Long term changes in zooplankton size distribution in the Peruvian Humboldt Current System: Conditions favouring sardine or anchovy

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MAIN UPWELLING SYSTEMS

- California Current
- Humboldt Current
- Canary Current
- Benguela Current

Legend:
- Major upwelling
- Area of high pressure
- Direction of ocean current
Pacific sardine
*Sardinops sagax*

Peruvian anchovy
*Engraulis ringens*
Trend of Mean Biomass of Peruvian ANCHOVY and SARDINE (Northern - Central stock)

Source: Guevara-Carrasco
Hypotheses to explain alternation

Salinity Anomalies

Oxygen Anomalies

RECRUITMENT

Source F. Chavez

Source R. Guevara-Carrasco
Hypotheses to explain sardine-anchovy alternation

- Size-selective feeding hypothesis
- Optimal growth temperature
- Avoidance of low oxygen waters (upwelling) by sardine (habitat change)
A few relevant facts

- Sardine distribution farther offshore than anchovy.
- Sardine predominate during warmer periods (El Niño, El Viejo), anchovy during colder (higher upwelling) periods (La Niña, La Vieja).
- Anchovy are more associated with cold coastal waters, sardine with offshore oceanic waters.
Size feeding hypothesis argument and support

• Both can filter feed, but sardine can filter feed energetically more efficiently and can take smaller organisms (up to 1 mm)
• Anchovy are mostly bite feeders and larger prey provide more nutrients
• More upwelling $\rightarrow$ more nutrients $\rightarrow$ larger phytoplankton $\rightarrow$ larger zooplankton $\rightarrow$ favor anchovy
• Less upwelling $\rightarrow$ scarce nutrients $\rightarrow$ smaller phytoplankton $\rightarrow$ smaller zooplankton $\rightarrow$ favor sardine
Examine size-feeding hypothesis

• Use zooplankton samples (formaldehyde stored) from 121 surveys 1963-2005 (> 15,000 samples)
Zooplankton Sampling

• Hensen nets, 300-um mesh
• 0-50 m vertical haul
• Remove gelatinous zooplankton and ichthyoplankton
• Zooplankton dominated by copepods and euphausiids
• Determined biovolume at time of sample
Qualitative sampling

- Classify organisms by size: small, medium, large zooplankton, euphausiids
- In each sample classify dominance of each size groups by integer between 0 and 3 (0=absent)
- Dominance is independent of biovolume (supposedly!)
Zooplankton analysis
1. Validation

Comparison with two data sets:

• A) Species enumerations for 2 surveys in 1996 and 1998 (species composition-abundance)

• B) Size distribution from Zooscan on 2 surveys in 1965 and 1967 (32 samples)
  
  small <1.3mm                        medium 1.3-2.9mm
  large > 2.9mm                       euphausiids 10-25mm
# Zooplankton Analysis

## 1. Validation - Correlation (r)

<table>
<thead>
<tr>
<th>Data</th>
<th>Small zooplankton (&lt; 1.3 mm)</th>
<th>Medium zooplankton (1.3-2.9 mm)</th>
<th>Large zooplankton (&gt;2.9 mm)*</th>
<th>Euphausiids (10-25 mm)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996,1998 species composition A</td>
<td>0.22 (p =0.027)</td>
<td>0.33 (p=0.0014)</td>
<td>0.24 (p=0.016)</td>
<td>0.519 (p=5x10^-7)</td>
</tr>
<tr>
<td>1965, 1967 Zooscan size composition B</td>
<td>0.433 (p=0.013)</td>
<td>0.526 (P=0.0019)</td>
<td>0.407 (0.0205)</td>
<td>0.761 (4.3 x10^-7)</td>
</tr>
</tbody>
</table>
Zooplankton analysis - GAM

• Generalized Additive Models Nonparametric regression – uses smooths instead of least square fits (not linear)

• Effect of covariates – Sea surface temperature (SST), surface salinity (SSS), latitude (lat), year, month (mo), time of day (time) and distance from 200-m isobath (dist200; determines on-off shelf location)
Zooplankton analysis
GAM- small zooplankton significant covariates

Abundance of small zooplankton along time

Seasonality of small zooplankton
Zooplankton analysis – GAM

- **euphausiids**

- **distance from 200-m isobath**

- **on-off shelf effect**

- **distance from 200-m isobath**

- **year effect**

- **year**

- **time of day**

- **diel effect**

- **time of day**

- **Abundance of euphausiid along time**
Zooplankton analysis – relationship to anchovy and sardine abundance
Zooplankton size – fish time series

Examine temporal pattern of size classes of zooplankton in relation to sardine and anchovy biomass time series:

- Cross correlation analysis at different time lags (i.e. years)
Zooplankton size – fish time series – cross correlation analysis

A – anchovy-euphausiids

B – sardine-small zooplankton
Cross correlation interpretation

- Anchovy in phase with euphausiids
- Sardine in phase with small zooplankton
- Other size groups not in phase with either
- This supports the size-feeding hypothesis for both anchovy and sardine