Climate effects on historic bluefin tuna captures in the Gibraltar Strait and Western Mediterranean

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Overview

1. Motivation
2. Material
3. Methods
4. Results and discussions
5. Conclusions

1 Motivation

- Literature about the relation between bluefin tuna (BFT) historical data and climate variables in the Eastern Atlantic and Western Mediterranean is scarce.
- Ravier & Fromentin (2004) found that long-term fluctuations in the BFT capture from trap fisheries located around the Mediterranean and the East Atlantic appeared to be negatively correlated with North Atlantic SST.
- Ganzedo et al. (2009) found a relation between BFT captures (from 1525 to 1756) from several almadrabas located in southern Europe and climate variables(AST, SST, GHG). They also suggested a potential connection between BFT captures and solar irradiance.
- More recently, Caballero-Alfonso (2011) presented a detailed analysis of the effect of surface temperature and solar irradiance on the North Atlantic BFT captures between 1525 and 1936.

1 Motivation

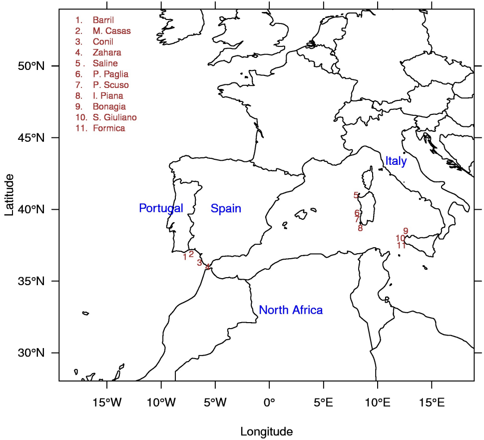
This study aims to shed new light on the roots of the fluctuations and evolution of BFT populations

In particular, it tries to elucidate the causes of the observed variations in the historical (1700–1936) BFT capture records from Gibraltar and Western Mediterranean, by showing that they could be related to changes in **solar irradiance and natural climate variability**.

This study was published last year:

Ganzedo,U., Polanco-Martínez, J. M.*, Caballero-Alfonso, A. M., Faria, S.H. ,Jianke, L. and Castro-Hernndez, J.J. (2016). **Climate effects on historic bluefin tuna captures in the Gibraltar Strait and Western Mediterranean**. *Journal of Marine Systems*, 158, 84-92. http://dx.doi.org/10.1016/j.jmarsys.2016.02.002.

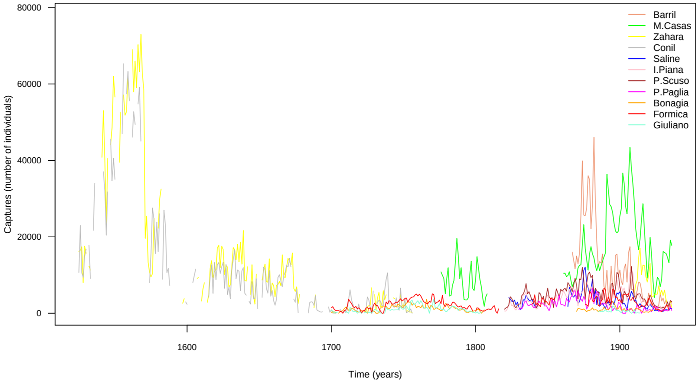
AREA OF STUDY



BFT capture records (Ganzedo, Polanco, et al. 2016).

BFT capture records from eleven traps were collected for this study from different sources (López-Capont, 1997; Ravier and Fromentin, 2001; Ravier, 2003; Lemos and Gomes, 2004).

RAW CAPTURES



BFT capture records (Ganzedo, Polanco, et al. 2016).

Each BFT capture time series spans more than 100 years within the period 1525–1936. After a preliminary inspection, we decided to limit our analysis to the time interval from 1700 to 1936, due to the scarcity and inhomogeneity of the two oldest capture time series.

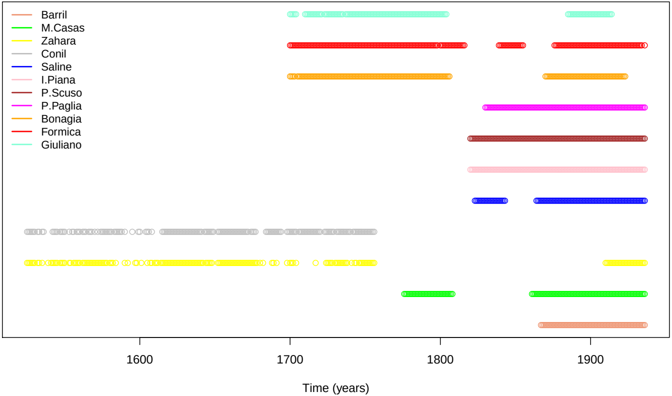
CLIMATE VARIABLES

Paleoclimate proxy reconstructions were preferred in this study, there are no observed climate data available for the whole time period

Paleoclimate reconstructions reveal long-term trends of the climate system and, to a certain extent, also higher-frequency variations

- We used reconstructed annual SST data from Mann et al. (2009):
  1. Global: SST1
  2. Northern Hemisphere: SST2
  3. averaged: SST3 [proxy local] over the region 35°N-45°N, 10°W-15°NE
- We included three independent Total Solar Irradiance (TSI) reconstructions:
  1. Lean (2000): TSI1
  2. Krivova et al. (2010): TSI2
  3. Velasco-Herrera et al. (2015): TSI3

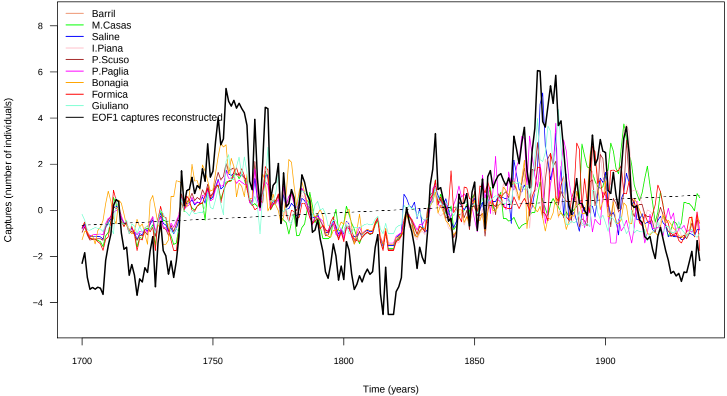
RECONSTRUCTED CAPTURES



Presence (o) and absence (blank) of the BFT captures time series (Ganzedo, Polanco, et al. 2016).

Taking into account the fact that all these traps were built and operated in the same way, we opted for reconstructing the missing data using the **Data INterpolating Empirical Orthogonal Functions** technique (DINEOF; Alvera-Azcárate et al. (2005)).

RECONSTRUCTED CAPTURES



Presence (o) and absence (blank) of the BFT captures time series (Ganzedo, Polanco, et al. 2016).

Taking into account the fact that all these traps were built and operated in the same way, we opted for reconstructing the missing data using the **Data INterpolating Empirical Orthogonal Functions** technique (DINEOF; Alvera-Azcárate et al. (2005)).

Time series analysis

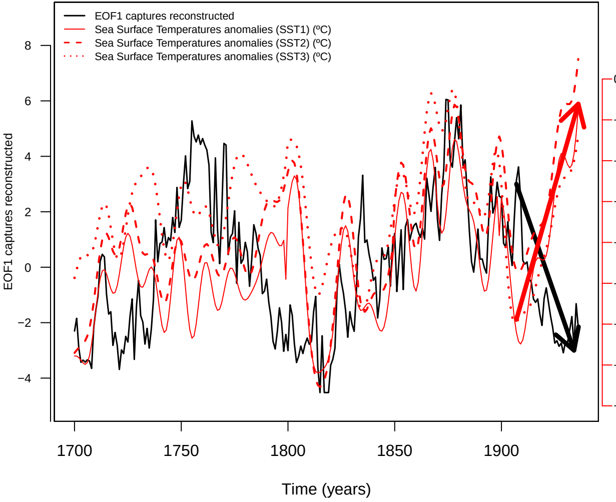
1. In order to verify whether the data sets under study contain statistically significant trends, we applied **the Mann–Kendall test** (Libiseller & Grimvall 2002).

2. The trend in the dependent variable (EOF1 of the reconstructed BFT captures) was determined by the trend in the independent variables (SSTs and TSIs). Therefore, we had performed a **partial Mann–Kendall test** (Libiseller & Grimvall 2002). *These tests are implemented in the R package "trend"* (Pohlert, 2015).

3. Potential relations between the independent variables and the EOF1 were investigated using the **"PearsonT" software** (Mudelsee 2003), in which the linear trend was removed and the bootstrap confidence interval from serially dependent time series was take into account.

4. Results and discussions: SSTs vs. BFT captures

- 1700-1810:
  - SST1: $r_p = -\mathbf{0.26}$
  - SST2: $r_p = -\mathbf{0.22}$
  - SST3: $r_p = -0.06$
- 1810-1907:
  - SST1: $r_p = \mathbf{0.54}$
  - SST2: $r_p = \mathbf{0.51}$
  - SST3: $r_p = \mathbf{0.50}$
- 1700-1907:
  - SST1: $r_p = \mathbf{0.23}$
  - SST2: $r_p = \mathbf{0.28}$
  - SST3: $r_p = \mathbf{0.31}$
- 1700-1936:
  - SST1: $r_p = 0.10$
  - SST2: $r_p = 0.14$
  - SST3: $r_p = \mathbf{0.26}$



Source: Ganzedo, Polanco, et al. (2016)

4. Results and discussions: SSTs vs. BFT captures

- Our negative correlation for the interval 1700-1810 is partially in agreement with Ravier and Fromentin (2004), who found that the air temperature at surface level negatively correlated with the BFT long-term fluctuations.
- This result is apparently contradictory with the literature, which predicts a positive correlation btw SST and BFT catches (temperature is a key ...
- Ravier and Fromentin (2004) explain that the negative relationship btw surface air temperatures and BFT captures could be due to changes in migration patterns attributable to modifications in oceanographic conditions.

We recall that during that period, the "Little Ice Age" (LIA) took place with noticeable effects in Europe (Guiot et al., 2005; Mann, 2002).

These migration changes proposed by Ravier and Fromentin (2004) could have been caused by this "cool" climate (drop of SST,...

There is evidence that during the LIA an intense storm activity took place: UK, continental Europe, Western Med. & French Med. Coast (Dezileau et al., 2011; Degeai et al., 2015).

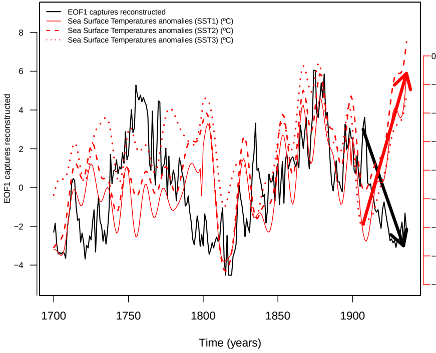
Source: Painting by Francis G. Maye (www.dandebat.dk/eng-klima7.htm#ni)

4. Results and discussions: SSTs vs. BFT captures

The explanation of the strong positive correlation ($0.50 < r_{xy} < 0.54$) btw the SSTs and the EOF1 for 1810-1907 may be explained as follows:

"Benign" meteor. & ocean. conditions could have provided good environ. conditions for the larval survival, growth, etc $\Rightarrow$ allowing a greater number of BFT catches.

During 1810-1907 (vs. 1700-1810) there was no intense storm activity in the Western Med. & French Med. Coast (Dezileau et al., 2011; Degeai et al., 2015).



Source: Ganzedo, Polanco, et al. (2016)

4. Results and discussions: SSTs vs. BFT captures

Table 4

Lagged Pearson correlation between the climatic variables (SSTs and TSIs) and the EOF1 of the 9 reconstructed BFT captures. SST1 is the Global temperature, SST2 is the Northern Hemisphere temperature and SST3 is averaged temperature over the region 35°N–45°N, −10°W–15°E (Mann et al., 2009). TSI1 (Lean, 2000), TSI2 (Krivova et al., 2010) and TSI3 (Velasco-Herrera et al., 2015) denote the Total Solar Irradiances. The linear trend and serial dependence were removed (Mudelsee, 2003a, 2003b). The r_p is the Pearson correlation, CI_l and CI_s are the lower and upper interval bound (95% confidence interval). N is equal to 237, that is, the number of elements of the time interval 1700–1936.

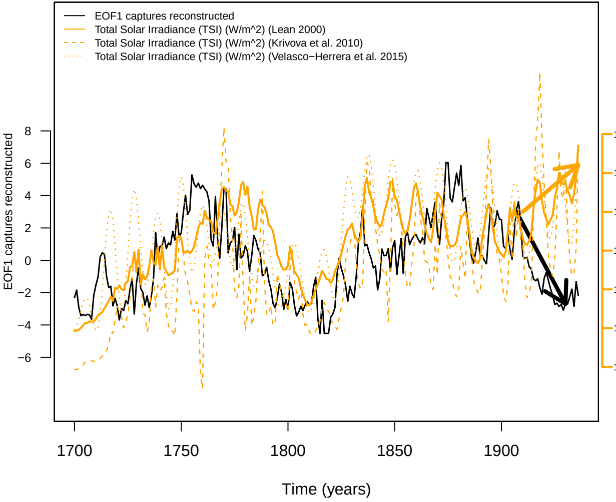
Time	Var.	1700–1810			1810–1907			1700–1907			1700–(N-Lag)		
lag	SST1	r_p	CI_l	CI_s	r_p	CI_l	CI_s	r_p	CI_f	CI_s	r_p	CI_l	CI_s
0		**−0.26**	−0.45	−0.08	**0.54**	0.41	0.67	**0.23**	0.08	0.36	0.10	−0.04	0.25
4		**−0.29**	−0.48	−0.10	**0.42**	0.26	0.55	0.14	−0.01	0.28	0.12	−0.03	0.24
5		**−0.26**	−0.46	−0.06	**0.43**	0.28	0.56	0.14	−0.02	0.28	0.13	−0.002	0.26
7		**−0.22**	−0.41	−0.02	**0.47**	0.30	0.61	0.15	−0.004	0.27	**0.16**	0.04	0.29
8		−0.18	−0.37	0.02	**0.49**	0.32	0.64	**0.15**	0.01	0.28	**0.18**	0.05	0.30
10		−0.13	−0.32	0.05	**0.50**	0.34	0.64	0.13	−0.002	0.26	**0.19**	0.07	0.31
12		−0.11	−0.30	0.08	**0.46**	0.29	0.61	0.09	−0.04	0.23	**0.16**	0.03	0.29
Lag	SST2												
0		**−0.22**	−0.41	−0.05	**0.51**	0.36	0.65	**0.28**	0.14	0.41	0.14	0.00	0.28
4		**−0.29**	−0.47	−0.11	**0.46**	0.31	0.59	**0.20**	0.05	0.34	**0.16**	0.02	0.28
5		**−0.27**	−0.47	−0.07	**0.48**	0.33	0.60	**0.19**	0.05	0.33	**0.17**	0.04	0.30
7		**−0.24**	−0.46	−0.06	**0.51**	0.36	0.63	**0.18**	0.04	0.30	**0.18**	0.06	0.31
8		**−0.22**	−0.43	−0.04	**0.52**	0.38	0.66	**0.17**	0.05	0.30	**0.19**	0.06	0.30
10		**−0.18**	−0.35	−0.006	**0.51**	0.37	0.64	**0.13**	0.01	0.25	**0.17**	0.07	0.29
Lag	SST3												
0		−0.06	−0.22	0.12	**0.50**	0.31	0.64	**0.31**	0.19	0.26	**0.26**	0.14	0.38
4		−0.04	−0.23	0.14	**0.50**	0.34	0.64	**0.28**	0.16	0.40	**0.32**	0.20	0.43
5		−0.01	−0.19	0.17	**0.51**	0.36	0.63	**0.28**	0.16	0.40	**0.33**	0.21	0.44
7		0.02	−0.16	0.20	**0.54**	0.37	0.67	**0.27**	0.16	0.38	**0.34**	0.23	0.44
8		0.04	−0.14	0.21	**0.56**	0.38	0.70	**0.26**	0.14	0.37	**0.34**	0.23	0.44

The SSTs increase their global cor. with the EOF1 at lags between 8-10 yr!

- Correlations for the SSTs computed in shorter intervals are practically invariants, except for the SST3 (1810-1907), which increases from 0.50 (lag-0) to 0.56 (lag-8).
- SST3 is a proxy of local SST and could have further effects on the dynamics of the BFT (from larvae state to catches).

The high cor. obtained when the BFT captures have been lagged by the average age of the catch suggest an effect on larval ecology and year class strength, rather than on a zero lag correlation based on changes in fish or fisherman's behaviour!

- 1700-1810:
  - TSI1: $r_p = \mathbf{0.63}$
  - TSI2: $r_p = \mathbf{0.32}$
  - TSI3: $r_p = \mathbf{0.45}$
- 1810-1907:
  - TSI1: $r_p = \mathbf{0.31}$
  - TSI2: $r_p = 0.10$
  - TSI3: $r_p = \mathbf{0.19}$
- 1700-1907:
  - TSI1: $r_p = \mathbf{0.45}$
  - TSI2: $r_p = \mathbf{0.23}$
  - TSI3: $r_p = \mathbf{0.31}$
- 1700-1936:
  - TSI1: $r_p = \mathbf{0.35}$
  - TSI2: $r_p = \mathbf{0.15}$
  - TSI3: $r_p = \mathbf{0.29}$



Source: Ganzedo, Polanco et al. (2016)

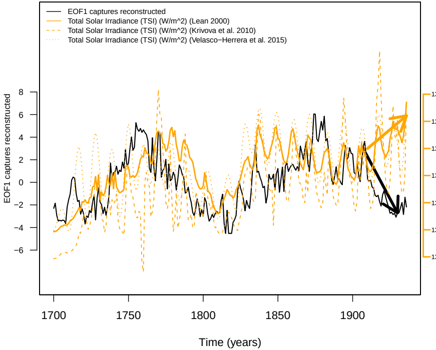
4. Results and discussions: TSIs vs. BFT captures

There is a $r_{xy} > 0$ btw TSIs & EOF1 for 1700-1936 with $0.15 < r_{xy} < 0.29$, this cor. is even stronger for several time periods with $0.19 < r_{xy} < 0.63$. 1700-1810 shows **strongest cor. in comparison to other time intervals**.

- Degeai et al. (2015) showed that solar activity could have primarily contributed to the storminess activities in the NW Mediterranean for the last 2700 years.
- This support "our" hypothesis that **high storm & wind activity** during this period could have affected the BFT fluctuations.

The most sensitive effect on the BFT can be expected in its spawning and larval stage!

Wind speed is one of the causes of variability in larval fish mortality and recruitment (Peterman and Bradford, 1987; Kato et al., 2008; etc.).



Source: Ganzedo, Polanco, et al. (2016)

4. Results and discussions: TSIs vs. BFT captures

The "lagged cor." btw TSIs & EOF1 (mean value BFT catches: 5-15 yrs):

⊙ The correlation for 1700-1810 does not increase; rather it decreases.

⇒ This means that BFT catches could reflect storm/wind-driven effects on fish or on fishermen.

△ The cor. TSI2 & TSI3 with EOF1 increases over 1700-1926/1938, and in 1810-1907, it increases for all TSIs, reaching the highest cor. at lag 8-10.

Lag	TSI1									
0	**0.63**	0.55	0.72	**0.31**	0.17	0.45	**0.45**	0.35	0.53	**0.35**
4	**0.52**	0.42	0.61	**0.39**	0.21	0.55	**0.38**	0.28	0.47	**0.33**
5	**0.51**	0.40	0.60	**0.38**	0.19	0.52	**0.36**	0.25	0.46	**0.32**
7	**0.50**	0.39	0.60	**0.36**	0.21	0.53	**0.33**	0.21	0.43	**0.30**
8	**0.51**	0.40	0.61	**0.36**	0.22	0.53	**0.32**	0.21	0.43	**0.30**
10	**0.50**	0.39	0.59	**0.32**	0.17	0.46	**0.29**	0.17	0.40	**0.27**
12	**0.47**	0.36	0.58	**0.29**	0.15	0.45	**0.25**	0.13	0.36	**0.24**
Lag	TSI2									
0	**0.32**	0.11	0.51	0.10	−0.06	0.26	**0.23**	0.10	0.37	**0.15**
4	**0.23**	0.09	0.37	**0.27**	0.10	0.44	**0.30**	0.11	0.34	**0.16**
5	**0.27**	0.11	0.41	**0.24**	0.05	0.39	**0.23**	0.10	0.34	**0.16**
7	**0.30**	0.14	0.46	**0.26**	0.08	0.41	**0.25**	0.13	0.37	**0.16**
8	**0.34**	0.21	0.47	**0.22**	0.07	0.39	**0.25**	0.14	0.35	**0.17**
10	**0.32**	0.15	0.49	0.14	−0.01	0.32	**0.20**	0.08	0.31	**0.13**
12	**0.33**	0.18	0.49	0.15	−0.01	0.31	**0.20**	0.09	0.31	**0.14**
14	**0.32**	0.20	0.45	**0.26**	0.08	0.45	**0.24**	0.14	0.34	**0.18**
Lag	TSI3									
0	**0.45**	0.32	0.57	**0.19**	0.03	0.35	**0.31**	0.20	0.43	**0.29**
4	**0.34**	0.19	0.50	**0.27**	0.09	0.46	**0.29**	0.16	0.42	**0.29**
5	**0.34**	0.17	0.50	**0.32**	0.13	0.48	**0.32**	0.18	0.45	**0.31**
7	**0.38**	0.20	0.56	**0.38**	0.22	0.53	**0.37**	0.24	0.49	**0.35**
8	**0.42**	0.24	0.59	**0.36**	0.20	0.53	**0.39**	0.27	0.51	**0.37**
10	**0.47**	0.28	0.62	**0.27**	0.10	0.42	**0.39**	0.27	0.51	**0.38**
12	**0.44**	0.26	0.61	**0.20**	0.05	0.37	**0.35**	0.23	0.47	**0.35**
14	**0.33**	0.16	0.49	**0.21**	0.04	0.40	**0.31**	0.20	0.43	**0.31**

△ suggest that the mechanism underpinning the cor. TSI & BFT catches could be through storm/wind-driven effects on spawning behav. & larval ecol., yr class strength.

It is well known that many marine fish species with pelagic eggs and larvae spawn in seasons and in locations that on average have favourable wind conditions for survival of offspring (Peterman and Bradford, 1987; Mariani et al., 2010). Strong winds could have more negative effects during the vulnerable egg stage ...

5. Conclusions

A novel conclusion from this work is that the total solar irradiance does influence the BFT population dynamics and its availability to the fishery in the Gibraltar Strait and Western Mediterranean domain.

We can distinguish two different physico-biological mechanisms to explain the BFT catches fluctuations for the period of study:

1. From 1700 to 1810, this mechanism could be high storm and wind activity, which would have made the BFT fisheries activities more difficult by reducing their efficacy.
2. From 1810 to 1907, the effects of wind and storms could be on spawning behaviour and larval ecology, and hence on year class strength, rather than on fish or fisherman's behaviour.

Further research is needed to explain the mismatch observed between EOF1 and the environmental variables during the interval 1907-1936

Thank you for your attention!

References

1) Alvera-Azcarate, A., Barth, A., Rixen, M., Beckers, J.M., 2005. Reconstruction of incomplete oceanographic data sets using empirical orthogonal functions: application to the Adriatic Sea surface temperature. Ocean Model. 9, 325-346.
2) Caballero-Alfonso, A.M., 2011. Recent and Historical Climate Variability Effects on the Population Dynamics of Several Marine Species Ph.D thesis Univ. de Las Palmas de Gran Canaria (270pp).
3) Degeai, J.P., Devillers, B., Dezileau, L., Oueslati, H., Bony, G., 2015. Major storm periods and climate forcing in the Western Mediterranean during the Late Holocene. Quat. Sci. Rev. 129, 37-56.
4) Dezileau, L., Sabatier, P., Blanchemanche, P., Joly, B., Swingedouw, D., Cassou, C., Castaings,J., Martinez, P., Von Grafenstein, U., 2011. Intense storm activity during the Little Ice Age on the French Mediterranean coast. Palaeogeogr. Palaeoclimatol. Palaeoecol. 299, 289-297.
5) Ganzedo, U., Zorita, E., Solari, A.P., Chust, G., Santana del Pino, A., Polanco, J., Castro, J.J. 2009. What drove tuna catches between 1525 and 1756 in southern Europe? ICES J. Mar. Sci. 66, 1595-1604.
6) Guiot, J., Nicault, A., Rathgeber, C., Edouard, J.L., Guibal, F., Pichard, G., Till, C., 2005. Last-millennium summer-temperature variations in western Europe based on proxy data. The Holocene 15, 489-500.
7) Kato, Y., Takebe, T., Masuma, S., Kitagawa, T., Kimura, S., 2008. Turbulence effect on survival and feeding of Pacific bluefin tuna Thunnus orientalis larvae, on the basis of a rearing experiment. Fish. Sci. 74, 48-53.
8) Krivova, N.A., Vieira, L.E.A., Solanki, S.K., 2010. Reconstruction of solar spectral irradiance since the Maunder Minimum. J. Geophys. Res. 115, 1978-2012.
9) Lean, J., 2000. Evolution of the Sun's spectral irradiance since the Maunder Minimum. Geophys. Res. Lett. 27, 2425-2428.
10) Lemos, R.T., Gomes, J.F., 2004. Do local environmental factors induce daily and yearly variability in bluefin tuna (Thunnus thynnus) trap catches? Ecol. Model. 177, 143-156.
11) Libiseller, C., Grimvall, A., 2002. Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. Environmetrics 13, 71-84.
12) Lopez-Capont, F., 1997. La Etapa Pesquera del Padre Sarmiento Y Su poca: de Los Atunes, Y Sus Transmigraciones Y Conjeturas, Sobre La Decadencia de Las Almadrabas, Sobre Los Medios Para Restituirlas. Ed. Caixa de Pontevedra, Spain (105 pp).

References

13) Mann, M.E., 2002. Little Ice Age. In: MacCraken, M.C., Perry, J.S. (Eds.), Encyclopedia of Global Environmental Change: Volume 1 - The Earth System: Physical and Chemical Dimensions of Global Environmental Change. John Wiley and Sons Ltd., pp. 504-509.
14) Mariani, P., MacKenzie, B.R., Iudicone, D., Bozec, A., 2010. Modelling retention and dispersion mechanisms of bluefin tuna eggs and larvae in the northwest Mediterranean Sea. Prog. Oceanogr. 86, 45-58.
15) Mudelsee, M., 2003a. Estimating Pearson's correlations coefficient with bootstrap confidence interval from serially dependent time series. Math. Geol. 35, 651-665.
16) Mudelsee, M., 2003b. The PearsonT software, ver. 1.10. Available at: http://www.manfredmudelsee.com/soft/pearsont/index.htm (Last accessed 10 April 2015).
17) Peterman, R.M., Bradford, M.J., 1987. Wind speed and mortality rate of a marine fish, the northern anchovy (Engraulis mordax). Science 235, 354-356.
18) Pohlert, T., 2015. Trend: non-parametric trend tests and change-point detection, R package version 0.2. https://cran.r-project.org/package=trend (Last accessed 9 December 2015).
19) Ravier, C., 2003. Fluctuations long terme du thon rouge - validit, origines et consquences PhD Thesis L'ecole Nationale Superieure Agronomique de Rennes, France (177 pp).
20) Ravier, C., Fromentin, J.M., 2001. Long-term fluctuations in the eastern Atlantic and Mediterranean bluefin tuna population. ICES J. Mar. Sci. 58, 1299-1317.
21) Ravier, C., Fromentin, J.M., 2004. Are the long-term fluctuations in the Atlantic bluefin tuna (Thunnus thynnus) population related to environmental changes? Fish. Oceanogr. 13, 145-160.
22) Velasco-Herrera, V.M., Mendoza, B., Herrera, G.V., 2015. Reconstruction and prediction of the total solar irradiance: from the medieval warm period to the 21st century. New Astron. 34, 221-233.