Journal of Marine Systems 164 (2016) 67–75

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Influence of climate variability on anchovy reproductive timing off northern Chile

Javier E. Contreras-Reyes [a,b,*], T. Mariella Canales [c], Pablo M. Rojas [d]

[a] División de Investigación Pesquera, Instituto de Fomento Pesquero, Blanco 839, Valparaíso, Chile
[b] Departamento de Matemáticas, Universidad Técnica Federico Santa María, Valparaíso, Chile
[c] Center of Applied Ecology and Sustainability (CAPES), Pontificia Universidad Católica de Chile, Santiago, Chile
[d] División de Investigación en Acuicultura, Instituto de Fomento Pesquero, Puerto Montt, Chile

ARTICLE INFO

Article history:
Received 15 January 2016
Received in revised form 10 August 2016
Accepted 11 August 2016
Available online 13 August 2016

Keywords:
Anchovy
Reproduction
Length
Environment
Northern Chile
Humboldt Current System

ABSTRACT

We investigated the relationship between environmental variables and the Gonadosomatic Monthly Mean (GMM) index of anchovy (*Engraulis ringens*) to understand how the environment affects the dynamics of anchovy reproductive timing. The data examined corresponds to biological information collected from samples of the landings off northern Chile (18°21′S, 24°00′S) during the period 1990–2010. We used the Humboldt Current Index (HCI) and the Multivariate ENSO Index (MEI), which combine several physical-oceanographic factors in the Tropical and South Pacific regions. Using the GMM index, we studied the dynamics of anchovy reproductive timing at different intervals of length, specifically females with a length between 11.5 and 14 cm (medium class) and longer than 14 cm (large class). Seasonal Autoregressive Integrated Mobile Average (SARIMA) was used to predict missing observations. The trends of the environment and reproductive indexes were explored via the Breaks For Additive Season and Trend (BFAST) statistical technique and the relationship between these indexes via cross-correlation functions (CCF) analysis. Our results showed that the habitat of anchovy switched from cool to warm condition, which also influenced gonad development. This was revealed by two and three significant changes (breaks) in the trend of the HCI and MEI indexes, and two significant breaks in the GMM of each time series of anchovy females (medium and large). Negative cross-correlation between the MEI index and GMM of medium and large class females was found, indicating that as the environment gets warmer (positive value of MEI) a decrease in the reproductive activity of anchovy can be expected. Correlation between the MEI index and larger females was stronger than with medium females. Additionally, our results indicate that the GMM index of anchovy for both length classes reaches two maximums per year; the first from August to September and the second from December to January. The intensity (maximum GMM values at rise point) of reproductive activity was not equal though, with the August–September peak being the highest. We also discuss how the synchronicity between environment and reproductive timing, the negative correlation found between MEI and GMM indexes, and the two increases per year of anchovy GMM relate to previous studies. Based on these findings we propose ways to advance in the understanding of how anchovy synchronize gonad development with the environment.

1. Introduction

The Humboldt Current Large Marine Ecosystem is a major Eastern Boundary Upwelling Ecosystem and extends from southern Chile (~45°S) to northern Peru and Ecuador (~4°S). It encompasses three well-defined upwelling subsystems: i) a productive seasonal upwelling system in central-southern Chile; ii) a lower productivity and rather large ‘upwelling shadow’ in northern Chile and southern Peru; and (iii) the highly productive year-round Peruvian upwelling system (Montecino and Lange, 2009). Three different anchovy (*Engraulis ringens*) stocks are supposed to inhabit each of these subsystems (Cubillos et al., 2007). This study concentrated in the anchovy off northern Chile (18°21′S-24°00′S) referred to as Northern Chilean Marine Ecosystem (NCME).

Climate variability in the NCME occurs at different temporal and spatial scales (Yáñez et al., 2008; Montecino and Lange, 2009). Large- and local-scale phenomena such as regimen shifts, ENSO cycle (El Niño-La Niña), seasonality, coastal-trapped waves and upwelling events have been postulated as driving biological processes in the NCME (Yáñez et al., 2008; Parada et al., 2013; Claramunt et al., 2014). Regime shifts in the Humboldt Current Ecosystem have been linked to long lasting periods (inter-decadal) of warm- or cold-water anomalies related to the

* Corresponding author at: División de Investigación Pesquera, Instituto de Fomento Pesquero, Blanco 839, Valparaíso, Chile.
E-mail addresses: jecontrr@uc.cl, javier.contreras@ifop.cl (J.E. Contreras-Reyes).

http://dx.doi.org/10.1016/j.jmarsys.2016.08.006
0924-7963/

proximity of the warm sub-tropical oceanic waters near the coast of Peru and Chile.

Small pelagic fish populations from upwelling ecosystems match their main spawning period with the cycles of the biological production to ensure the survival and growth of their offspring (Cole and McGlade, 1998), for if food is available the spawning process can take place (Hjort, 1914; Cushing, 1973). It has been postulated that the spawning season is matched with the biological production (plankton) for Chilean small pelagic fish populations. Cubillos et al. (2001) note that species such as *Engraulis ringens* and *Strangomera bentincki* (36°S-40°S) principally spawn around early spring, during high biological production, because of the upwelling season. The reproductive strategy of anchovy and sardine is to spawn at the end of August (austral winter), when the environment is characterized by a gradual alternation between northerly and southerly winds. The former promotes onshore transport, while southwesterly winds produce moderate upwelling events during the spawning season. Onshore transport produces coastal convergence, favoring concentration and retention of eggs and larvae, while moderate upwelling events enrich surface waters (Cubillos et al., 2001; Rojas and Landaeta, 2014).

The spawning period of the Chilean northern anchovy shows a smaller decrease in the summer compared to the anchovy stock of the central south, probably in response to environmental fluctuations (Claramunt et al., 2014). The synchronization of the main spawning period with physical environmental conditions has also been proposed for a more local population of *Engraulis ringens* located between 25°S and 32°S. In this context, it is hypothesized that circulation patterns and upwelling centers facilitate the retention and development of anchovy eggs (Rojas et al., 2002; Rojas and Landaeta, 2014; Canales and Leal, 2009). Leal et al. (2011) posited that the inter-annual frequency of the reproductive indexes of *Sprattus fuegensis* might be linked to the biological productivity and temperature of Chiloé's inland seawater.

The size-structure of the species population plays an important role in the reproductive timing. Cubillos and Claramunt (2009) found that larger females of *Strangomera bentincki* reach the reproductive peak earlier in the season than younger females at first maturity. However, compared to first-time spawners, larger anchovy females have a later reproductive peak. The reason for a differential effect of the reproductive peak with size in these two species is related to energy storage. Small fish are still growing, and their investment in the reproduction process is lower than that of adults, thus shortening the reproductive period of smaller females (Cubillos and Claramunt, 2009).

Also, environmental processes of a lower frequency such as ENSO and regime shifts potentially influence the intra-annual variation of the reproductive process of a small pelagic fish population (Rojas et al., 2011; Parada et al., 2013). Indeed, Ñiquen and Bouchon (2004) reported that the intra-annual variability of the reproductive timing of anchovy off northern Peru might alters when a climate event such as ENSO takes place. The event can disrupt and diminish reproductive timing, as happened during the one of 1997–98. Claramunt et al. (2014) argue that an increase in the duration of the spawning period of the Chilean northern anchovy since 1986 seems to coincide with the regime shift reported for the HCS in the mid-1980s.

For this paper, we investigated novel understandings of how environmental variability influences the reproductive timing of anchovy off northern Chile, and if anchovy body length changes with the environmental effect. We conducted an exhaustive temporal statistical analysis of environmental variables: Humboldt Current Index (HCI) and Multivariate ENSO Index (MEI) helped us to identify inter-annual variability such us ENSO and seasonal events. We used biological data, collected from the landing ports, to obtain a Gonadosomatic Monthly Mean (GMM) index for anchovy. We explored the data to search for and predict missed information, followed by the study of the trend of each time series. Then, we related the reproductive index of two classes of length with each environmental variable. In doing so, we addressed the following questions: Are the environmental changes significantly affecting the variability of the reproductive timing of anchovy? Does the environmental effect differ according to anchovy's length? We discuss the main results of the paper to answer these questions and suggest further research.

2. Data and methods

2.1. Data

The area of study is restricted to anchovy landings in the north of Chile (18°21′S-24°00′S), i.e., from the maritime limit between Chile and Peru until the Antofagasta port (Fig. 1). The registered anchovy landings were situated up to 60 nautical miles from the Chilean coast. Only environmental data (see Section 2.1.1) covers a larger area, depending on the index.

2.1.1. Environmental data

The environmental variability on an inter-annual and inter-decadal scale was studied with the Humboldt Current Index (HCI, http://www.bluewater.cl/HCI/) that represents ocean-atmosphere activity along the shore of the Chilean coast (Blanco, 2004). The HCI also allows us to identify the presence of El Niño (warm event) or La Niña (cold event) conditions through monthly averages of sea level pressure (SLP), obtained from the meteorological stations in Antofagasta (23°43′S, 70°45′W) and on Easter Island (27°9′S, 109°25′W). This index corresponds to the atmospheric pressure difference between the Pacific high-pressure system and the continental low pressure, and therefore represents the atmospheric activity that is the principal

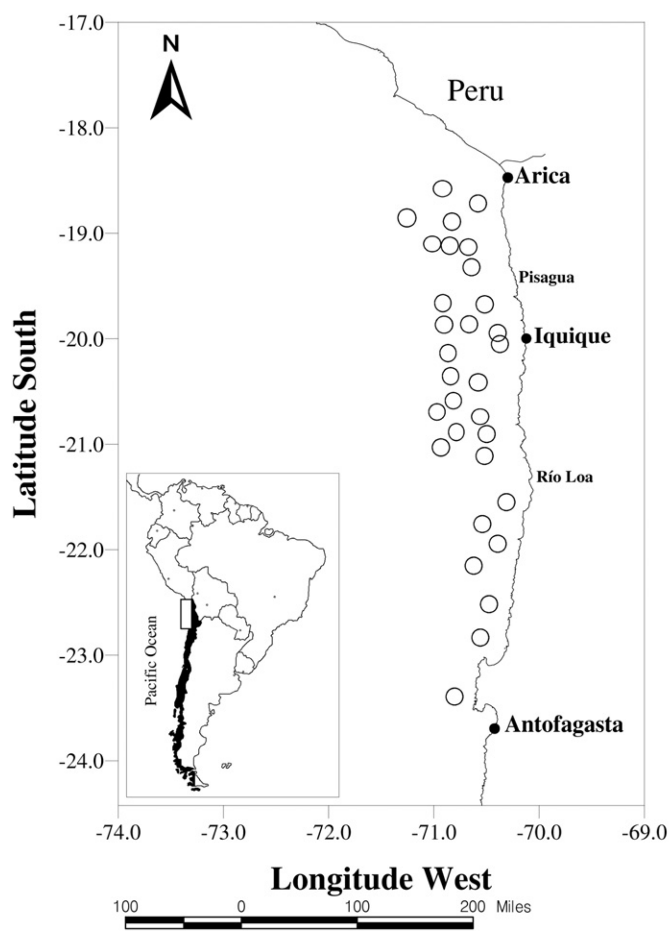

Fig. 1. Study area restricted to anchovy landings in the North of Chile (18°21′S-24°00′S). The circles represent gravity centers of CPUE distributions of anchovy in northern Chile during the study period (1990–2010).