Ecological and functional role of key fish species from the pelagic community of the NW Mediterranean Sea

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The Ebro delta continental shelf is an important spawning ground of anchovy and sardine.

Due to their high biomass SPF play a key role transferring energy from lower to higher trophic levels (Coll et al., 2008)
Anchovy and sardine landings (t) in the GSA06 region from 1940 to 2014
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News from local newspapers about declines of sardine landings (03/03/2016)
We need ecological knowledge on the specific trophic interactions and energy dynamics between species.
To investigate the seasonal **energy dynamics** and the **trophic relationships** between the main species of the pelagic compartment, focusing on European anchovy and European pilchard
How do we study the ecological role of SPF?

Stable Isotopes

- $\delta^{15}N$
- $\delta^{13}C$

Diet/Trophic level

Habitat/food resources
Stable Isotopes

Research questions:
1. Which species present trophic overlap?
2. Is there a seasonal variation of the community structure?
How do we study the ecological role of SPF?

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Energy Density

Direct Bomb calorimetry
How do we study the ecological role of SPF?

**Stable Isotopes**

*Research questions:*
1. Which species present trophic overlap?
2. Is there a seasonal variation of the community structure?

**Energy Density**

*Research questions:*
1. Which are the pelagic species with higher energy density-prey quality?
2. Is there a variation of the seasonal energy density?
Mean and standard deviation of $\delta^{13}$C and $\delta^{15}$N values


- No major shifts in the relative position of species across seasons
- Sardine and anchovy had the lowest trophic positions
Standard ellipses \( \rightarrow \) measure trophic niche overlap

**Small pelagic fishes adults**

- Sardine and anchovy overlapped their niches.
- Although the three species are plankton feeders, sardinella segregated the isotopic niche from sardine and anchovy.

**Why?**
Anchovy preyed mainly on copepods (Tudela & Palomera MEPS160: 121-124)

Sardine preyed mainly on copepods, cladocerans, and diatoms (Costalago & Palomera 2014 Sci Mar 78:41-54)
How do we study the ecological role of SPF?

Research questions:

1. Which is the niche position of each group (SPF, MPF, Predator) respect to the others?
2. Is there a variation of the community structure between seasons?

Stomach Content Analysis

Stable Isotopes

Energy Density

Bomb calorimetry
How do we study the ecological role of SPF?

**Stable Isotopes**

*Research questions:*

1. Sardinella segregate the trophic niche from the other SPF
2. Overall community structure is stable through the year
3. Sardinella prey on gelatinous zooplankton

**Energy Density**

Direct Bomb calorimetry
Energy Density of Small and Medium Pelagic Fishes

- Sardine had high ED in comparison to the other SPF due to the accumulation of fat reserves for spawning.
- Species were classified in Moderate or High quality following Spitz et al., (2010).

Pairs of means differing significantly (P <0.05) by pairwise tests between species are indicated by the letters - species with the same letter were not significantly different (Albo-Puigserver et al., 2017 Deep-Sea Res pt II, In press).
**E. encrasicolus**: High ED during spawning season $\rightarrow$ income breeder

**S. pilchardus**: Accumulation of energy during Spring and summer $\rightarrow$ capital breeder

**S. aurita**: Previous accumulation of energy before spawning and a decrease during spawning $\rightarrow$ high plasticity

Albo-Puigserver et al., 2017
Dynamic Energy Budget Model: *Engraulis encrasicolus*

Responses of European anchovy vital rates and population growth to environmental fluctuations: An individual–based modeling approach

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2 IFREMER, Research Unit: Fisheries Resources, Centre de Sète, France
3 University of California Santa Barbara, Department of Ecology, Evolution and Marine Biology, Santa Barbara, CA 93106-9620, USA
Dynamic Energy Budget Model: *Sardina pilchardus*

- Sardine is a multiple spawner that rely in energy stored during summer as fat for reproduction during late autumn-winter.
- The Mediterranean Sea is a climate change hotspot. Shifts in plankton productivity and increase of the SST are expected.

How variations on temperature and food availability would affect the life-cycle of *Sardina pilchardus*?

ENVIRONMENT
Food & Temperature

Ingestion $\rightarrow$ Assimilation $p_A \rightarrow$ Reserve $\rightarrow$ Maturation (Larvae & Juveniles) $\rightarrow$ Reproduction (Adults) $\rightarrow$ Gametes

- Sardina is a multiple spawner that rely in energy stored during summer as fat for reproduction during late autumn-winter.
- The Mediterranean Sea is a climate change hotspot. Shifts in plankton productivity and increase of the SST are expected.

**Models**

- Dynamic Energy Budget Model: *Sardina pilchardus*
Dynamic Energy Budget Model: *Sardina pilchardus*

**Model calibration**

**Environmental scenarios**

Bioenergetics simulations successfully captured ontogenetic and seasonal growth patterns, not the energy patterns.
How do we study the ecological role of SPF?

**Stable Isotopes**

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*Research questions:*
1. Sardine classified as high quality prey
2. Sardine and anchovy have a capital and income breeding behavior, respectively
3. Increase of temperature or decrease in food availability decrease sardine’s fecundity?
How do we study the ecological role of SPF?

**Stable Isotopes**

**Research questions:**
1. Sardinella, mackerels and horse-mackerels segregate
2. Despite intraspecific seasonal variability, overall community structure is stable through the year
3. Sardinella prey on gelatinous zooplankton

**Energy Density**

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**Previous studies and knowledge**

**Qualitative modeling in complex systems**

**Precision**

**Generality Realism**
Qualitative modelling: being useful to rapidly assess alternative assumptions about system structure

From the signed digraph one can examine the feedback properties of a system (stability analysis)
Qualitative modelling: hypotheses testing

Core model

Alternative model structure

1. Predators don’t limit round sardinella
2. SPF don’t compete for food
3. Jellyfish prey on anchovy larvae and zooplankton

Hypotheses

<table>
<thead>
<tr>
<th>Temperature</th>
<th>( H_1 ). Increase T (9) reduces reproduction rate of sardine (1)</th>
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<td>SPF</td>
<td>( H_2 ). Increase T (9) changes zooplankton composition (5) with lower quality of food for sardine, anchovy and round sardinella (SPF)</td>
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Fisheries

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<th>( H_3 ). Fisheries (8) prefer and have overexploited anchovy (2) and switch to sardine (1) when anchovy (2) is low</th>
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<td>( H_4 ). Recruitment highly fished (8) on sardine (1) and anchovy (2)</td>
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Predators

| \( H_6 \). Recovery of Tuna (7) decreases the abundance of sardine (1) and anchovy (2) |

Qualitative modelling: hypotheses testing

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Qualitative modelling: hypotheses testing

"Qualitatively Specified Community Matrix (S\(A\))"

\[
\begin{pmatrix}
-1 & 0 & 0 & 1 & 1 & 0 & -1 & -1 & 0 \\
0 & -1 & 0 & 0 & 1 & 0 & -1 & -1 & 0 \\
0 & 0 & -1 & 0 & 1 & 1 & -1 & 0 & 0 \\
-1 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 1 & 0 & -1 & 0 & 0 & 1 \\
1 & 1 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{pmatrix}
\]

"weighted predictions (W)"

\[
\begin{pmatrix}
0.60 & 0.25 & 0.20 & 0.31 & 0.14 & 0.20 & 0.43 & 0.22 & 0.20 \\
0.33 & 0.41 & 0.38 & 0.18 & 0.41 & 0.38 & 0.13 & 0.15 & 0.38 \\
0.38 & 0.11 & 0.52 & 0.20 & 0.067 & 0.52 & 0.18 & 0.24 & 0.52 \\
0.30 & 0.38 & 0.27 & 0.43 & 0.60 & 0.27 & 0.23 & 0. & 0.27 \\
0.38 & 0.12 & 0.11 & 0.20 & 0.85 & 0.11 & 0.82 & 0.25 & 0.11 \\
0. & 0.33 & 0.25 & 0.27 & 0.44 & 0.38 & 0. & 0.17 & 0.11 \\
0. & 0.33 & 0.33 & 0.44 & 0.33 & 0.33 & 0.60 & 0.19 & 0.33 \\
1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.32 & 1.0 \\
1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 1.0 & 0.32 & 1.0
\end{pmatrix}
\]

Press perturbation analysis

Divided by the total feedback matrix

Dambacher et al., 2003 Am Nat 161, 876-888
Qualitative modelling: hypotheses testing

Predictions of qualitative response to a positive input

<table>
<thead>
<tr>
<th>Input and response variable</th>
<th>M</th>
<th>M_{H1}</th>
<th>M_{H2}</th>
<th>M_{H1,2}</th>
<th>M_{H3}</th>
<th>M_{H4}</th>
<th>M_{H5}</th>
<th>M_{H3,4}</th>
<th>M_{H3,5}</th>
<th>M_{H6}</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Input to temperature</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Anchovy</td>
<td>(-)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
</tr>
<tr>
<td>Sardinella</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
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<td>(+)</td>
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<tr>
<td>b) Input to fisheries</td>
<td></td>
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</tr>
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<td>Sardinella</td>
<td>(+)</td>
<td>(+)</td>
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<td>(+)</td>
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<tr>
<td>c) Input to predators</td>
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<td></td>
</tr>
<tr>
<td>Sardine</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
<td>(-)</td>
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"Qualitatively Specified Community Matrix (\(\delta A\))"

\[
\begin{bmatrix}
-1 & 0 & 0 & 1 & 1 & 0 & -1 & -1 & 0 \\
0 & -1 & 0 & 0 & 1 & 0 & -1 & -1 & 0 \\
0 & 0 & -1 & 0 & 1 & 1 & -1 & 0 & 1 \\
-1 & 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0
\end{bmatrix}
\]

\[
A :=
\begin{bmatrix}
-1 & -1 & -1 & 1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 1 & 0 & -1 & 0 & 0 & 1 \\
1 & 1 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1
\end{bmatrix}
\]

Press perturbation analysis

"adjoint (\(-A\))"

\[
\begin{bmatrix}
12 & -4 & -2 & 8 & -2 & -2 & -6 & -8 & -4 \\
-6 & 14 & -5 & -4 & 7 & -5 & -3 & -8 & -10 \\
-6 & -2 & 11 & 4 & -1 & 11 & -3 & 8 & 22 \\
-6 & 6 & 3 & 12 & -9 & 3 & -3 & 0 & 6 \\
-6 & -2 & -1 & 4 & 11 & -1 & 9 & 8 & -2 \\
0 & 8 & -8 & 8 & -8 & 16 & 0 & -8 & 8 \\
0 & 8 & 4 & 8 & 4 & 12 & -8 & 8 & 8 \\
0 & 0 & 0 & 0 & 0 & 0 & 24 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 24
\end{bmatrix}
\]

Divided by the total feedback matrix

Dambacher et al., 2003 Am Nat 161, 876-888
Most of the model structures tested were sign stable. However, when we include recruitment overfishing was unstable and the system collapse.

The high proportion of sign indeterminacy (?) indicated that small changes can reverse the direction of the response;

Lower quality zooplankton (bottom-up control) and fisheries (top-down control) in combination with an increase of temperature (press perturbation) lead to a decrease in sardine and anchovy and an increase in sardinella, in line with field observations;

Probably environmental fluctuations and bottom-up control alone do not explain the decline on sardine and anchovy without considering the impact of fishing.
Thank you!

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For more information see Posters:
S2-P4; S3-P4; S5-P1