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ENVIRONMENTAL VARIABLITY IN THREE MAJOR MEDITERRANEAN TUNA SPAWNING GROUNDS

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SUMMARY

We propose four different environmental indicators, three related to temperature variability in three major spawning grounds of tuna species in the Mediterranean, and one related to the sea surface salinity variability in the Balearic Sea. These oceanographic indicators show the annual variability of environmental parameters affecting growth and survival of tuna eggs and larval. The indicators are intended to provide quick access to assessment working groups and fisheries scientist to identify potentially anomalous years.

RÉSUMÉ

Nous proposons quatre indicateurs environnementaux différents, trois liés à la variabilité de la température dans trois principales frayères d'espèces de thonidés en Méditerranée, et un relatif à la variabilité de la salinité à la surface de la mer des Baléares. Ces indicateurs océanographiques montrent la variabilité annuelle des paramètres environnementaux affectant la croissance et la survie des œufs et des larves de thonidés. Les indicateurs sont destinés à fournir un accès rapide à l'information aux groupes de travail d'évaluation et aux halieutes pour identifier les années potentiellement anormales.

RESUMEN

Se proponen cuatro indicadores medioambientales diferentes, tres relacionados con la variabilidad en la temperatura en las tres principales zonas de desove de especies de túnidos en el Mediterráneo y uno relacionado con la variabilidad de la salinidad de la superficie del mar en el mar Balear. Estos indicadores oceanográficos muestran la variabilidad anual de los parámetros medioambientales que afectan al crecimiento y supervivencia de las larvas y huevos de túnidos. Estos indicadores tienen como finalidad proporcionar un acceso rápido a la información a los grupos de trabajo de evaluación y a los científicos pesqueros para que puedan identificar años potencialmente anómalos.

KEYWORDS

*Mediterranean, spawning grounds,
mixed layer depth, temperature, salinity, spawning season*

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1. Introduction

Environmental variability at the spawning grounds of tuna species in the Mediterranean Sea affects a number of ecological processes driving the location of the spawning sites, egg hatching and larval survival. One of the most relevant hydrographic variables driving these processes is the temperature within the mixed layer depth, (Alvarez-Berastegui *et al*. 2016; Reglero *et al.* 2018a), which provides information on environmental drivers affecting recruitment processes and timing of spawning (Harford *et al.* 2017, Reglero *et al.* 2018a). It is a common issue of discussion in SCRS working groups whether a particular year shows specific anomalies in temperature and how they can affect interpretability of the catches by the fleets and recruitments observed in the assessment models. Therefore, it should be useful to have quick access to time series of sea temperature in the mixed layer depth at the most relevant spawning grounds of tuna species in the Mediterranean Sea during their spawning seasons. This would provide fisheries scientists with a reference data set to explore temperature trends and to identify potentially anomalous years. Recent hydrodynamic models covering the entire Mediterranean basin provide temperature data at various depths that can be used for comparison of the trends in difference areas for long time series. Sea surface temperature is accurately estimated from these models (Simoncelli *et al*. 2014).

The mean water salinity in the mixed layer depth provides a proxy for the water masses distribution in the Balearic Sea (Western Mediterranean, see figure 1), which affects the spatial distribution of the spawning areas (Alemany *et al.* 2010; Alvarez-Berastegui *et al.* 2014; Reglero *et al*. 2017). This variable has proved to improve standardization of larval abundance indices in the Balearic Sea, both for bluefin tuna *Thunnus thynnus* (Ingram *et al*. 2017) and for *T. alalunga* albacore (Alvarez-Berastegui *et al*. 2017). Nevertheless, the hydrodynamic models at the Mediterranean basin show lower capabilities to provide good estimations of the salinity distributions than for temperature, therefore when this variable has to be used it is necessary to apply previously assessed models for this parameter. In the Balearic Sea, the Western Mediterranean Sea Operational Forecasting System (WMOP) provides this characteristic covering the period from 2009 to present for the Balearic Sea (Juza *et al*. 2016).

Considering the relevance of these two hydrographical parameters and the availability of hydrodynamic models, we propose two indicators to assess the environmental variability of spawning grounds in the Mediterranean.

The two indicators provide information on:

1) The mean water temperature in the mixed layer depth in the main tuna spawning areas in the Mediterranean during the spawning season. The temperature data from a Mediterranean regional scale hydrodynamic model (Simoncelli *et al.* 2014). This indicator is computed at three different spawning areas, the Balearic Sea in the Western Mediterranean, the Tunisia-Malta in the Central and Cyprus in the Eastern Mediterranean (**Figure 1**).
2) The mean water salinity in the mixed layer depth in the Balearic Sea spawning ground during the spawning season from the WMOP high resolution hydrodynamic model (Juza *et al*. 2016)

2. Methods

2.1 Indicators

A. Mean temperature in the Balearic Sea Spawning ground (Western Mediterranean), acronym: "Temp_Bal_SG"

B. Mean temperature in the Tunisia-Malta Spawning ground (Central Mediterranean), acronym: "Temp_Tunisia-Malta_SG"

C. Mean temperature in the Cyprus Spawning ground (Eastern Mediterranean), acronym "Temp_Cyprus_SG"

These three indicators (A, B, C) are computed from the temperature field of the "CMEMS MED-MFC" hydrodynamic model, that provides two different datasets: i) the Mediterranean Sea Physics Reanalysis product, covering the period for 1990 to 2014 period (Simoncelli *et al*. 2016), and ii) the Mediterranean Sea Physics Analysis and Forecast product covering the period from 2016 to present (Clementi *et al.* 2017) (see details below).

Details on the "CMEMS MED-MFC" Mediterranean Sea Physics Reanalysis product. Values estimated from 1987 to 2016. The data set and complete description of the modeling process are available at: http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_REANALYSIS_PHYS_006_004

Details on the "CMEMS MED-MFC" Mediterranean Sea Physics Analysis and Forecast. Values estimated from 2016. The data set and complete description of the modeling process are available at: http://marine.copernicus.eu/services-portfolio/access-to-products/?option=com_csw&view=details&product_id=MEDSEA_ANALYSIS_FORECAST_PHY_006_013

Data was extracted from the daily resolution product at the 10.5-meter depth, as a proxy for the mean temperature for the mixed layer depth, which is about 25 meters during reproduction in the Western spawning ground (Alemany *et al*., 2010). This depth has been selected in the basis of the vertical distribution of tuna larvae from vertical-resolution sampling and experimental work (Reglero *et al.,* 2018b). The diary temperature data for each spatial region presented in **Figure 2** are monthly averaged from May to August. This time coverage has been selected since it covers the spawning season of most tuna species in the region (Reglero *et al.,* 2018a, Saber *et al.;* 2015). Values were scaled to represent the indicators.

D. *Mean Salinity in the Western Mediterranean Spawning ground (Balearic Sea), acronym "Sal_Bal_SG".*

This indicator is computed from the salinity field of the Western Mediterranean Sea Operational Forecasting System (WMOP). In order to provide better approximations of salinity fields the WMOP is based on a 2km-resolution regional ocean configuration of the ROMS model implemented over the Western Mediterranean Sea. The model is forced by high-resolution winds (5 km, 3 hours).

Data is extracted from the daily resolution product at the surface. The diary temperatures for the Western spawning ground (Balearic Sea, **Figure 3**) are monthly averaged a from May to August, both included. This time coverage has been selected since it covers the spawning season of most tuna species in the region (Alemany *et al.,* 2010, Saber *et al,* 2015). Values are scaled to represent the indicators.

Values from 2009 to 2015 are obtained from the "WMOP reanalysis" provided by SOCIB (www.socib.es) under request.

Values from 2016 to 2017 are obtained from the "WMOPforecast" provided online by SOCIB at:

http://thredds.socib.es/thredds/catalog/operational_models/oceanographical/hydrodynamics/wmop_3d/catalog.html.

Detailed information on the model configuration can be found at http://www.socib.es/?seccion=modelling&facility=modelling_overview

The operational validation of the model, including salinity can be accessed real time at: http://www.socib.es/?seccion=modelling&facility=wmedvalidation

2.2 Data

All data are available on-line or by request, as indicated in the previous section. Each indicator is a combination of different data sources providing reanalysis data in previous years or forecast data for the last 2 or 3 years (for further detail see Section 2.1)

2.3 Regions

The indicators proposed provide information on the environmental variability in the Mediterranean spawning grounds of main tuna species. Indicators must be interpreted at regional scale.

2.4 Goals and objectives

The objective of these indicators is to provide the ICCAT/SCRS assessment working groups with quick access to information on the environmental variability at the spawning grounds, facilitating the identification of anomalous years and the task of CPUE standardization. These indicators also helps interpreting the outputs of the assessment models.

3. Interpretation

The three indicators based on temperature data (Temp_Bal_SG; Temp_Tunisia-Malta_SG; Temp_Cyprus_SG) provide information on the potential effects of environmental variability on bluefin tuna tuna (*Thunnus thynnus*) and Albacore tuna (*Thunnus alalunga*) eggs and larval survival and growth (Reglero *et al.* 2018) in the three different Mediterranean spawning grounds, and the potential recruitment scenarios (Harford *et al.* 2017). The variability of salinity in the Balearic Sea (Sal_Bal_SG) provides information on the water masses distribution in the area, which are associated to the spatial distribution of larval habitats (Alvarez-Berastegui *et al.* 2016). Higher mean salinity is related to larval habitats located south of the archipelago which favors dispersal out of the area.

Positive values of temperature in the spawning grounds would indicate higher potential growth and survival for bluefin tuna and albacore tuna. Other tuna species in the areas may be also favored in higher temperatures. This indicator does not account for other factors affecting growth and survival such prey availability or dispersal rates.

Higher values in the salinity in the Balearic archipelago would indicate lower inflow of recent Atlantic water into the Balearic Sea. This is related with the bluefin tuna larval habitats to be located south of the archipelago and potentially displaced out of the retention larval feeding areas. A more robust indicator will be developed directly measuring retention/dispersion ratios in the area.

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Table 1. Indicators derived from the Mediterranean Copernicus model for the Western Mediterranean Spawning ground (Balearic Sea) "Temp_Bal_SG"; Central Mediterranean (Tunisia; Malta) "Temp_Tunisia-Malta_SG" and Eastern Mediterranean (Cyprus) "Temp_Cyprus_SG".

Year	*Temp_Bal_SG*	*Temp_Tunisia-Malta_SG*	*Temp_Cyprus_SG*
1990	22,31326	22,48707	23,01869
1991	21,08693	21,31543	23,10998
1992	21,10479	21,45401	22,93647
1993	21,62844	22,414	22,76052
1994	22,20179	23,74159	23,64557
1995	21,87702	22,3482	23,28192
1996	21,97704	22,39694	23,64748
1997	21,88322	22,65884	22,78506
1998	22,0235	22,50415	23,52717
1999	22,38905	22,45661	24,1048
2000	22,25918	22,67464	24,10256
2001	22,196	22,45492	24,28715
2002	21,70595	22,21708	24,1185
2003	23,0975	22,77247	24,38149
2004	21,50611	22,01937	23,76087
2005	22,40847	22,5848	24,40889
2006	22,33461	22,82936	23,94056
2007	22,23789	22,79213	24,18599
2008	22,20893	23,04452	24,47711
2009	22,33265	23,01559	24,35793
2010	21,76708	22,52389	24,36406
2011	22,70065	22,70924	24,10992
2012	22,42244	23,36165	24,26414
2013	21,6483	22,47342	24,55104
2014	22,35795	22,48634	24,57975
2015	22,96503	22,83309	23,97105
2016	22,13526	22,20636	24,7757

Table 2. A subset of the indicators derived from the WMOP model for the Western spawning ground (Balearic Sea) data prior to scaling.

Year	*Temp_Bal_SG_wmop*	*Sal_Bal_wmop*
2009	23,44416	37,60975
2010	22,40927	37,37421
2011	22,86239	37,23452
2012	23,17471	37,50134
2013	22,19917	37,81337
2014	22,64914	37,51789
2015	23,7575	37,31666
2016	22,41781	37,54759
2017	23,32326	37,38186

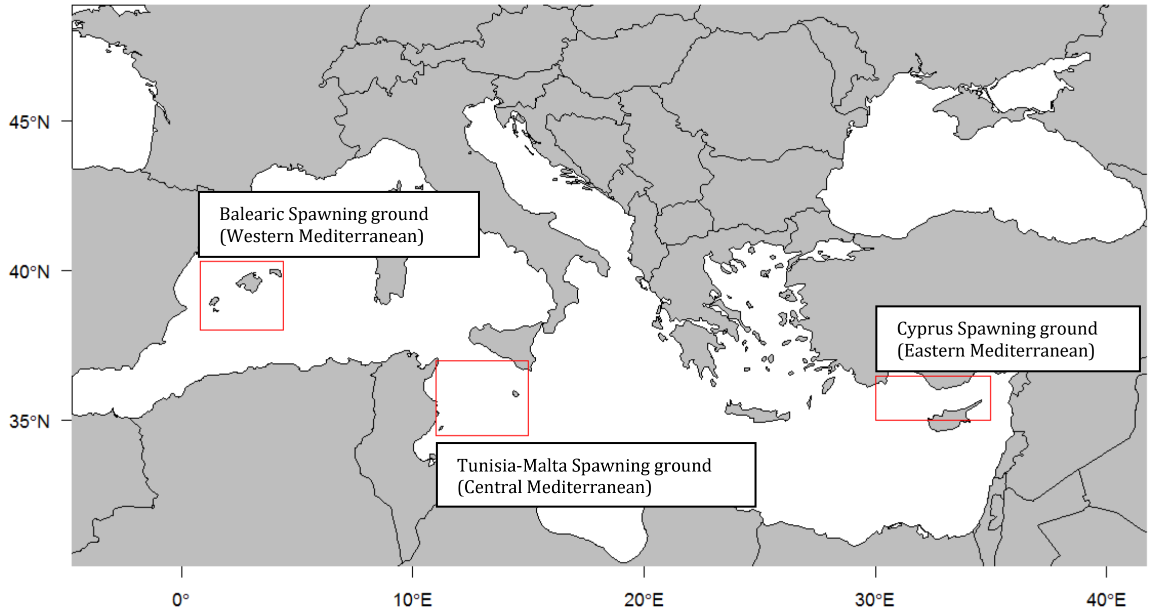

Figure 1. The Mediterranean Sea, red boxes indicate the geographical limits of the spawning grounds (Balearic Sea in the Western, Tunisia-Malta in the Central, and Cyprus in the Eastern Mediterranean) used for the spatial integration of the oceanographic variables. The geographical areas also coincide with the ICCAT aerial surveys.

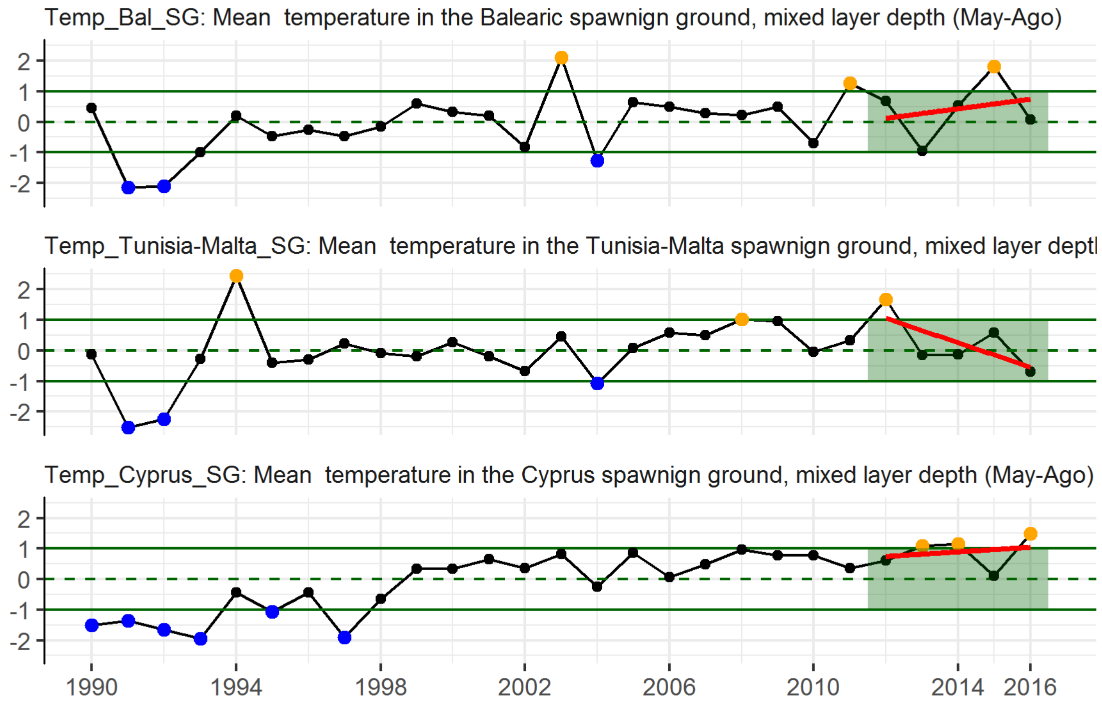

Figure 2. Mean temperature in the Western Mediterranean Spawning ground (Balearic Sea); Central Mediterranean (Tunisia; South Sicily) and Eastern Mediterranean (Cyprus). Temperature values are presented after standardization to the mean of the time sereies. Data from the CMEMS MED-MFC hydrodynamic model. Indicators of ecosystem status. Values ≥1 std are orange. Values ≤-1 std are blue. Red trend lines are for the last 5 years and were fit with a linear model.

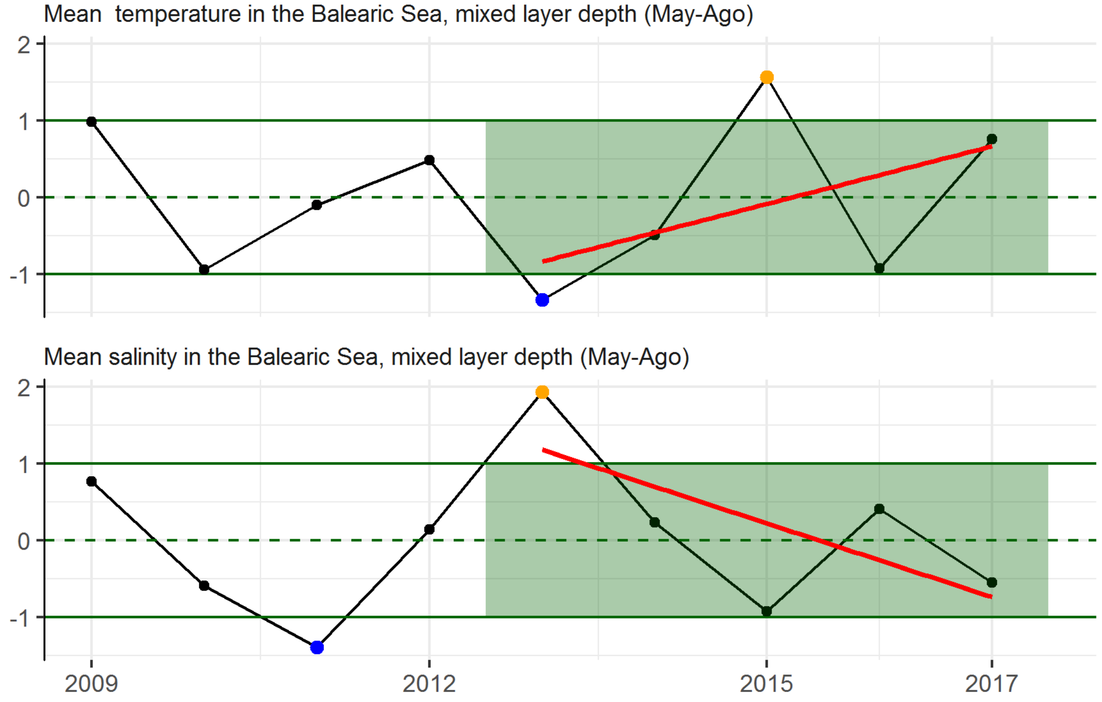

Figure 3. Mean temperature and salinity in the Balearic Spawning ground (Western Mediterranean). Data from the WMOP (Western Mediterranean Sea Operational Forecasting System). Temperature values are presented after standardization to the mean of the time series. Indicators of ecosystem status. Values >= 1 std are orange. Values <= -1 std are blue. Red trend lines are for the last 5 years and were fit with a linear model.