Temporal variations in otolith shape population structure of a small pelagic fish, the European sardine *Sardina pilchardus* (Walbaum, 1792), in a decadal period

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Introduction / Condensed Abstract

Otolith shape analysis can be considered a biological marker and indirectly infer connectivity among fish populations making otoliths efficient tools for distinguishing fish populations spatially and temporally. Here, we explored the possible temporal differences in population structure in the European sardine *Sardina pilchardus* (Walbaum, 1792), a fast-growing and short-lived coastal pelagic fish species, with an excellent dispersal capacity, as well as variable population dynamics. Population structure results from a recent year (2019) were compared with those from previous studies using samples collected over the last ~20 years (2003 and 2013), which includes years of higher (2003) and lower fish biomass (2013 and 2019) following an extensive period of poor recruitment, providing temporal variation insights in the population structure of the species. Following the methodology used in the previous studies, a combination of Elliptic Fourier descriptor and shape indices was explored using multivariate statistical methods. The overall results comparison among studies on that decadal time scale revealed differences in the population structure and connectivity patterns compared to the earlier period. The major temporal differences pertain to the Mediterranean and Atlantic waters separately. Still, all studies agree that the Strait of Gibraltar is not an effective obstacle to the separation of European sardine stocks, suggesting instead that individuals might migrate among adjacent areas. These differences may be attributed to changes in environmental variables leading to changes in population dynamics but can also be the result of the sharp decrease in sardine biomass that occurred in the last decade.

Objectives

Contribute to the knowledge of sardine population structure using otolith morphometry

- Use shape analysis to study sardine population structure
- Compare shape analysis results between different years
  - enclosing a marked species biomass breakdown period

Methodology

- Otoliths were collected under the scope of the SARDINOMICS project (Mar2020), in a total of 18 areas, representing almost the whole distribution range (Figure 1).
- Otolith images were analyzed using ShapeR package and shape coefficients descriptors were calculated, based on Fourier transformation.
- General shape parameters were extracted, as well as the otolith shape indices calculated.
- To evaluate the shape of the otoliths multivariate statistical analyzes of descriptive otolith information were used, such as discriminant and clustering methods.

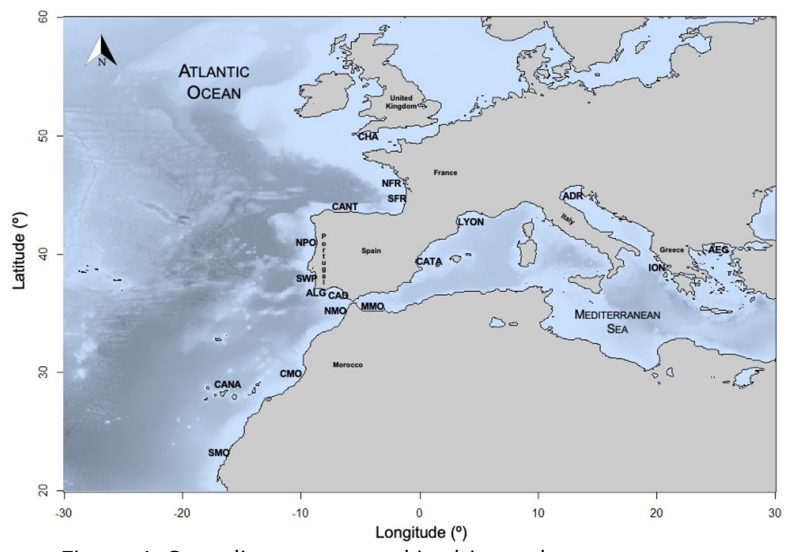

Figure 1. Sampling areas used in this study

In the last decades...

- ➔ European sardine **catches declined**, and **stocks are recognized as fully or heavily exploited** in almost all of its geographic distribution (FAO, 2018, 2019; ICES, 2018)
- ➔ Mediterranean waters - **biomass decrease and increasing risk of overexploitation (smaller and poor condition individuals)** (FAO, 2018)
- ➔ Northwestern Africa waters - **stocks biomasses stable and the total catch increased** (FAO, 2019)
- ➔ Atlantic European waters - **biomass declined by 71%, from 2006 to 2013** (ICES, 2018) - due to an **extended low recruitment period** and slowly recovering in the last years
- ➔ Biomass and density could **influence the dynamics and migration patterns of the species**, as previously demonstrated (Silva *et al.*, 2019)

Discriminant and Clustering analysis

Linear Discriminant Analysis

- backward stepwise selection adopted
- 38 Elliptic Fourier descriptors and 4 Shape Indices

Some **populations seems to agregate**, related with **proximity/geographic location** (Fig. 2a)

Hierarchical Cluster Analysis

- discriminant analysis pattern **validated by the cluster analysis**
  - suggesting **4 main clusters** (Fig.2b)

Each group has a recruitment hotspot (except F3)

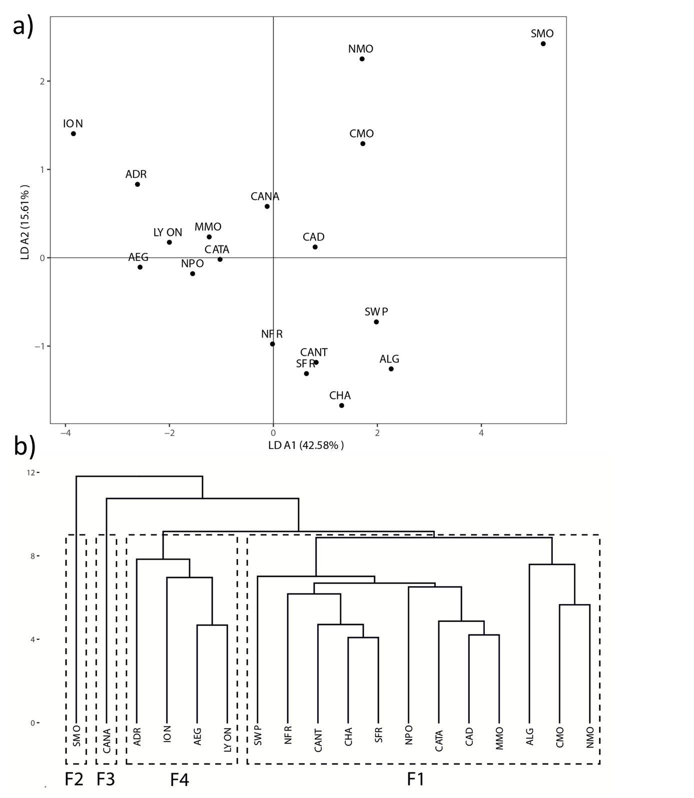

Figure 2. (a) LDA scores for the classification of European sardine otoliths by sampling area, and (b) cluster analysis defining the linkage dendrogram based on Euclidean distances

Temporal Population Structure Comparison

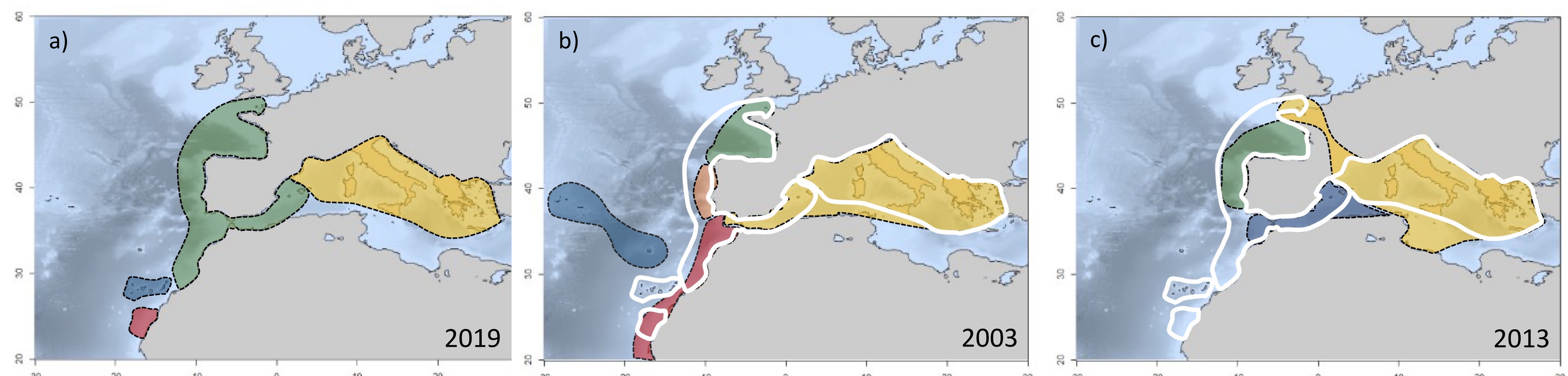

Figure 3. Map showing the identified groups based on Elliptic Fourier otolith shape analysis from a) the present study, using samples collected in 2019; and samples collected b) before (2003) (Neves *et al.*, 2021) and c) after (2013) (Jemaa *et al.*, 2015) the biomass breakdown. White lines in b) and c) represent the identified groups from a).

All studies present a **similar latitudinal distribution**

- ➔ No separation between Atlantic and Mediterranean waters
  - ➔ Possible **migrations between western Mediterranean and Atlantic Moroccan coast or Gulf of Cadiz**
- ➔ Atlantic islands separated from mainland areas - *although different islands/archipelagos*

  2003 (Azores + Madeira Archipelagos) vs 2019 (Canary Islands) (Fig. 3a,b)

Major differences

Mediterranean waters

➔ Mediterranean separated in **one group** (2003) (Fig. 3b) VS **two groups** (2013 and 2019) (Fig. 3,a,c)

Atlantic waters

➔ Atlantic waters divided by **three groups** (**Northern Iberia** + **Portuguese western coas** + **African coast**) (2003) (Fig. 3b)

VS **two groups** (**All Iberian areas** + **North Morocco with West Mediterranean**) (2013) (Fig. 3c)

VS **one group** (**together with Western Mediterranean**) (2019) (Fig. 3a)

➔ South of Morocco as an **isolated group** (2019) vs South of Morocco **belonging to the African coast group** (2003)

Considerations:

Different covered areas could lead to distinctive outcomes

e.g. 2013 study had limited sampling outside the Mediterranean Sea (African coast and south of Iberian areas) (Fig. 3c)

Conclusions

➔ Otolith shape of fish collected in the same areas **may vary through time** (could be an environmental effect)

➔ Population structure variation as a **temporal effect**

- ➔ Possibly dependent on specific events occuring during these temporal intervals – e.g. **biomass breakdown**
  - ➔ **Biomass influencing species dynamics and migration patterns**
    - ➔ **Developing population structure disparities at a phenotypical level**

      particularly species with **marked fluctuations of population biomass** through time ("boom and bust" species), such as *Sardina pilchardus*

Future work

- **Add more years** - different population abundance / biomass
  - e.g. Several years of low biomass and high biomass
- Similar covered areas and distribution range
- Statistically comparison among years

  Interpret results in relation to **environmental parameters** (e.g SST, Chla) and **fisheries pressure influence**

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