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Variations in fish length, distribution, biomass, and omega 3 content of anchovy (*Engraulis ringens*) off the Peruvian coast between 1998 and 2022 with repercussions to fishery management

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Introduction

- Upwelling systems are characterized by a high abundance of small pelagic fish populations with variations not necessarily correlated to classic climatic indexes. Thus, the continuous observation of a changing ocean and the search of other variables is critical.
- Peruvian Anchovy's amino acid composition of fish protein matches the requirements of human beings. Anchovies have some of the highest levels of omega-3 fatty acids.
- Peruvian anchovy fishery yields the world's largest supplier of marine ingredients. 2 to 3 billion of USD/year, 1.5 to 2% of Peru's National Gross Production.
- However, there is a high variability reinforced by successive El Niño events: 2010, 2012, 2014, 2015, 2016, and 2017.
- Under the IMARPE's Adaptive Precautionary Management (APM) advice, the Vice Ministry of Fisheries (PRODUCE) enacted:
 1. A complete set of legal regulations (as described by Arias-Schreiber 2011)
 2. Precautionary quotas system;
 3. Cancellations of several fishing seasons (2010,2012,2014, 2016, 2019 and 2022);
 4. Quasi-real-time closures of fishing grounds (DS-024) etc

Data and methods

- Anchovy was assessed by up to three acoustic surveys per year from 1998 to 2022.
- Landings data has been collected by harbors and months from 1998 to 2022.
- Fishing companies along the coast collected Omega 3 values (% EPA, DHA) from 1998 to 2021.
- Catches by vessels and polygons for precautionary closing of fishing areas available from 2017 to 2022.
- Sea surface temperature anomalies (SSTA) in the El Niño 1+2 region were used as a proxy for habitat conditions.
- Changes in fish meal and fish oil prices were analyzed against the performance of catches
- We analyzed the latitudinal biomass by springs and summers to detect differences in recruitment.
- GAMs, boxplots, and Hovmoller diagrams were made to detect latitudinal variations in fish length, biomass, and omega 3.
- SSTA were compared with fish abundance from 1998 to 2022.
- 2D plots by fishing seasons were made to show the geographical location of fishing sets and polygons of closed areas to fishing from 2017 to 2022.

Results

During the last 25 years, the anchovy population was characterized by a large proportion of juveniles at some times (e.g. 2002 to 2005), a situation that has become common since 2016.

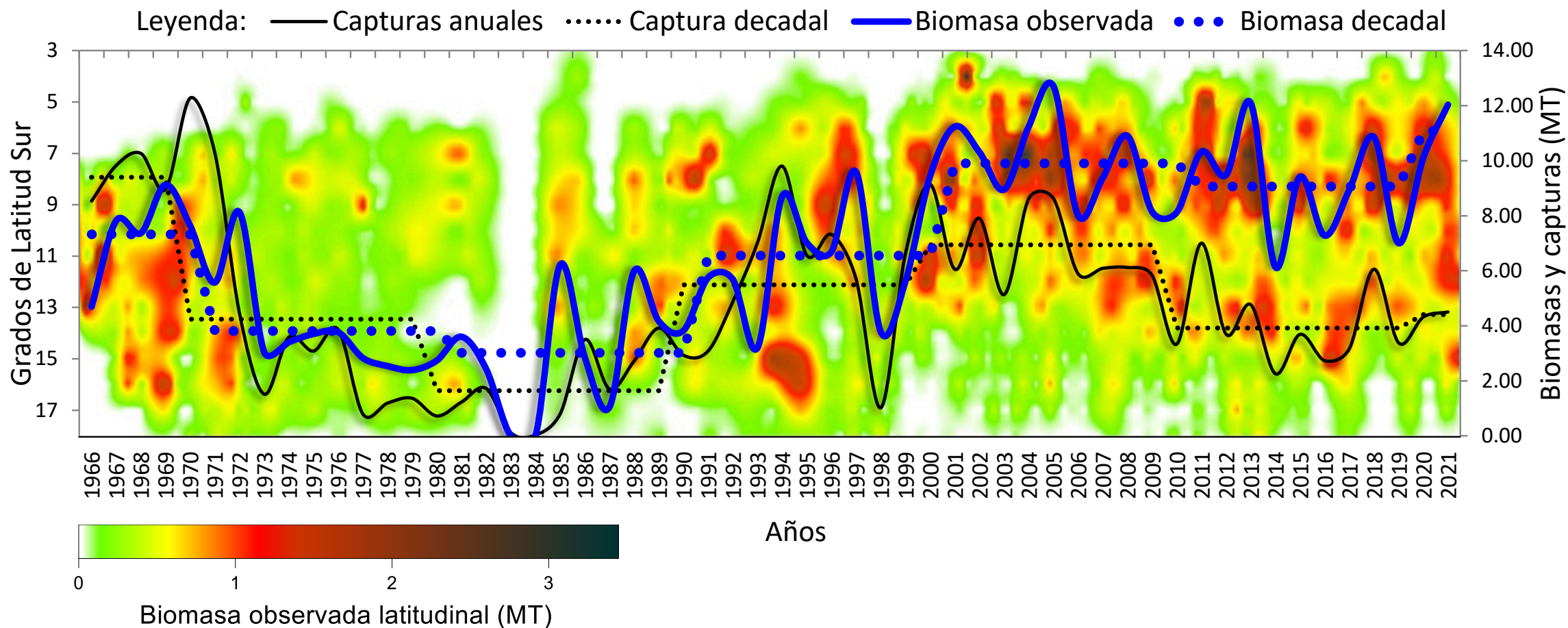
Concomitant with these changes, the mean size of catches has decreased, and recruitment is higher by the end of every year.

These variations have caused that the second fishing season of 2010, 2012, 2014, 2015 and 2016, 2019, and 2022 canceled due to the in-place adaptive precautionary management, although with economic consequences to the sector.

To reduce the catch of juvenile fish a decree was issued in 2016 (DS-024) to implement a dynamic precautionary closing of areas whose effectivity we evaluated.

We found that the warm period 2014-17 had consequences on omega 3 fatty acids contents, where EPA strongly reduced while DHA increased.

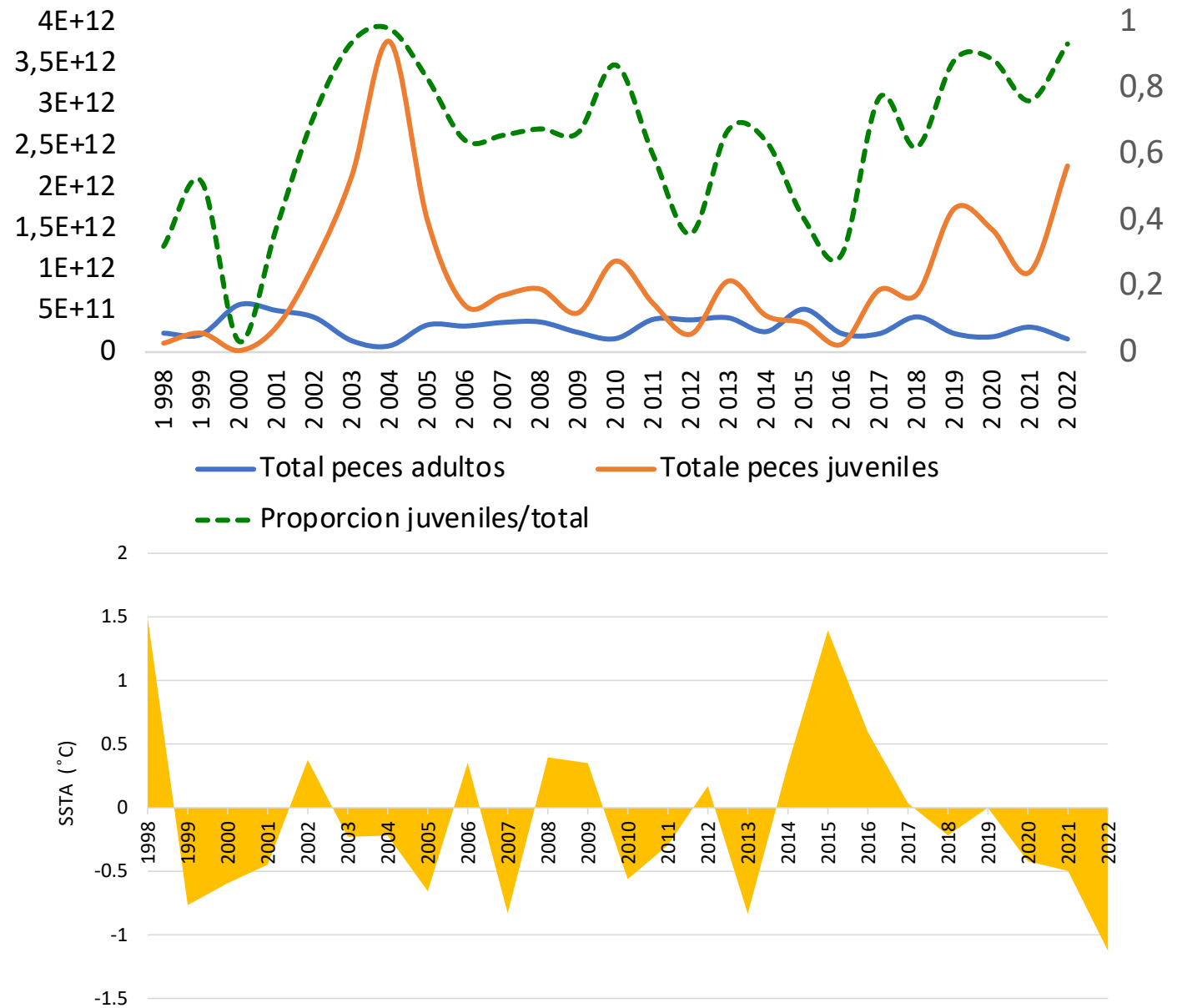
Latitudinal acoustic biomass during summers 1966-2022



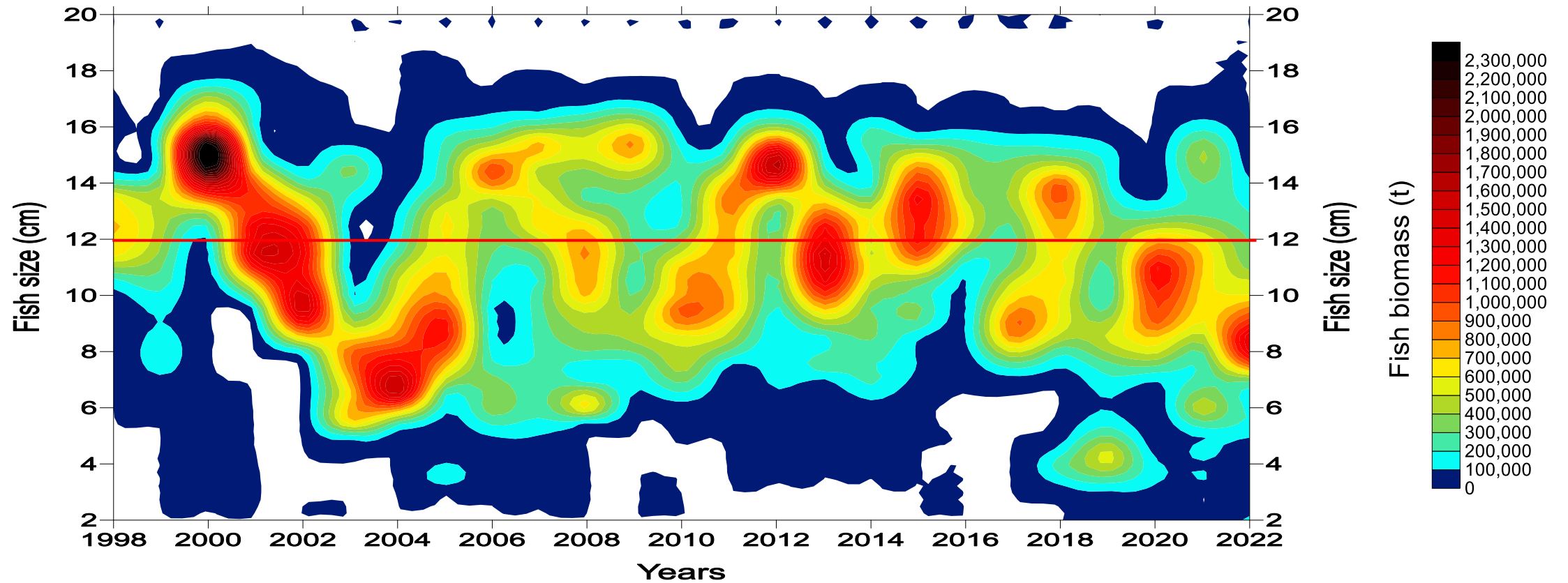
- Despite the changes that occurred, the biomass has remained at a high level (~10 million tons) since 2000.
- There is a variation of the distribution area in three sectors: north of 10°S, where adults are dominant; between 10 to 12°S where the biomass dramatically decreased; and south of 12°S where the juveniles are abundant.

Total adults and juveniles in number, ratio among them and SSTA (1998-2022)

- Warmer conditions during the summers 1998-2022 correspond to the smaller abundance of juveniles.
- Overall percentage of juveniles is 60% compared to the total number of fish.

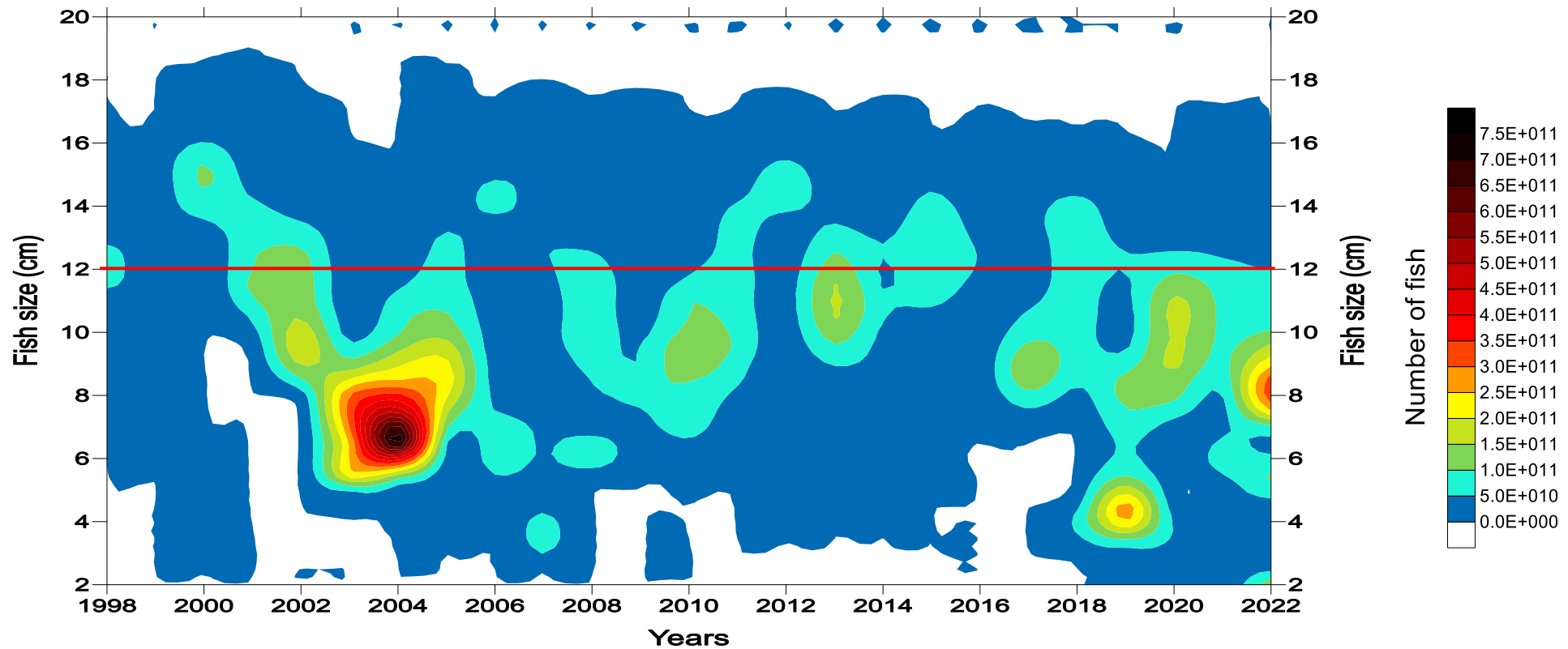


Fish biomass by size intervals during summers 1998-2022



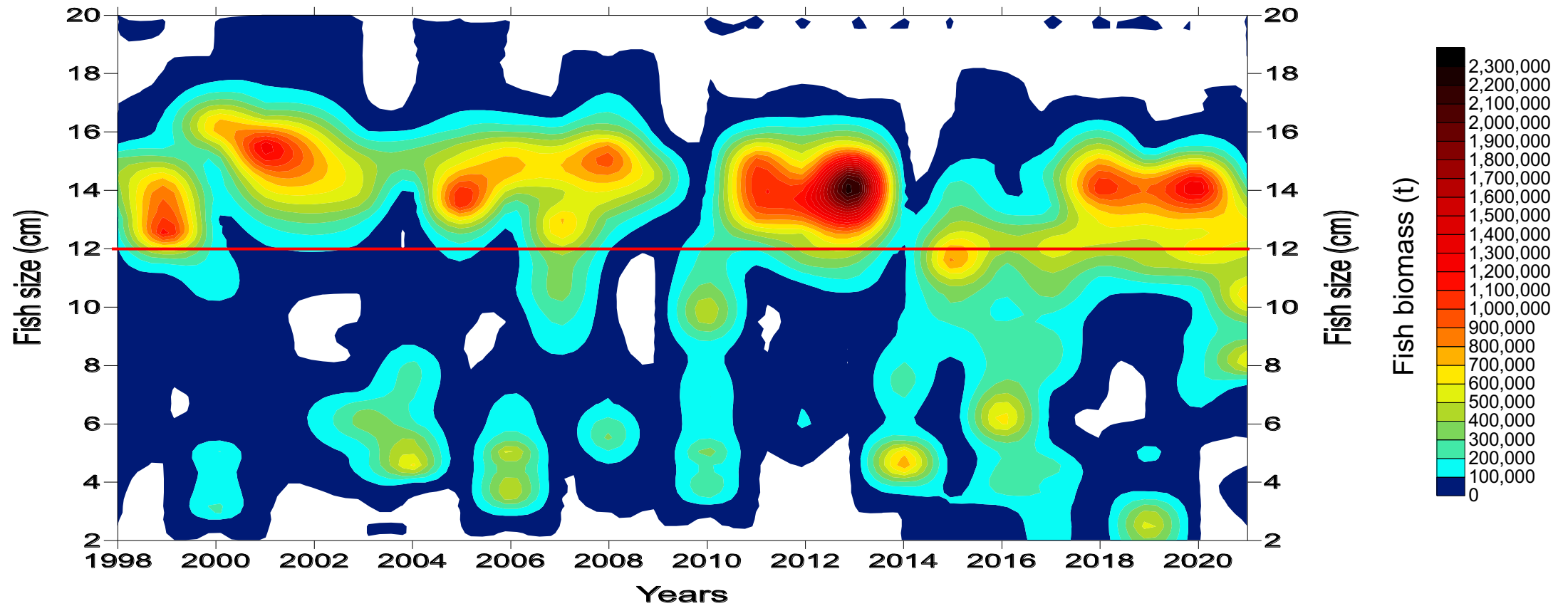
- There is an increase in biomass for smaller sizes, especially after 2016.

Abundance (number of fish) by size intervals during summers 1998-2022



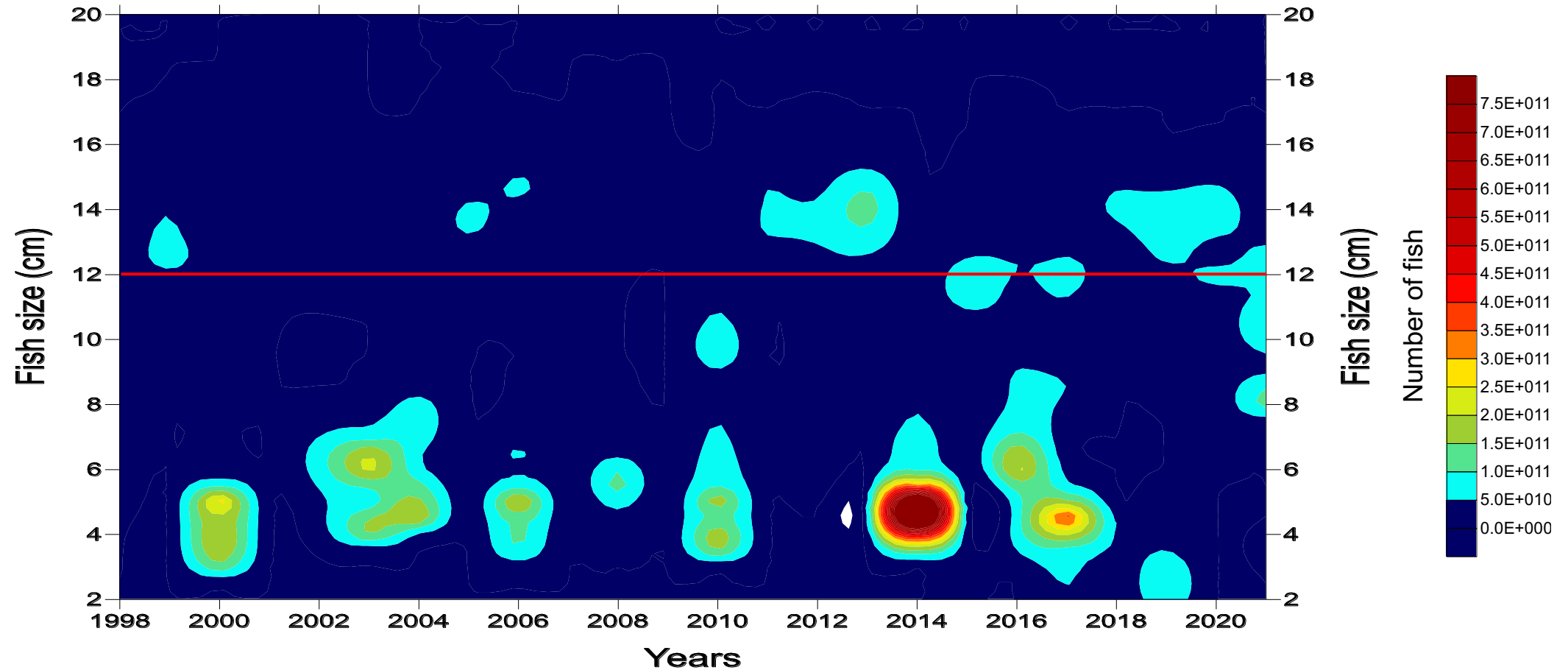
- There is an increase in abundance for smaller sizes, especially after 2016.

Fish biomass by size intervals during springs 1998-2022



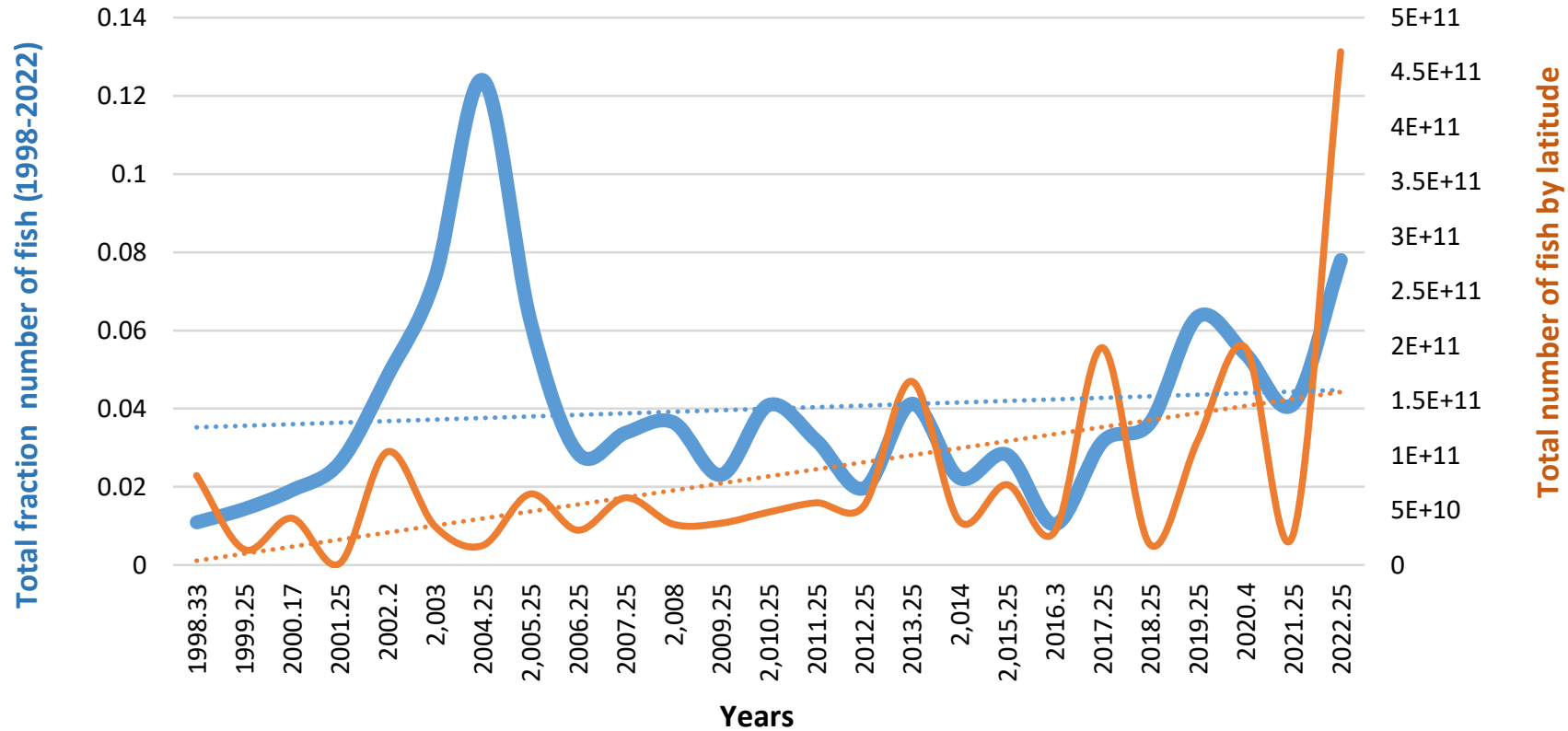
- During springs it is observed higher biomass of adults.

Abundance (number of fish) by size intervals during springs 1998-2022



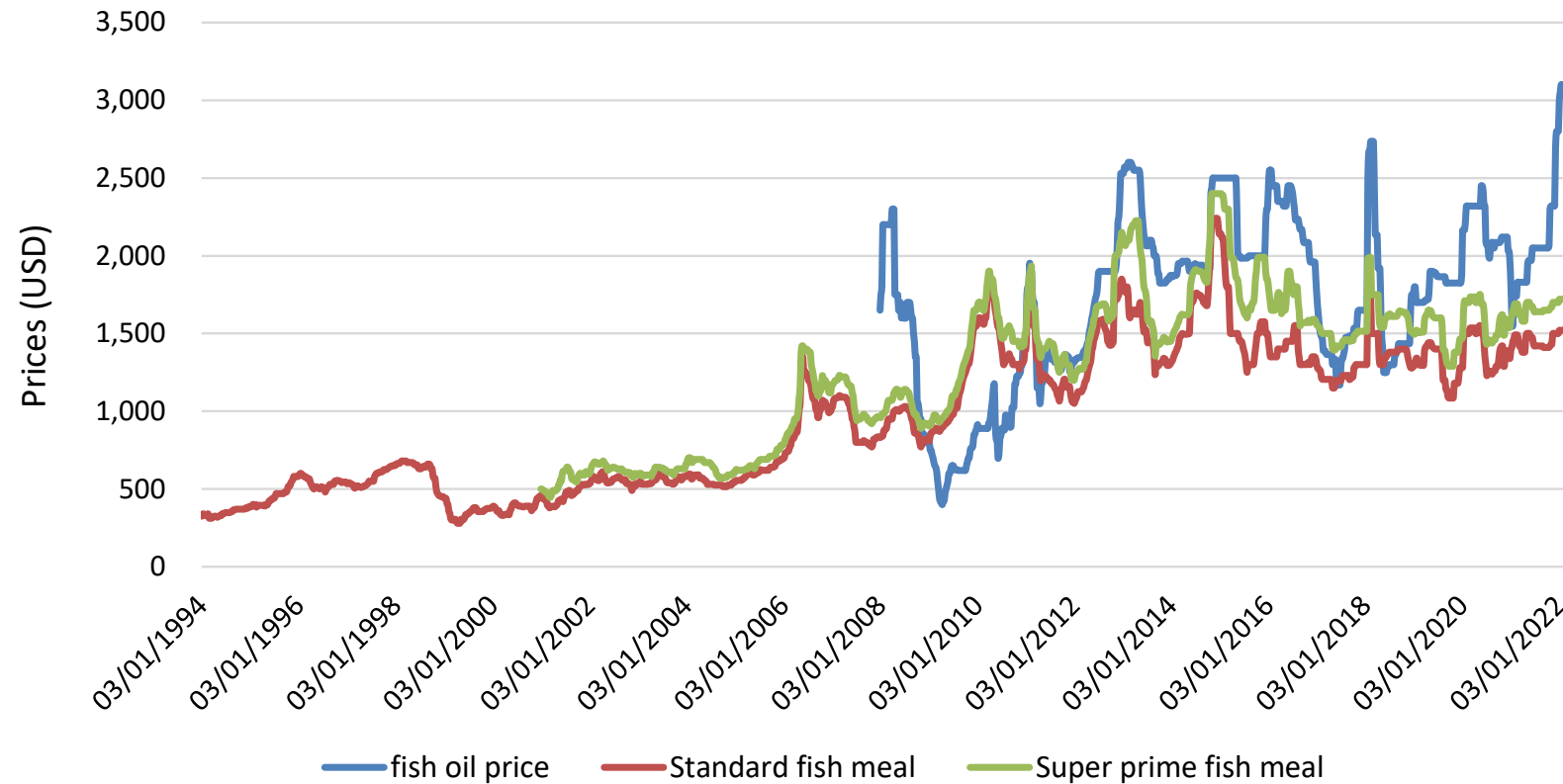
- In despite the larger biomass of adults during springs, the number of juveniles (recruitment) is much higher than adults.

Total fraction of fish compared to abundance in the Pisco area (14°S)



- Variability of the fish abundance increased in certain areas such as in the Pisco area, fewer amounts of adult fish are observed after 2012.

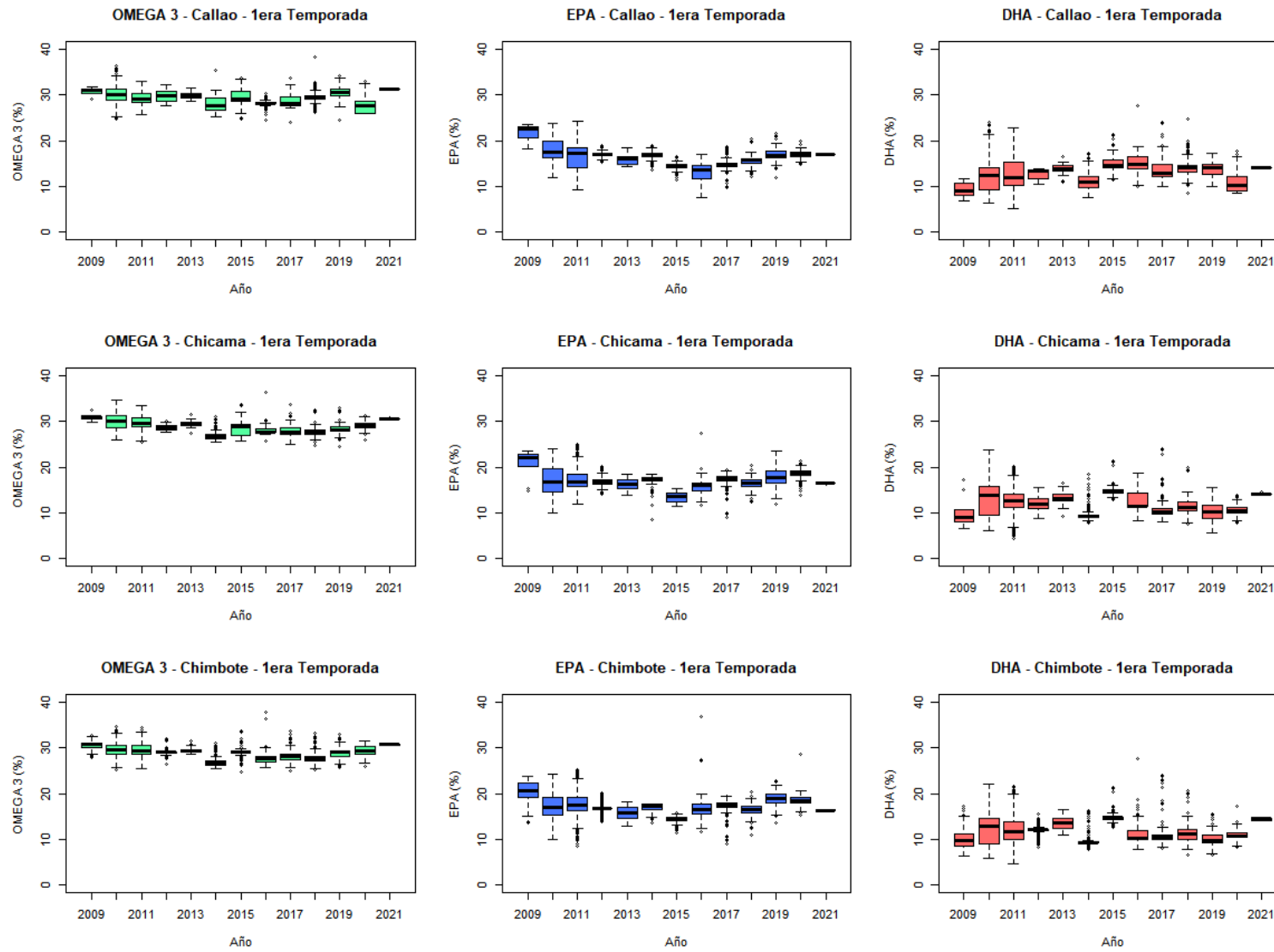
Peruvian fish meal and fish oil prices (1994 to 2022)



Source: IFFO

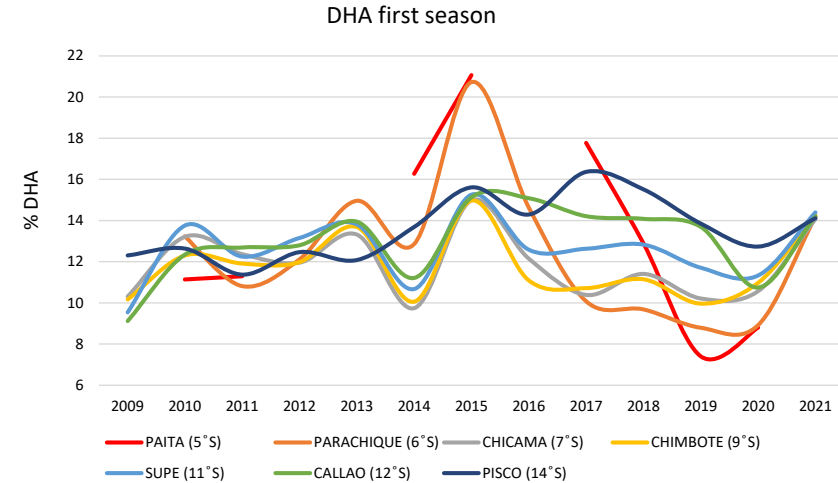
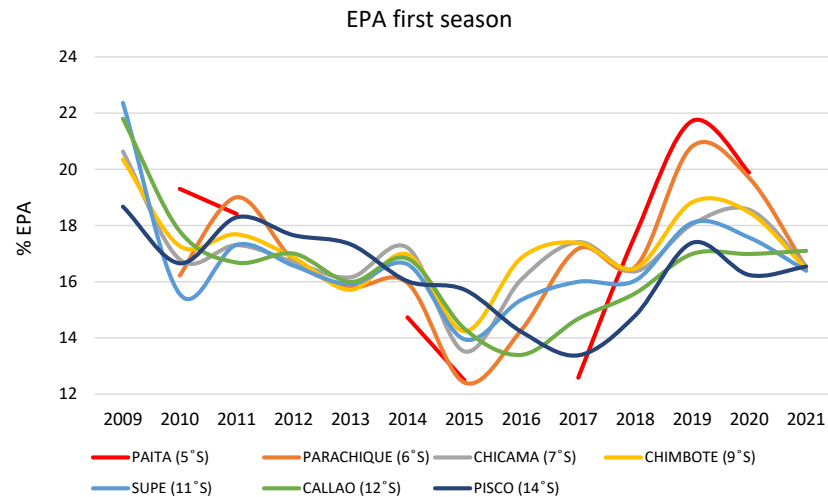
- Prices of Peruvian fish meal and fish oil increased since 2006.
- The smaller quotas provided since 2010 have contributed to cause an increase in prices, particularly for fish oil.

Typical variation in Omega 3 (EPA and DHA) by harbors by years (2009 – 2021)



- The overall concentration (%) of omega 3 has been kept stable at around 30%, but there are some large differences between EPA and DHA.

Latitudinal variation of Omega 3 (EPA and DHA) by years by fishing seasons (2009 – 2021)

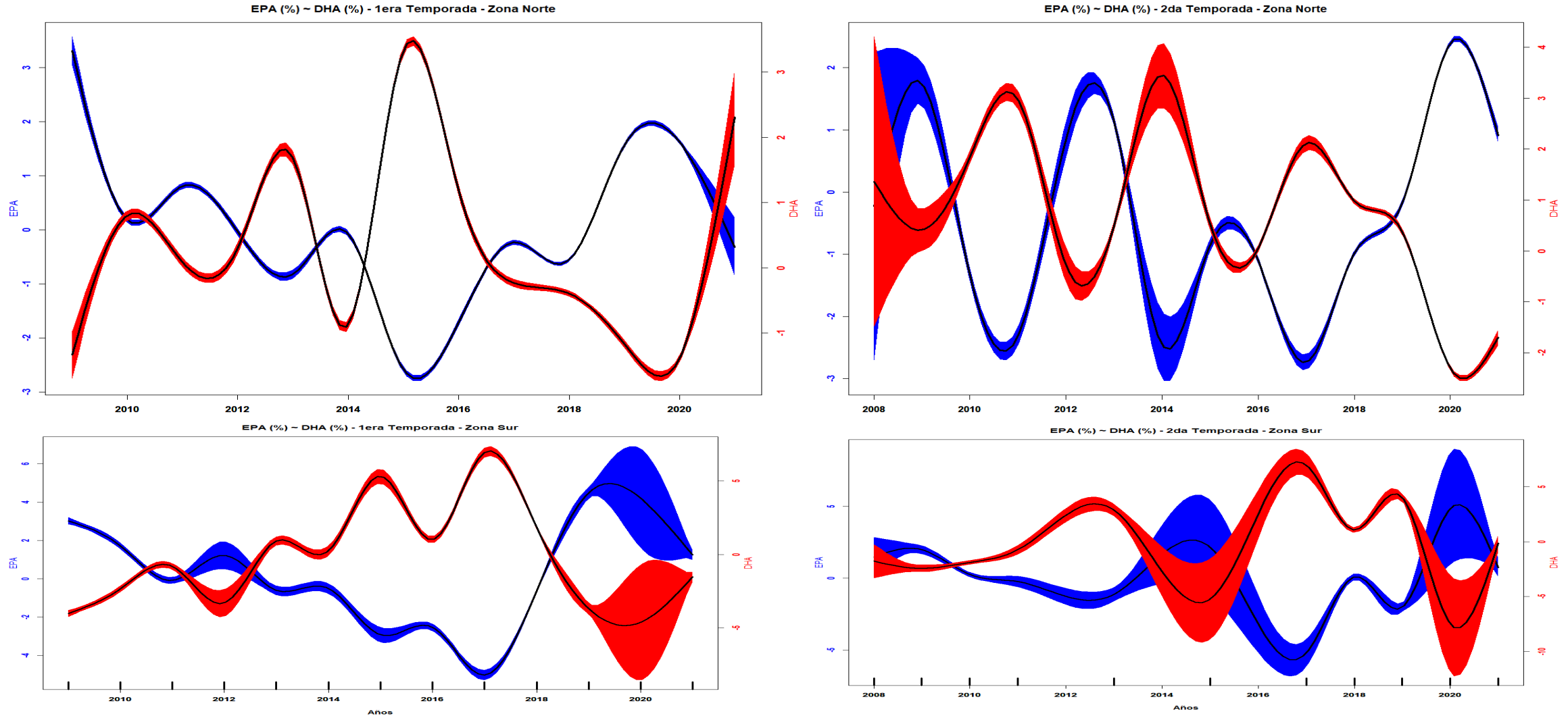


EPA second season

DHA second season

- There is a stronger latitudinal gradient of omega 3 from 2015 to 2020, EPA decreased from north to south during the first seasons (May to August) while DHA decreased proportionally.
- During second seasons (November to January).....

GAMs on variation of Omega 3 (EPA and DHA) by years by fishing seasons (2009 – 2021)



- In the central-north zone DHA increases when EPA decreases. Higher concentration of DHA is observed for warmer years (e.g. 2015 – 2016).
- In southern Peru DHA has been consistently higher than EPA from 2013 to 2017 during the first seasons, and from 2018 to 2021 during the second seasons.

Closing of fishing areas after the DS-024 (2017 – 2022)

- To be included...

Discussion

Regime shift ?

What tells omega 3 to explain these changes ?

DS 024 is OK ?

Económico impact, prices of fishmeal and fish oil

Proposed improvements to management, world's food security.

Conclusions

Our knowledge is based on short-term time series where ephemeral correlation can be observed. We should be cautious, particularly in the current context of global change or regime shift.

Anchovy habitat presented better conditions for recruitment after El Niño 2002, being less beneficial for adults.

Omega 3.....

Management system reacted by adapting to these conditions. The standing biomass remained at around 10 MT since 2000.

APM has successfully been applied to the anchovy fishery since mid the '90s to deal with strong ecosystem changes, demonstrating its efficiency.

The decline of anchovy catches observed in 2010, 2012, 2014, 2015, 2016, and 2019 is more the result of the APM adapted to every specific situation than an actual fishery-induced biomass decline.

