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

Marta Albo-Puigserver, Joan Navarro, Isabel Palomera and Marta Coll

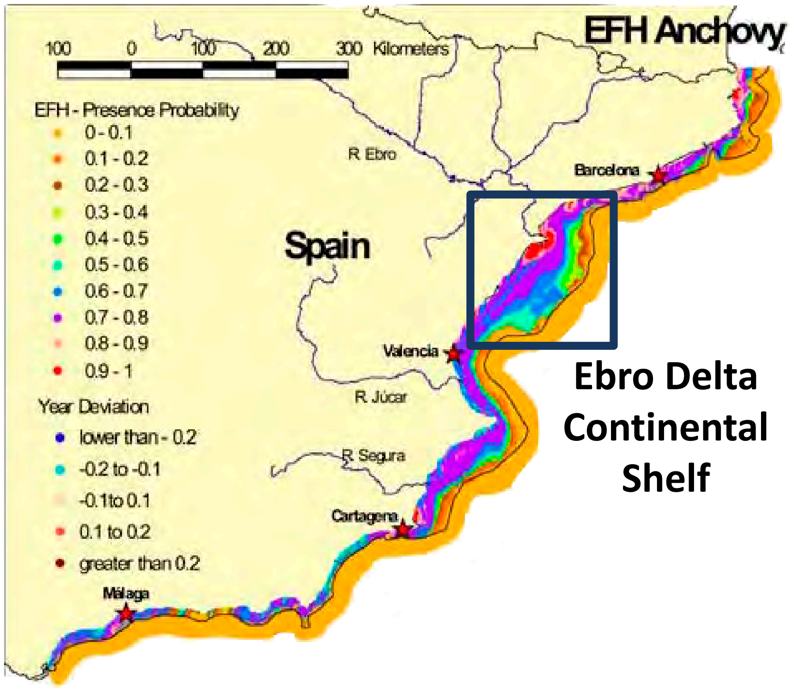
Institut de Ciències del Mar (ICM-CSIC), Barcelona, Spain
E-mail: albo@icm.csic.es

Institut de Ciències del Mar

ECOTRANS

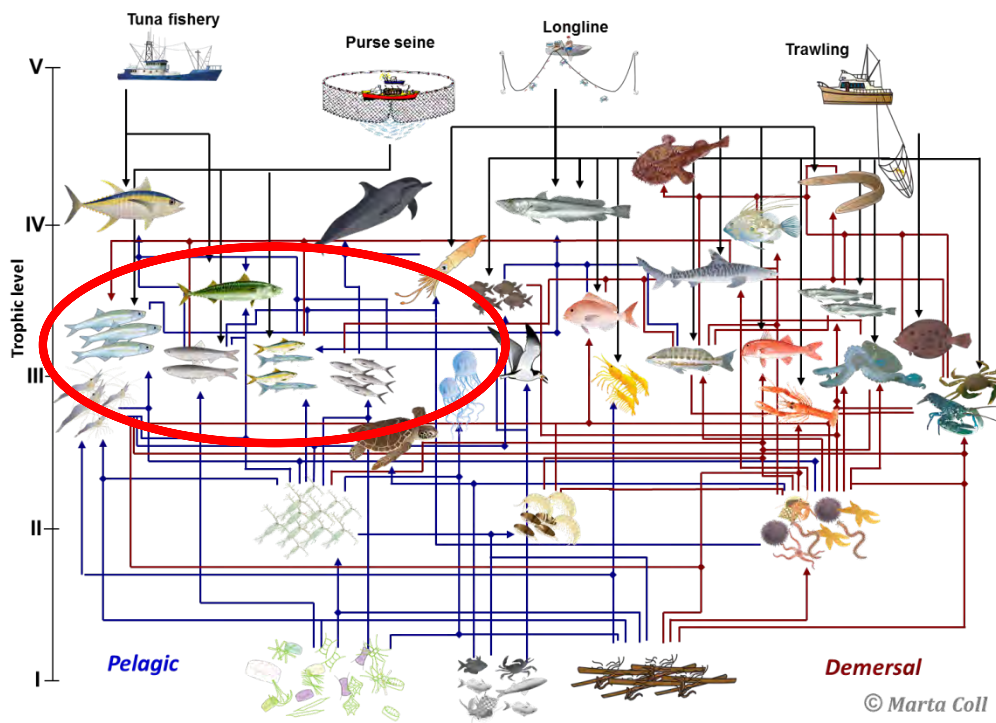

Mediterranean Sea

Essential Fish Habitat map

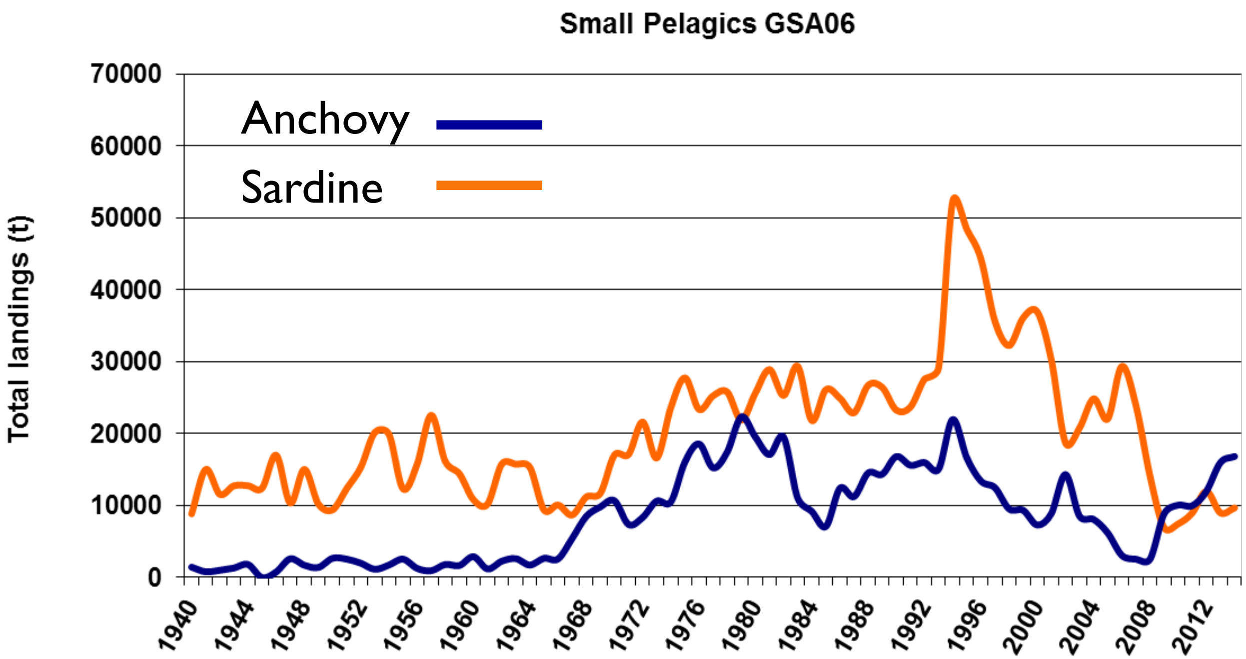


Essential Fish Habitat map showing the predicted probability of presence of anchovy (Bellido et al., 2008, Hydrobiol 612:171-184)

- 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)



Representation of the NW Mediterranean food-web



Anchovy and sardine landings (t) in the GSA06 region from 1940 to 2014

Progress in Oceanography 151 (2017) 149–162

Contents lists available at ScienceDirect

Progress in Oceanography

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

Spatio-temporal patterns and environmental controls of small pelagic fish body condition from contrasted Mediterranean areas

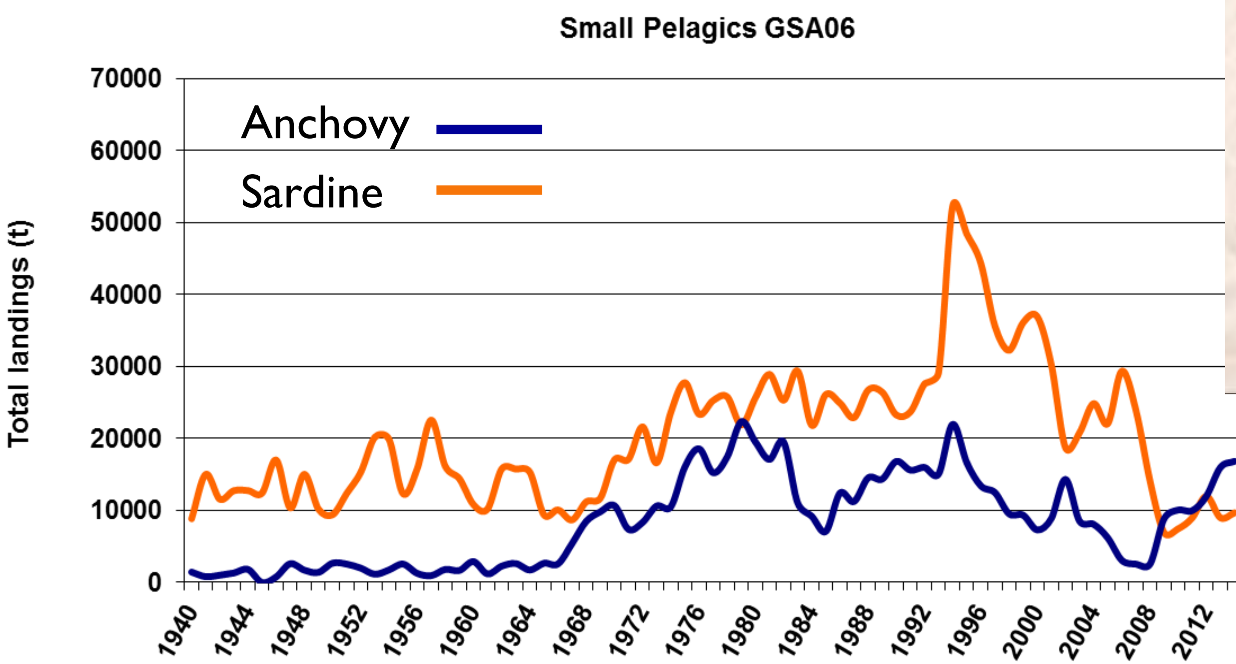
Pablo Brosset [a,b,*], Jean-Marc Fromentin [b], Elisabeth Van Beveren [b], Josep Lloret [c], Virginie Marques [b], Gualtiero Basilone [d], Angelo Bonanno [d], Piera Carpi [e,f], Fortunata Donato [e], Vanja Čikeš Keč [g], Andrea De Felice [e], Rosalia Ferreri [d], Denis Gašparević [g], Ana Giráldez [i], Ali Gücü [h], Magdalena Iglesias [j], Iole Leonori [e], Isabel Palomera [k], Stylianos Somarakis [l], Vjekoslav Tičina [g], Pedro Torres [i], Ana Ventero [j], Barbara Zorica [g], Frédéric Ménard [m], Claire Saraux [b]

Mar Biol (2014) 161:1809–1822
DOI 10.1007/s00227-014-2463-1

ORIGINAL PAPER

Rapid changes in growth, condition, size and age of small pelagic fish in the Mediterranean

Elisabeth Van Beveren · Sylvain Bonhommeau · Jean-Marc Fromentin · Jean-Louis Bigot · Jean-Hervé Bourdeix · Pablo Brosset · David Roos · Claire Saraux



Anchovy and sardine landings (t) in the GSA06 region from 1940 to 2014

PESCA

La captura de sardinas cae un 86% en siete años

Los pescadores califican la situación de dramática y reclaman medidas urgentes para evitar la desaparición del sector

elPeriódico SOCIEDAD

El desplome de las capturas de sardinas pone en jaque a la flota de cerco

Las cofradías catalanas han solicitado al Gobierno y la Generalitat medidas urgentes

News from local newspapers about declines of sardine landings (03/03/2016)

Progress in Oceanography 151 (2017) 149–162

Contents lists available at ScienceDirect

Progress in Oceanography

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

Spatio-temporal patterns and environmental controls of small pelagic fish body condition from contrasted Mediterranean areas

Pablo Brosset [a,b,*], Jean-Marc Fromentin [b], Elisabeth Van Beveren [b], Josep Lloret [c], Virginie Marques [b], Gualtiero Basilone [d], Angelo Bonanno [d], Piera Carpi [e,f], Fortunata Donato [e], Vanja Čikeš Keč [g], Andrea De Felice [e], Rosalia Ferreri [d], Denis Gašparević [g], Ana Giráldez [i], Ali Gücü [h], Magdalena Iglesias [j], Iole Leonori [e], Isabel Palomera [k], Stylianos Somarakis [l], Vjekoslav Tičina [g], Pedro Torres [i], Ana Ventero [j], Barbara Zorica [g], Frédéric Ménard [m], Claire Saraux [b]

Mar Biol (2014) 161:1809–1822
DOI 10.1007/s00227-014-2463-1

ORIGINAL PAPER

Rapid changes in growth, condition, size and age of small pelagic fish in the Mediterranean

Elisabeth Van Beveren · Sylvain Bonhommeau · Jean-Marc Fromentin · Jean-Louis Bigot · Jean-Hervé Bourdeix · Pablo Brosset · David Roos · Claire Saraux

Bottom up

Overfishing

Top-down

Climate change

Competition

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

Small Pelagic

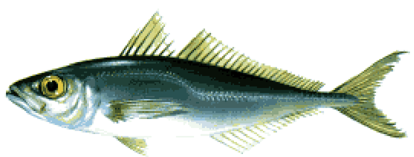
E. encrasicolus

S. pilchardus

S. aurita

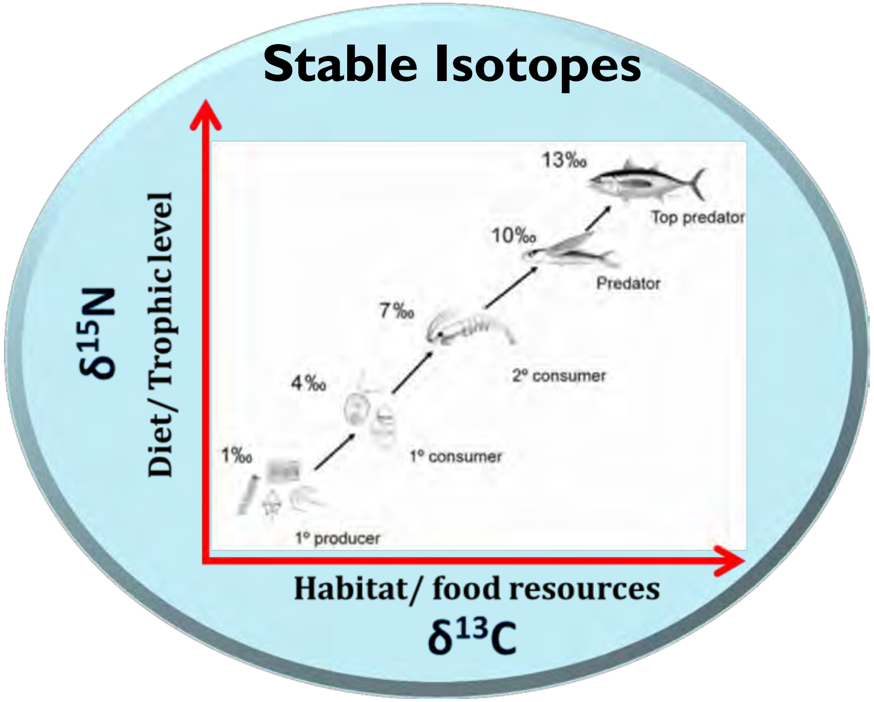
Medium Pelagic

Trachurus spp.



Scomber spp.

How do we study the ecological role of SPF?



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?

How do we study the ecological role of SPF?

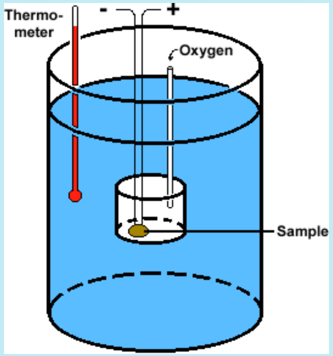
Stable Isotopes

Research questions:

1 - Which species present trophic overlap?

2- Is there a seasonal variation of the community structure?

Energy Density



Direct
Bomb calorimetry

How do we study the ecological role of SPF?

Stable Isotopes

Research questions:

1- Which species present trophic overlap?

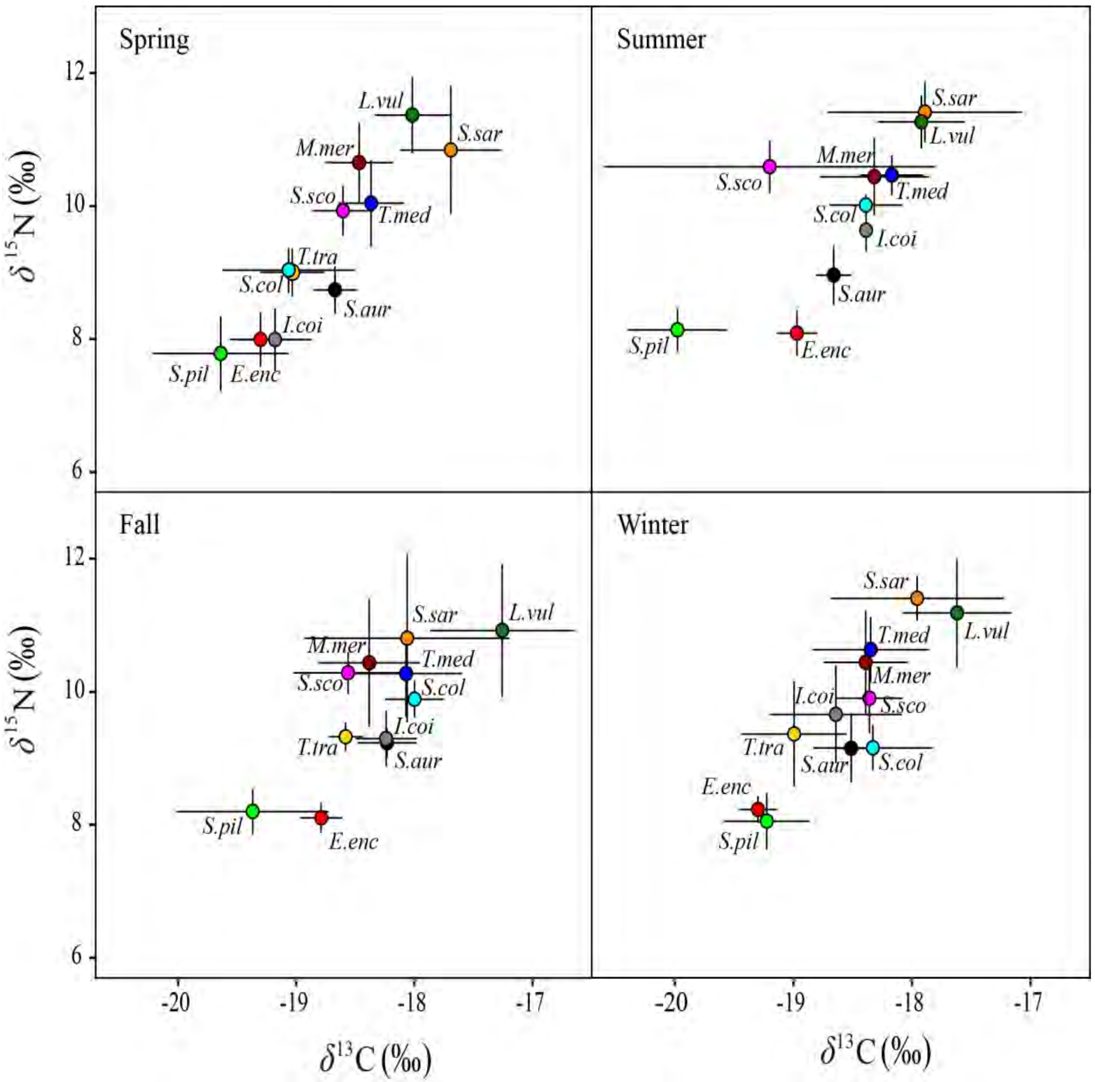
2- Is there a seasonal variation of the community structure?

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?

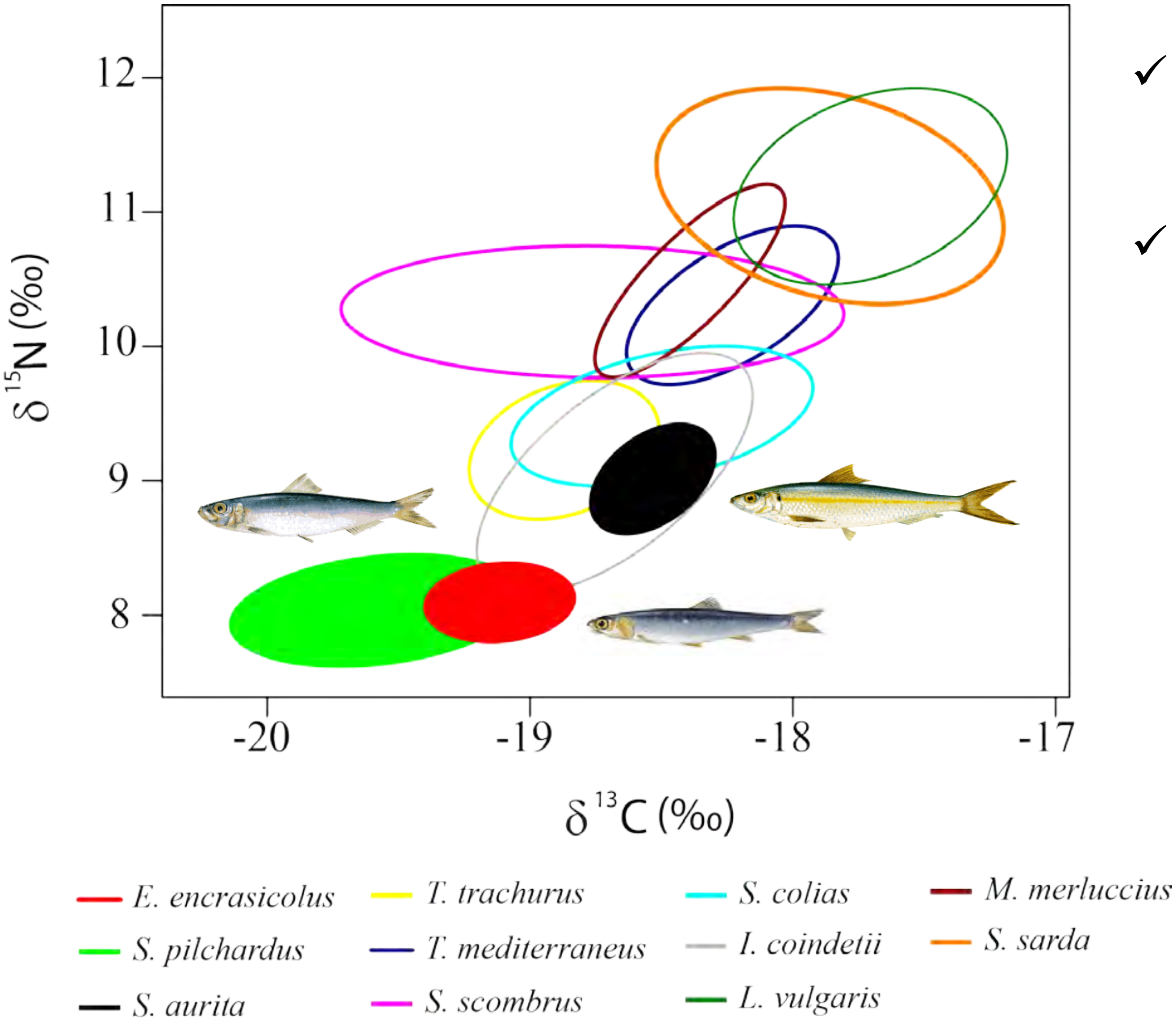


Mean and standard deviation of $\delta^{13}C$ and $\delta^{15}N$ values

(Albo-Puigserver et al., 2016 J Sea Res 117:27-35)

- ✓ No major shifts in the relative position of species across seasons
- ✓ Sardine and anchovy had the lowest trophic positions

Standard ellipses → measure trophic niche overlap

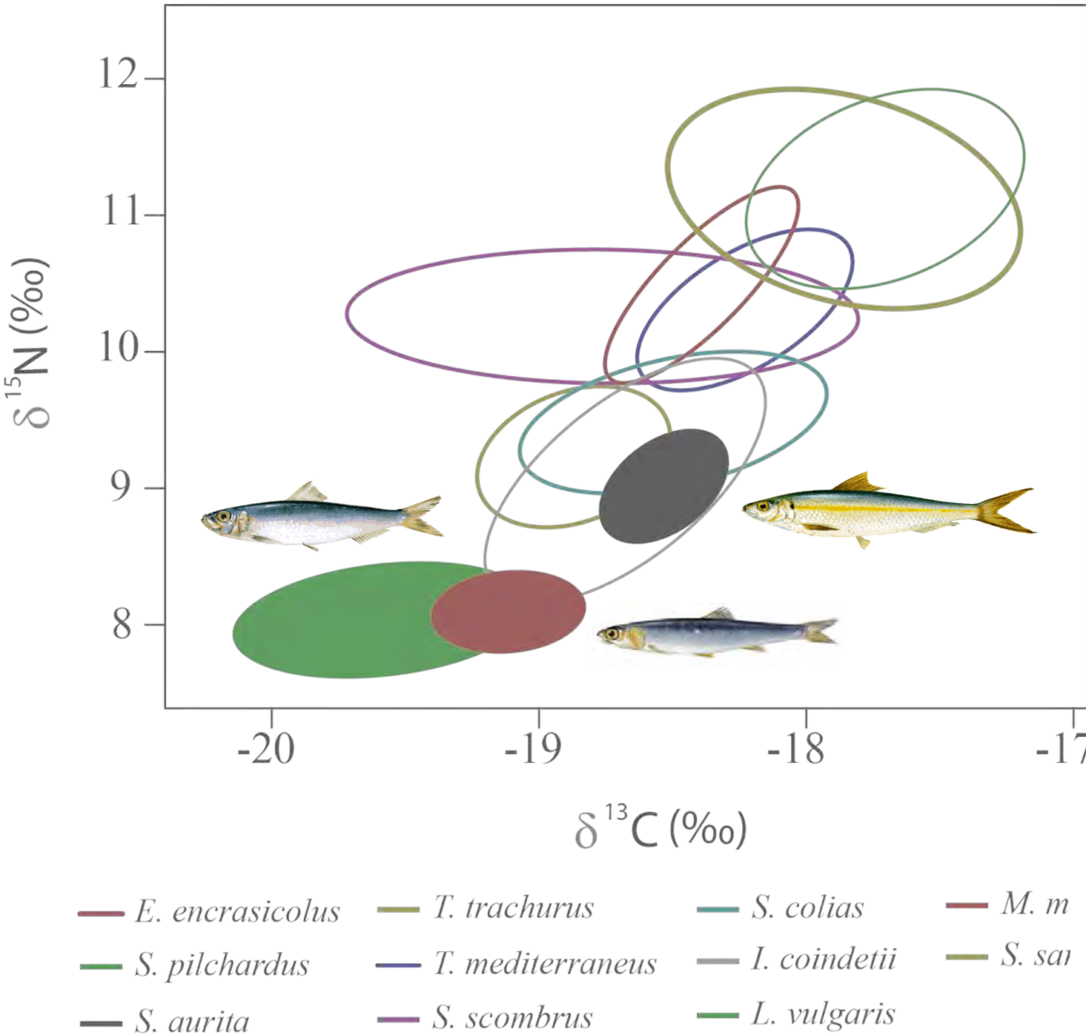


Small pelagic fishes adults

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

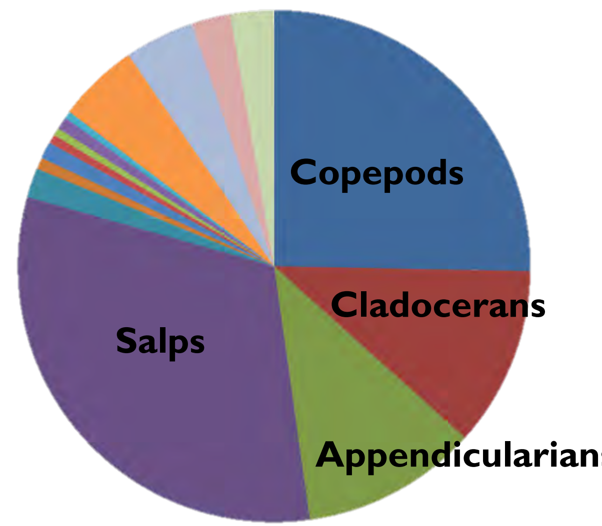
Why?

Standard ellipses → measure trophic niche overlap



Small pelagic fishes adults

Stomach content analysis of Sardinella (% N)



- ✓ 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?

Stable Isotopes

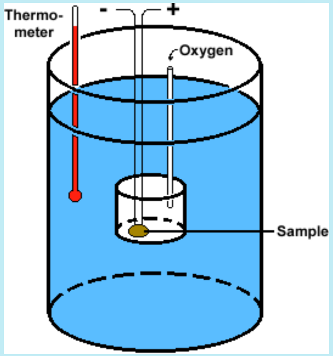
Research questions:

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

Energy Density



Bomb calorimetry

How do we study the ecological role of SPF?

Stable Isotopes

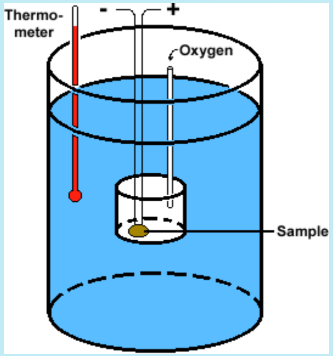
Research questions:

1 -Sardinella segregate the trophic niche from the other SPF

2- Overall community structure is stable through the year

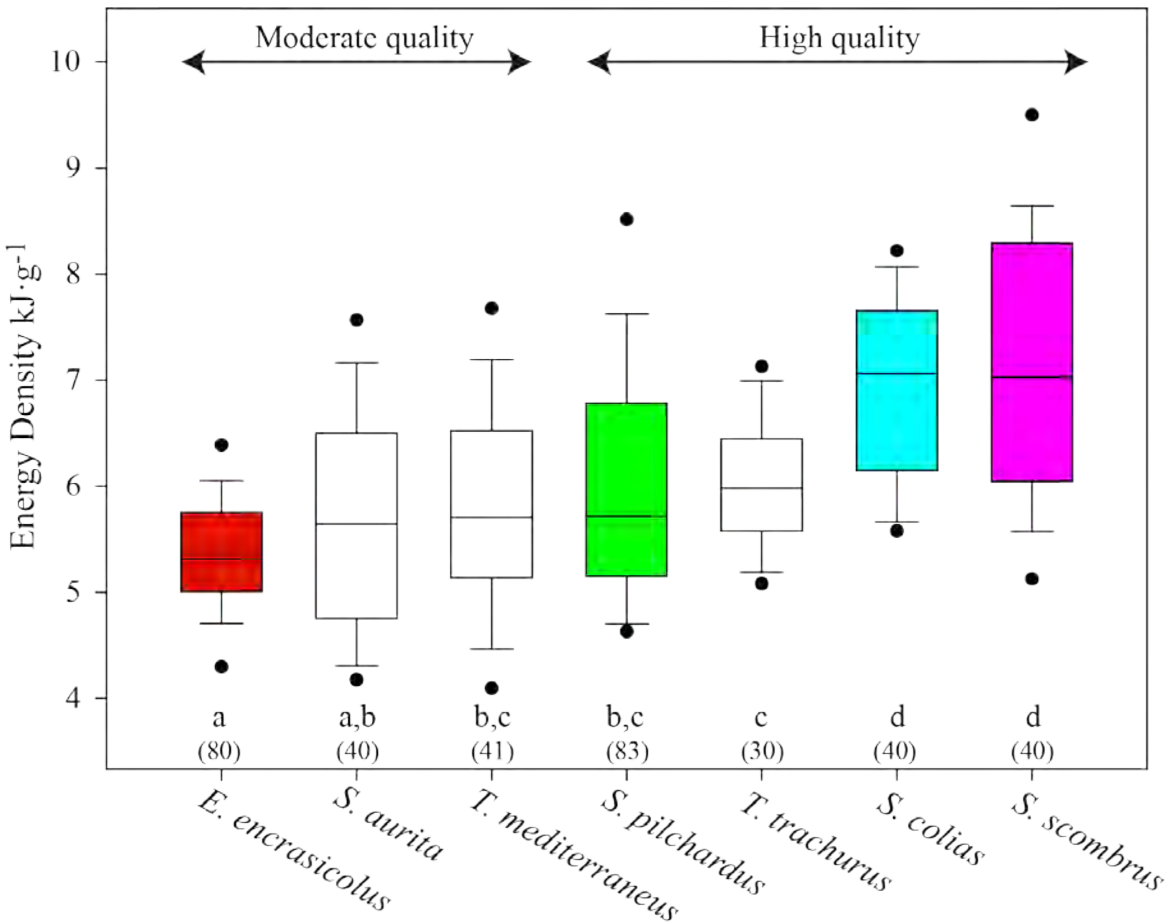
3- Sardinella prey on gelatinous zooplankton

Energy Density



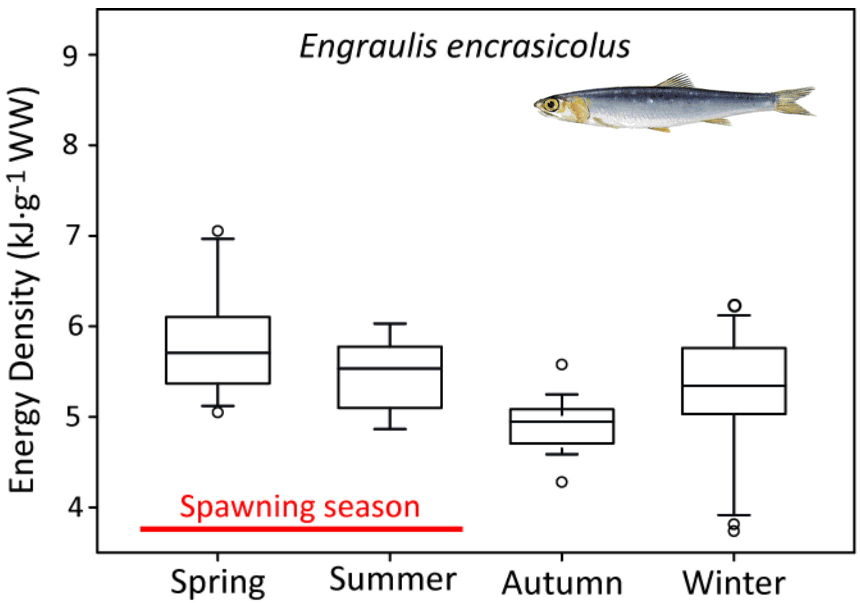
Direct
Bomb calorimetry

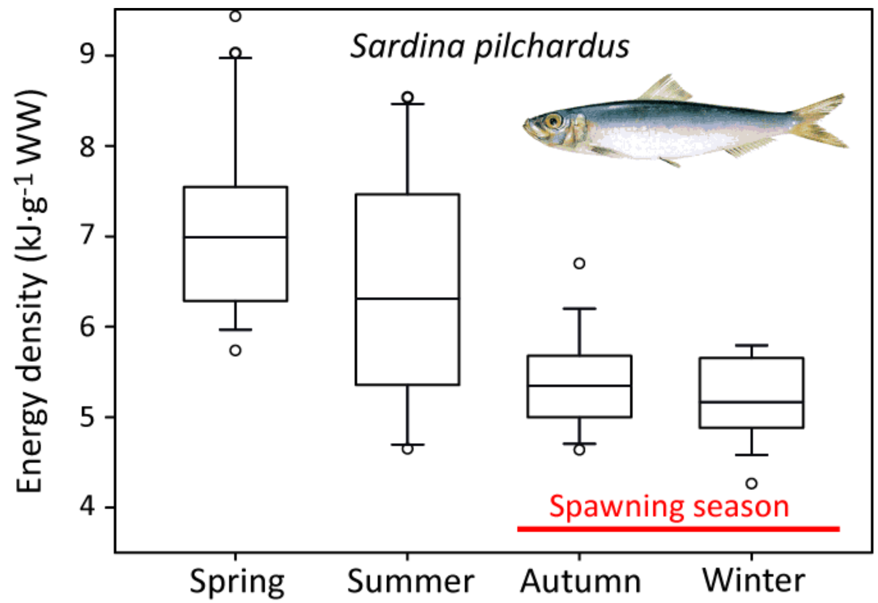
Energy Density of Small and Medium Pelagic Fishes



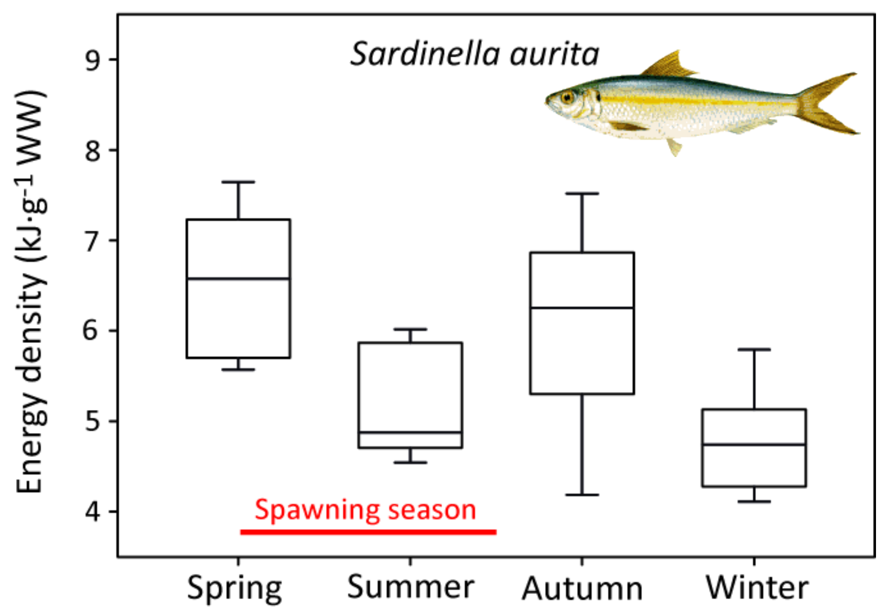
- ✓ Sardine had high ED in comparison to the other SPF due to the accumulation of fat reserves for spawning
- ✓ Species were classify in Moderate or High quality following Spitz et al., (2010)

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).



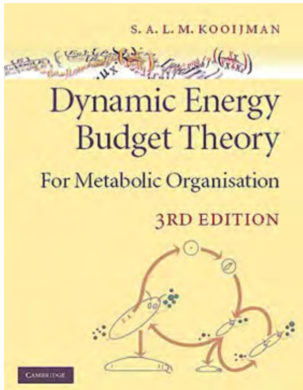


- ✓ ***E. encrasicolus***: High ED during spawning season → income breeder
- ✓ ***S. pilchardus***: Accumulation of energy during Spring and summer → capital breeder
- ✓ ***S. aurita***: Previous accumulation of energy before spawning and a decrease during spawning → high plasticity



Albo-Puigserver et al., 2017

Dynamic Energy Budget Model: *Engraulis encrasicolus*



Ecological Modelling 250 (2013) 370–383

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

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

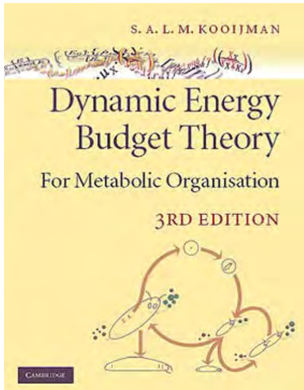
ELSEVIER

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

H. Pethybridge[a,*], D. Roos[b], V. Loizeau[a], L. Pecquerie[c], C. Bacher[a]

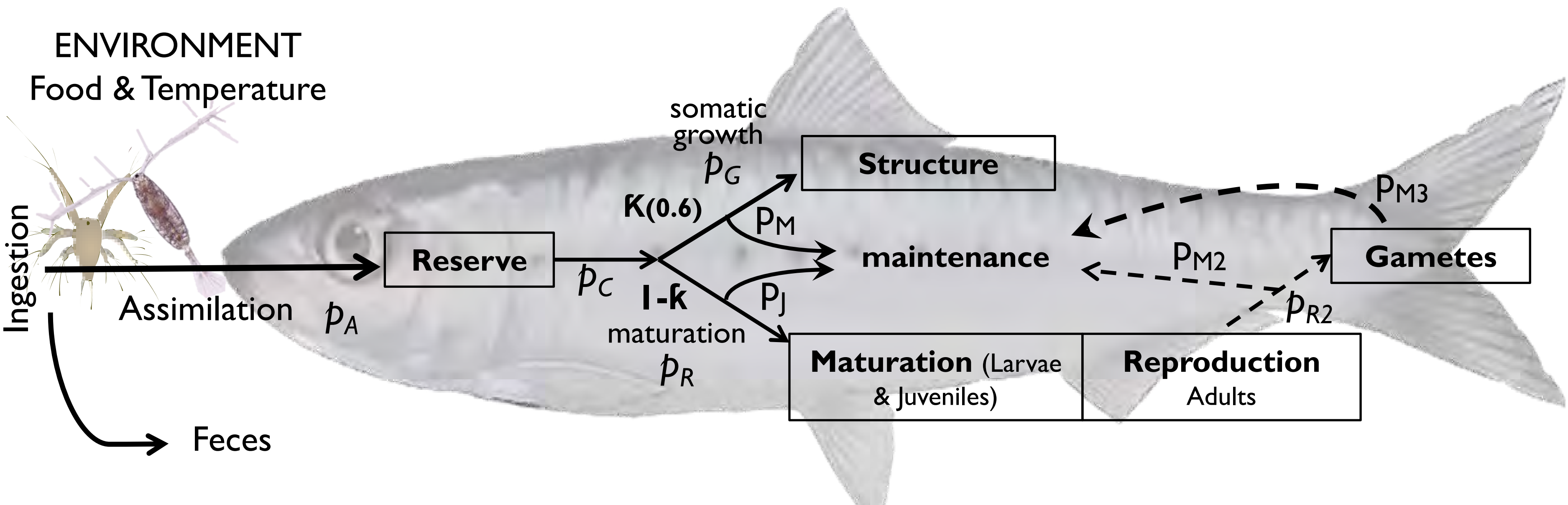
[a] IFREMER, Research Unit: Biogeochemistry and Ecotoxicology, Centre de Brest, 29280 Plouzané, France
[b] IFREMER, Research Unit: Fisheries Resources, Centre de Séte, France
[c] University of California Santa Barbara, Department of Ecology, Evolution and Marine Biology, Santa Barbara, CA 93106-9620, USA

Dynamic Energy Budget Model: *Sardina pilchardus*



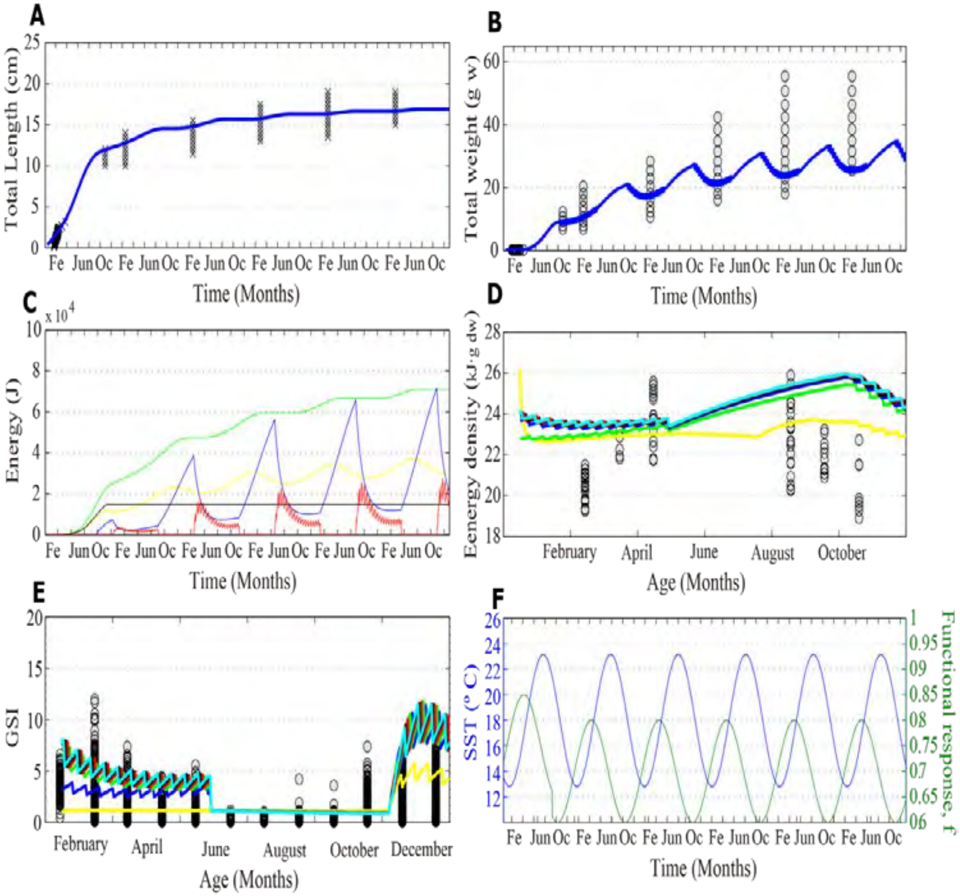
- ✓ Sardine is a multiple spawner that rely in energy stored during summer as fat for reproduction during late autumn-winter
- ✓ The Mediterranean Sea is a climate change hotspot. Shifts in plankton productivity and increase of the SST are expected

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



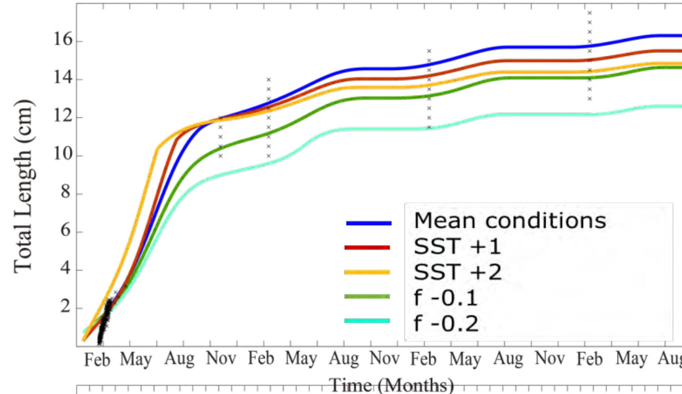
Dynamic Energy Budget Model: *Sardina pilchardus*

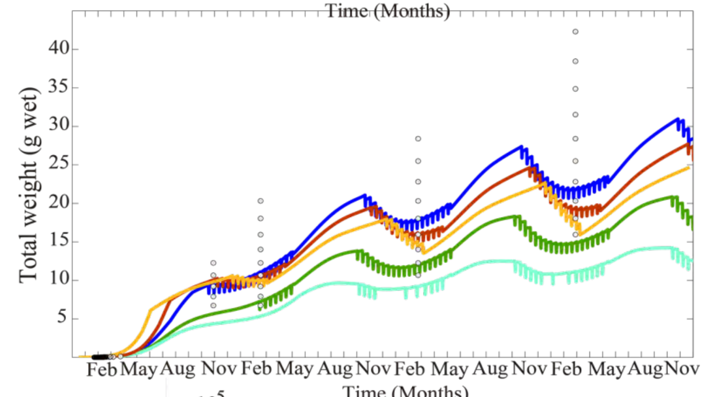
Model calibration

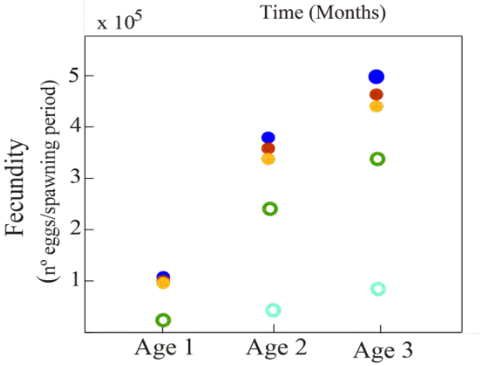


Bioenergetics simulations successfully captured ontogenetic and seasonal growth patterns, not the energy patterns

Environmental scenarios







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

Research questions:

1- Which are the pelagic species with higher energy density-prey quality?

2- Is there a variation of the seasonal energy density?

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

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

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¿?

\+

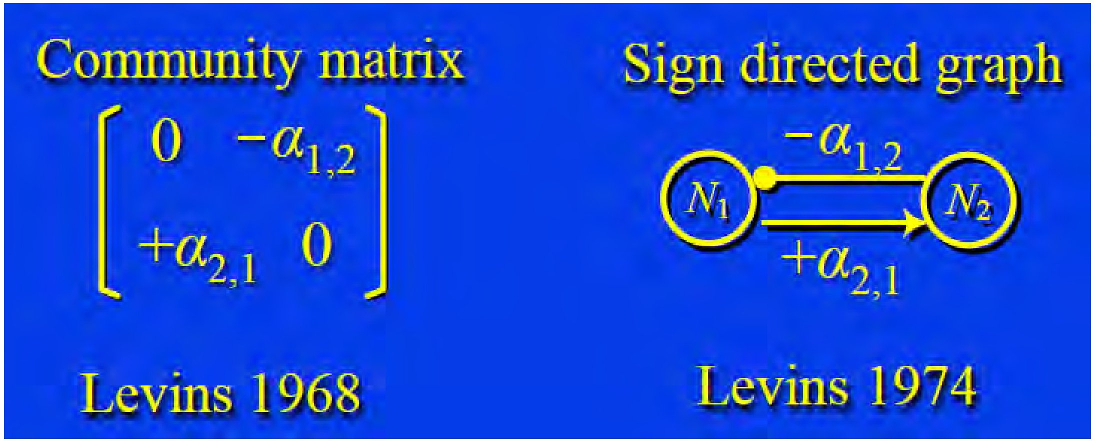
Previous studies and knowledge

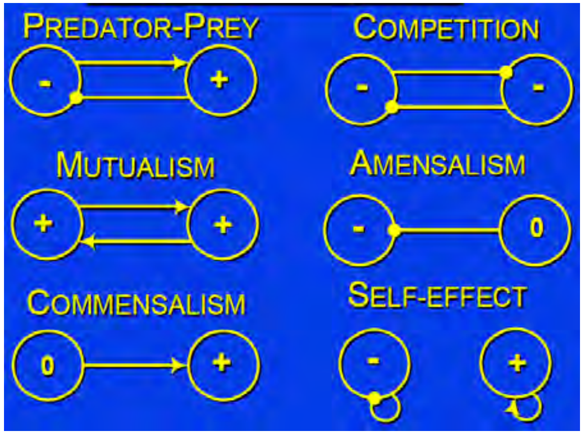
Qualitative modeling in complex systems

Precision

Generality Realism

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

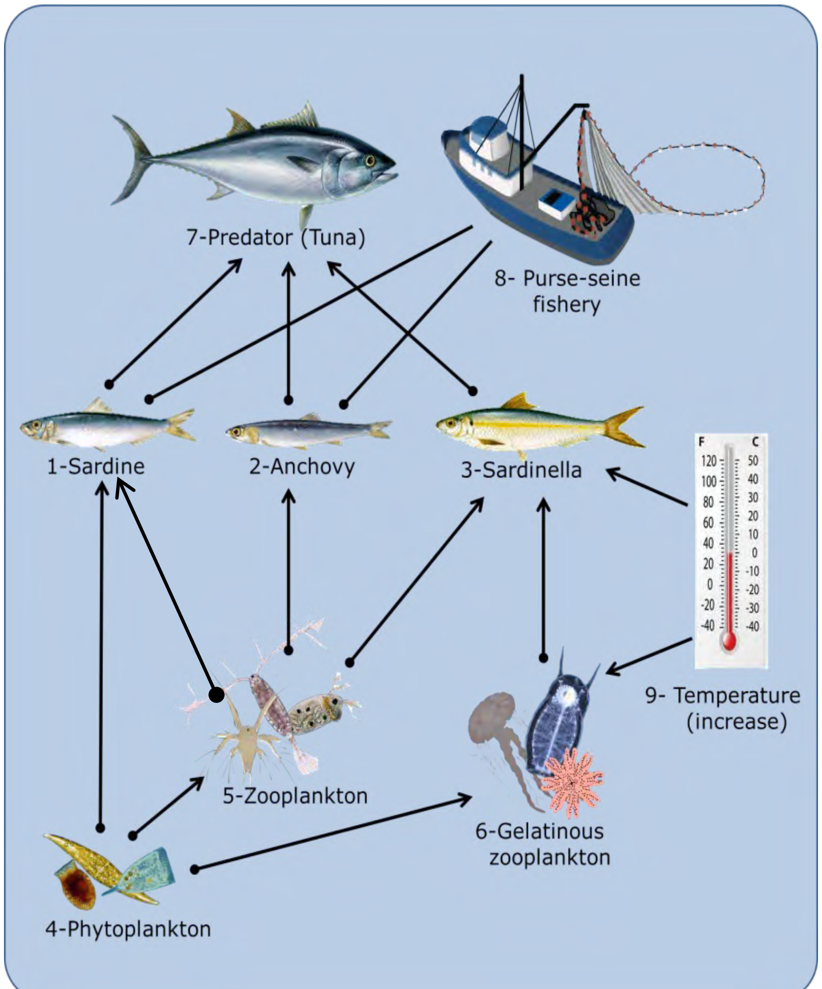




From the signed digraph one can examine the feedback properties of a system (stability analysis)

Qualitative modelling: hypotheses testing

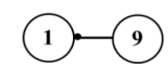
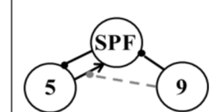
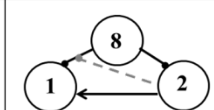
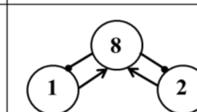
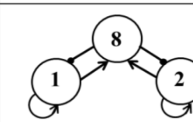
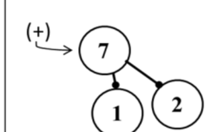
Core model



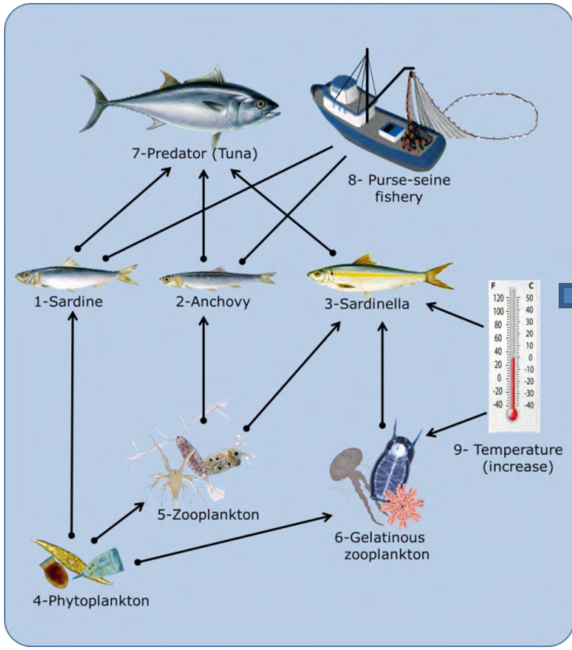
Alternative model structure

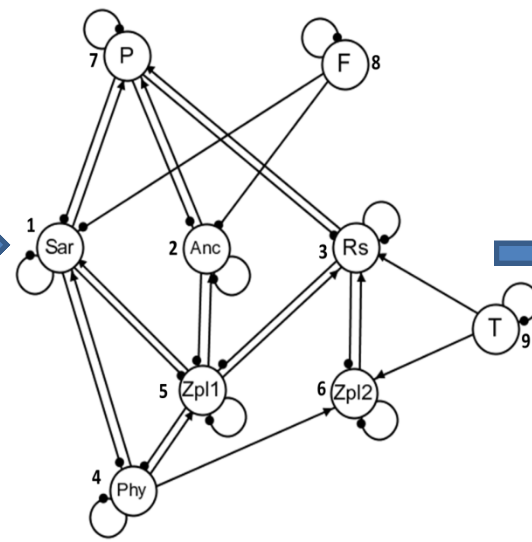
- **1**-Predators don't limit round sardinella
- **2**-SPF don't compete for food
- **3**-Jellyfish prey on anchovy larvae and zoopl

Hypotheses

Temperature	**H$_1$**. Increase T (9) reduces reproduction rate of sardine (1)	
	H$_2$. Increase T (9) changes zooplankton composition (5) with lower quality of food for sardine, anchovy and round sardinella (SPF)	
Fisheries	**H$_3$**. Fisheries (8) prefer and have overexploited anchovy (2) and switch to sardine (1) when anchovy (2) is low	
	H$_4$. Recruitment highly fished (8) on sardine (1) and anchovy (2)	
	H$_5$. Recruitment overfishing (8) on sardine (1) and anchovy (2)	
Predators	**H$_6$**. Recovery of Tuna (7) decreases the abundance of sardine(1) and anchovy(2)	

Qualitative modelling: hypotheses testing





"Qualitatively Specified Community Matrix (°A)"

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

Press perturbation analysis

"adjoint (-A)"

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

Divided by the total feedback matrix

"weighted predictions (W)"

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

Dambacher et al., 2003 Am Nat 161, 876-888

Qualitative modelling: hypotheses testing

Predictions of qualitative response to a positive input

Input and response variable	M	M_{H1}	M_{H2}	$M_{H1,2}$	M_{H3}	M_{H4}	M_{H5}	$M_{H3,4}$	$M_{H3,5}$	M_{H6}
a) Input to temperature										
Sardine	?	?	(-)	?	(-)	?	?	?	?	?
Anchovy	(-)	(-)	(-)	?	(-)	(-)	?	(-)	?	(-)
Sardinella	+	+	+	?	+	+	?	+	?	+
b) Input to fisheries										
Sardine	?	?	?	?	(-)	?	?	(-)	?	?
Anchovy	?	?	?	?	?	?	?	?	?	?
Sardinella	(+)	(+)	(+)	(+)	(+)	(+)	?	(+)	?	(+)
c) Input to predators										
Sardine	(-)	(-)	(-)	(-)	(-)	(-)	?	(-)	?	-
Anchovy	?	?	?	?	?	?	?	?	?	-
Sardinella	?	?	?	?	?	?	?	?	?	?

"Qualitatively Specified Community Matrix (°A)"

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

Press perturbation analysis

"adjoint (-A)"

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

Divided by the total feedback matrix

"weighted predictions (W)"

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

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!

Marta Albo-Puigserver, Joan Navarro, Marta Coll, Isabel Palomera

albo@icm.csic.es

ACKNOWLEDGMENT:

Raquel Sáez-Liante,
Craig A. Layman
Heidi Pethybridge
Diego Borme
Valentina Tirelli
Jeffrey Dambacher

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

Institute of Marine Sciences ICM
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

GFCM CGPM
General Fisheries Commission for the Mediterranean
Commission générale des pêches pour la Méditerranée

OGS
CSIRO
NC STATE UNIVERSITY