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The relationship of anchovy and sardine to water masses in the Peruvian Humboldt Current System from 1983 to 2005

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ABSTRACT

The Humboldt Current System (HCS) is dominated by two pelagic species; Peruvian anchovy or anchoveta (*Engraulis ringens*) and sardine (*Sardinops sagax*). Using data from 43 acoustic surveys conducted from 1983 through 2005 by the Peruvian Marine Institute (IMARPE), we examined the distribution of these two species relative to water masses. We tested the hypothesis that anchovy was found more frequently in upwelled cold coastal water (CCW) and mixed waters (MCW) than in other water types and that sardine was more associated with more offshore oceanic surface subtropical water (SSW). Surface temperature, salinity, latitude, season and distance to the coast data were used to define water masses. Results using generalized additive models (GAM), modelling sardine and anchovy presence–absence as a function of year, water body, bottom depth and latitude, showed that anchovy were primarily found in CCW and MCS, while sardine were more ubiquitous relative to water masses with some predilection for SSW. These results were supported by various indexes of anchovy and sardine distribution versus water mass as well as temporal and location variables.

1. Introduction

The Humboldt Current System (HCS) off Peru is one of the most productive coastal upwelling systems in the world (Carr, 2002). It supports the world's largest tonnage fishery for Peruvian anchovy or anchoveta (*Engraulis ringens*) (Bouchón et al., 2000) and has in the past also supported a major sardine (*Sardinops sagax*) fishery (Csirke et al., 1996). The HCS experiences year-round upwelling (Thomas et al., 2001). The abundance of anchovy and sardine appears to be linked both to El Niño Southern Oscillation (ENSO) events (frequency of 2–7 years) and to decadal-length regime shifts (Lluch-Belda et al., 1992; McFarlane et al., 2002; Chavez et al., 2003; Alheit and Niquen, 2004). Additionally, the abundance of the anchovy population appears to fluctuate out of phase with sardine in the HCS (Lluch-Belda et al., 1989, 1992; Csirke et al., 1996; Schwartzlose et al., 1999; Bakun and Broad, 2003; Fréon et al., 2003). Chavez et al. (2003) proposed the term 'El Viejo' to define the warm, decadal 'sardine regimes' and 'La Vieja' to define the cold decadal 'anchovy regimes'. However, little is known about the processes underlying the functional response of these species to ENSO events and decadal regime (Bertrand et al., 2004).

It has been hypothesized that cold upwelling water, which supports elevated levels of phytoplankton (Thomas et al., 2001; Chavez et al., 2003), provides overall favourable conditions, in particular for feeding, for anchovy while sardine appears to be favoured in warmer oceanic and frontal waters (Bertrand et al., 2004; Gutiérrez et al., 2007). Sardine is a more efficient filter feeder on phytoplankton and small zooplankton, while anchovy operates more efficiently preying on larger zooplankton (Konchina, 1991; van der Lingen et al., 2006, in press; Espinoza and Bertrand, 2008). Thus, more favourable feeding conditions for sardine may predominate in small and for anchovy in large-zooplankton areas, presumably corresponding to warmer oceanic water and cooler upwelling water, respectively (Mackas et al., 2001; Peterson et al., 2002; Zamon and Welch, 2005). Bertrand et al. (2004) hypothesized that variation in the range of favourable habitat leads to variation in spatial extent of the fish populations. In that sense, dramatic biomasses of anchovy can be concentrated in very small refuge areas when conditions are adverse, as occurred, for instance, during the El Niño event of 1997–1998 (Bertrand et al., 2004). When the range of favourable habitat increases very quickly (at the beginning of La Niña condition for instance) the fish range of distribution can increase drastically even if the population is still not very abundant (Bertrand et al., 2004; Gutiérrez et al., 2007). Gutiérrez et al. (2007) provide evidence that environmentally mediated alterations in habitat range can lead to population changes. In that paper habitat was defined using a very simple proxy, the coast-wide temperature anomaly (Gutiérrez et al., 2007) over a long time period, while the other paper used a more

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complex water mass definition but with a short time series (Bertrand et al., 2004).

Here we examine the hypothesized relationships using a complex water mass definition over a long time series. Within this context our objective is to describe the co-variation of water masses and fish spatial distributions and to test hypotheses concerning fish association with water masses. To this end, we used data from 43 acoustic surveys off the Peruvian coast from 1983 to 2005.

2. Data and methods

2.1. Acoustic survey data

Acoustic data were collected from 1983 to 2005 by the Peruvian Marine Institute (IMARPE), most commonly using the R/V Humboldt (76 m long), the R/V Olaya (41 m long) or the R/V SNP-1 (36 m long). At least two acoustic surveys were run in most years. Survey design was composed of parallel transects averaging 90 nautical miles (167 km) long with an inter-transect distance varying between 14 and 16 nautical miles (26–30 km) depending on the cruise.

The surveys intended to cover most of the range of anchovy distribution (transects shown in Fig. 1), which varied from survey to survey. Extensive midwater trawl sampling completed the acoustic surveys for species identification. The seasonal and temporal distributions of scientific acoustic surveys were: spring (1983, 1986, 1989, 1990, 1996–2005), summer (1990–1996, 1999–2005), autumn (1985, 1986, 1997, 2 surveys in 1998), and winter (1984, 1987–1989, 1991, 1998–2005 with 2 winter surveys in 1999, 2000 and 2001). The acoustic surveys deployed Simrad (Kongsberg Simrad AS, Kongsberg, Norway) scientific echosounders EK, EKS, EK400 before 1995, and EY500 and EK500 (the EK60 was also used 2001–2005 in one vessel) thereafter. After 1998 at least two vessels were used for each survey to reduce survey time and the bias from changes in distribution of studied species during the survey. Calibration and intercalibration of the echosounders were undertaken before each survey. Calibration up until 1992 used hydrophones and after 1992 sphere calibration followed a standard procedure (Foote et al., 1987). A bias may exist in acoustic backscatter over the years due to the use of different calibration methods, but more likely due to the use of different acoustic systems. The magnitude of this latter bias is unknown but is assumed to not be a major factor since some calibrations between the systems were made. Acoustic back-scattered energy by surface unit (s_A) was recorded in each geo-referenced elementary sampling distance unit (ESDU) of 2 n.mi. (1983–1993) or 1 n.mi. (1994–2005). Acoustic echo identification was performed using fishing trawl composition and echotrace characteristics. Biomass estimation based on both the trawls and acoustic backscatter for each species was carried out by IMARPE for each survey. There were between 55 and 660 trawls for each survey (average of 190 trawls) .Surface temperature and salinity were measured and interpolated per ESDU for almost all surveys (exceptions are missing samples in summer 1990 for both temperature and salinity and additionally summer 1994 and spring 2000 for salinity), while surface oxygen levels were measured for about half the surveys but were not used because the coverage (number of surveys) was deemed insufficient.

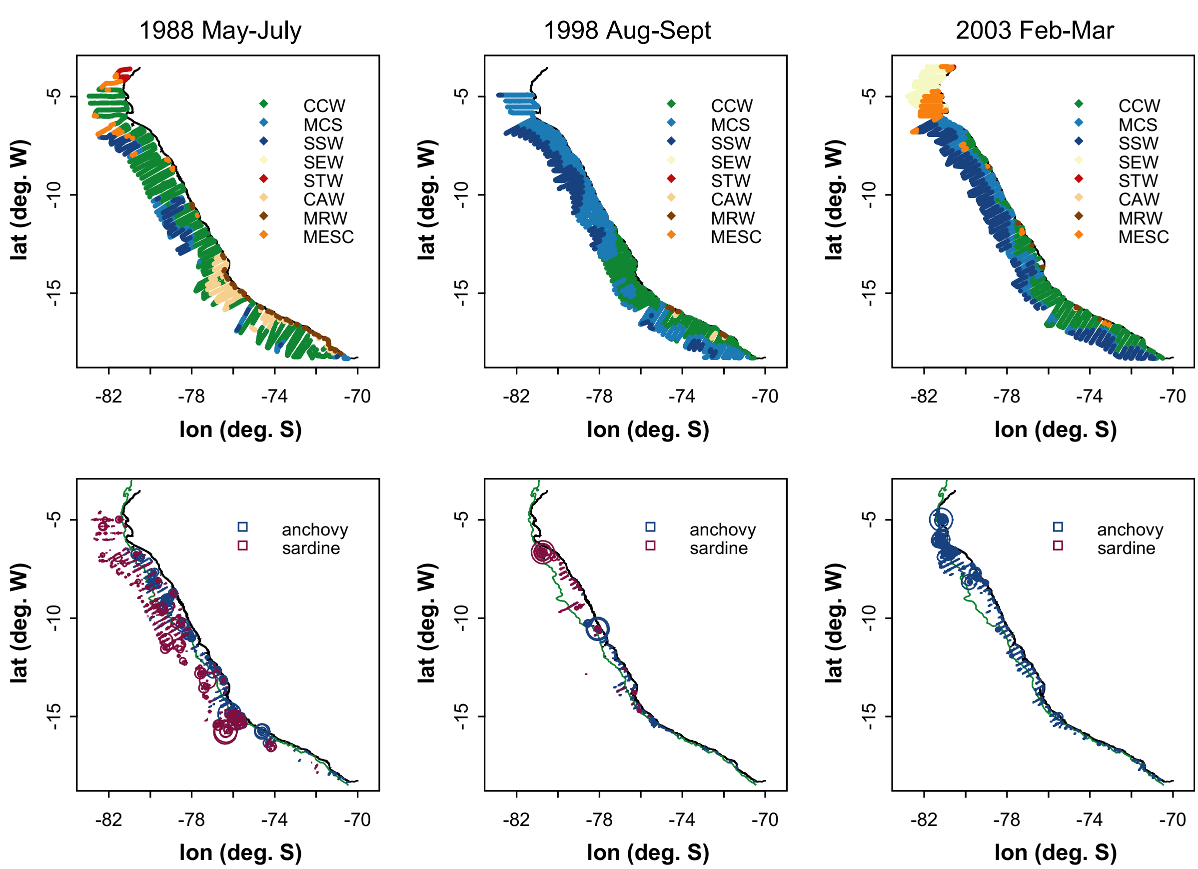

Fig. 1. Plots of the spatial distribution of anchovy (blue circles) and sardine (red circles) abundance (acoustic s_A; lower panels) and of eight water mass categories (upper panels) from acoustic surveys off the coast of Peru in (left to right) 1988, 1998, and 2003. The 200 m isobath is shown on the lower panels.