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Ichthyoplankton sampling design to monitor marine fish populations and communities

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ABSTRACT

The ability to assess, model, predict and manage the impacts of climate change and other anthropogenic stressors on marine ecosystems depends on having adequate ecological time series. Unfortunately the development of ecological time series considerably lags those for the physics and chemistry of the oceans. Ichthyoplankton time series are proposed here to fill this gap in ocean observations. Marine fish species spanning a wide range of families, habitats, feeding guilds, and trophic levels broadcast large numbers of their reproductive products into the open waters. For a limited period, the larvae generally reside in the upper 200 m of the water column, where they may be quantitatively sampled with plankton nets. Larval abundance provides a relative index for adult spawning stock biomass, enabling diverse fish communities to be monitored quantitatively by relatively simple means. Recent analyses of the ichthyoplankton time series extending back to 1951 from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program indicate that non-commercial as well as commercially-exploited taxa have experienced dramatic change in recent decades. The CalCOFI data set is re-sampled here to show that a reduced sampling program—one based on a few stations along a single transect (cf >50 stations along 6 transects for CalCOFI) or one based on a shorter time series—can, within limits, obtain similar single-species and multivariate patterns of abundance. Ichthyoplankton survey programs may thus provide the basis for a global system of ocean ecological observations in addition to their primary use today for fisheries stock assessment.

1. Introduction

Revelle and Seuss [37] famously noted that "human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future" and pointed to the need to "adequately document" it. More than half a century later, the increase in global atmospheric CO_2 concentrations has indeed been well documented, and satellites, profiling Argo floats and other sensor arrays provide global coverage of changing physical and chemical conditions in the world's oceans. However, although the Global Ocean Observing System (GOOS) was established in the 1990s, time series for the potentially changing ecology of the global ocean remain a patchwork [15,16].

Marine fishes would seem a prime candidate for inclusion in ocean observation programs, being ubiquitous in the world's oceans, diverse, ecologically critical, and highly valued economically, socially and culturally. In fact, however, they are poorly represented in most ocean observing systems [15,16]. There is a global system of reporting marine fishery landings as well as many fishery assessment surveys, but commercial fisheries comprise a small sub-set of the approximately 28,000 marine fish species [33]. Landings statistics are fraught with biases due to the influence of market conditions, changing technology, and regulations. Comparison of landings data with fishery-independent time series has shown that commercial time series can be highly misleading as indices of population trends [17].

A vast literature, global in extent and extending back for decades, documents the response of commercial fish populations to climate [8,14]. Likewise, there is growing evidence that non-commercial fish populations may vary substantially due to the impacts of climate [11,20,24,35], deoxygenation [19], pollution [9] and other anthropogenic stressors. Fishes appear to be sensitive indicators of ecosystem change, but without sustained ocean time series, changes to fish communities will likely not be detected, and

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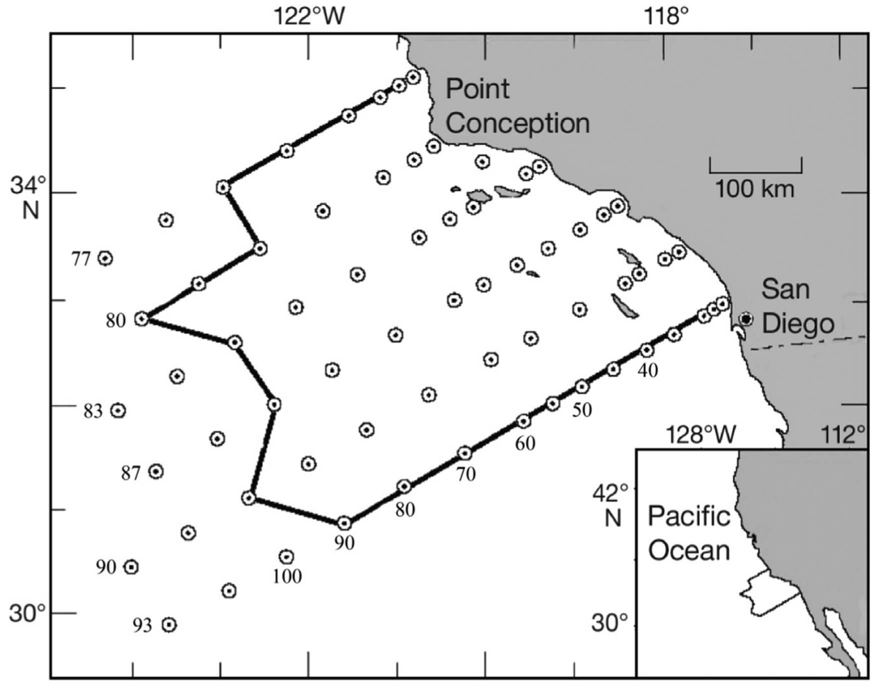

Fig. 1. The CalCOFI core survey design showing line (or transect) and station numbers. The 51 stations within the dark lines were most consistently sampled and used in analyses. Sub-sampling was carried out to stations 40, 60, or to the end of each transect.

Table 1
The common and scientific names and habitat of the 12 most abundant taxa in the CalCOFI ichthyoplankton data set used in time series analyses.

Common name	Scientific name	Habitat
Sand dabs	*Citharichthys* spp.	Demersal shelf
Northern anchovy	*Engraulis mordax*	Epipelagic, coastal
California smoothtongue	*Leuroglossus stilbius*	Mesopelagic
Eared blacksmelt	*Lipolagus ochotensis*	Mesopelagic
Pacific hake	*Merluccius productus*	Semi-pelagic, shelf and slope
Pacific sardine	*Sardinops sagax*	Epipelagic
Croakers	Sciaenidae	Demersal, shelf
Rockfish	*Sebastes* spp.	Demersal and semi-pelagic, shelf and slope
Shortbelly rockfish	*Sebastes jordani*	Semi-demersal/pelagic, shelf and slope
Northern lampfish	*Stenobrachius leucopsarus*	Mesopelagic
Jack mackerel	*Trachurus symmetricus*	Epipelagic
Panama lightfish	*Vinciguerria lucetia*	Mesopelagic

even if detected, there will be limited ability to distinguish the effects of secular climate change or anthropogenic stressors from background climate variability.

A key impediment to the widespread inclusion of fishes in ocean observation programs is the perceived cost of fish surveys. Surveying a region's diverse fish populations is potentially a daunting prospect, given their typically patchy distributions over vast areas and varied benthic and pelagic habitats. Fishery surveys, whether carried out with nets, acoustics or visually are typically massive, costly endeavors.

However, ichthyoplankton surveys may afford a low-tech, relatively simple opportunity to quantitatively monitor much of the exceptional diversity of marine fishes. Most marine fishes broadcast their reproductive products into the open waters in great profusion (their fecundity is generally on the order of 10^4–10^7 offspring per female). The larvae of most species, even deep-sea fishes, generally inhabit the upper 200 m of the water column, so marine fishes inhabiting a diverse array of habitats from the epipelagic to the deep sea can be quantitatively sampled with simple plankton nets during their egg and early larval stages.

Larval abundance is a function of spawning stock size, fecundity, and mortality during the early life history. Larval abundance alone is therefore not useful to estimate *absolute* stock biomass. However, numerous studies have found larval abundance to be significantly correlated with adult spawning stock biomass, particularly where stock size has varied significantly, thereby providing a useful *relative* index or proxy [12,17,19,28–30,38]. It should be noted that fish larvae are predominantly sampled with plankton nets for only a brief period after spawning during their pre-flexion stage, when motility and escapement are limited and they have experienced limited mortality. Because the taxonomy of fish during their larval stages is well-described for many parts of the world (e.g. [28,25]), quantitative larval fish time series can be developed for diverse assemblages of species.

Analyses of the CalCOFI ichthyoplankton time series, extending from 1951 to the present with quantitative data on >400 taxa, indicate that such time series may provide considerable insight into the response of diverse regional fish communities to changing ocean conditions. Koslow et al. [19] reported a 63% decline in abundance across a broad suite of midwater fishes (24 taxa from 8 families) related to reduced midwater oxygen concentrations and expansion of the oxygen minimum zone. The CalCOFI data set also revealed an ~70% decline since about 1970 of a suite of taxa with cool-water affinities that included several of the most abundant taxa in the region [17,20]. These dramatic changes in major fish assemblages of the southern CCS were not apparent from commercial landings data or stock assessments carried out for commercial species [41].

Greater use of ichthyoplankton time series holds promise for vastly improving the ecological monitoring, assessment and management of the oceans [15]. However, ichthyoplankton time series are often perceived to be expensive and difficult to maintain, requiring large ship-based systematic sampling programs. In large part, this is because many such programs have as their primary objective to survey the egg and larval distribution of open-water broadcast spawners (e.g. sardine, anchovy, pollock, or mackerel)