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Productivity and biomass of fishes in the California Current Large Marine Ecosystem: Comparison of fishery-dependent and -independent time series

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ABSTRACT

Commercial landings are often the only data available to assess the status of marine fish populations, but may reflect economics, technology and management policy in addition to stock size. In the California Current Large Marine Ecosystem (CCLME), the availability of CalCOFI ichthyoplankton data enabled us to compare commercial landings with a fishery-independent time series from 1951 to 2011. Fishery landings for the CCLME generally increased over this period, peaking about 1990 and displaying no clear subsequent trend. However, the abundance of ichthyoplankton in the southern CCLME has declined by ~70% since about 1970, based on the decline of taxa with cool-water affinities, apparently related to ocean warming and reduced productivity, and of mesopelagic taxa since the 1990s in response to declining midwater oxygen concentrations. These results highlight the importance of sustained fishery-independent time series at a time of secular climate change.

Calibration of the larval fish abundance time series with stock assessments and acoustic/trawl surveys provided a proxy time series of spawning stock biomass for epi- and mesopelagic planktivores since 1951. We estimate that mesopelagic fishes comprised ~83% of the biomass of plankton-feeding fishes in the southern CCLME, but their prey consumption appears approximately equivalent to that of epipelagic planktivores because of the greater metabolic requirements of epipelagic fishes. The "wasp-waist" paradigm for eastern boundary currents needs to be re-assessed based on revised assessments for the abundance of mesopelagic fishes.

1. Introduction

Studies of the effects of climate on marine fish generally focus on commercial fisheries, in part because of the socio-economic importance of fisheries but also because commercial fishery statistics and stock assessments often provide the only time series available for marine fishes. However, it is estimated that >80% of global fish landings are from fisheries that lack formal stock assessments (Costello et al., 2012). As a result, studies often rely on the fishery itself and, in particular, on the record of commercial landings, as their primary source of data (e.g. Myers and Worm, 2003; Teixeira and Cabral,

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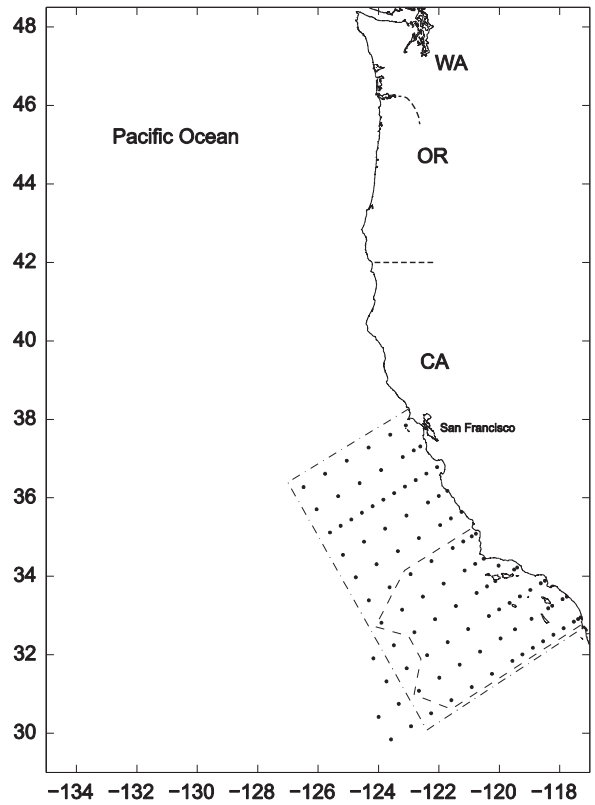

Fig. 1. The region off California, Oregon and Washington from which fishery landings were obtained for the California Current Large Marine Ecosystem (CCLME). The standard CalCOFI survey stations are shown from San Francisco south, which are surveyed in winter and spring for Pacific sardine. The large box shown in dash–dot lines is the area included in estimation of both larval abundance and mesopelagic fish biomass. The dashed lines around most of the six southern-most CalCOFI transects enclose the core stations used to estimate larval abundance in Koslow et al. (2011, 2013).

2009). However, it is well known that such data are subject to a variety of biases, such as misreporting, the effects of market conditions, changing technology, and fishery regulations. Even where fishery-independent data are available, they may pertain only to a relatively few commercial species. This bias toward commercial fisheries is also unfortunate in that it greatly limits the scope of oceanographic investigations. Fishes are by far the most diverse vertebrates on the planet, filling a great variety of ecological niches, but only a small fraction of fish taxa are subject to significant fisheries. Indeed, non-commercial taxa appear to dominate the fish biomass over most of the world' oceans (Irigoien et al., 2014; Davison et al., 2015).

In the California Current Large Marine Ecosystem (CCLME), it is possible to examine the implications of relying on commercial landings data and to go beyond such data to examine how the region's broader fish communities are responding to climate and other potential drivers. Ichthyoplankton surveys have been carried out as part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program since 1951, with surveys conducted mostly on a monthly-to-quarterly basis. All larval fish are removed, identified and enumerated from oblique net tows to ~210 m depth at a grid of stations that consistently covers southern and central California (Fig. 1). Most marine fishes are broadcast spawners and inhabit the upper 200 m during their early life history so plankton collections can quantitatively sample most of a region's fish community, including mesopelagic taxa, as eggs and larvae. Because the larvae in these collections are predominantly at a preflexion early stage, their abundance provides an index of spawning stock biomass, as demonstrated for a number of key species in the CCLME, such as Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), various rockfishes (*Sebastes* spp.), and California halibut (*Paralichthys californicus*) (Moser and Watson, 1990; Moser et al., 2000, 2001; Koslow et al., 2011).

Recent studies based on the CalCOFI ichthyoplankton and other fishery-independent time series have described dramatic patterns of decline across broad segments of the fish communities in the southern CCLME. Some 24 taxa across 8 families of mesopelagic fishes have declined by approximately 60% since the 1990s, highly correlated with declining midwater oxygen concentrations and a concomitant expansion of the oxygen minimum zone (OMZ) (Bograd et al., 2008; McClatchie et al., 2010; Koslow et al., 2011). Nearshore fishes quantitatively sampled since 1972 from the cooling water intakes of southern California power plants have declined > 70%, related to a northward shift in the community composition (Miller and McGowan, 2013). This trend is highly correlated with an ~70% decline in the overall abundance of larval fishes in the CalCOFI time series, due to a decline of taxa with cool-water affinities, including several of the most abundant taxa in the