Influence of mesoscale oceanographic structures on larval distribution and survival in jack mackerel (*Trachurus murphyi*) off Central Chile.

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Abstract

The jack mackerel is of ecological and commercial importance in the south-east Pacific Ocean. The main spawning ground of jack mackerel is located in the oceanic zone off Chile, while its nursery grounds are situated in the coastal zone off southern Peru and northern Chile. The eggs and larvae spawned in the region are likely to be transported to these nursery grounds. However, the mechanisms of the transport and the physical processes involved have not clarified yet. On the other hand, mesoscale eddies and strong energetic meanders are recurrent structures in the reproduction area of jack mackerel and could play a key role in the recruitment process that supports the population. Therefore, we assessed the association between jack mackerel larvae and mesoscale structures using the Ohkubo-Weiss parameter along with information from otolith microstructure. The results showed that i) there was a significant increase in increment age with distance onshore. The largest/oldest specimens were collected at the limit of onshore sampling suggesting that transport processes could promote a larval entrance toward coastal zones; ii) surface circulation patterns, based on the trajectories of satellite-tracked drifters observed, provide an onshore transport mechanism for the larvae, and iii) an anticyclonic water circulation dominates the overall circulation and could be related with high meandering activity observed in our study. This latter seems to be the major mechanism affecting the jack mackerel early life history and could drive the transport to the nursery ground.

Keywords: eggs and larvae, Ohkubo-Weiss parameter, mesoscale eddies, meandering currents, recruitment, transport.
Introduction

The jack mackerel (*Trachurus murphyi*) is a medium-sized pelagic fish of ecological and commercial importance in the south-east Pacific Ocean. It inhabits from the Chilean and Peruvian coasts to beyond 1000 nautical miles from the central coast of Chile (Cárdenas *et al*., 2009). From the distribution of eggs and larvae, juveniles and mature females it had been inferred that the population structure of jack mackerel includes three different habitats off the eastern coast of South America: i) a nursery ground located in the coastal zone off southern Peru and northern Chile, ii) a feeding ground located in the central-south zone off Chile, where occurs the recruitment (2 - 3 year-old individuals) and finally, iii) an extensive dispersion to the oceanic zone off central Chile where take place the spawning during spring (Figure 1).

The abundance of marine fish populations is primarily dependent on the strength of yearly recruitment, which is mainly determined by survival during early life stages. Among various physical processes affecting the recruitment, the transport of eggs and larvae from the spawning grounds to their nurseries is one of the most important. The connection between spawning and nursery grounds, during the planktonic stage of marine species, requires eggs and larvae to be transported to specific locations where favorable conditions for the growth exist (Hare and Cowan, 1993). This process is particularly relevant when the nursery ground is distant from the spawning area, like occurs in jack mackerel. The high geographic distance (up to 1000 km) that separate the jack mackerel spawning zone from the nursery grounds, means that an efficient mechanism is needed to transport eggs and larvae from the deep ocean to the productive coastal zone during the stages when they are unable to transport themselves actively. The oceanographic structures involved in this transport have a deep impact because they can affect the larval survival and subsequent recruitment. Structures as large-scale meanders, jet currents and mesoscale eddies have been observed influencing the distribution of larval fish (Bruce *et al*., 2001), affecting the fish recruitment and consequently modulating the fluctuations in fish stocks (Watanabe, 1982, Nakata *et al*., 2001).

Mesoscale eddies and strong energetic meanders are ubiquitous features which are forming a highly dynamic coastal transition zone (CTZ) off central Chile (Hormazabal
et al., 2004; Correa-Ramirez et al., 2007), been these structures recurrent features in the reproduction area of jack mackerel. These mesoscale eddies have been observed traveling westward with a speed near to the theoretical speed of a Rossby wave (Hormazabal et al., 2004; Correa-Ramirez, 2007; Leth and Sahffer, 2001; Chaigneau & Pizarro 2005). However, drifters deployed between 1979-2004 around the 35ºS in the zone of the Subtropical Front (STF) shows that the meanders associated to these eddies flows eastward with velocities around 7 cm s⁻¹, connecting the deep ocean with the coastal zone (Chaigneau & Pizarro 2005). Since the jack mackerel spawning area has been associated with sea surface temperatures between 15 – 18ºC on the STF zone (Evseenko, 1987), the larvae hatched in STF during October-December could be transported by way of meander currents to the coastal zone in northern Chile and southern Peru, where the coastal upwelling provides a suitable nursery ground and enough food supply. The interannual fluctuations in the proportion of recruits derived from the oceanic spawning zone off Chile would be important in structuring population of jack mackerel. However, several aspects of the early life history of jack mackerel and the transport process from the spawning area to nurseries area remain unknown. In this paper, therefore, we will assess the association between jack mackerel larvae and mesoscale structures using the Ohkubo-Weiss parameter along with information from otolith microstructure. The main processes associated to the transport and survival of the early stages of jack mackerel is discussed.

Material and methods

Sampling and ageing
Jack mackerel eggs and larvae where sorted from planktonic samples collected in the oceanic zone off central Chile during three research cruises carried out using fishing during November/December, 2003-2005 (Table I). The jack mackerel early developmental stages were collected through vertical hauls with a WP-2 net (60 cm diameter, 303 μm mesh size) from 100 m to depth. The reported abundance was standardized to a unit of sea surface (10 m²) based on the volume filtered and the maximum depth sampled. All *T. murphyi* were measured (to the nearest 0.1 mm) using an ocular micrometer. Jack mackerel larvae were aged by examining saggittal otolith microstructure following Campana (1992). The increment deposition was assumed to be daily, based on previous studies carried out in congeneric species which age validation
has been previously documented (Theilacker, 1978; Jordan et al., 1994; Xie et al., 2005). Increments counts were taken from 100, 112 and 118 otoliths for 2003, 2004 and 2005 respectively. The number of increments counted for each year was used in calculations of larvae age. Gompertz model was used to describe the growth and estimate the age of jack mackerel larvae. Finally, the larvae abundance was grouped in five days classes in order to observe the spatial structure of different ontogenetic stages and their association with the mesoscale structures.

**Physical oceanography and mesoscale structures**

In order to assess the association between *T. murphyi* eggs and larvae distribution with environmental variability and mesoscale structures, we compiled data from three sources; cruise data, satellite data on sea surface temperature (SST), *chl a*, and geostrophic velocity obtained from sea level height for the *in situ* sampling period, and satellite-tracked drifters to examine the circulation patterns. Eddies and meander currents were identified by applying the Okubo-Weiss parameter (*W*), which allows separating vorticity-dominated regions (Isern-Fontanet et al., 2004). A threshold value of $1 \times 10^{-12}$ was used to distinguish and isolate the coherent eddies structures from the background field, which is mainly associated to meanders currents flowing around the eddies (Figure 2). Eddies with diameters <70 km were not considered. Cyclonic and anticyclonic eddies were distinguished by the vorticity sign (- or +, respectively). Finally, in order to verify the association between jack mackerel eggs and larvae, we calculated the frequency of eggs and larvae inside of cyclonic and anticyclonic eddies and on the meander currents.

**Results and discussion**

*Eggs and larvae distribution and oceanographic conditions*

The spatial distribution of Sea Surface temperature (SST) and Chlorophyll-a (CHL-a) are shown in Figure 2 (a and b respectively). The jack mackerel spawning zone was widely characterized for the presence of the Subtropical Front (STF) that separates Subantarctic waters in the south from warmer Subtropical waters in the north. The STF extended southward in a broad wedge and its position was highly correlated with the position of 16°C isotherm and the main bulks off jack mackerel eggs and larvae (Figure
The CHL-a distribution showed a marked east-west gradient with high concentrations in the coastal zone related with productive upwelling centers. The action of mesoscale eddies and upwelling filaments promotes an extension of CHL toward the oceanic zone, favoring a biological enrichment in the zone where jack mackerel reproduction occurs. A total of 913, 2163 and 1798 (5 – 45 days old) *T. murphyi* were recorded in 2003, 2004 and 2005 respectively. Jack mackerel larvae were widely distributed in all three years and were recorded up to the limit of sampling, 1900 km offshore. There was a significant increase in larval age with distance onshore (Figure 3). The largest/oldest specimens were collected at the limit of onshore sampling (200 km) suggesting that transport processes could promote a larval entrance toward coastal zones.

**Influence of mesoscale structures on eggs and larvae**

Mesoscale eddies and meandering currents were the main mesoscale structures observed in the jack mackerel spawning area. The generation of mesoscale eddies are associated to a high eddy kinetic energy in the Chilean coastal zone between 30° and 38°S as product of baroclinic instabilities (Leth and Shaffer, 2001). These oceanographic features tend to travel westward and promote transport of trapped particles from the coastal zone to the deep ocean (Morales *et al*., 2010). On the other hand, Chaigneau and Pizarro (2005) showed that the mean surface circulation around the 35° flows eastward with velocities around 7 cm s⁻¹ due to the presence of an anticyclonic recirculation cell. Surface circulation patterns, based on the trajectories of three satellite-tracked drifters observed, provide an onshore transport mechanism for the larvae. Once onshore, the behavior of these drifters suggests that surface circulation patterns may also facilitate the retention of early stages within the coastal zone and may provide a mechanism for the arrival of larvae toward the nursery grounds. In addition, given the size of the larval recorded on the onshore limit and presumed swimming capabilities, active orientation and movement may play a role. Through the use of Ohkubo-Weiss parameter we detect the presence of several mesoscale eddies in the study area (Figure 2; b and c). The association between jack mackerel eggs and larvae and mesoscale eddies was less than de 50% for the three years studied (37.8, 35.5 and 41.0% for eggs; 39.5, 31.7 and 42.3% for larvae; in 2003, 2004 and 2005 respectively). Consequently, jack mackerel larvae once entrained by the mesoscale eddy would be transported offshore, away from the nursery grounds. In addition, we detected the presence of strong meander currents in the
vicinity of mesoscale eddies flowing often eastward and may constitutes an relevant mechanism for the larval transport toward the coast.

**Summary**

The results indicated that two major source of transport affecting the early stages of jack mackerel. The first associated to mesoscale eddies that travel westward and could transport jack mackerel eggs and larvae offshore, away from nursery grounds, and the second associated to anticyclonic water circulation that dominates the overall circulation and could be related with the meandering activity observed in our study. The spatial distribution of older jack mackerel larvae suggest that the latter mechanism could drive the jack mackerel larvae intrusion into coastal waters, contributing to jack mackerel recruitment to the nursery grounds.
**Table 1.** Description of the surveys performed in the jack mackerel oceanic spawning area.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>Latitudinal Range</th>
<th>Inter-transect distance (nm)</th>
<th>Number of stations</th>
<th>Positive Stations (%)</th>
<th>Study area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>10/11 – 22/11</td>
<td>33°06’ – 38°00’</td>
<td>20</td>
<td>694</td>
<td>60,4</td>
<td>871.179</td>
</tr>
<tr>
<td>2004</td>
<td>21/11 – 01/12</td>
<td>33°00’ – 38°00’</td>
<td>20</td>
<td>910</td>
<td>72,3</td>
<td>1.385.613</td>
</tr>
<tr>
<td>2005</td>
<td>22/11 – 02/12</td>
<td>33°00’ – 38°40’</td>
<td>20</td>
<td>784</td>
<td>41,6</td>
<td>1.222.143</td>
</tr>
</tbody>
</table>
Figure 1. Conceptual model for jack mackerel population off Chile (Modified after Arcos et al., 2001)

Figure 2: Distribution of satellite SST (a), surface chlophyll (b), jack mackerel eggs (c) and jack mackerel larvae (d). In panels c) and d) distribution of dynamic field and mesoscale identified by the Okubo–Weiss parameter are shown (anticyclonic in grey; cyclonic in black).
Figure 1. Relationship between jack mackerel larval age and distance offshore for 2003 (a), 2004 (b) and 2005 (c).
Figure 5. Trajectories of three satellite-tracked surface drifters in the southeastern Pacific Ocean.
References


