

BIOLOGICAL OCEANOGRAPHY & FISHERIES MANAGEMENT

TREVOR PLATT[1] AND SHUBHA SATHYENDRANATH[2,1]

[1] Biological Oceanography Division, Bedford Institute of Oceanography, Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2.

[2] Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1

ABSTRACT

Despite one hundred years of research on the relation between oceanographic factors and fish recruitment, it has proved very difficult to demonstrate causal connections between properties of the marine ecosystem and the success of fisheries. Some authors have been led to conclude that such causal connections therefore do not exist: a corollary would be that biological oceanography is of limited relevance to fisheries issues. It will be argued that it is too early to dismiss biological oceanography as a tool in fisheries management. If we have not been able to implicate ecosystem factors as a significant source of variance in fish recruitment, it may be because the search has been conducted at an inappropriate scale, a necessary consequence of the limitations of ships as oceanographic platforms. The advent of remotely-sensed data from satellites greatly extends the time and space scales at which synoptic oceanography can be carried out. During the Joint Global Ocean Flux Study, considerable progress has been made in our ability to interpret and exploit ocean-colour data. It will be argued that access to such data allows a wider range of hypotheses to be tested, than is possible with ships alone, on the relationship between ecosystem factors and recruitment.

HISTORICAL INTRODUCTION

The inaugural meeting of the International Council for the Exploration of the Sea (ICES) was held in 1902. At least since then, the community of fisheries scientists has debated the relative importance of fishing pressure and environmental conditions as determinants of recruitment to exploited stocks (Mills 1989; Smith 1994). In turn, these debates have given rise to enormous expenditures on research designed to elucidate and quantify the contribution of fluctuations in environmental conditions to variance in recruitment. "Environmental conditions" is understood here to include both physical properties, such as temperature, and ecological properties, such as the abundance and growth of plankton.

With respect to the physical properties of the environment, progress has been made in understanding, for example, the preferences for temperature and salinity of exploited species. This new knowledge has been applied effectively in many harvest fisheries, such as that for tuna, and to understand the migrations by populations of demersal fish, such as cod.

With respect to the properties of the ecosystem, however, progress has been less easy to demonstrate. Although it is true that the basis for our present-day understanding of seasonal changes in the pelagic ecosystem was laid down early in the life of ICES, it has proved altogether more difficult either to apply this knowledge to improve our understanding of variability in recruitment or to integrate it into the emerging discipline of fisheries management. The collective failure to demonstrate a convincing, causal connection between variance in the pelagic ecosystem and variance in recruitment has led at least one author to assert that such a link does not exist (Sinclair 1988). This may be an extreme view, but it is certainly a provocative one, one that challenges us to make a strong counter, and finds us wanting.

A principal result of the inability to translate advances in understanding plankton dynamics into operational capital for fisheries management has been that fisheries science and biological oceanography have developed more independently of each other than would have seemed desirable in 1902. Thus, generally speaking, the theory of fish populations has been based on the premise that predictions about future stock size could be made using as independent variables only the population structure of the present stock, that is to say without consideration, implicit or explicit, of the requirement of the stock (in all its life stages) to nourish itself.

Dissent has arisen, from time to time, against this way of thinking (*eg.* Paloheimo & Dickie 1970), stimulating further research devoted to building an ecological context for fisheries management. However, although much elegant work has been done, it has nevertheless proved difficult to merge the results into the body of principles on which fisheries management is based. If a causal thread does indeed exist, it is slipping through our fingers.

During the decade of the 1990s, collapse of a number of major fish stocks around the world has brought into focus the fragility of a resource upon which so many depend for a livelihood and for a source of protein. More than that, however, it has emphasised once again our inability to account for the fluctuations in fish stocks by partitioning the variance into contributions arising from fishing pressure and contributions from the ecosystem. In particular, the science of biological oceanography has been able to add but little to the debate concerning possible causes of collapse in these stocks.

In this paper, it will be argued that the failure of biological oceanography, to date, to demonstrate the influence of ecosystem fluctuations on recruitment of exploited species is a consequence not necessarily of the lack of such a link, but rather of the inadequacy of the tools available so far to biological oceanographers, in particular to the limitations of ships as oceanographic platforms. The nature of the tools available controls the way the research questions can be posed. The advent of instruments for remote sensing of an important ecosystem property (ocean colour) expands the range of questions that can be addressed, and offers the possibility that biological oceanography can develop an operational component to complement its research component.

RECENT ACCOMPLISHMENTS OF BIOLOGICAL OCEANOGRAPHY

One of the disappointments in contemporary biological oceanography has been its inability to contribute to the debates that followed the collapse of several major exploited fish stocks around the world, of which we may take the northern cod stocks of eastern Canada as an example. When the possible causes of this crisis were being discussed (increased fishing pressure, changes in the large-scale patterns of currents and temperature, changes in the structure and intensity of ecosystem processes), biological oceanography had little or nothing to bring to the table. In other words, there was no synoptic and serial record describing the history of the ecosystem in the eastern north Atlantic Ocean over, say, the past twenty years.

It is legitimate to ask, then, what issues the field of biological oceanography had been occupied with during this period, if not with developing and maintaining a protocol for monitoring of the state of the ecosystem. We see the preoccupations of this community of scientists to have been threefold: conceptual, theoretical and methodological.

On the conceptual level, important advances have been made in understanding how the pelagic ecosystem works, in particular how the carbon and nitrogen cycles are interrelated. These developments have been critical to research aimed at elucidation of the role of the pelagic microbiota in the planetary carbon cycle, and therefore in the general suite of phenomena that we refer to collectively as climate change (Platt *et al.* 1989). This was a challenge with undoubted socio-economic connotations, and one to which biological oceanographers responded well. An obvious example would be the work of the Joint Global Ocean Flux Study (JGOFS).

One of the recurring problems in field work with ships at sea, such as that undertaken during JGOFS, is the gross undersampling that we are obliged to accept, a simple consequence of the speed of ships and the size of the ocean. Thus, we are faced continually with the task of extrapolation of sparse data sets if we wish to produce conclusions at the regional and larger scales of interest to fisheries scientists and climatologists. Within the last ten years, a tool of enormous power has been introduced that simplifies (but does not eliminate) the task of extrapolation: remote sensing of ocean colour (Esaias *et al.* 1986). With this tool we can see, for the first time, the synoptic distribution of a biologically-important quantity (surface-layer chlorophyll concentration) at the regional scale of the ocean. The images obtained by remote sensing of ocean colour have sensitised biological oceanographers to the enormity of the extrapolation problem, even while facilitating its solution.

When, some ten years or so ago, global flux studies began to be discussed as a field for major expansion of research effort, ocean-colour data were just being released into the public domain (Esaias *et al.* 1986). Thus it is fair to say that, in biogeochemistry, the advent of JGOFS marked the end of the era of strictly-ship-borne, biological oceanography. The challenge for the emerging JGOFS program, then, was to learn how to assimilate ocean-colour data to the best advantage. In particular, these data were expected to play an important rôle in the synthesis function of JGOFS, that is to say, the interpretation, at large spatial scales, of observational data collected from ships at a small number of widely-spaced stations. The understanding gained in this work is of direct interest to those engaged in fisheries research.

On the theoretical level, considerable progress been made in modelling the pelagic ecosystem, much of it, again, under the auspices of JGOFS. Important in this work has been the development of mathematical descriptions for significant ecosystem fluxes and their dependence on physical forcing. An example is the mathematical treatment of primary production, parametrised in terms of quantities that can be measured routinely at sea and that have a clear physiological interpretation, with the compiling of an archive of these parameters in a range of ecosystem types. As we shall see, all this work is immediately applicable to monitoring the state of the marine ecosystem using remotely-sensed data on ocean colour.

On the methodological level, our ability to census, automatically, the abundance of the pelagic biota in a variety of size classes has improved dramatically over the last twenty years through the development of instrumentation to be deployed from moving ships. The limitation, however, continues to be the ship itself. As a platform for the study of processes in the marine ecosystem and for the development of prototype instrumentation, the ship is ideal. As a platform for synoptic coverage of the ocean, however, the ship, because of its slow speed and lack of peripheral vision, is far from perfect. In spatially-distributed systems, such as the pelagic ecosystem, the value of synoptic-scale observations is widely recognised. For example, the quality of local weather forecasts is greatly enhanced if local observations can be set in a broader synoptic context. At sea, the conventional observation platform (the research vessel) can deliver data of very high quality, but is too slow, and cuts too narrow a swath, for any pretension to synopticity.

Within the limitations of the tools available to it, biological oceanography has made substantial advances during the past two decades. During this time interval, another important tool was emerging that gave an immense stimulus to the field of biological oceanography: images of ocean colour collected from instruments carried on satellites. The instrument responsible was the Coastal Zone Color Scanner (CZCS). The resulting images could be calibrated for the concentration of chlorophyll, an index of the abundance of phytoplankton. Through application of the theoretical work mentioned above, they could also be interpreted as fields of primary production. Therefore, the potential existed for the synoptic estimation of the two most important properties of the marine ecosystem in a serial manner. Remote sensing of ocean colour provided the only synoptic-scale entrée we have into the pelagic ecosystem. It is likely to remain the only such option into the foreseeable future.

Compared with the data that can be collected by ship, the data collected by remote sensing are of lower precision and lack information on vertical structure. However, they make up in sample size what they lack in precision. For example, a ship might be able to sample 50 points on the perimeter of a 100 km box in one day. At a local resolution of 1 km, the satellite will provide 10^4 simultaneous observations inside the box. Given that, generally speaking, sampling variance is inversely proportional to the number of observations, this is a powerful attribute indeed. Furthermore, remote sensing will show how conditions inside the box relate to those outside, even as far as the edges of the ocean. And it will do it all over again tomorrow, and the next day, for as long as we remain interested in the data. Finally, sea surface temperature can be collected by remote sensing on the same time and space scales, opening the possibility of a multidisciplinary, synoptic approach to marine ecosystem.

It is one of the tragedies of the history of oceanography that just when our ability to apply remotely-sensed data on ocean colour was beginning to mature, the data stream dried up. There is no reason, beyond the hiatus in the flow of data, why ecosystem monitoring for all the coastal zones of the world (resolution 1 km) might not already be at least ten years old. The picture is about to change for the better, but ten years will have been lost for ever, and for reasons entirely outside the control of the biological oceanographer. If the ocean-colour data had been continuous through this period, biological oceanography would certainly have been able to make useful contributions to the debate about the decline of the northern cod stocks.

THE WAY AHEAD

In the coming year, we may expect to see up to three new satellites in orbit carrying ocean-colour sensors. Given the experience of ten years of famine, the Intergovernmental Oceanographic Commission has established, in consort with the Committee on Earth Observation Satellites (CEOS), an International Ocean Colour Coordinating Committee (IOCCG), with a view to optimising returns from this new feast. All those with an interest in the existence and maintenance of long data series on the continental shelves should, when opportunities arise, speak in favour of the view that the ocean-colour record should never be interrupted again.

With the new data, the pelagic ecosystem can be monitored in a way that has not been possible before. It will be possible to characterise the ecosystem in ways that would be completely inaccessible to ships, even with unlimited availability of ship-days.

For example, we could look at a phenomenon such as the spring bloom of phytoplankton in the following ways: the amplitude of the peak, the width (duration) of the peak, the timing (phase) of the peak, the spatial structure and statistical moments of all of these properties, and their variation between years. A cost function could be developed from these properties that would serve as an index of ecosystem function for comparison against fluctuations in recruitment of exploited stocks. This index, and its components, could be computed with a spatial resolution of one kilometre over a spatial domain commensurate with the lifetime range of the exploited stock of interest.

Further, because sea-surface temperature can be estimated from satellites at the same scales of time and space as ocean colour, we can begin to treat the dependence of ecosystem function of physical forcing at a scale that is relevant to the fish. That is to say, we can begin to practise operational biological oceanography. Hitherto (using ships), it has not been possible to address the possible connection between ecosystem fluctuations and variability in recruitment at an appropriate scale. We have been blocked by lack of suitable tools.

An increasing reliance on satellites does not mean that ships will become superfluous to the conduct of oceanography. The best work will combine the excellence of data that can be achieved using ships with the spatial and temporal coverage that can be achieved with satellites. Ships will always be required to calibrate satellite signals. If we are to get the most out of satellite data we must continue to have access to oceanographic vessels of the highest quality. The future lies in the optimal blending of the best features of data derived from satellites and ships.

SUMMARY

Given the limitations of what can be accomplished from ships, it has not been possible to elucidate the connection between fluctuations in the pelagic ecosystem and variability in recruitment of exploited stocks. The appropriate scales of time and space become accessible with the availability of remotely-sensed data on ocean colour: these data yield synoptic fields of phytoplankton biomass and production. Although biological oceanographers have made considerable progress in developing the scientific basis for exploiting these data, especially under the stimulation of international programs such as JGOFS, the application of their work to fields such as fisheries science has been thwarted by an interruption in the flow of new data on ocean colour that has lasted for some ten years. The new understanding achieved by biological oceanographers on the conceptual, theoretical and methodological fronts will be of immediate use to fisheries scientists as tools for monitoring the state of the pelagic ecosystem, once new data on ocean colour begin to flow.

Remote sensing of ocean colour gives us the possibility to examine the spatial gradients of primary production, their seasonal variation, and their fluctuations between years. It is the best option we have to establish the long-term history of the pelagic ecosystem in any region. If we become expert in its use (and it is our duty to do so), we can contribute intelligently to discussions about the influence of ecosystem trends on trends in exploitable stocks. It is an opportunity not to be discarded.

New data series are expected to become available in the very near future, providing the basis for a new partnership between fisheries managers and biological oceanographers, allowing questions of mutual interest to be addressed at the correct scales for the first time. In this way, the two fields of research may finally achieve the coordinated development hoped for by the founders of ICES.

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