Navigating Changes in Small Pelagic Fish and Forage Communities: Climate, Ecosystems, and Sustainable Fisheries

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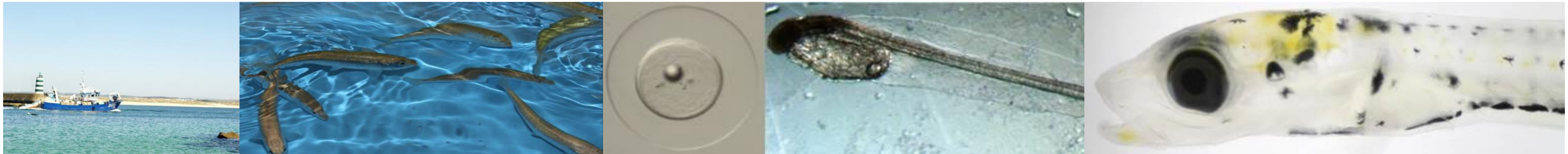
IPMA

Spatiotemporal variation of European sardine, *Sardina pilchardus*, recruitment in the Northeast Atlantic and Western Mediterranean Sea: Implications for fisheries management

<u>Inês Pereira</u>, Alexandra Silva et al.

ICES/PICES/FAO SPF and Forage Fish Symposium, La Paz, Mexico, May 2026



Introduction

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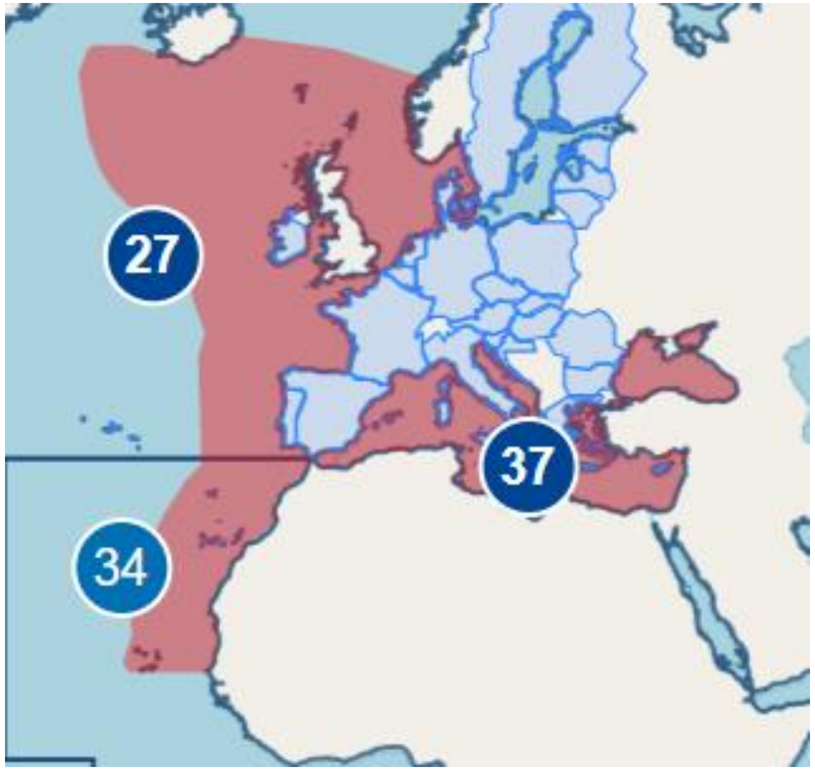
Sardina pilchardus

- Small pelagic coastal fish
- Fast growing and short-lived
- Valuable fishery resource

Distribution of the European sardine



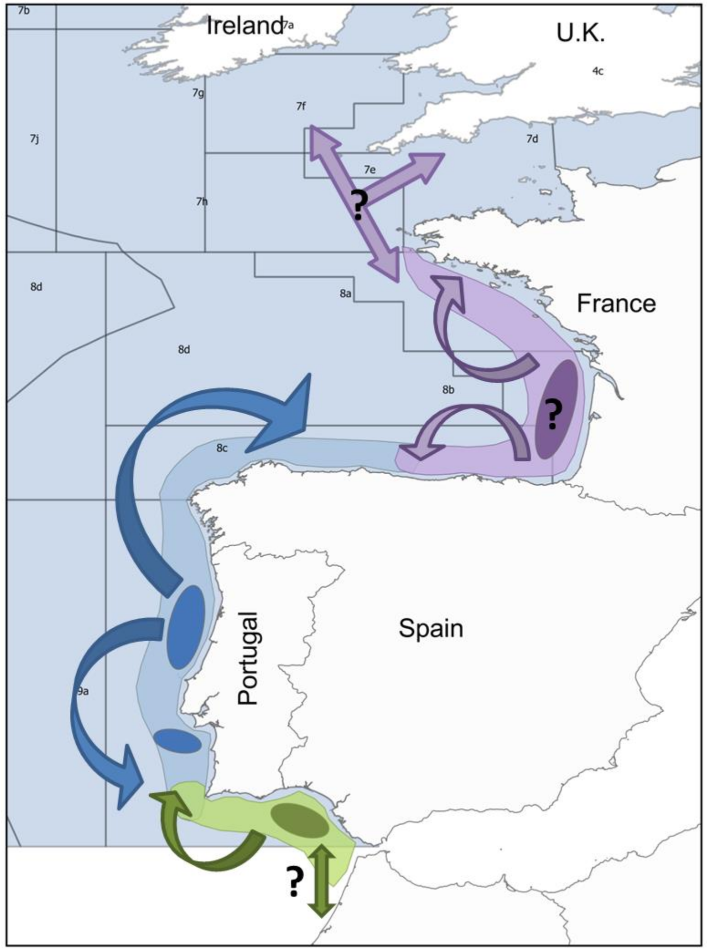
Source: FAO

High social and economic importance

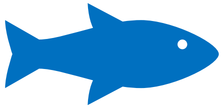
Employs thousands of fishers

Profitable canning industry

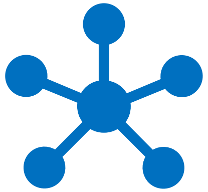
Spatial population dynamics of sardine on the Northeast Atlantic

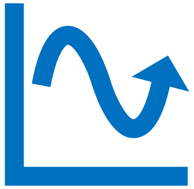


Source: Silva et al. (2022).



Sardine recruitment spatiotemporal dynamics





Objective

Investigate common trends in the population dynamics of sardines and assess connectivity among populations in the northeast Atlantic Ocean and Western Mediterranean Sea.

Questions

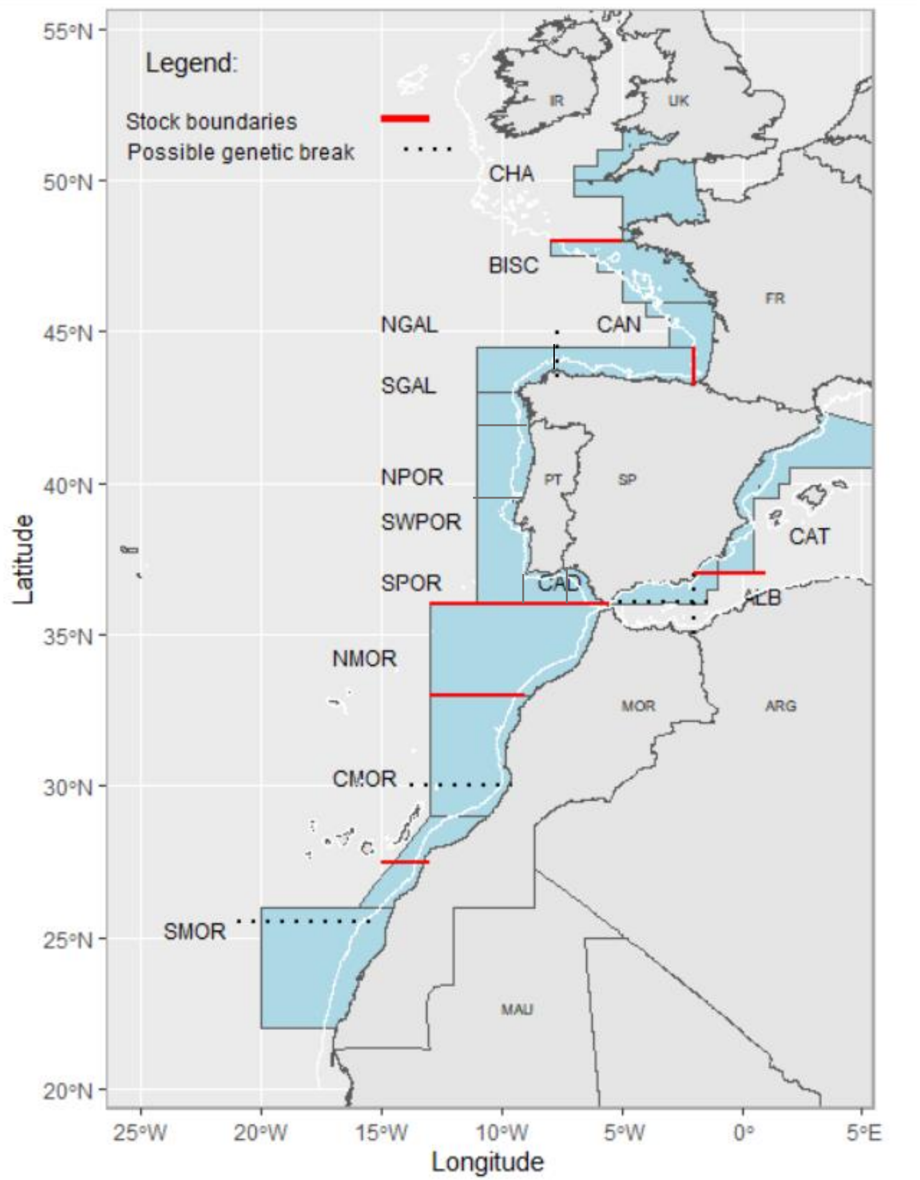
Is there synchrony in population dynamics between recruitment hotspot areas?

Are there common patterns between the recruitment hotspots time series?

Are recruitment hotspots supplying their neighbouring areas?

13 study areas (except North of Morocco)

Abundance and biomass per age group and per area from acoustic surveys



13 study areas

Abundance and biomass per age group and per area from acoustic surveys

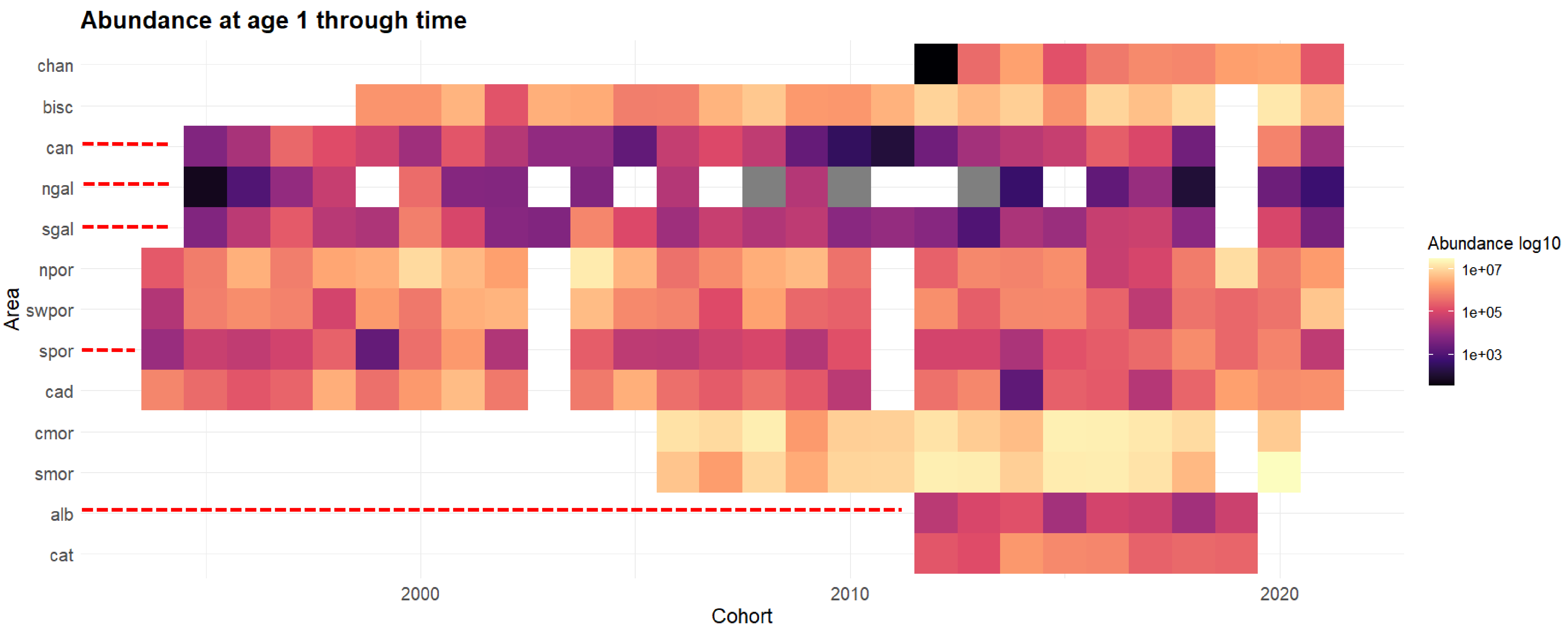
Modelling cohort abundance and predict R_{age0} (GAM)

```
gam(number~ survey + s(age,by=cohort,k=k_age)
```

Family: Negative Binomial / Tweedie | Method: REML | Model Selection: AICc + residual diagnostics

To identify high recruitment areas, we analyzed abundance over time at age 1.

The Cantabrian Sea (can), the Galicia areas (ngal, sgal), South of Portugal (spor), and the Northern Alboran Sea (alb) were discarded as high recruitment areas.



Data Analysis

Cross Correlation Function (CCF) to estimate:

- Synchrony between R_{age0} in different areas.
- Connectivity between R_{age0} and $SSB_{1,2,3}$ in diferente areas.

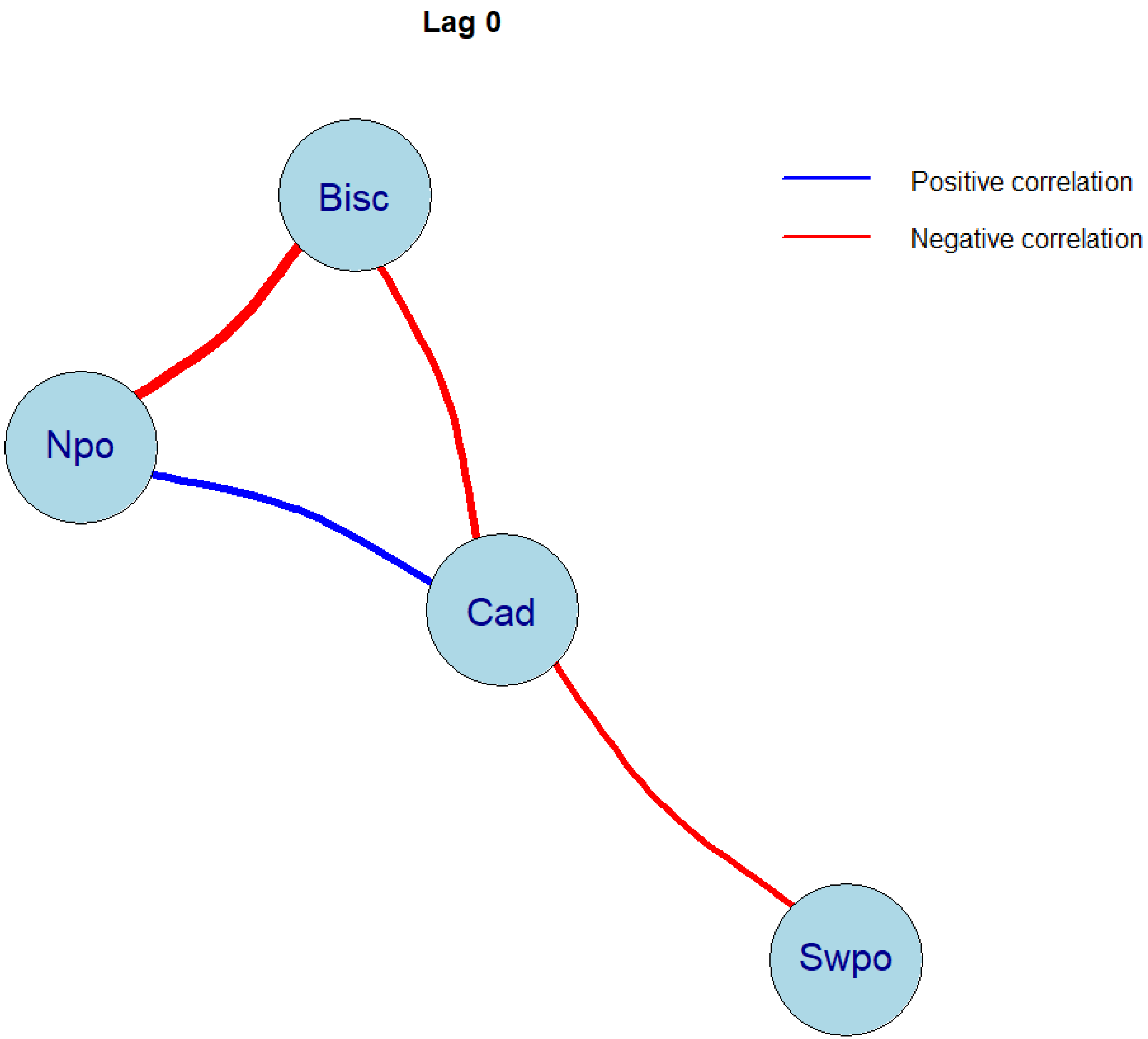
Dynamic Factor Analysis (DFA) to determine common trends between recruitment dynamics (R_{age0}) in different areas.

DFA Models

Number of Trends	Explanatory Variables
1 to 3	-
	NAOw
	EAw
	NAOw + EAw

Winter period: December to February.

Model selection through AIC



Recruitment Synchrony

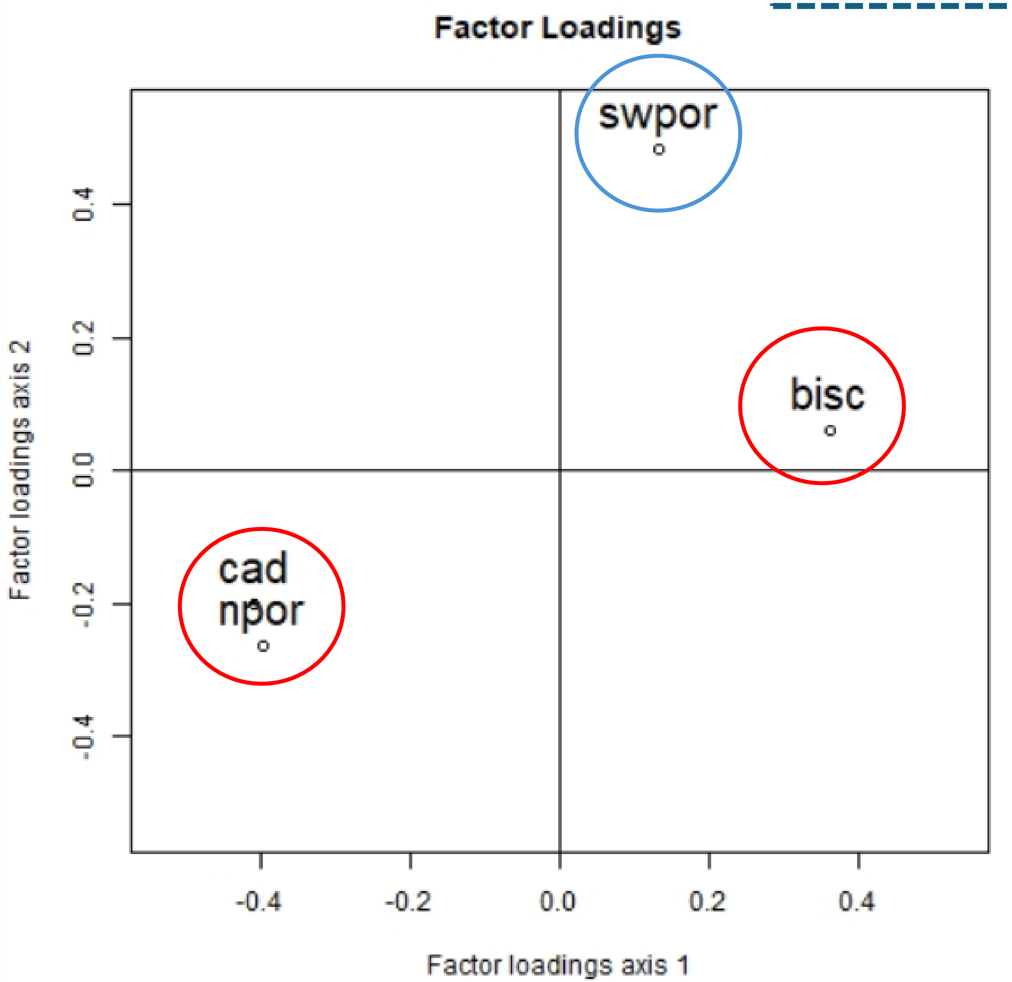
- Npor and Cad synchronous co-movement in the same direction
- Swpor and Cad synchronous co-movement in opposite directions
- Npor & Cad with Bisc: synchronous co-movement in opposite directions
- No relationship:
  - Cmor <-> Smor
  - Alb <-> Cat
  - NW Africa <-> European <-> Mediterranean

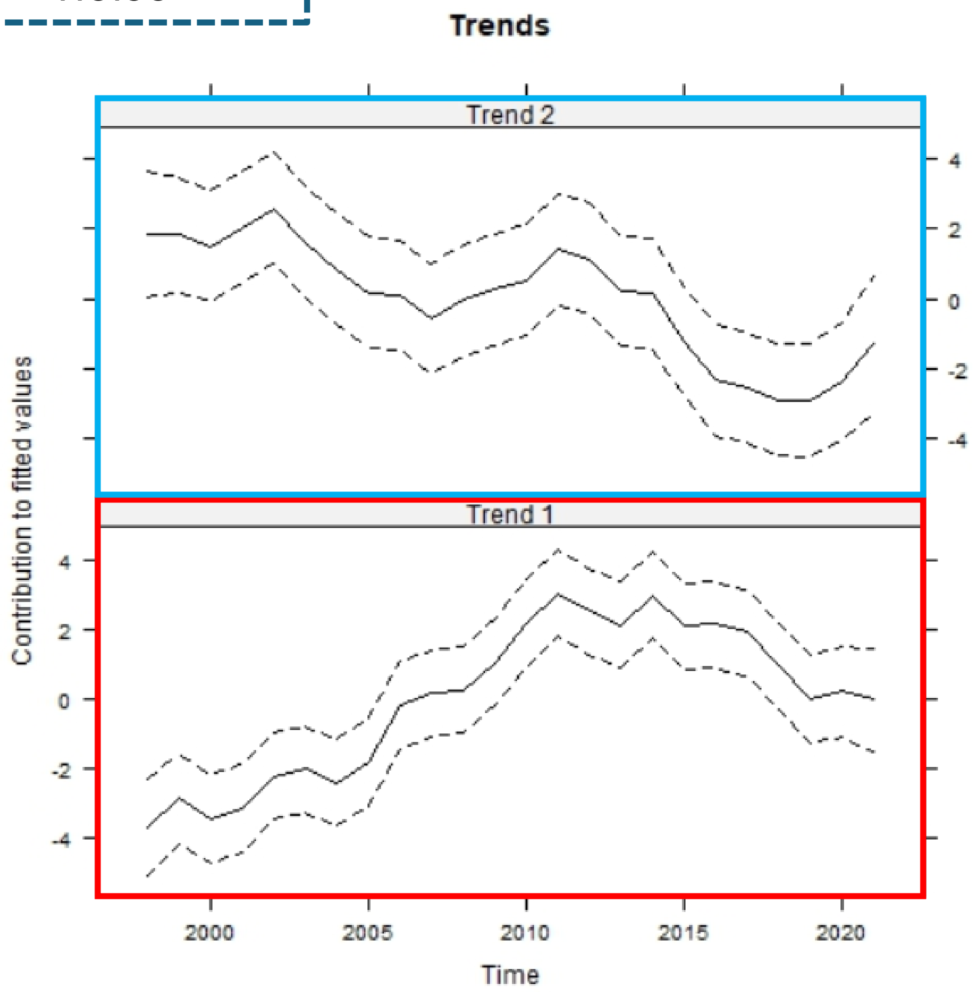
Bay of Biscay and Iberian Peninsula areas

Time Period: 1998 - 2021

Best fit Model

data = 2 common trends + noise





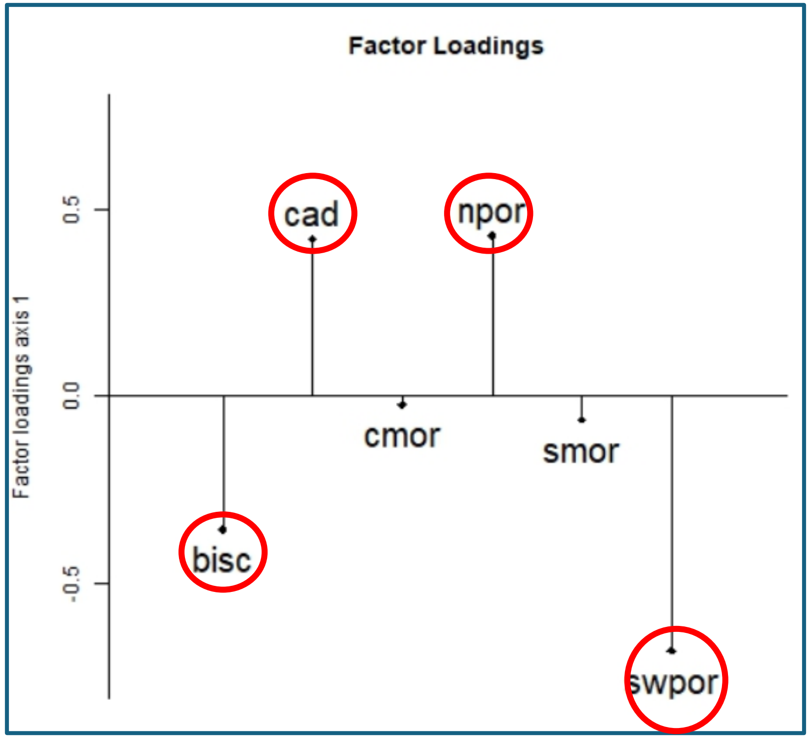
Bay of Biscay, Iberian Peninsula and Moroccan areas

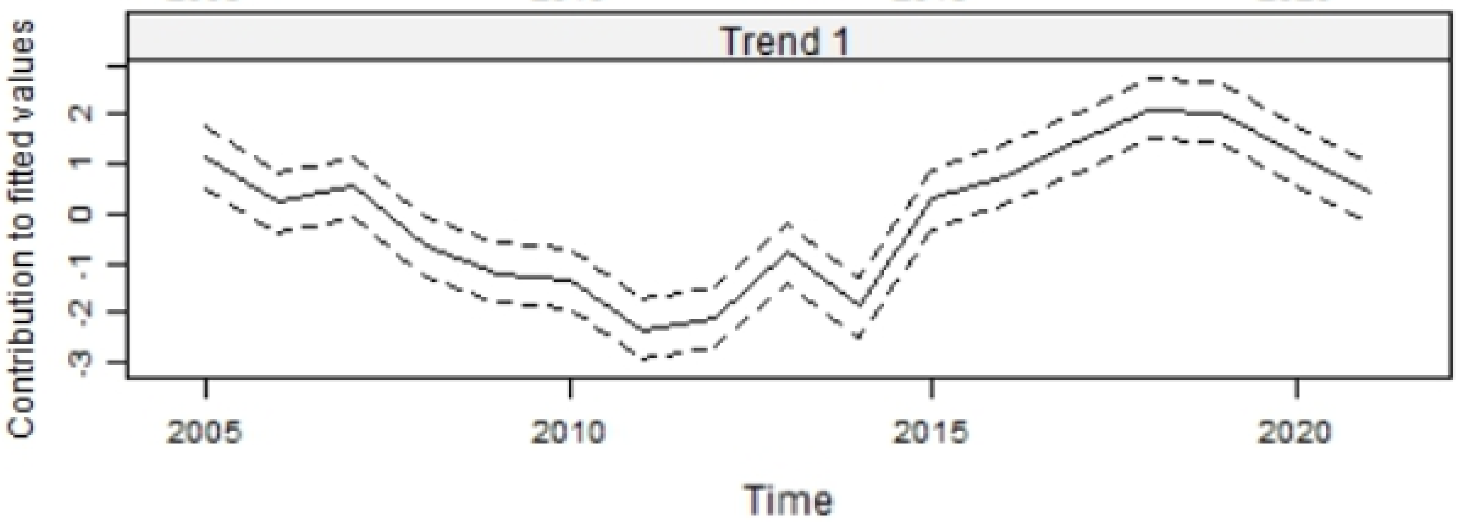
Time Period: 2005 - 2021

Best fit model

data = 3 common trends + explanatory variables + noise

NAOw + EAw





Bay of Biscay, Iberian Peninsula and Moroccan areas

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Best fit model

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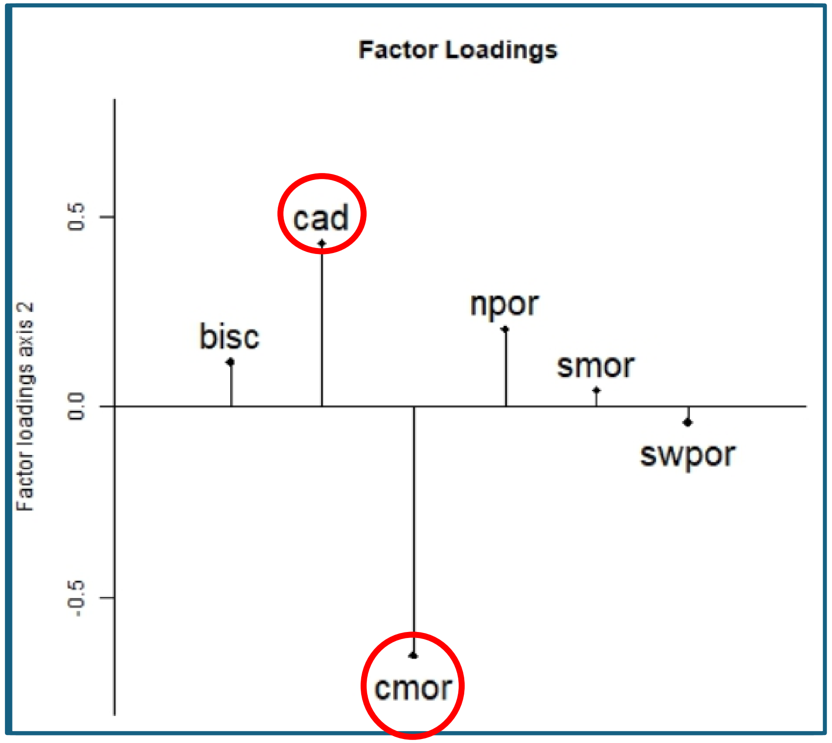
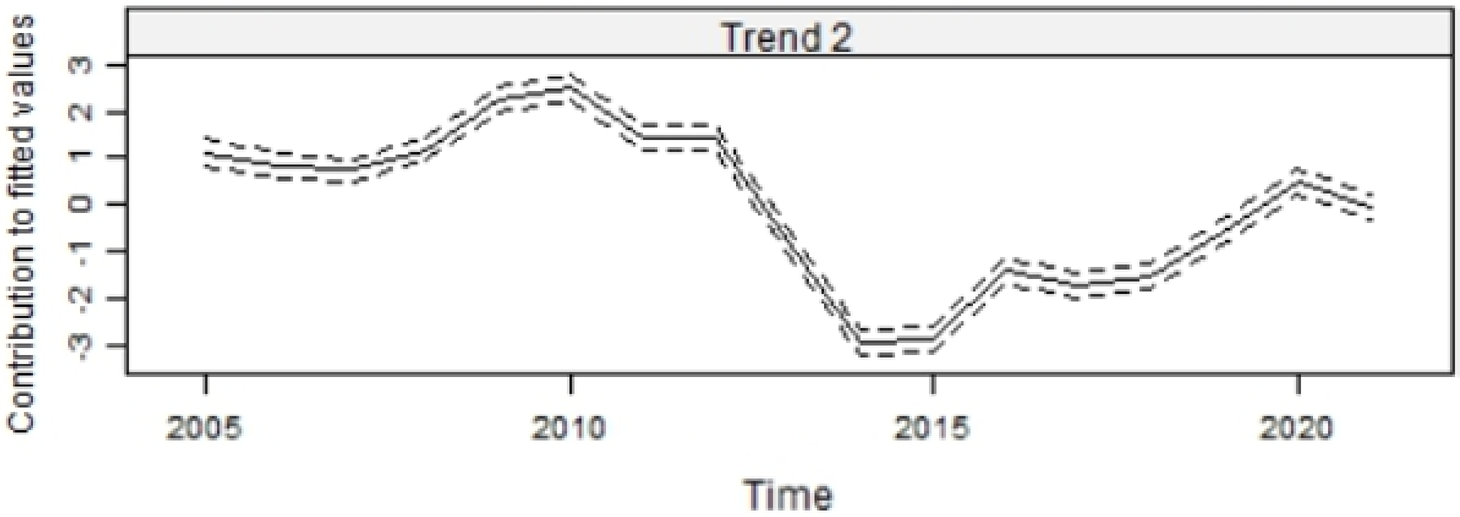
NAOw + EAw





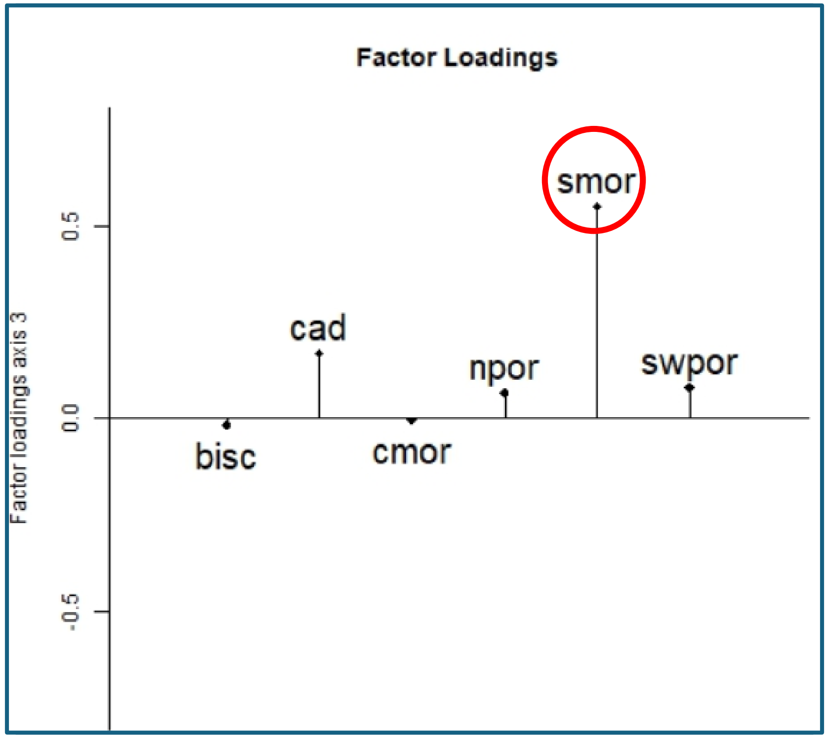
Bay of Biscay, Iberian Peninsula and Moroccan areas

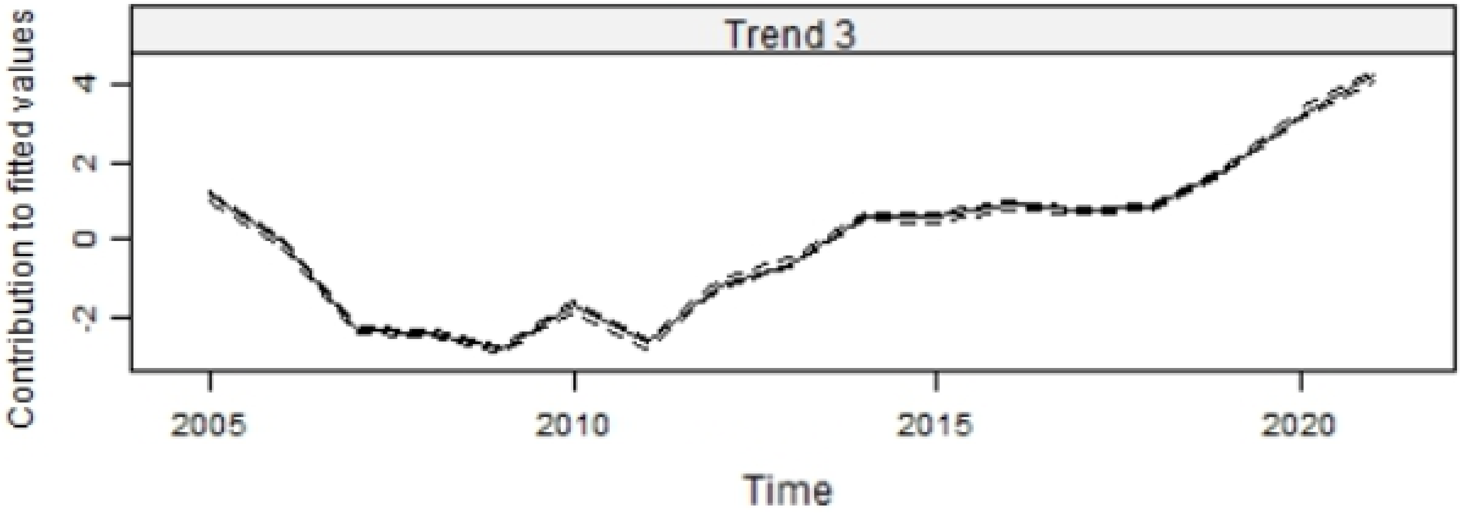
Time Period: 2005 - 2021

Best fit model

data = 3 common trends + explanatory variables + noise

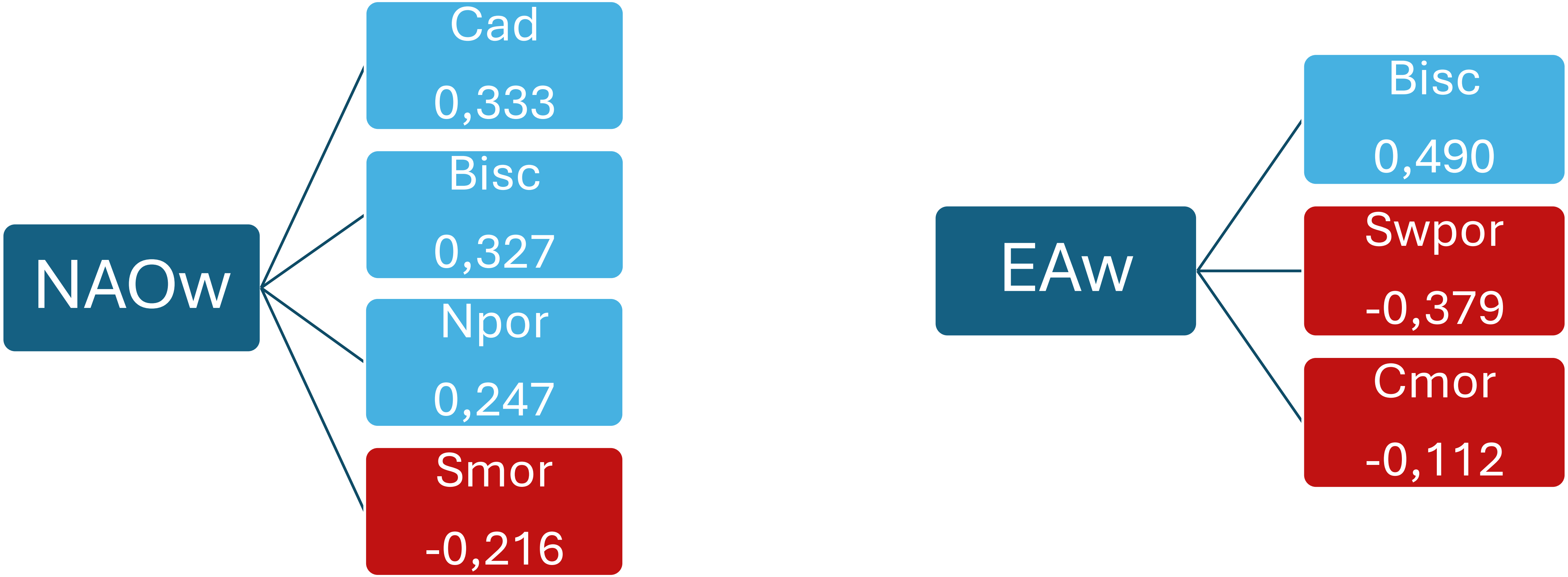
NAOw + EAw





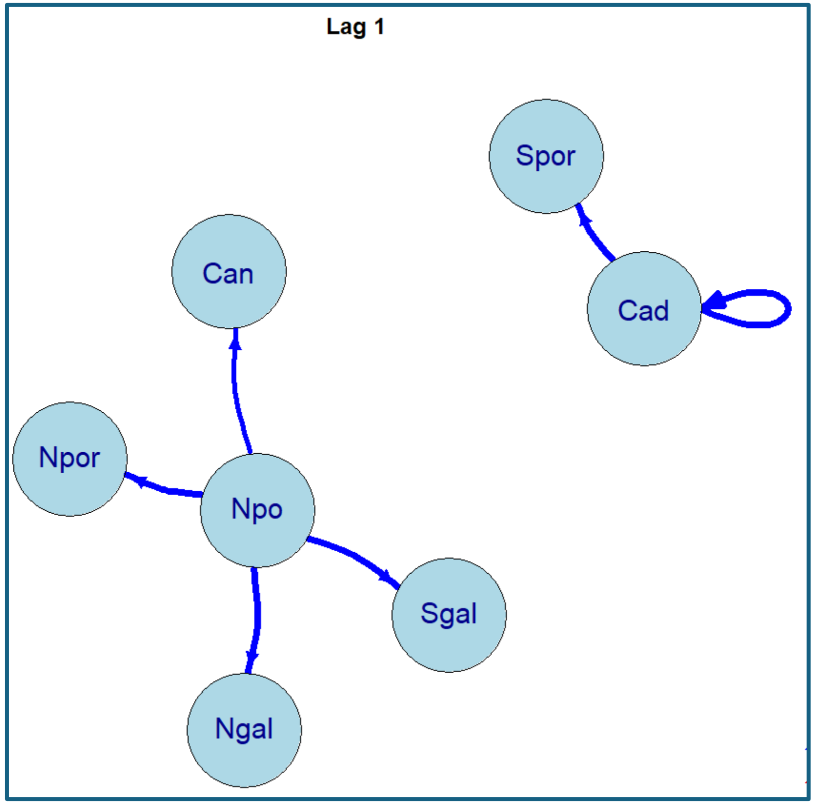
DFA analysis
Bay of Biscay, Iberian Peninsula and Moroccan areas

Effects of the Explanatory Variables

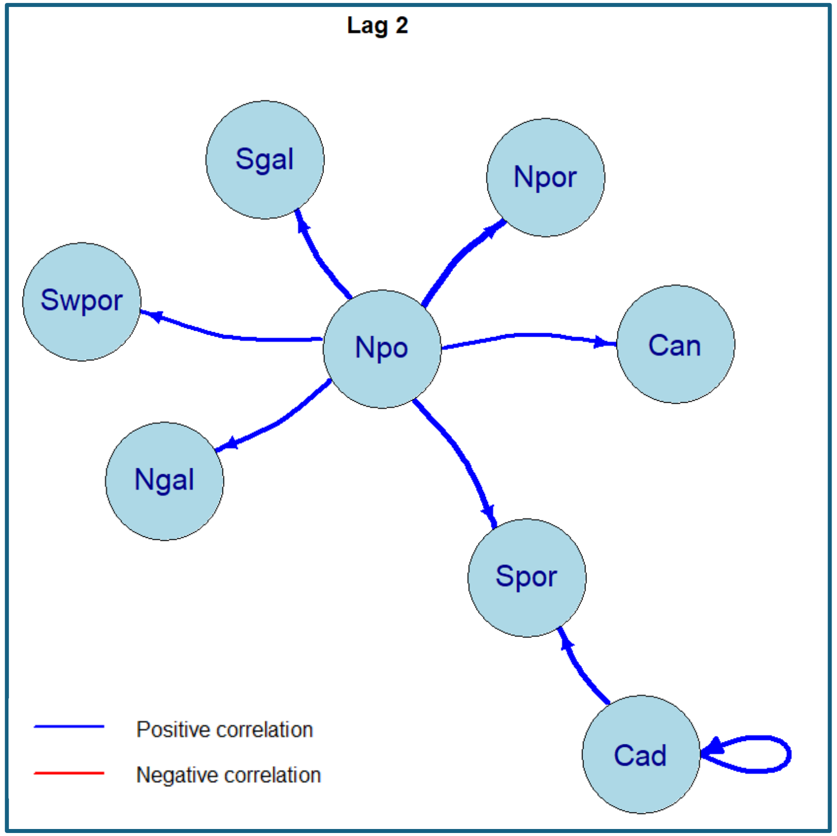


Recruitment –> SSB Connectivity

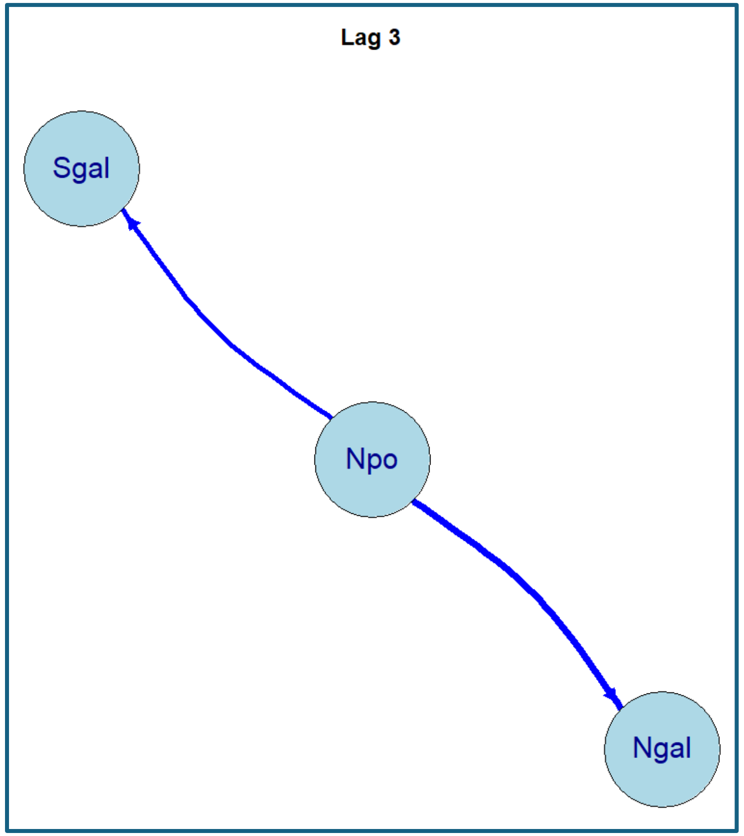
SSB1

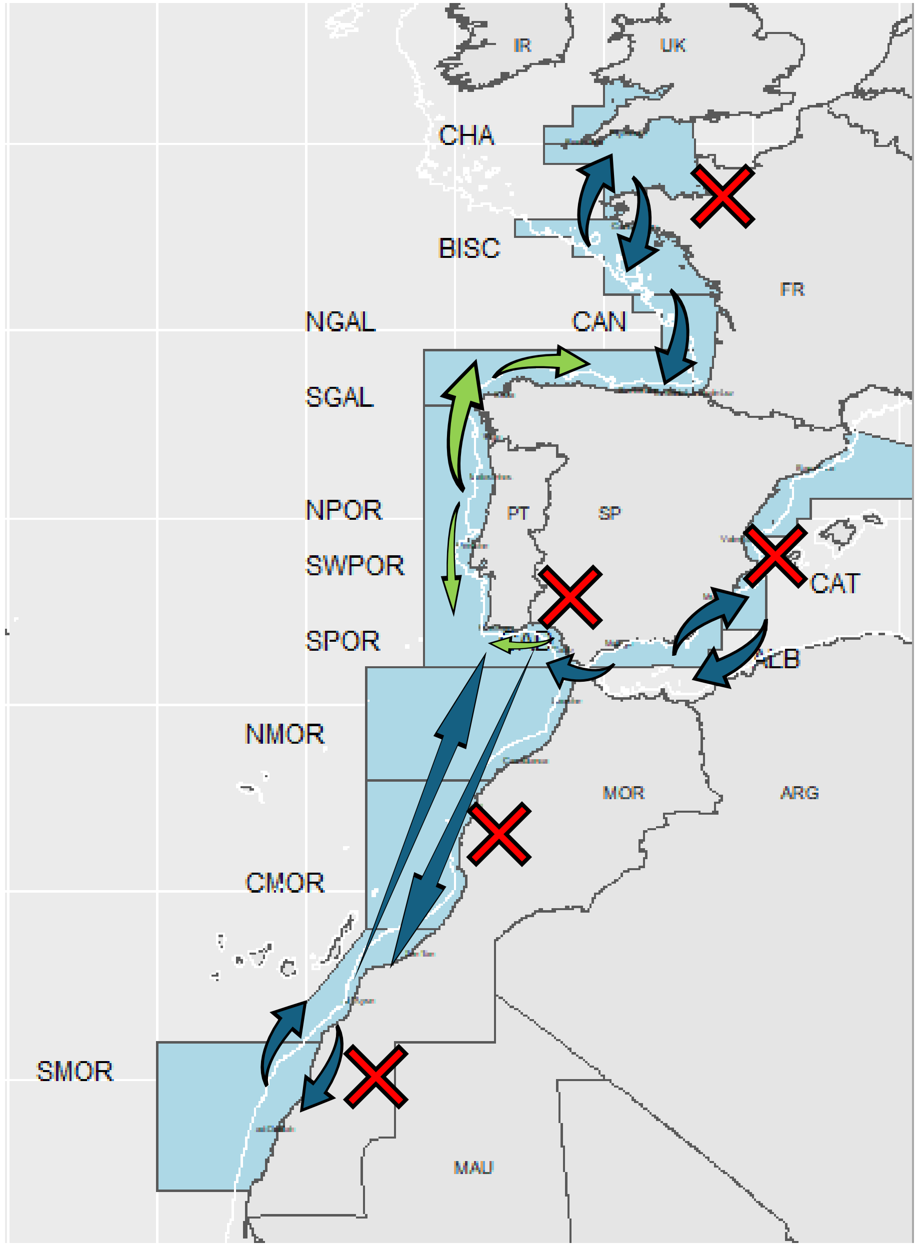


SSB2



SSB3




IR
UK
CHA
BISC
FR
NGAL
CAN
SGAL
NPOR
PT
SP
SWPOR
CAT
SPOR
ALB
NMOR
MOR
ARG
CMOR
SMOR
MAU

North of Portugal and Gulf of Cadiz high recruitment areas

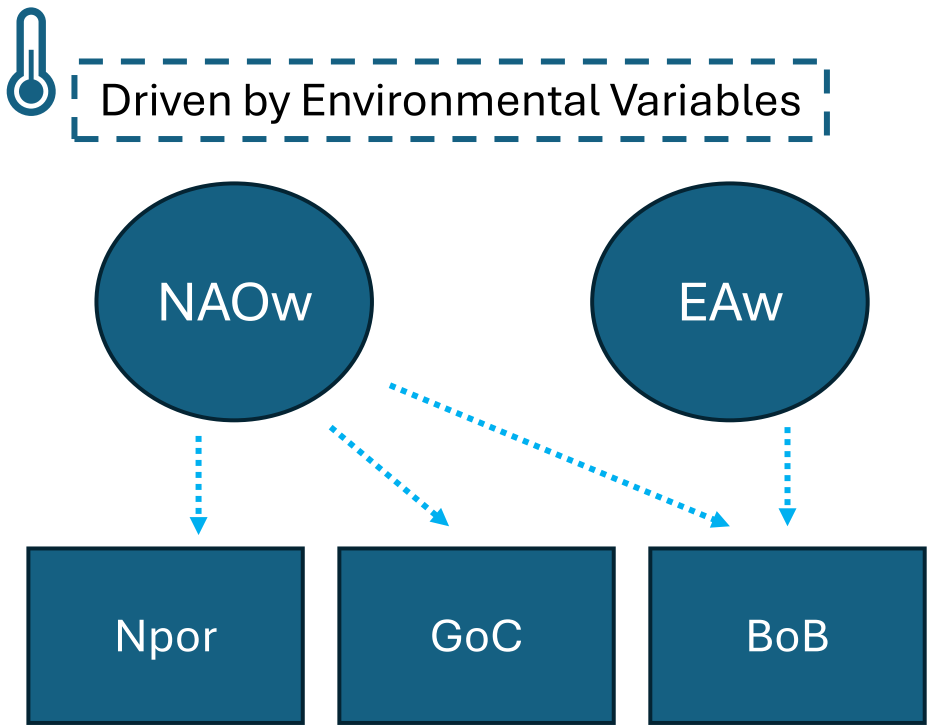
E.g. Santos et al. (2004; 2007; 2018); Correia et al. (2014); Silva et al. (2019).

North of Portugal and Gulf of Cadiz high recruitment areas

E.g. Santos et al. (2004; 2007; 2018); Correia et al. (2014); Silva et al. (2019).

Contrasting recruitment dynamics between North of Portugal and Gulf of Cadiz with the Bay of Biscay

Positive EA phase – Higher temperatures in Europe



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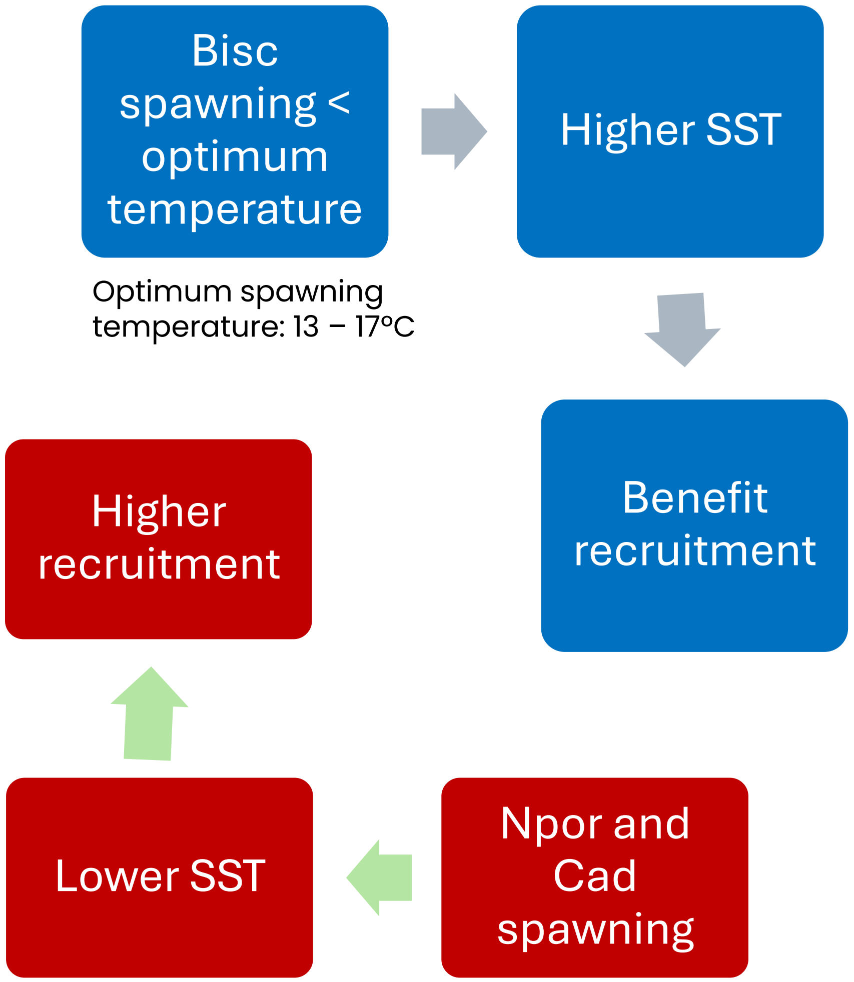
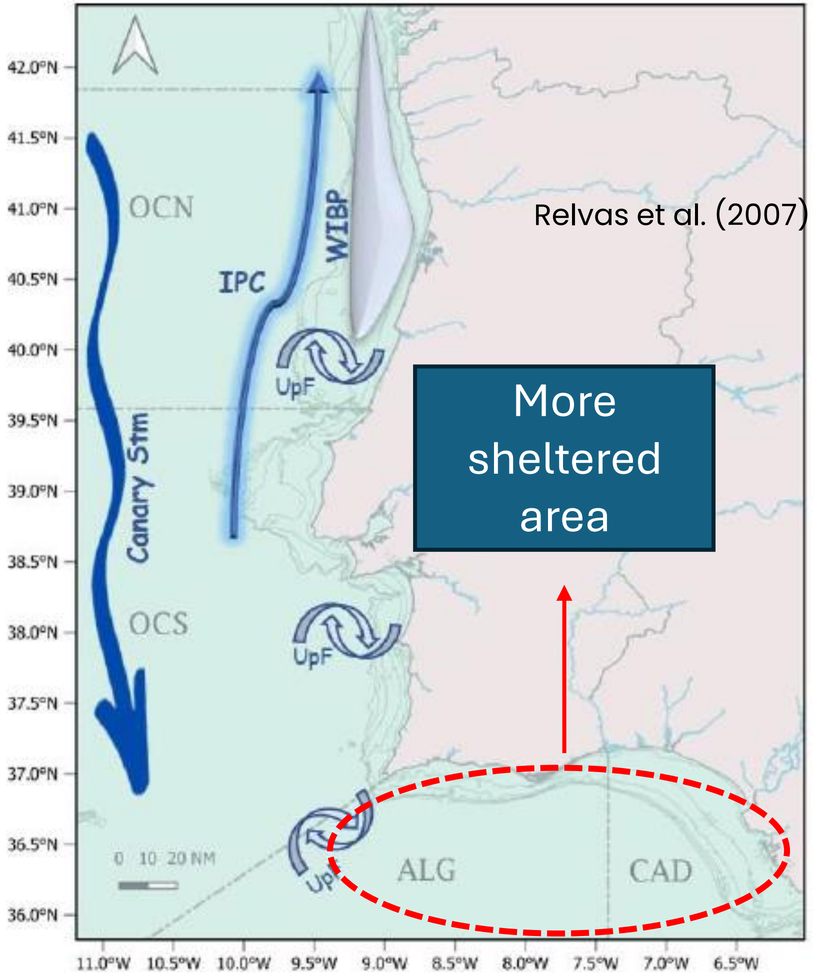


Garrido et al. (2017)

Swpor (OCS in the map) is a complex transition zone, with the Iberian Poleward Current (IPC) and upwelling influence, possibly creating an interannual variability not shared by its adjacent areas. It is a very heterogeneous area, with different lengths in the continental shelf, and more river discharge in the north. This could help understand why this area has its own recruitment dynamic.

Furthermore, while the Algarve and Cadiz regions are generally more sheltered from upwelling-favorable winds and act as retention zones for eggs and larvae, Swpor is exposed to intense and variable upwelling. This may partly explain the negative recruitment correlation observed between Swpor and Cad in the CCF synchrony analysis.

Swpor with its own recruitment dynamic



Antunes et al. (2023)

North of Portugal and Gulf of Cadiz high recruitment areas

E.g. Santos et al. (2004; 2007; 2018); Correia et al. (2014); Silva et al. (2019).

Contrasting recruitment dynamics between North of Portugal and Gulf of Cadiz with the Bay of Biscay

Swpor with its own recruitment dynamic

In Winter

Intensification of IPC in OCS

Santos et al. (2018)

Intensification of WIBP in OCN

Relvas et al. (2007)

Warmer, saltier surface current

Arístegui et al. (2009)

Retention increases with IPC

Relvas et al.(2007)

Less larval conditions in OCS

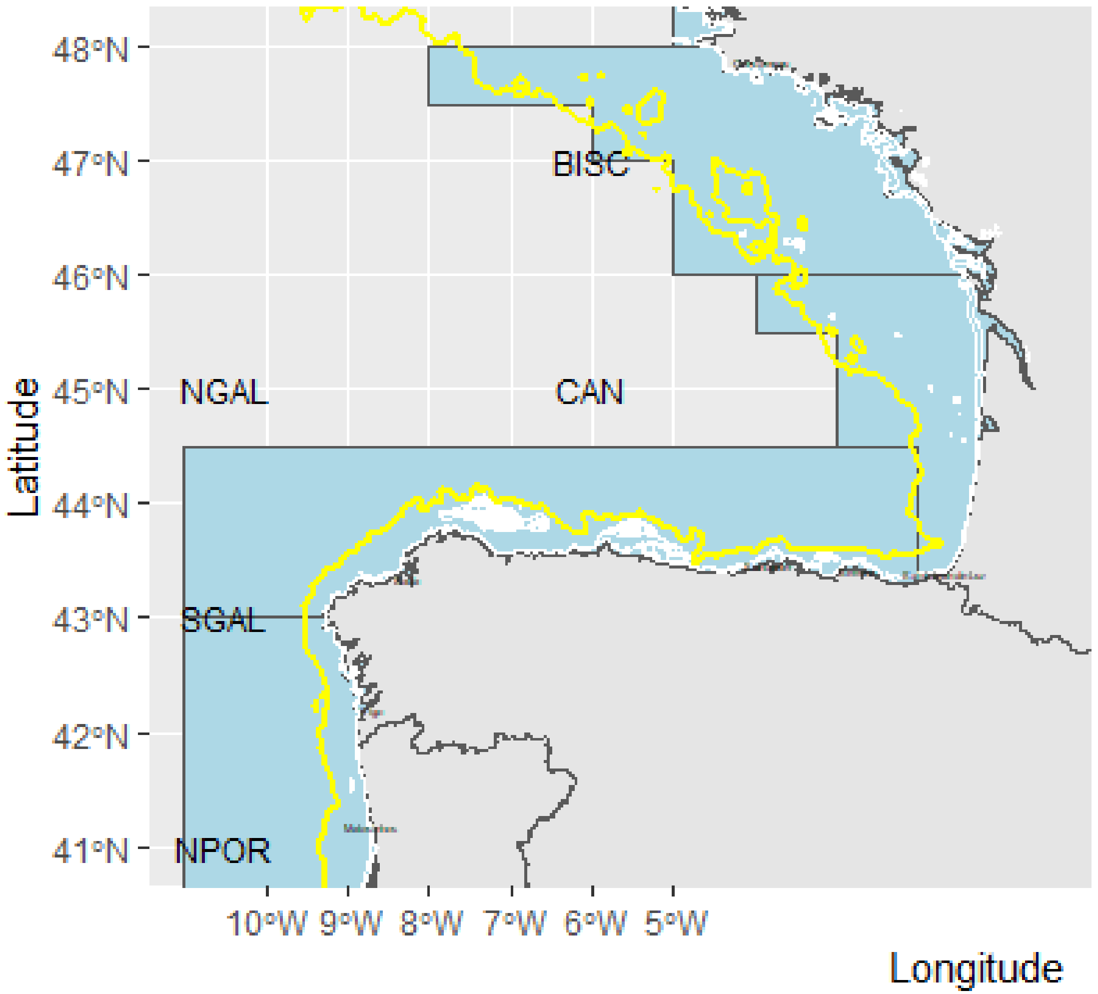
Increase in larval survival in OCN

English Channel and BoB as isolated populations

BoB did not show connectivity with its low recruitment adjacent areas

BoB recruitment → Can abundance and biomass did not increase

Silva et al. (2019)



English Channel and BoB as isolated populations

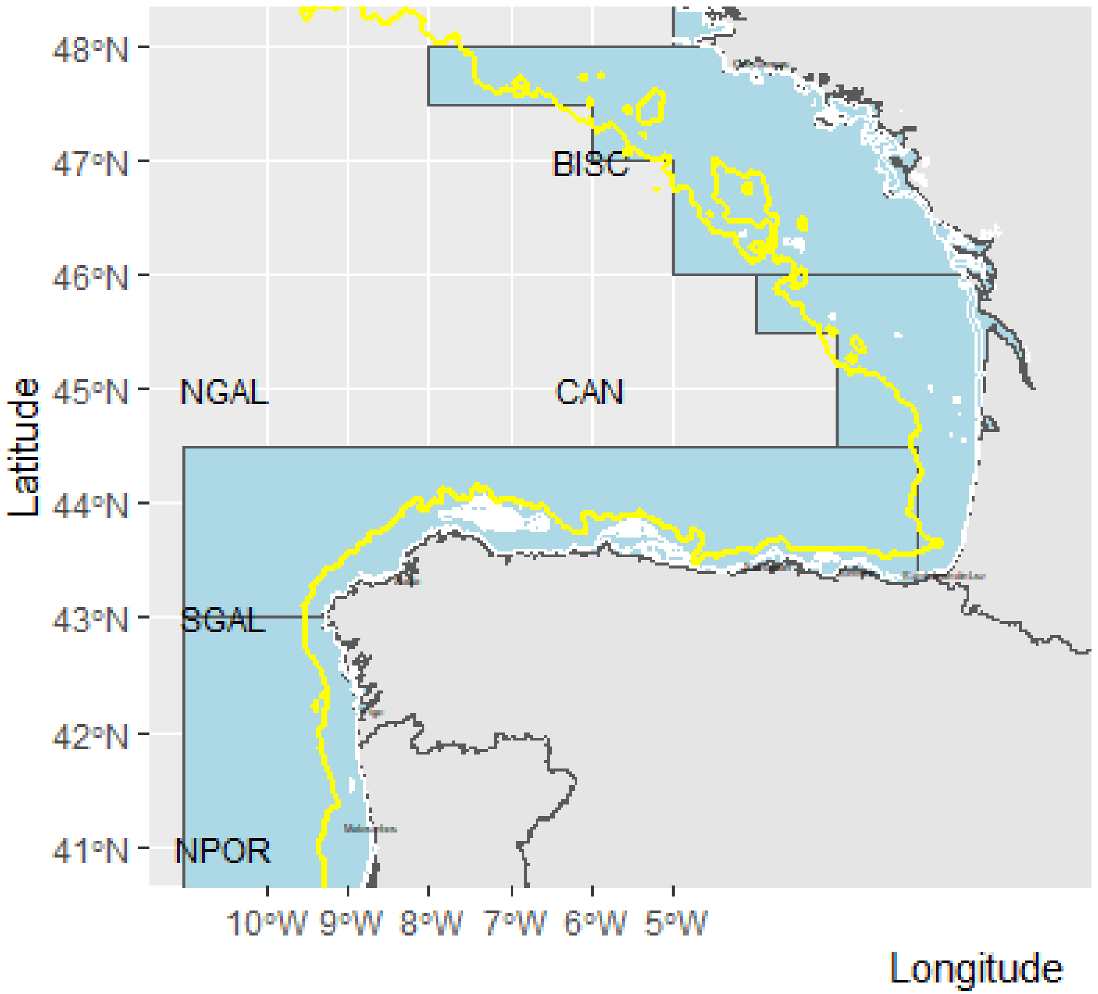
BoB has a large continental shelf (yellow on the map)

Silva et al. (2019)

Sufficient productivity to sustain sardine population

Silva et al. (2019)

Less outflow of individuals



English Channel and BoB as isolated populations

Same genetic stock

McKeown et al. (2024); Sabatino et al. (2025)

Also seen in otolith studies

E.g. Neves et al. (2023)

Differences on life history traits

Silva et al. (2008); Gatti et al. (2018)

+

No infomation on connectivity between these two areas

→

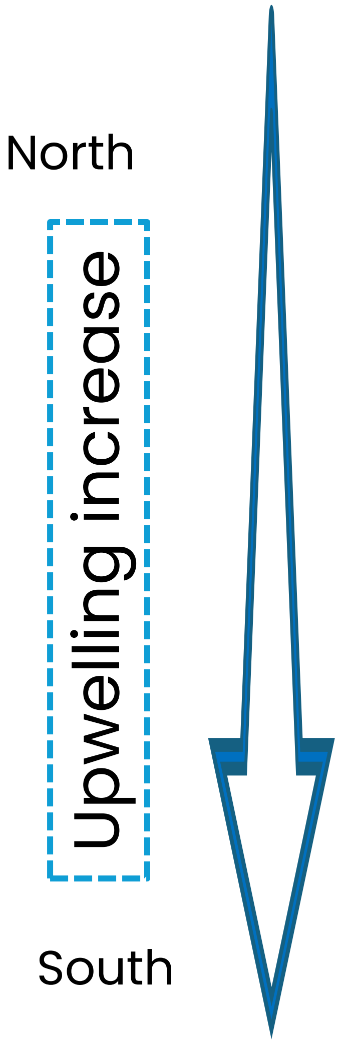
Managed as separate stocks

English Channel and BoB as isolated populations

Moroccan areas as isolated populations

Genetic studies (Chlaida et al., 2006; Sabatino et al., 2025), otolith studies (Neves et al., 2023; Mounir et al., 2023), differences in body morphology (Silva et al., 2008), feeding habits (Nielancl, 1980 in Kafini, 1998)

Sardines in the south of Morocco are more adapted to the near-permanent upwelling conditions, which may lead to morphological differences — as reported in some studies — and eventually genetic differences, as observed in others. This, coupled with other oceanographic characteristics, may explain the differences in recruitment dynamics and the lack of connectivity between these areas, observed in this study.



Belmajdoub et al., 2023

English Channel and BoB as isolated populations

2 subspecies found by Atarhouch et al. (2006).

Morphological differences (Silva et al. (2008).

Genetic differences found by Sabatino et al. (2025).

Moroccan areas as isolated populations

Genetic studies (Chlaida et al., 2006; Sabatino et al., 2025), otolith studies (Neves et al., 2023; Mounir et al., 2023), differences in body morphology (Silva et al., 2008), feeding habits (Nielancl, 1980 in Kafini, 1998)

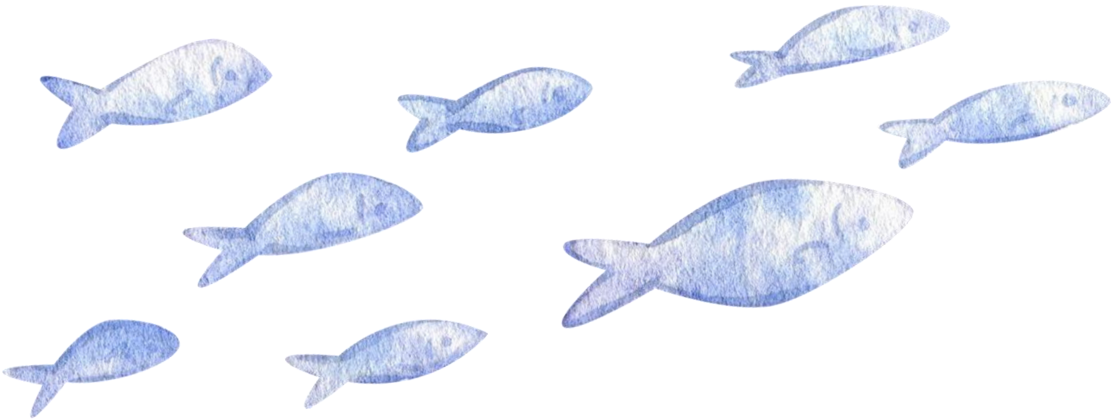
Mediterranean populations are not connected with the Atlantic populations

Santos et al. (2018) results showed 8% of larvae from Algarve transport into the Mediterranean.

Antoniou et al. (2023) saw an overlap in the northern Alboran Sea – sardines from the Atlantic and sardines with mixed genetics.

Thank you!

I am available for any questions/suggestions you might have!



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Inês Pereira, Ana Teles-Machad, Jilali Bensbai, Pablo Carrera, Leire Citores, Erwan Duhamel, Leire Ibaibarriaga, Magdalena Iglesias, Ana Moreno, Richard Nash, Lionel Pawlowski, Isabel Riveiro, Fernando Ramos, Rosana Ourens, Andres Uriarte, Jeroen Van der Kooij, Fabio Campanella, Pedro Torres, Ana Ventero, Laura Wise, Susana Garrido, Renato Rosa, Isabel Domingos and Alexandra A. Silva

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References

Antoniou, A., Manousaki, T., Ramírez, F., Cariani, A., Cannas, R., Kasapidis, P., Magoulas, A., Albo-Puigserver, M., Lloret-Lloret, E., Bellido, J. M., Pennino, M. G., Follesa, M. C., Esteban, A., Saraux, C., Sbrana, M., Spedicato, M. T., Coll, M., & Tsigenopoulos, C. S. (2023). Sardines at a junction: Seascape genomics reveals ecological and oceanographic drivers of variation in the NW Mediterranean Sea. *Molecular Ecology*, *32*(7), 1608–1628. https://doi.org/10.1111/mec.16840

Antunes, S. L. D. (2023). *Efeitos Ambientais nas Condições de Crescimento dos Estados Larvares de Sardina pilchardus na Costa Portuguesa e Golfo de Cádis*. Faculdade de Ciências da Universidade de Lisboa.

Arístegui, J., Barton, E. D., Álvarez-Salgado, X. A., Santos, A. M. P., Figueiras, F. G., Kifani, S., Hernández-León, S., Mason, E., Machú, E., & Demarcq, H. (2009). Sub-regional ecosystem variability in the Canary Current upwelling. *Progress in Oceanography*, *83*(1–4), 33–48. https://doi.org/10.1016/j.pocean.2009.07.031

Atarhouch, T., Rüber, L., Gonzalez, E. G., Albert, E. M., Rami, M., Dakkak, A., & Zardoya, R. (2006). Signature of an early genetic bottleneck in a population of Moroccan sardines (Sardina pilchardus). *Molecular Phylogenetics and Evolution*, *39*(2), 373–383. https://doi.org/10.1016/j.ympev.2005.08.003

Belmajdoub, H., Minaoui, K., El Aouni, A., Hilmi, K., Saadane, R., & Chehri, A. (2023). A New Upwelling Index for the Moroccan Atlantic Coast for the Period between 1982–2021. *Remote Sensing*, *15*(14), 3459. https://doi.org/10.3390/rs15143459

Chlaida, M., Kifani, S., Lenfant, P., & Ouragh, L. (2006). First approach for the identification of sardine populations Sardina pilchardus (Walbaum 1792) in the Moroccan Atlantic by allozymes. *Marine Biology*, *149*(2), 169–175. https://doi.org/10.1007/s00227-005-0185-0

Correia, A. T., Hamer, P., Carocinho, B., & Silva, A. (2014). Evidence for meta-population structure of Sardina pilchardus in the Atlantic Iberian waters from otolith elemental signatures of a strong cohort. *Fisheries Research*, *149*, 76–85. https://doi.org/10.1016/j.fishres.2013.09.016

Garrido, S., Silva, A., Marques, V., Figueiredo, I., Bryère, P., Mangin, A., & Santos, A. M. P. (2017). Temperature and food-mediated variability of European Atlantic sardine recruitment. *Progress in Oceanography*, *159*, 267–275. https://doi.org/10.1016/j.pocean.2017.10.006

Gatti, P., Cominassi, L., Duhamel, E., Grellier, P., Le Delliou, H., Le Mestre, S., Petitgas, P., Rabiller, M., Spitz, J., & Huret, M. (2018). Bioenergetic condition of anchovy and sardine in the Bay of Biscay and English Channel. *Progress in Oceanography*, *166*, 129–138. https://doi.org/10.1016/j.pocean.2017.12.006

Jardim, E., Eero, M., Silva, A., Ulrich, C., Pawlowski, L., Holmes, S. J., Ibaibarriaga, L., De Oliveira, J. A. A., Riveiro, I., Alzorriz, N., Citores, L., Scott, F., Uriarte, A., Carrera, P., Duhamel, E., & Mosqueira, I. (2018). Testing spatial heterogeneity with stock assessment models. *PLOS ONE*, *13*(1), e0190791. https://doi.org/10.1371/journal.pone.0190791

Kifani, S. (1998). Climate dependent fluctuations of the Moroccan sardine and their impact on fisheries. *Global versus Local Changes in Upwelling Systems*.

McKeown, N. J., Campanella, F., Silva, J. F., Roel, B. A., Healey, A. J. E., Shaw, P. W., & Van Der Kooij, J. (2024). Genomic analysis of NE Atlantic sardine (*Sardina pilchardus*) reveals reduced variation in a recently established North Sea population and directs reconsideration of management units. *Ecology and Evolution*, *14*(8), e70101. https://doi.org/10.1002/ece3.70101

Mounir, A., Hassan, A., Nor-eddine, C., Nawal, H., & Safaa, B. (2022). Habitats and Characteristics of Sardina pilchardus, off the Moroccan Atlantic coast. *Annals of Marine Science*, *6*(1), 007–020. https://doi.org/10.17352/ams.000027

Neves, J., Veríssimo, A., Múrias Santos, A., & Garrido, S. (2023). Comparing otolith shape descriptors for population structure inferences in a small pelagic fish, the European sardine *Sardina pilchardus* (Walbaum, 1792). *Journal of Fish Biology*, *102*(5), 1219–1236. https://doi.org/10.1111/jfb.15369

Relvas, P., Barton, E. D., Dubert, J., Oliveira, P. B., Peliz, Á., da Silva, J. C., & Santos, A. M. P. (2007). Physical oceanography of the Western Iberia Ecosystem: Latest views and challenges. *Progress in Oceanography*, *74*, 149–173.

Santos, A. M. P., Chícharo, A., Dos Santos, A., Moita, T., Oliveira, P. B., Peliz, Á., & Ré, P. (2007). Physical–biological interactions in the life history of small pelagic fish in the Western Iberia Upwelling Ecosystem. *Progress in Oceanography*, *74*(2–3), 192–209. https://doi.org/10.1016/j.pocean.2007.04.008

Santos, A. M. P., Nieblas, A.-E., Verley, P., Teles-Machado, A., Bonhommeau, S., Lett, C., Garrido, S., & Peliz, A. (2018). Sardine (Sardina pilchardus) larval dispersal in the Iberian upwelling system, using coupled biophysical techniques. *Progress in Oceanography*, *162*, 83–97. https://doi.org/10.1016/j.pocean.2018.02.011

Santos, A. M. P., Peliz, A., Dubert, J., Oliveira, P. B., Angélico, M. M., & Ré, P. (2004). Impact of a winter upwelling event on the distribution and transport of sardine (Sardina pilchardus) eggs and larvae off western Iberia: A retention mechanism. *Continental Shelf Research*, *24*(2), 149–165. https://doi.org/10.1016/j.csr.2003.10.004

Silva, A., Carrera, P., Massé, J., Uriarte, A., Santos, M. B., Oliveira, P. B., Soares, E., Porteiro, C., & Stratoudakis, Y. (2008). Geographic variability of sardine growth across the northeastern Atlantic and the Mediterranean Sea. *Fisheries Research*, *90*(1–3), 56–69. https://doi.org/10.1016/j.fishres.2007.09.011

Silva, A., Garrido, S., Ibaibarriaga, L., Pawlowski, L., Riveiro, I., Marques, V., Ramos, F., Duhamel, E., Iglesias, M., Bryère, P., Mangin, A., Citores, L., Carrera, P., & Uriarte, A. (2019). Adult-mediated connectivity and spatial population structure of sardine in the Bay of Biscay and Iberian coast. *Deep Sea Research Part II: Topical Studies in Oceanography*, *159*, 62–74. https://doi.org/10.1016/j.dsr2.2018.10.01