



## 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.

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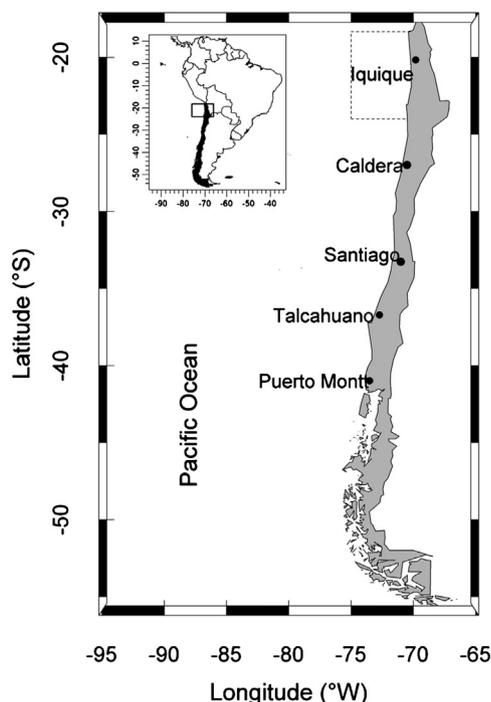
### 1. Introduction

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 the 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:

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

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  $j$ .

Mean length of the assemblage of species ( $L_{\text{bar}}$ ) was computed as:

$$L_{\text{bar}} = \frac{\sum_i \sum_j C_{i,j} l_j}{\sum_i \sum_j C_{i,j}} \quad (2)$$

This indicator quantifies the mean fish length in the catches of the pelagic fishery regardless the species.

Maximum length ( $L_{0.95}$ ) was obtained as the 95% percentile of the length distribution sampled from catches in each year for each species (Rochet et al., 2005). This indicator was used to investigate whether large individuals of each species had been decreasing in abundance in the pelagic catches. Time series of jack mackerel and mackerel lengths are influenced by the reduction in selectivity over the period 1990–2008. This change can disguise the cause of any trend in  $\bar{L}_i$ . For instance, a decrease in the  $\bar{L}_i$  can be a consequence of an increase of small fish caught or a decrease in large individuals caught.  $L_{0.95}$  helps to disentangle this effect.

The mean maximum length ( $L_{\text{max}}$ ) from all species was calculated as:

$$L_{\text{max}} = \frac{1}{C} \sum_i C_i L_{i,\infty} \quad (3)$$

where  $C_i$  is the number of individuals caught of species  $i$ ,  $C$  is the total number of individuals caught when the catches of all species are combined, and  $L_{i,\infty}$  is the asymptotic length of species  $i$ . This metric quantifies the life-history trait composition within the total catches of the pelagic fishery signaling if catches are mainly dominated by large or small body size species. Reported asymptotic lengths are: 20.25 cm for anchovy (Cubillos, 1991), 38.6 cm for sardine (Serra et al., 1979), 44.4 cm for mackerel (Aguayo and Steffens, 1986) and 70.8 cm for jack mackerel (Gili et al., 1995).

It is necessary to analyse the SBFIs in conjunction with the trend in abundance in the catches to understand the trend (e.g. decrease, stationary) of the SBFIs at the species level (Rochet et al., 2005). Thus, the total nominal catch per unit effort (CPUE) on a logarithmic scale was used as an indicator of the number of individuals caught of all sizes per fishing trip. The CPUE was computed for each species by dividing the number of individuals caught in each year by the number of fishing trips taking place per year. This unit of effort was selected because the duration of the fishing trips could not be obtained from the information available. In addition, CPUE of the adult fraction of each species was calculated as the adult nominal CPUE, including only individuals with length greater than length at 50% of maturity, reported to be: 12.5 cm for anchovy (Canales and Leal, 2009), 26 cm for sardine (Cárdenas and Mendo, 1985), 26 cm for mackerel (Pardo and Oliva, 1992) and 25.5 cm for jack mackerel (Cubillos and Alarcón, 2010).

Annual catch size spectra were calculated by summing all individuals within each size class across all species caught. Community size spectra were expressed as the logarithm of abundance or biomass of a community as a function of the logarithm of body size (Duplisea and Castonguay, 2006). The slope of a linear fitted relationship to log abundance versus log size reflects the relative abundance of small and large fish in the community, whereas the intercept reflects the overall productivity of the system (Blanchard et al., 2005). When survey data is used, the size-spectrum slope has typically been taken as an indicator of the impact of fishing on the fish community. Here, the size-spectrum slope from the catches is expected to become steeper as large individuals become relatively scarce in the catches.

To calculate the size spectrum slope from the fisheries data, individual length (cm) was transformed to weight (g) using the species-specific length-at-weight regression coefficients, and body

weights were transformed to a logarithmic scale with base 2. Catch biomass (g) per fishing trip was binned in 0.4 intervals on a logarithmic scale. The size spectrum of the catch was computed yearly between 1990 and 2008, using the relationship between  $\log_2$  normalised catch biomass against midpoint class of  $\log_2$  body weight class. The  $\log_2$  scale was based on the range of observed sizes in the catch. Compiled body weights spanned from 1 and 1875 g. However, only fully recruited fish in the range of 16–450 g were considered when estimating slopes and intercepts of size spectra. Catch size spectra were standardised to remove the correlation between the slope and intercept by subtracting the mean from the independent variable (Trenkel and Rochet, 2003). A linear regression analysis was applied in order to estimate the slope of the annual size spectrum in the multispecies fishery catch.

### 2.1.2. Environmental indicators

Three sources of environmental data were used to construct environmental indicators. First, sea surface temperatures (SST °C) from 1990 to 2008 for NCME were obtained from Advanced Very High Resolution Radiometer (AVHRR) pathfinder (<http://poet.jpl.nasa.gov/>) at a spatial resolution of 4 km. Second, as a proxy indicator of the productivity, monthly averages of Chlorophyll-a (CHL) were obtained from the sea-viewing Wide Field-of-View satellite sensor (SeaWiFS) from <http://oceancolor.gsfc.nasa.gov/> at a spatial resolution of 9 km. These records were only available for the period 1997–2008. Values of SST and CHL were converted to annual means. Third, SST data from the El Niño 3.4 region from <http://www.cpc.noaa.gov/data/indices/> were used to identify the presence of El Niño (warm event) or La Niña (cold event) conditions in the Equatorial Pacific Ocean (Arcos et al., 2001) and establish El Niño or La Niña year in the SST in the NCME. Anomalies meeting or exceeding  $\pm 0.5$  °C were used to identify El Niño or La Niña events.

## 2.2. Statistical analysis

Linear regression analysis was used to test for monotonic trends over time in the environmental and biological indicators. We started by fitting a linear regression to each indicator time series using ordinary least-squares (OLS). The following linear model was used  $y(x) = \hat{\beta}_0 + \hat{\beta}_1 x + \varepsilon$ , where  $y$  corresponds to an indicator,  $\hat{\beta}_0$  is the intercept of single regression,  $\hat{\beta}_1$  is a parameter for the predictor variable  $x$  (year), and  $\varepsilon$  is a normal distributed error  $\varepsilon \sim N(0, \sigma^2)$ . Analysis of variance (ANOVA) was conducted to test if a linear model was significantly better than a null model (only intercept, no linear change) using the  $F$ -test. The Durbin–Watson test with a maximum three-year lag was used to test for autocorrelation in the residuals, and Shapiro–Wilk test was used to test the normality assumption. A maximum lag of three years for autocorrelation was considered adequate owing to the short length of the time series. The critical value for rejecting the null hypotheses of no autocorrelation and normality was taken as  $\alpha = 0.05$ . When autocorrelated residuals were identified, we fitted the linear model with generalised least-squares (GLS) which allows the error to be time dependent, in this case using an autoregressive process of order 1 (Blanchard et al., 2010). When residuals showed a significant departure from normality, the linear trend was fitted using robust linear regression (RLM) (Venables and Ripley, 2002). We identified a few cases where both conditions (autocorrelation and departure from normality) were present when carrying out a GLS fitting. The coefficient of determination ( $R^2$ ) for the GLS was calculated according to Nagelkerke (1991), and the adjusted  $R^2$  coefficient for the RLM was based on Renaud and Victoria-Feser (2010).

**Table 1**  
Number of anchovy, sardine, jack mackerel and mackerel measured by the Monitoring Program of the Pelagic Fishery off Northern Chile between 1990 and 2008.

Year	Anchovy	Sardine	Jack mackerel	Mackerel
1990	77,868	75,683	15,197	13,316
1991	80,989	37,855	20,438	17,823
1992	128,142	73,115	25,918	2597
1993	17,4783	30,635	41,184	5395
1994	280,706	12,599	37,104	2638
1995	80,720	6162	14,365	4415
1996	252,222	7060	59,550	8504
1997	27,724	1520	6982	2066
1998	191,055	9139	20,955	6001
1999	25,360	3260	2646	558
2000	540,020	2795	84,178	6679
2001	368,139	5871	463,413	71,297
2002	620,004	2771	81,100	73,499
2003	286,351	522	104,198	102,243
2004	544,536	240	34,841	21,978
2005	36,660	172	5446	2159
2006	217,065	–	46,092	20,597
2007	332,872	3	41,372	8813
2008	276,656	46	39,924	4846

We used linear relationships between environment and indicators. SST and CHL in their real scales ( $^{\circ}\text{C}$  and  $\text{mg}/\text{m}^3$ ) examine the influence of environment (SST and CHL) on single and multi-species indicators. For each environment-indicator pair, we fitted a linear regression model using GLS. A forward selection of the predictor variable (SST or CHL) was conducted starting from a null model (intercept only). ANOVA based on the F-test was conducted to identify if a linear model was significantly better than null model. The effect of this variable could only be studied on a subset of data since CHL data were only available for 1997–2008. A significance level  $\alpha = 0.05$  was used for all models except for CHL where  $\alpha = 0.1$  was used because of the short time series of data. All analyses were carried out using R version 2.12.0.

### 3. Results

Table 1 shows the number of individuals sampled by year and species from 1990 to 2008. Anchovy is the species with largest number of individuals measured per year, followed by jack mackerel and mackerel. Sardine showed an important decline in sample size in 1995 and in 2003. The scarce landings of sardine from 2003 onwards made its sample size especially small, and SBFIs for this species were not constructed beyond 2005.

**Table 2**  
Statistical tests for linear trends of the indicators over time at the species level. The numbers of the first row for each species shows the probability of no linear trend based on an ANOVA F-test. The numbers in brackets represent the coefficient of determination ( $R^2$ ) of a time series regression. Bold numbers identify a significant trend at  $\alpha = 0.05$ , and D means direction of the trend in the indicator: (↑) upward trend, (↔) no trend, (↓) downward trend.

Species	$\bar{L}_i$ (cm)		$L_{0.95}$ (cm)		CPUE		Adult CPUE	
	P-value	D	P-value	D	P-value	D	P-value	D
	( $R^2$ )		( $R^2$ )		( $R^2$ )		( $R^2$ )	
Anchovy	0.112 (0.105)	↔	0.751 (0.006)	↔	0.050 (0.207)	↔	0.274 (0.069)	↔
Sardine	<b>0.029</b> (0.227)	↓	0.085 (0.161)	↔	<b>&lt;0.001</b> (0.453)	↓	<b>&lt;0.001</b> (0.448)	↓
Mackerel	0.137 (0.102)	↔	0.417 (0.035)	↔	0.217 (0.096)	↔	<b>0.036</b> (0.233)	↓
Jack mackerel	<b>&lt;0.001</b> (0.327)	↓	<b>0.015</b> (0.301)	↓	0.445 (0.035)	↔	<b>&lt;0.001</b> (0.623)	↓

### 3.1. Trends in SBFIs and external pressures

At the species level, anchovy did not show trends in the SBFIs, but important outliers in  $\bar{L}_i$  and adult CPUE were present during the El Niño event in 1997–98 (Table 2, Figs. 2a and 3a). Downward linear trends in  $\bar{L}_i$ , total CPUE and adult CPUE were detected for sardine (Table 2; Figs. 2b and 3b). Mackerel indicators included a downward trend in adult CPUE, but not in the body size ( $\bar{L}_i$ ,  $L_{0.95}$ ) (Table 2; Figs. 2c and 3c). A downward trend in mean and maximum length and adult CPUE of jack mackerel catch indicators was also evident (Table 2; Figs. 2d and 3d).

SBFIs for all species together  $L_{bar}$  and  $L_{max}$  (Fig. 4a, b) did not show trends (GLS:  $p = 0.425$ ,  $R^2 = 0.042$  and GLS:  $p = 0.981$ ,  $R^2 = 0.001$  respectively), but a significant steepening of the size-spectrum slope was found (OLS:  $p = 0.022$ ,  $R^2 = 0.229$ ) (Fig. 4c). No trend was found in the intercept (GLS:  $p = 0.70$ ,  $R^2 = 0.01$ ) (Fig. 4d).

SST did not exhibit a significant trend over the study period 1990–2008 (Fig. 5a) (OLS:  $p$ -value = 0.417,  $R^2 = 0.040$ ). However, important SST anomalies were identified during this period (Fig. 5a) which coincided with El Niño (positive) or La Niña (negative) events. These events were also detected in the SST of El Niño3.4 region. Warm events in the NCME were observed during 1992, 1997 and 1998, with 1997 being the highest ( $> +1^{\circ}\text{C}$ ) (Fig. 5a). The coolest anomaly in NCME was observed in 2000 ( $< -0.5^{\circ}\text{C}$ ). Although other cold and warm events have been observed in the NCME (Yáñez et al., 2008), they were not clearly visible in the local SST time series (Fig. 5a). CHL showed a close to significant upward trend (GLS:  $p$ -value = 0.069,  $R^2 = 0.252$ ) over the period 1997 to 2008 (Fig. 5b).

### 3.2. Environment-indicator relationships

Single direct effects of the environment on anchovy and sardine were detected, but not on mackerel, jack mackerel or on all species together. In anchovy, a negative effect of SST on  $\bar{L}_i$  led to a significant improvement over a null model (ANOVA, F-test) ( $\bar{L}_i \sim 29.870 - 0.763\text{SST}$ ;  $p = 0.041$ ,  $R^2 = 0.243$ ). In sardine, a negative effect of CHL on CPUE also led to a significant improvement over the null model (CPUE  $\sim 18.331 - 7.792\text{CHL}$ ;  $p = 0.019$ ,  $R^2 = 0.798$ ).

### 4. Discussion

Several changes in body-size distributions of the catches of the main pelagic fish species occurred in NCME from 1990 to 2008, and some impacts of climate variability occurred over this period. In addition, the slope of the catch size spectra after aggregating over species had a significant downward trend with time. This has not previously been reported for the pelagic fishery of the NCME

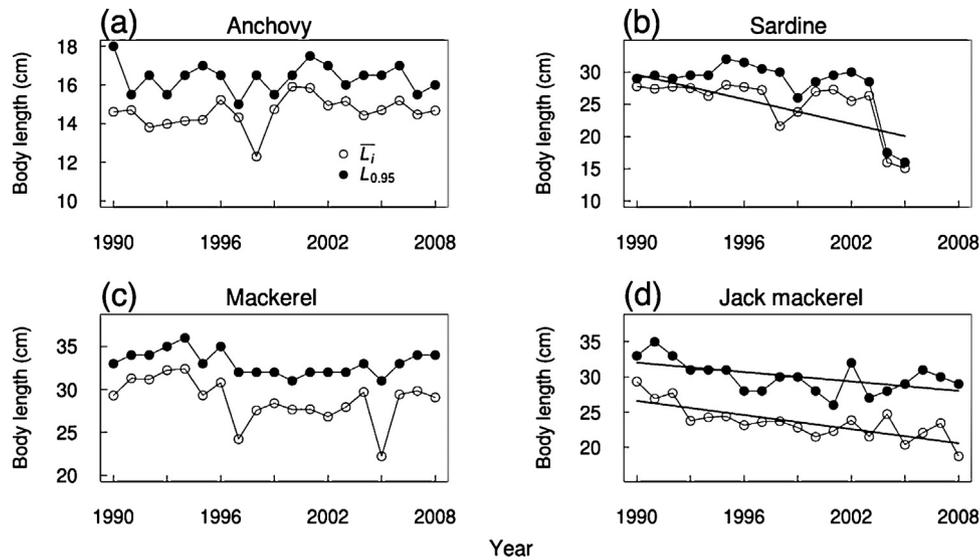


Fig. 2. Species-specific size-based fishery indicators: mean length ( $\bar{L}_i$ ) and maximum length ( $L_{0.95}$ ) of catches. (a) Anchovy, (b) sardine, (c) mackerel and (d) jack mackerel.

because multispecies and body-size distributions of the catches have not been analysed before.

Examining changes in the overall size-structure of the catch, as well as disaggregating into species provides detailed insights into the changes that have occurred in this multispecies fishery. The steepening of the slope of the catch size spectra indicates a shift towards size-structures of catches increasingly dominated by smaller fish. Although anchovy, the main species caught in the system, neither decreased nor increased from 1990 to 2008, larger individuals of commercial species (sardine and jack mackerel) became rarer in catches of the pelagic fishery, making the slope steeper. Also smaller jack mackerel became progressively more abundant in the catches.

We did not find a significant correlation between any of the environmental variables and the slope of the size spectra. However, the steepening of slope of the size spectra the aggregated catch could reflect both a shift in the abundance of the anchovy-sardine system in the HCS driven by climate variability, and also a shift in size-structure of jack mackerel driven by fishing. Anchovy

increased its abundance off Northern Chile following the shift to cooler conditions in the 1980s (Yáñez et al., 2008). Gutiérrez et al. (2007) noted that anchovy became a dominant species in the pelagic community off Northern Peru in the 1980s, when that part of the HCS shifted to cooler conditions. Thus, increasing dominance of anchovy in the HCS, the smallest species studied here could have contributed to a steepening of the catch size spectra over the period 1990 to 2008. Our trend analyses of CPUE support this hypothesis by showing declines in the adult and total CPUE of sardine, and in the adult CPUE of jack mackerel and mackerel, whereas the CPUE of anchovy remained stable throughout the time series.

Anchovy is a key species for the functioning of the fish pelagic community off Northern Chile, as well as for the commercial fishery. It is a source of food for larger fish predators and many other fish species, and the growth rates of its predators are likely to fall if stocks of anchovy are depleted (Andersen and Pedersen, 2010). In addition, such depletion could increase the time required to rebuild the predator stocks, even if fishing mortality on them was reduced. Such predator-prey dynamics have been postulated, for instance,

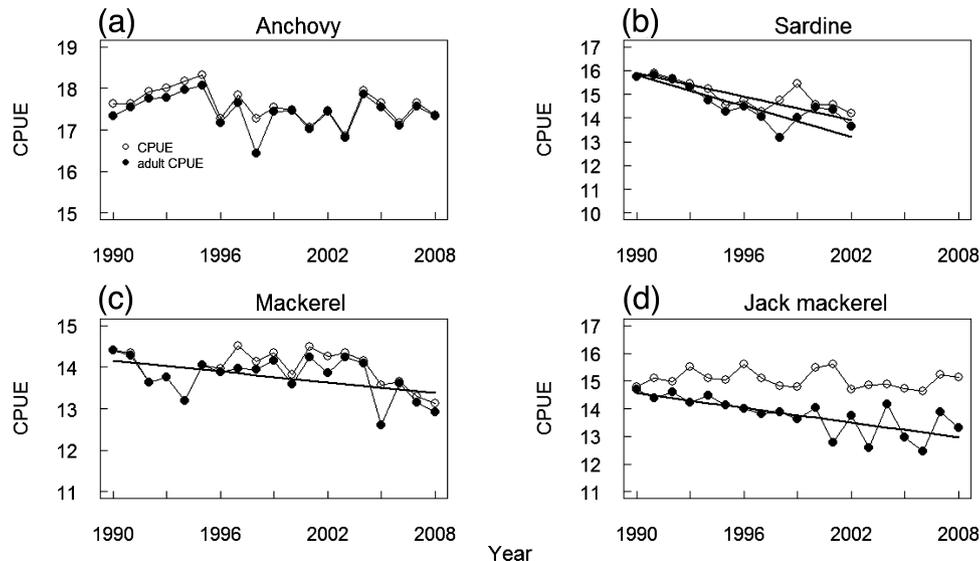


Fig. 3. Catch per unit effort (number of individuals per fishing trip). Total data (open circles) and only adult individuals (solid circles). Y-axis is in natural log scale. (a) Anchovy, (b) sardine, (c) mackerel and (d) jack mackerel.

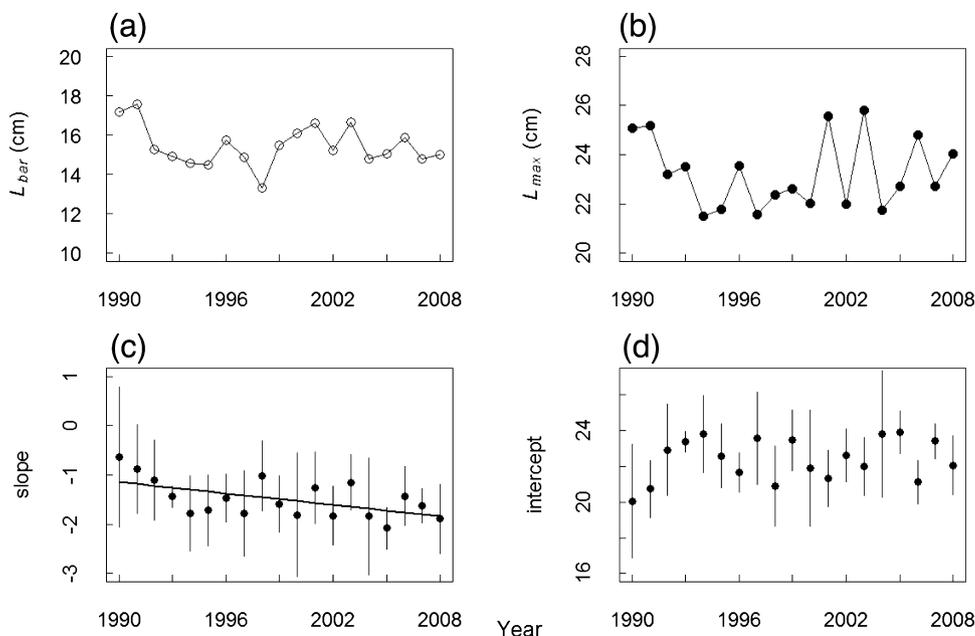


Fig. 4. Catch multispecies size-based fishery indicators. (a) Mean length ( $L_{\text{bar}}$ ) and (b) mean maximum length ( $L_{\text{max}}$ ). (c) Slope and (d) intercept of the catch size-spectrum.

as a cause of the lag observed in the recovery of the demersal community after a long period of low harvesting (Heath and Speirs, 2012).

The results also show a significant decrease in the mean length of sardine and in the SBFIs for jack mackerel. In a closed population, changes in mean length of the catch mostly depend on recruitment magnitude, somatic growth, survival and vulnerability to fishing. Both the environment and fishing activity affect these processes, so changes in size-based indicators obtained from fisheries data should be interpreted with caution. The simultaneous decrease in the mean and maximum length indicators for jack mackerel suggests a continuous shift towards smaller body sizes. Although several causes could explain the decrease in these indices, fishing is likely to have played an important part.

Information on fishing mortality ( $F$ , year<sup>-1</sup>) from stock assessment reports (SPFRMO, 2013; Serra and Barría, 2001) can support our hypothesis about a potential fishing effect in SBFIs of jack mackerel and sardine. The jack mackerel stock experienced a high fishing mortality before 2000, including the part of the stock caught in NCME (Fig. 6a). Such high  $F$  applied to jack mackerel could cause both a reduction in the catch and a loss of larger individuals over

time (Froese, 2004). Indeed, SUBPESCA (2010) reported that the jack mackerel population is at 9–14% of its level prior to exploitation, and downward trends found in oldest individuals caught of jack mackerel, together with a high proportion of juvenile individuals in the catch were reported in the stock assessment (Serra and Canales, 2009). The decline of SBFIs based on jack mackerel catches could be the result of heavy exploitation experienced by the stock, and also the result of the shift in selectivity in 2001 when minimum landing size restrictions were removed (Böhm, pers. com.). Sardine also showed high fishing mortality rate during 1980s (Fig. 6b). High fishing mortality in combination with the shift to cooler condition in the HCS (Gutiérrez et al., 2007; Yáñez et al., 2008) might explain the decline of the mean length of the catches of the sardine stock.

Environmental influences were detected for the anchovy and sardine indicators. The negative relationship between mean length of anchovy and SST is consistent with previous work, suggesting that El Niño shifts the size distribution of anchovy over space in such a way that adults are not found in the usual fishing zones (Ñiquen and Bouchon, 2004). The sharp decrease in the mean length of anchovy in 1998, when the El Niño event in 1997–1998 was taking place, is particularly clear. The absence of adult individuals during

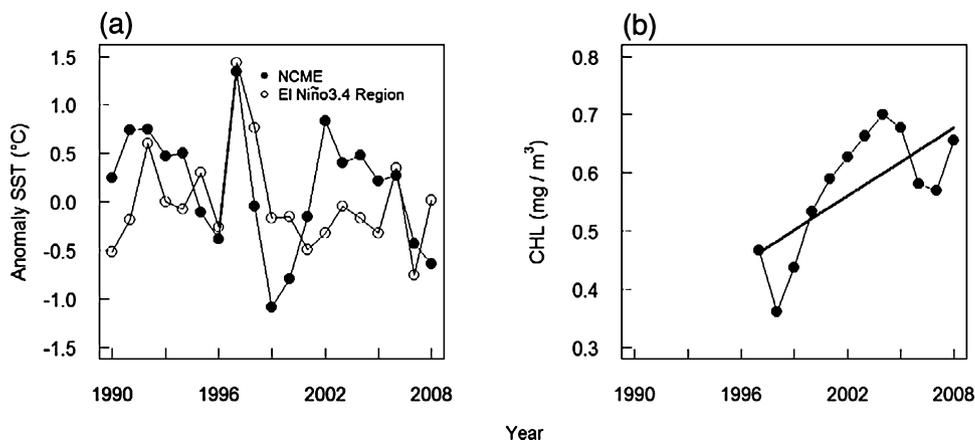
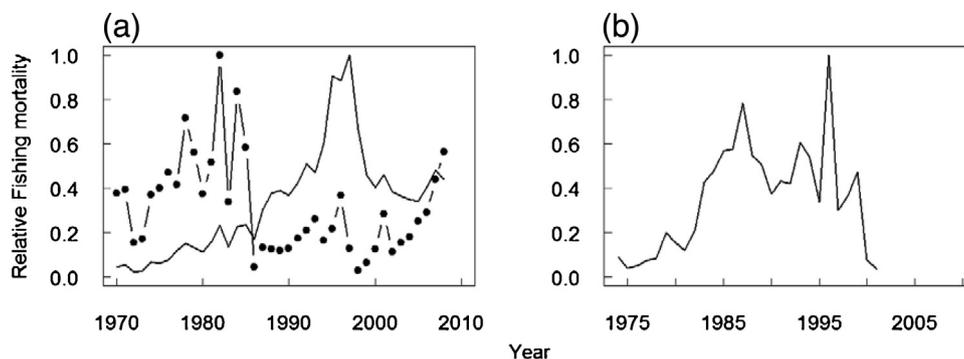


Fig. 5. (a) SST anomalies for the Northern Chilean Marine Ecosystem and at El Niño3.4 Region; anomalies were used graphically to detect El Niño and La Niña years. (b) CHL at the Northern Chilean Marine Ecosystem.



**Fig. 6.** Annual fishing mortality relative to their maximum reported for each stock. (a) Jack mackerel, (b) sardine (no stock assessment available after 2001). Continuous line represents the relative fishing mortality value for the complete stock of jack mackerel and sardine. Dotted line indicates values of the relative fishing mortality of jack mackerel caught in the North of Chile.

this phase of El Niño seems to be a characteristic feature of the HCS (Ñiquen and Bouchon, 2004). The mean length of anchovy in the catches recovered in 1999 when non-El Niño conditions returned. Short-term changes in size distribution of anchovy during El Niño have also been reported in the Northern Humboldt Peruvian system, where it was suggested that temporal changes in the habitat caused by El Niño affect anchovy's three-dimensional spatial distribution (Ñiquen and Bouchon, 2004). At the end of an El Niño event, anchovy schools become patchier, moving southward and deeper into the water column, making the exploitable part of the population less available for fishing (Bertrand et al., 2004, 2008; Yáñez et al., 2008).

The negative relationship between adult sardine CPUE and CHL could also be explained by the way in which the changing environment leads to re-arrangement of spatial distribution of fish. During cold conditions, CHL increases close to the coast and sardine moves offshore. Thus, the decrease in sardine abundance at high levels of CHL could be a consequence of a failure of sardine to effectively use the high productivity available in the coastal area (Bertrand et al., 2004; Alheit and Niquen, 2004; Ñiquen and Bouchon, 2004; Gutiérrez et al., 2007). However, the lack of data points after 2000 sardine, together with the short time series in CHL, preclude further analyses of a mechanistic relationship between CPUE and CHL. Indeed if CHL is an adequate proxy for sardine food availability we might expect the relationship to be positive, although there are clearly difficulties associated with ensuring both indicators are matched at the appropriate spatio-temporal time/space scale and resolution.

This study has shown that, when survey data are not available, catch data still can provide some information on the size-structures of fish communities in marine ecosystems. This has to be done with caution, as effects of the environment and a fishery cannot be unequivocally disentangled from fishery data alone. However, the results do show some signals of changes in the composition and structure of the commercial species and multispecies-level catches. Since NCME is part of the world's most important and productive upwelling system, there is clearly need for regular, systematic, fishery-independent, recording of the fish community in this system. Implementing an ecosystem-approach to fisheries in this region calls for the development of an appropriate and regionally/temporally coordinated monitoring program.

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