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Changes in the size-structure of a multispecies pelagic fishery off Northern Chile

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ABSTRACT

Size-based indicators are important tools for understanding how environmental variability and fishing impact on marine populations and communities. Ideally, they would standardise fishery-independent survey data. However, this is not possible in many of the world's ecosystems with important commercial fisheries. Using fishery-dependent data we investigated changes in the size–structure of pelagic catches off Northern Chile and whether or not these changes are influenced by the environment. We computed single- and multispecies, size-based fishery indicators (SBFIs) from 1990 to 2008 for the main commercial species, anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*), jack mackerel (*Trachurus murphyi*) and mackerel (*Scomber japonicus*). SBFIs indicated a downward trend of body size in the catches taking all species together; a decrease of large sardine, an increase of small jack mackerel together with a decrease of larger sizes. Anchovy remained stable in body size and catch per unit of effort over the time period. Significant effects of the environment on mean length and catch per unit of effort were found for anchovy and sardine, respectively. We conclude that catches of pelagic species have shifted to smaller body sizes, with anchovy becoming the dominant species in the catches. We discuss the changes in the context of simultaneous, long-term, climate variability and fishing mortality.

1. Introduction

Indicators are now widely accepted tools to monitor changes in the state of populations, communities and ecosystems, and they play a key role in implementing the ecosystem approach to management of marine communities (Rochet and Trenkel, 2003; Rochet et al., 2010). Size-based indicators are particularly important in the context of the ecosystem approach because they have strong theoretical and empirical support, summarise how the state of a system changes with respect to a specific or multiple pressures or impacts, and are easily communicable to managers and stakeholders (Rice and Rochet, 2005; Shin et al., 2005). They are particularly suitable for tracking changes in populations and communities driven by forces of environment and fisheries. Such forces leave their mark on key processes like recruitment success, individual growth rate and survival. For instance, increments in temperature are thought to speed up growth and predation rates, shifting populations and communities towards smaller-sized individuals (Daufresne et al., 2009; Shackell et al., 2010). Increased primary productivity can either decrease mean size in the short term due to a recruitment pulse or lead to larger sizes in the longer term (Beverton and Holt, 1957). For instance, greater primary production could affect the mean size of *Merluccius gayi* due to an increase of recruited fish (Landaeta and Castro, 2012).

The Humboldt Current System (HCS) along the coast of South America is highly productive in terms of small pelagic fish, and climate variability drives the system at different temporal and spatial scales (Montecino and Lange, 2009). Climate variability in the HCS is driven in part by the El Niño/La Niña-Southern Oscillation taking place on an interannual scale (every 5–7 years) and decadal-scale shifts (Alheit et al., 2009). These two types of temporal variability are of significant magnitude and lead to major alterations in the whole ecosystem (Alheit and Niquen, 2004). Under El Niño or the warm regime, the system is characterised by warm sea surface temperature, a deeper thermocline, weaker upwelling, and lower productivity. Opposite conditions apply during the 'normal' La Niña or the cold regime, with a prevalence of cold coastal water, a shallow thermocline, stronger upwelling and higher productivity

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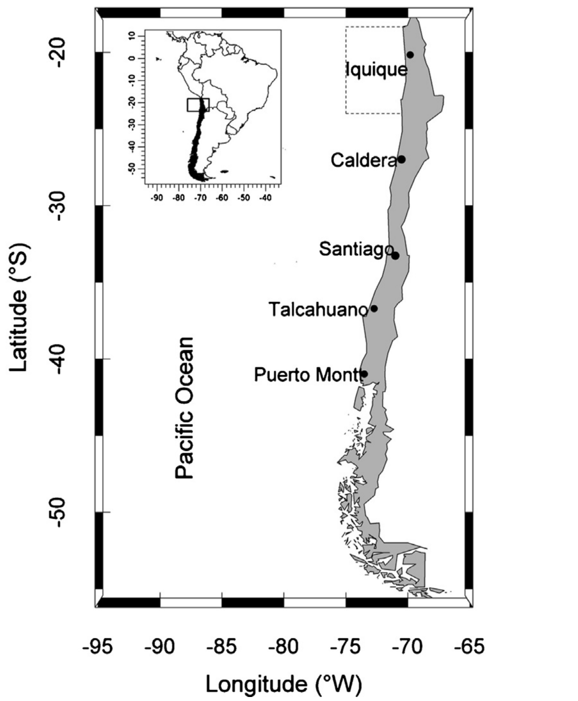

Fig. 1. Northern Chilean Marine Ecosystem (18°21′S–24°00′S). Dotted line indicates the fishing area of the pelagic purse seine fleet between 1990 and 2008.

(Bertrand et al., 2004, 2008; Alheit and Niquen, 2004; Yáñez et al., 2008; Chavez et al., 2008; Alheit et al., 2009). The El Niño/La Niña oscillation is thought to lead to increase in biomass of organisms such as zooplankton at low trophic levels under cold temperatures and decrease during warmer periods (Ayón et al., 2008). Warm conditions also affect species at higher trophic levels. Changes in spatial distribution, size–structure and the intensity and duration of spawning have been reported for small pelagic fishes in the area (Ñiquen and Bouchon, 2004; Alheit et al., 2009). Pelagic fishes become more patchy in space, are found closer to the coast and/or deeper in the water column, and exhibit a southward migration (Bertrand et al., 2004; Ñiquen and Bouchon, 2004; Yáñez et al., 2008). These changes in the population biology and ecology of pelagic fishes have profound effects on community functioning, and a change from single-species (anchovy based) to multi-species fisheries has been reported (Bertrand et al., 2004, 2008; Ñiquen and Bouchon, 2004).

The importance of the pelagic fisheries in HCS, together with a strong environment-driven current system, makes it an especially instructive ecosystem for studying the influence of the environment on body size distributions. Although single-species studies relating environmental variability to abundance and biomass of small pelagics in the HCS are available (Bertrand et al., 2004, 2008; Yáñez et al., 2008), there are no empirical studies on how this variability affects body size distributions at the species or multispecies level. In addition, existing integrated stock assessments models do not account for changes in size–structure.

Ideally, fishery-independent data from surveys would be used to construct size-based indicators and explore changes in body-size distributions. However, in the Northern Chilean Marine Ecosystem (NCME), an important part of HCS (Fig. 1), there is no established monitoring programme to track the size–structure of the pelagic fish community (only sparse survey information is available). Thus, as a first step, this paper explores information that can be obtained directly from fishery data in NCME.

There has been an important, industrial, purse-seine fishery in the region since the 1950s, fishing on anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*), jack mackerel (*Trachurus murphyi*) and mackerel (*Scomber japonicus*). It operates between 18°21′S and 24°00′S, and accounts for nearly 42% of the Chilean pelagic fish landings (Yáñez et al., 2008). Landings were almost exclusively of anchovy when exploitation of the pelagic fish community started in the middle of 1950s. The greatest development of the fishery took place in the late 1970s and early 1980s, with landings reaching a peak of over 3 million tonnes in 1986, with the large catches being sustained by sardine and jack mackerel rather than by anchovy. From the late 1980s onwards, landings decreased due to a decline in sardine abundance, and anchovy became the main species caught, especially after 2001. Landings of jack mackerel also decreased gradually, but since 2001 have become relatively stable. Mackerel landings have been stable since the start of the 1990s, but the relative proportion to the other species is low. Management of the pelagic fishery off Northern Chile is based on single species considerations, and since the beginning of 2000s a total allowable catch (TAC) system has been used to control fishing mortality. In addition, regulations such as a minimum landing size have been implemented for sardine and jack mackerel. Between 1990 and 2008, the minimum landing size for sardine was set at 20 cm, and the minimum landing size was set at 26 cm in jack mackerel between 1990 and 2000. However, the minimum landing size restrictions were removed for jack mackerel in 2001. This shift in selectivity for the jack mackerel fishery also affected the size structures of mackerel catches because these are usually constructed from bycatch information. The anchovy fishery is not regulated by minimum landing size; instead, recruitment and spawning seasonal closures have been implemented.

Here, we use detailed length-structured fishery information from the main pelagic species caught in NCME to construct size-based indicators, here referred to as size-based fishery indicators (SBFIs). We investigate changes in body size distributions at species and multispecies levels during 1990–2008, and examine the influence of sea surface temperature and primary productivity (chlorophyll-a) on these changes.

2. Methods

2.1. Data

2.1.1. Size-based fishery indicators (SBFIs).

The pelagic fishery in Northern Chile is routinely monitored by the Instituto de Fomento Pesquero (IFOP-Chile). Data on length structure and landings by species and year were obtained from this sampling program. We used this information to compute size-based fishery indicators from 1990 to 2008 for all commercial species combined and for each species separately. The total number of individuals caught by length class (in cm) by year and species was scaled up to the total landings, taking into account the stratified sampling design of the commercial purse seine fleet (Saavedra, 2006).

SBFIs were obtained as follows. Mean length of species i ($\bar{L}_i$) was calculated as:

$$\bar{L}_i = \frac{\sum_j C_{i,j}\, l_j}{\sum_j C_{i,j}} \tag{1}$$

where, $C_{i,j}$ is the number of individuals of species i in the length class j, and l_j is the midpoint of the length class j.