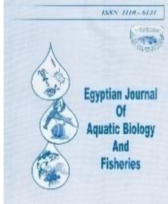
Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 25(5): 553 – 571 (2021)
www.ejabf.journals.ekb.eg



Temporal analysis of the distribution of thynnus thunnus in relation to environmental factors along the Algerian coast

Firad Benyahia[1]*, Bachari Nour El Islam[2], Khalid Amarouche[3], Ghoulam Allah Kames[4], Lamine Salim[2,5].

1.laboratory of marine and coastal ecosystems, SUPERIOR NATIONAL SCHOOL OF SEA SCIENCES AND COASTAL PLANNING, University Campus ‹Dély Ibrahim 16320, Algiers, Algeria,
2.Laboratory of Biological Oceanography and Marine Environment, Faculty of Biological Sciences, University of Sciences and Technology Houari Boumediene (USTHB), BP. 32, El-Alia Bab-Ezzouar 16111, Algiers, Algeria.
3.Department of Civil Engineering, Bursa Uludağ University, Gorukle Campus, 16059 Bursa, Turkey.
4. Pelagic-ecosystem Laboratory, Faculty of Biological Sciences, University of Sciences and Technology Houari Boumediene (USTHB), BP. 32, El-Alia Bab-Ezzouar 16111, Algiers, Algeria.
5.Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, SY23 2DB Wales, United Kingdom.

*Corresponding Author: firadbenyahia@gmail.com

ARTICLE INFO

Article History:
Received: June 11, 2021
Accepted: July 27, 2021
Online: Oct. 30, 2021

Keywords:
Thunnus thynnus,
Chlorophyll a,
Oxygen; salinity,
Temperature,
Algerian coast.

ABSTRACT

The distribution of the large pelagic Atlantic bluefin tuna extends from the North Atlantic Ocean and its adjacent seas, particularly the Mediterranean. In this study, thegeo-referenced fisheries data were integrated with remotely sensed oceanographic datasets to answer the suggested question; what are the environmental determinants that contribute to the temporal distribution of bluefin tuna along the Algerian coast? This tuna-environment research was conducted with three objectives: i) to understand the behaviour and distribution of tuna in the face of variability in environmental factors, ii) to assist the scientist in stock management, and iii) to assist fishermen in fishing their short-term quotas and to assist the competent authorities in controlling the fishermen. The results of this study proved that the environmental factors (temperature, salinity, chlorophyll a, current speed, wave height, oxygen, and nitrate) are the determining factors of bluefin tuna distribution along the Algerian coast. Multiple linear regression analysis defined the equation of the best linear correction model, chlorophyll a, dissolved oxygen, salinity and temperature, explaining 70.3% of the variability in the total length of bluefin tuna.

INTRODUCTION

The Atlantic bluefin tuna (*Thunnus thynnus*) is a valuable species, **(Garcia &Gordon, 1992; Durieu de Madron *et al.*, 2011)** and one of the most important fisheries resources in the Mediterranean Sea.

The distribution of the Atlantic bluefin tuna (*thunnus thynnus*) extends from the North Atlantic Ocean to its adjacent seas,specifically, the Mediterranean **(d'Ortenzio and Ribera d'Alcalà, 2009)** , from Gibraltar to the Black Sea **(COMP, 1950)** .

The bluefin tuna has been a study target for a long time and considering it as a great migrator. However, over the last ten years, new research using tagging techniques has advanced the issue and showed that the tuna is capable of greater movements than was previously thought **(Lutcavage *et al*., 2000)**.

Bluefin tuna is also a shared resource with high economic value and is exploited on an ocean-wide scale by some 20 countries including Algeria. The quota granted to Algeria has been increasing exponentially over the last decade; in 2000 it was 130 tonnes while in 2019 it reached 1437 tonnes**("ICCAT·CICTA·CICAA," 2019)** ,(International commission for the conservation of atlantic tunas). Nevertheless, few scientific works showed interest in this species during the last decade; only six works along the Algerian coast could be found **(Nouar and Labidi, 2009; Abdelhadi *et al*., 2011; Labidi and Nouar (2013a, 2013b); Neghli and Nouar, 2014)**.In this study, thegeo-referenced fisheries data were integrated with remotely sensed oceanographic datasets to answer the following questions; firstly: How does the environment contribute to the temporal distribution of bluefin tuna? The conditions favourable to the temporal distribution of *Thunnus thynnus*, Bluefin Tuna (BFT) were determined. The second question was: What are the environmental determinants that contribute to the temporal distribution of bluefin tuna along the Algerian coast?

It is worthy to mention that the changes in temperature, salinity, wind field and currents can affect the productivity and distribution of fish stocks **(Gushing and Dickson, 1977; Southward *et al*., 1988; Dickson and Brander, 1993; Lehodey *et al*., 1997; Alheit and Hagen, 2001).**

This tuna-environment research had three objectives: i) to understand the behaviour and distribution of tuna in the face of variability in environmental factors, ii) to assist the scientist in the management of the stocks, and iii) to assist fishermen to fish their quotas in the short term and to assist the competent authorities in controlling the fishermen.

MATERIALS AND METHODS

Study Area

Algeria has a coastline of about 1622 km **(Kacemi, 2013),** from the Algerian-Moroccan border in the west to the Algerian-Tunisian border in the east.

Fig. (1); shows the geographical limits of the study area and the sampling sites using the fishing gear (long surface longline). The study area is located in the southwestern part of the Mediterranean, the central and eastern part of the Algerian coast between Ténès in the west and the Algerian-Tunisian border in the east.

The Algerian coast is characterised by two superimposed water layers; namely, the modified Atlantic water and the Mediterranean water. Remarkably, the Atlantic water penetrates into the Alboran Sea where its initial characteristics begin to alter, thus giving rise to the modified Atlantic water **(Millot, 1989).**

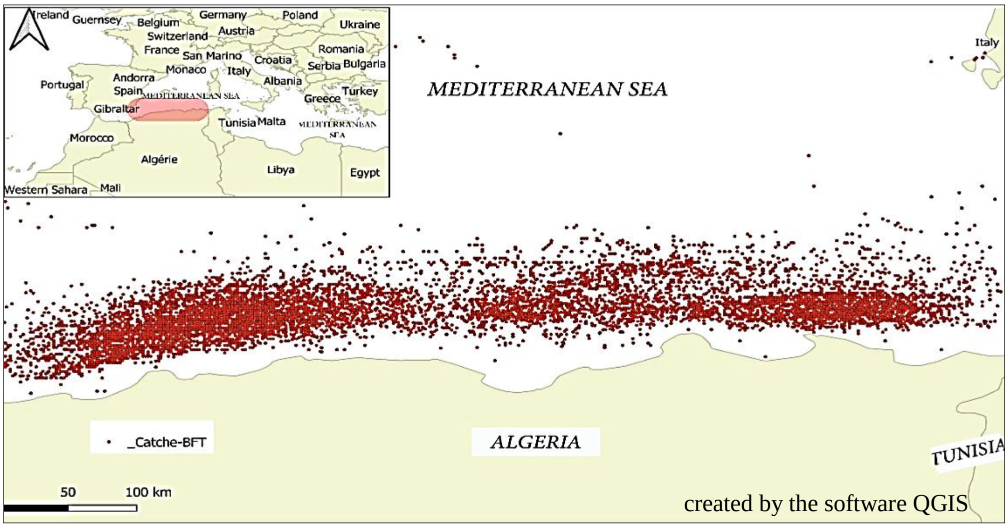


Fig. 1. A map of bluefin tuna fishing areas in the Algerian coast

Data

The present work is based on two types of data; bluefin tuna catch data and environmental data over a period of nineteen years, from 2000 to 2019.Firstly, geo-referenced bluefin tuna catch data were collected from the Algerian Ministry of Fisheries and Fishery Resources. These were recorded on board of each vessel during the fishing period by the Ministry's inspectors; during the BFT fishing campaigns carried out each year by Japanese longliners. The afore-mentioned data was also originated from the official website of ICCAT ("ICCAT-CICTA-CICAA," n.d.). Secondly, the environmental data where temperature (T) in °C, salinity (S) in psu, chlorophyll (chl a) in $mg.m^{-3}$, nitrate (NO_3), dissolved oxygen (O_2) in $mmol.m^{-3}$ were downloaded from the official website of the European programme, COPERNICUS ("Marine Copernicus,"http://resources.marine.copernicus.eu"" n.d.), a programme that brings together all the data obtained from environmental satellites and on-site measuring instruments to produce a comprehensive global view of the state of the planet Earth. In addition, the evolution of the occupation and the current speed in m/s, the wave height in m. have all been calculated using the high-resolution Swan model for the Mediterranean basin **(Amarouche *et al.,* 2019; Amarouche *et al.,* 2020)**. The data extraction is explained by a conceptual diagram in Fig. (2).

Data processing

The data processing is performed by R software version i386 3.6.3, in order to complete all statistical analyses of this study, namely: the size-weight relationship of the size frequency distributions for the study species (*Thunnus thynnus*), Bartlett's Sphericity Test, as well as Multiple Regression Analysis, and Analysis of Variance (ANOVA). Additionally, the Principal Component Analysis (PCA) Data extraction was performed using MATLAB R2017a software. Regarding the map of bluefin tuna fishing areas, it was created by the software QGIS (Quantum Geographic Information System).

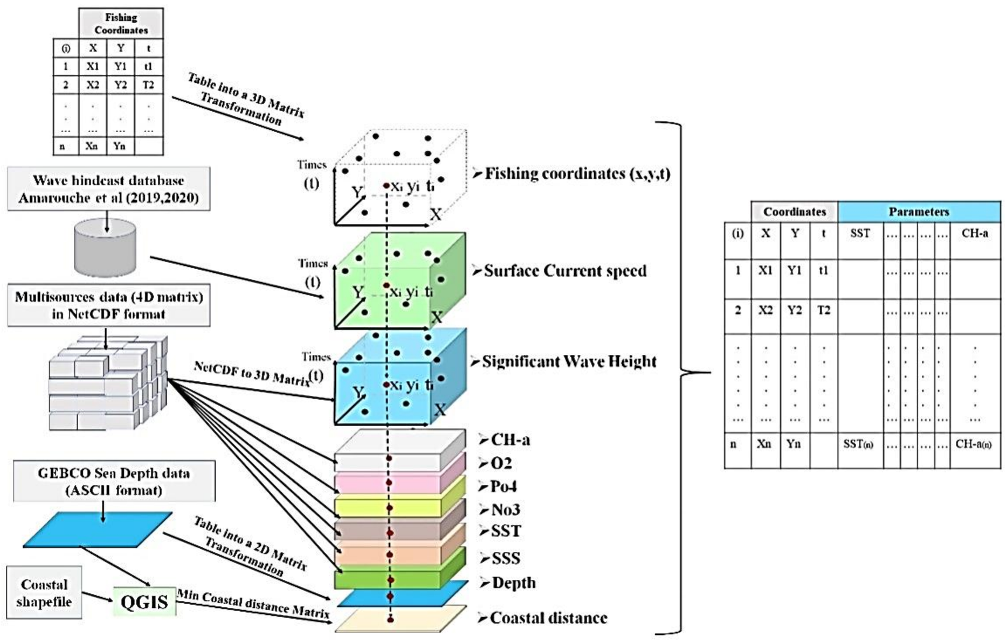


Fig.2. Conceptual diagram of environmental data extraction

Statistical analysis

Size-Weight Relationship

The relationship between the total length of the fish and their weight is generally exponential. It is represented by the following equation **(Le Creen, 1951):**

$Wt = a\ Lt^b$; where Wt = total weight of the fish in kg; Lt = total length of the fish in cm; a and b are characteristic factors of the environment and the species.

The coefficient b varies between 2 and 4. It expresses the relative shape of a fish's body.

If b = 3, the growth is said to be isometric.

If $b \neq 3$ and different from 3, the growth is allometric.

If coefficient b was greater than 3, it would indicate a better growth in weight than in length and vice versa **(Micha, 1973)**.

Bartlett Sphericity Test

Bartlett's sphericity test **(BARTLETT, 1966)** is used only in the case of Pearson correlation or covariance. It is used to validate or invalidate the hypothesis that the variables are not significantly correlated. The hypotheses of the curent study are :

H0: There is no correlation significantly different from 0 between the variables.

Ha: At least one of the correlations between the variables is significantly different from 0.

Analysis of variance (ANOVA) **(Saporta, 2006)** was used to compare bluefin tuna abundances in differnt seasons. To do this, the following question was posed:

Does the abundance of bluefin tuna in the Mediterranean change according to the season?

RESULTS AND DISCUSSION

1. Statistical analysis

Table (1) illustrates the descriptive statistical summary of the different environmental variables in more than 18,000 points along the Algerian coasts and the biological variables, size and weight of 2601 individuals of bluefin tuna.

Table 1. Summary of descriptive statistics by variable

	Lt (cm)	Wt (kg)	Chl a (mg.m-3)	NO3 (mmol.m-3)	O2 (mmol.m-3)	SSS (psu)	SST (°c)	Crrt spd (m/s)	Ht Vg (m)	Dist_cot (degree)
N	22601	22601	21192	21172	21172	19586	19586	19438	18448	22498
Max	312.88	474.39	6.59	8.14	329.92	39.52	28.19	0.91	5.23	2.72
Min	39.00	2.00	0.06	0.01	203.29	31.74	9.20	0.00	0.00	0.00
Avr	186.83	133.53	0.19	0.30	237.94	36.86	18.67	0.22	1.08	0.37
Dev-str	52.85	76.72	0.43	0.81	8.97	0.55	1.69	0.14	0.62	0.22
IC 5%.	0.69	1.00	0.01	0.01	0.12	0.01	0.02	0.00	0.01	0.00
Avr *+ic*	187.52	134.53	0.19	0.31	238.06	36.87	18.70	0.22	1.09	0.38
Avr *-ic*	186.14	132.53	0.18	0.29	237.82	36.85	18.65	0.22	1.07	0.37
CV	0.28	0.58	2.28	2.69	0.04	0.02	0.09	0.64	0.57	0.58

NB : N : Sample size ; Max : Maximum ; Min : Minimum ; Avr : Average ; IC : Confidence interval ; CV : coefficient of variation ; Dev-str : standard deviation ; Lt : Total length ; Wt : total weight ; Chl a : Chlorophyll a ; NO3 : Nitrate ; O2 : Oxygen ; SSS : Sea Surface Ssalinity ; SST : Sea surface temperature ; Crrt spd : current speed ; Ht Vg : wave height ; Dist-cot : distance from the coast.

1.1. Analysis of variance

According to the analysis of variance (Table 2), the calculated p-value (0.0002) was below the significance level alpha=0.05, thus the null hypothesis H0 was rejected or excluded and the alternative hypothesis H1 was retained, taking a 0.02% risk of being wrong. The effect of the season was measured using a variance ratio (F = 7.7411) (Table 1), the higher was the ratio, the more significant the effect of the season. We conclude that there is a significant effect of season on the abundance of Thunnus thynnus in the Mediterranean and particularly along the Algerian coast.

Table 2. Results of analysis of variance

Source	DDL	Somme des carrés	Moyenne des carrés	F	Pr > F
Modèle	3	10104715,7424	3368238,5808	7,7411	0,0002
Erreur	57	24801249,5035	435109,6404		
Total corrigé	60	34905965,2459			

Fig. (3) and Table (3), show a significant difference in bluefin tuna abundance according to season, with quarter 2 (spring season) being the most frequent season, showing an abundance of 18402 individuals out of 22601, while quarter 3 (summer season) recorded an abundance of 3550 individuals.

Table 3. Abundances (number of individuals) of *Thunnus thynnus* by quarter

	Abundance
Quarter 1	107
Quarter2	18402
Quarter3	3550
Quarter4	542
Sum(season)	22601

The presence of BFT in the Mediterranean in May (spring season) and August (summer season) is related to breeding **(Cort, 1990; Ottersen *et al*., 2004; Royer, 2005; Mylonas *et al*., 2007; MacKenzie and Mariani, 2012).**

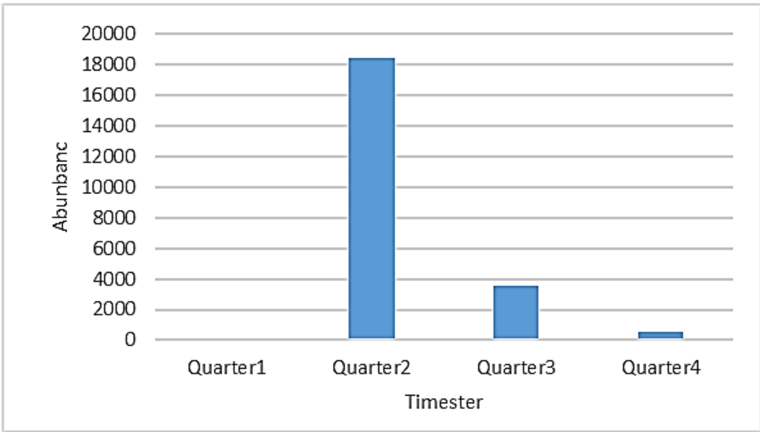


Fig. 3. Abundances of *Thunnus thynnus* according to seasons

This significant difference in bluefin tuna abundances directed the current work to be based on the two seasons (Spring and Summer) in order to answer the problematic concept of the study.

1.2. Principal component analysis

Table 4. Bartlett sphericity test result

Chi-square (Observed value)	176.9874
Chi-square (critical value)	61.6562
DDL	45
p-value	< 0.0001
Alpha	0.05

Principal component analysis has allowed the reserchers to extract a lot of interesting information from the collected dataset, (Fig. 4 and Table 5), and summarize well the information on the correlation between the different variables. According to Bartlett's test of sphericity (Table 4), the calculated p-value (0.0001) was found below the significance level alpha=0.05, thus it was concluded that at least one of the correlations between the variables was significantly different from zero.

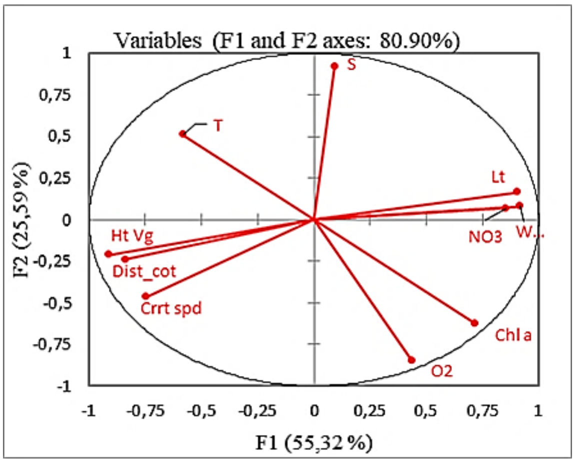


Fig. 4. Correlation circle between variables biotic and abiotic

The positioning of the variables in Fig. (4) (80.90% inertia) as well as the values in Table (5), suggest a definite link between the variables. Around the F1 axis (55.32% inertia), it is observed that the total length (Lt) of *Thunnus thynnus* is characterised by a linear relationship on the one hand, positive with respect to its total weight (Wt) ($r = 0.967$, $p < 0.0001$) and to the two parameters of its environment such as NO3 and chlorophyll (a) with a correlation coefficient ($r = 0.717$, $p < 0.0001$) and ($r = 0.470$, $p < 0.0001$), respectively.

Table 5. Correlation matrix

Variables	Lt	Wt	Chl a	NO3	O2	S	T	Crrt-spd	Ht Vg	Dist_cot
Lt	**1.00**	**0.97**	**0.47**	**0.72**	0.23	0.24	**-0.52**	**-0.68**	**-0.79**	**-0.71**
Wt	**0.97**	**1.00**	**0.57**	**0.68**	0.32	0.20	**-0.55**	**-0.67**	**-0.79**	**-0.71**
Chl a	**0.47**	**0.57**	**1.00**	**0.62**	**0.87**	**-0.53**	**-0.57**	-0.31	**-0.52**	**-0.47**
NO3	**0.72**	**0.68**	**0.62**	**1.00**	0.28	0.04	-0.27	**-0.68**	**-0.83**	**-0.71**
O2	0,23	0.32	**0.87**	0.28	**1.00**	**-0.65**	**-0.64**	0.01	-0.22	-0.11
S	0,24	0.20	**-0.53**	0.04	**-0.65**	**1.00**	0.31	**-0.49**	-0.28	-0.24
T	**-0,52**	**-0.55**	**-0.57**	-0.27	**-0.64**	0.31	**1.00**	0.13	0.43	0.34
Crrt spd	**-0.68**	**-0.67**	-0.31	**-0.68**	0.01	**-0.49**	0.13	**1.00**	**0.74**	**0.67**
Ht Vg	**-0.79**	**-0.79**	**-0.52**	**-0.83**	-0.22	-0.28	0.43	**0.74**	**1.00**	**0.84**
Dist_cot	**-0.71**	**-0.71**	**-0.47**	**-0.71**	-0.11	-0.24	0.34	**0.67**	**0.84**	**1.00**

On the other hand, negative to other parameters of its biotope such as: temperature (r = -0 .523, $p < 0.0001$), current speed (r = -0 .681, $p < 0.0001$), wave height (r = -0 .791, $p < 0.0001$) and distance from the coast (r = -0 .710, $p < 0.0001$) On the F2 axis (25.59% inertia), it was noted that the temperature factor is negatively related to the factors: Oxygen (r = -0.652,
$p < 0.0001$) and chlorophyll (a) (r=-0.568, p<0.0001). Studying the physico-chemical parameters of the bluefin tuna biotope aims to better understand the conditions of their

distribution, migration, nutritions and reproduction. The results obtained by the PCA urged the researchers to determine the limits of the variations of each biotope factor that can influence the life cycle of the studied species.

1.3. Length -weight relationship

Fig. (5), shows the results of the analysis of the relationship between the total length and the total weight of Thunnus *thynnus*.

The study of fish growth requires the use of the weight-length method of **(Da *et al.*, 2018)**. $\boldsymbol{wt = 10^{-4} * Lt^{2,668}}$ (r= 0.87; b=2.668, p= 0.0001).

The correlation coefficient represents a functional relationship between the two biological parameters of the species studied.

The coefficient (b = 2.67) shows an allometric type of growth in favour of total length. Bluefin tuna length growth occurs in the first three years, followed by mass growth from the fourth year **(Cort, 1990)**. In fisheries ecology, growth is an indicator of fish habitat quality **(Searcy *et al.*, 2007)** .

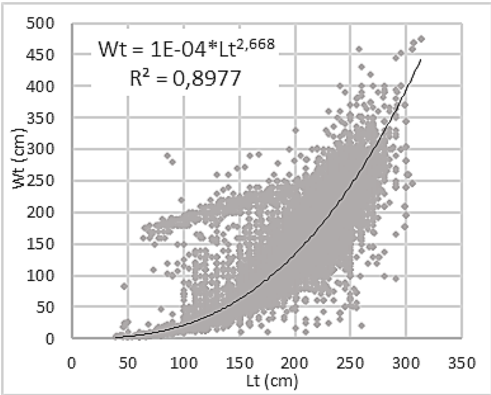


Fig.5. Biometric correlation in *Thunnus thynnus*

1.4. Multiple regression models

Table (6), provides details on the results of the multiple linear regression analysis. Multiple linear regression analysis allowed the researchersto define the equation for the best linear correction model (equation 1) which expresses the relationship between the total length of the BFT and the environmental factors. In this study, **70.3%** of the variability is explained by chlorophyll a, dissolved oxygen, salinity and temperature. The rest of the variability may be due to effects (other explanatory variables) that are not taken into account in the current study. The Fisher F test was used. Since the recorded probability associated with the F in this case was less than **0.0003939**, this means that a risk of being wrong is less than 0.05% in concluding that the explanatory variables bring a significant amount of information to the model.

Table 6. The results of the multiple linear regression analysis

Multi-correlation with results of regression model				
	Coefficients : Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	123,806	596,224	0,208	0,83872
Chl.a	75,905	18,442	4,116	0.00122 **
O2	-2,96	1,308	-2,263	0.04137 *
Sal	25,944	9,348	2,775	0.01576 *
Temp	-11,602	3,859	-3,007	0.01011 *

Adjusted R-squared: 0.703; F-statistic: 11.06 on 4 and 13 DF, **p-value: 0.0003939**

Equation 1. Best model multiple linear regression analysis.

$$Lt = 75.90\,(\boldsymbol{Cha}) - 2.96\,(\boldsymbol{O2}) + 25.94\,(\boldsymbol{Sal}) - 11.60\,(\boldsymbol{Temp}) + 123.80$$

2. Temporal analysis of bluefin tuna distribution in relation to environmental factors

The maximum and minimum values noted from the BFT height and weight data are (312.88 cm; 474.38 kg) and (39 cm; 2 kg), respectively (Table1). This fish can reach a size of 313 cm and a weight of 680 kg **(Magnuson *et al.*, 1994; Block *et al*., 2019)**.

The total lengths of bluefin tuna vary seasonally, averaging 146-181 cm in the spring season and 244-255 cm in the summer season (Fig.8); these were recorded in surface waters. Surface waters are characterised by seasonally varying physical and chemical factors. Among these factors the following variables were determined: temperature, salinity, current speed, wave height, chlorophyll a, dissolved oxygen and nitrate.

2.1. Physical factors

Temperature and salinity are the main hydrological factors describing water masses in a marine environment **(Aminot & Kérouel, 2004)**.

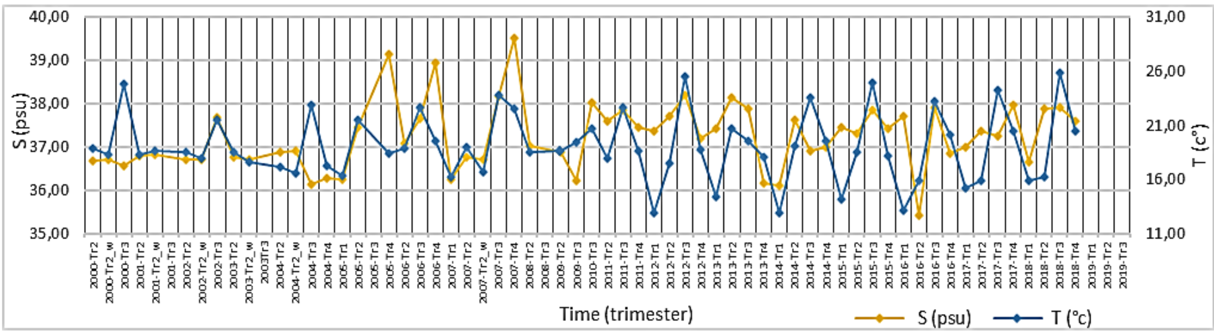


Fig. 6. Seasonal variation of physical factors: temperature and salinity

The important variations of the two factors are in function of the seasonal cycle, moreover Fig. (6), represents well this variation with the wire of the seasons, a resemblance was noted between the two curves, of temperature and salinity, the increase of the temperature followed by an increase of the salinity, in the same way in the opposite case. In the summer season, the temperatures were obviously very high (on average between 21.5 and 25.8°C), as is the salinity (on average between 36 and 39 psu). In the winter season, the water masses cooled down due to the effect of lower temperatures (on average 12.8 to 16°c), and with respect to the salinity, it dropped on average from 35.4 to 37 psu. **Fréon and Misund, (1999)** reported that, the distribution of bluefin tuna depends on the environmental temperature, which recorded averages of 10-28°C. In Atlantic bluefin tuna farms, the temperature should be in the range of 18-26°C **(Caill- Milly *et al*., 2002)**. Bluefin tuna have been fished in surface waters of great variation in temperature and salinity (Table 2), they can withstand low water temperatures of 9.2°c and have the potential to live in warm waters, up to 28.19°C. **Block *et al.* (2001)** cited: tagging and tracking data from the archives testified that the BFT can withstand cold (up to 3°C) as well as warm temperatures (up to 30°C) and it maintains a stable internal body temperature. The temperature in the spring season warms the marine water masses.

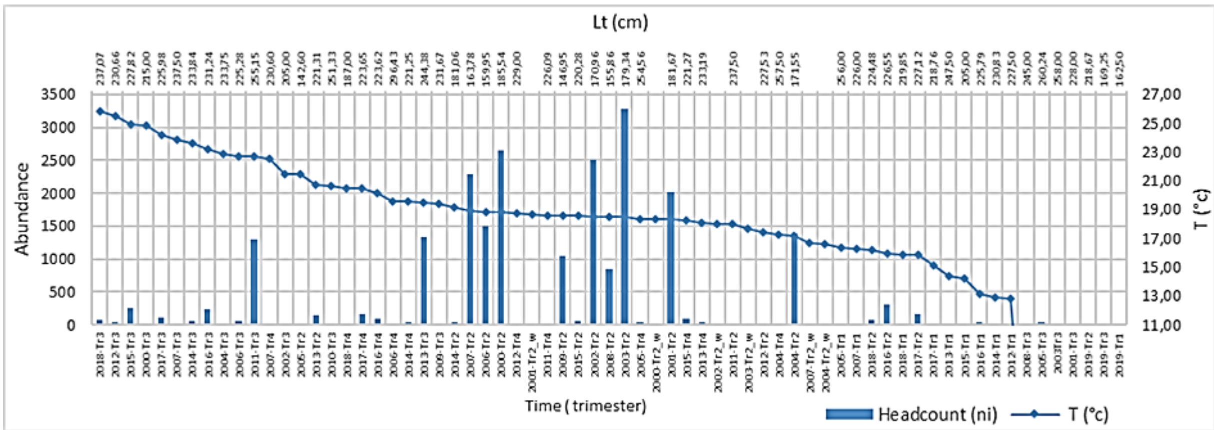


Fig. 7. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factors, temperature

These not very warm water masses (average temperature varies between 17 and 19.5°C) mark the presence of an overabundance of bluefin tuna (average total length from 146 to 181 cm), (Fig.7). In addition to this, large individuals averaging 250 cm, may be frequent in warmer waters (average temperature of 22°C) in the summer period. Moreover, the largest catches are recorded in areas with a temperature between 17 and 20°C. These are in agreement with the observations of **Lozano Cabo (1958) and Tiews K. (1963)** who noted that, the best catches of bluefin tuna from the Moroccan and Spanish traps were taken in areas with surface temperatures between 19.25 and 20.5 °C. According to **Ottersen Geir *et al*. (2004)**, the temperature factor can influence the spawning periods. The spawning period of bluefin tuna in the Mediterranean Sea is June-July**; (Collette and Nauen, 1983 and Cort, 1990; Mylonas *et al*., 2007 ; MacKenzie and Mariani, 2012)**. Eminently, low temperatures slow down spawning because of the slow development of the gonads. Whereas high temperatures allow earlier spawning because of the rapid development of the gonads.

The surface waters of fishing areas with high bluefin tuna productivity are characterised by stable salinity levels, which vary on an average from 36.6 to 37.1 psu and from 37.8 to 37.9 psu in spring and summer respectively (Fig.8). Bluefin tuna have demanding requirements, mainly forstable salinity and well oxygenated water **(Caill-Milly *et al*., 2002).** Furthermore, there is a relationship between the total length of the species studied and the current speed.

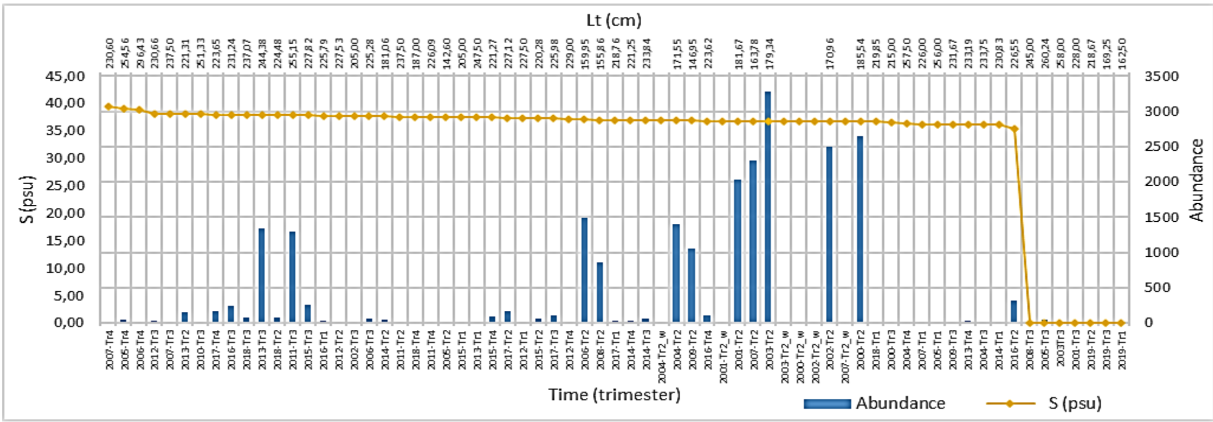


Fig. 8. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factors, salinity

Figs (9 & 10) clearly show this relationship, and the presence of bluefin tuna is noted in areas with a current speed of 0.85 m/s. In the spring period, overabundances were found in water bodies with an average current speed between 0.17 m/s and 0.3 m/s. In contrast to the summer period, the current speed is very low, varying between 0.07 m/s and 0.15 m/s**. (Arena, 1959a)** when investigating the influence of different factors on the catch of a tuna trap near Trapani, on the west coast of Sicily, noted that low catches of bluefin tuna are associated with a south-westerly current speed of 0.49 m/sec, while the best catches were made in areas with a north-easterly current speed of 0.73 m/sec. The coefficient of variation is 0.60 (Table 1), which means that the distribution of current speed values is heterogeneous. Notably, bluefin tuna have the ability to live in an environment of great variability with respect to the speed of the sea current.

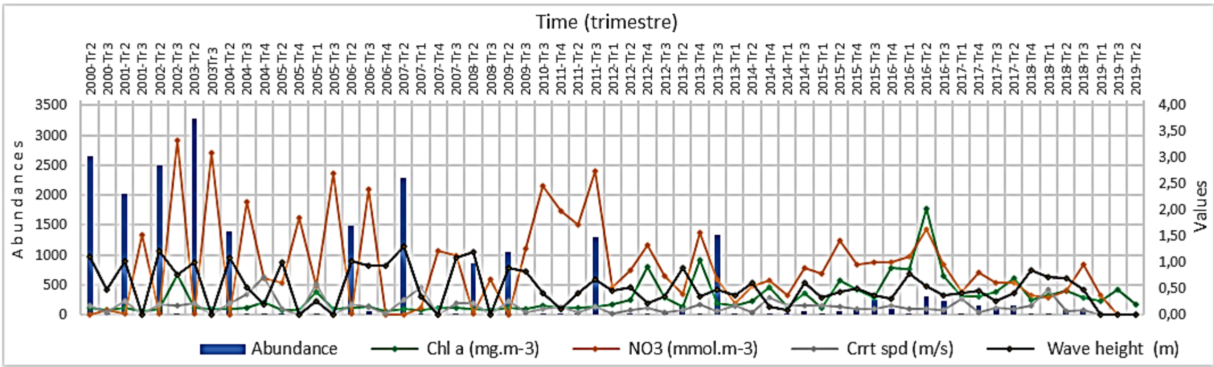


Fig. 9. Seasonal variations in bluefin tuna abundances in relation to environmental factors: Chlorophyll a, Current speed, Wave height, and nitrate (NO3)

The distribution of bluefin tuna is related to the oceanic front for several reasons: either for food needs, as oceanic fronts are favoured areas for energy transfer along trophic chains **(Royer, 2005)**; or for migration needs, as they are able to associate with the limits of the Gulf stream current so that they can distribute in the European territory on the North Atlantic side **(Lehodey *et al*., 1997)**; or for breeding requirements, as anticyclonic eddies or frontal areas are potentially favourable for the survival and development of eggs and larvae **(Bakun, 1996; García *et al*., 2003)**. In addition, Figs. (9&11) show the abundance of *Thunnus thynnus as a* function of seasonal variability in sea state (wave height).

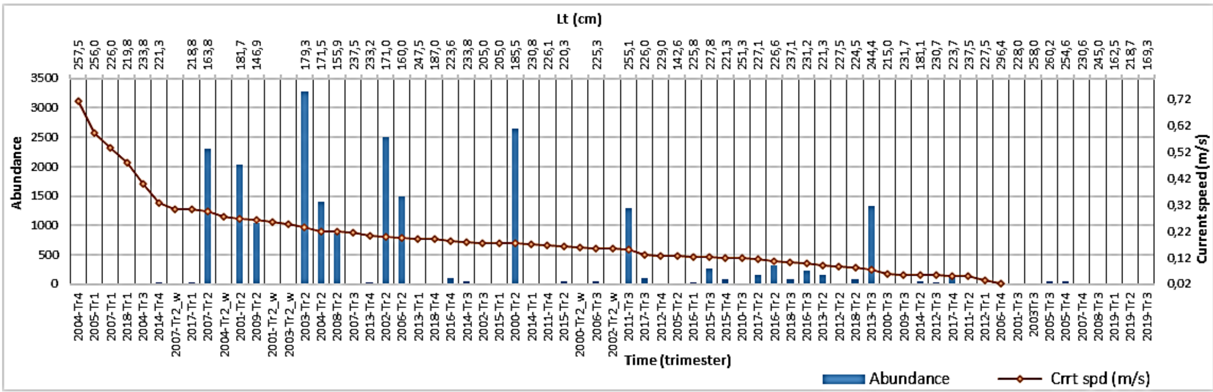


Fig. 10. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factors, current speed.

The wave height in areas of high catch averages from 0.9 to 1.33 m in spring and 0.49 to 0.62 m in summer. The coefficient of variation is high, at 0.57 (Table 1), Bluefin tuna have the ability to swim in waters with a high variability in energy. It has been found in calm, low energy waters (about 0 m wave height on average) and even in very rough, high-energy waters due to the effect of wind on the sea surface, with waves of 5.2 m in height. According to **(Teo *et al*., 2007)**, *Thynnus thynnus* in the breeding phase frequents areas with moderate wind speeds (5-7 m. s-1). Breeding Western Atlantic BFTs favour areas with moderate eddy kinetic energy, where mesoscale eddies are present **(Teo *et al*., 2007)**.

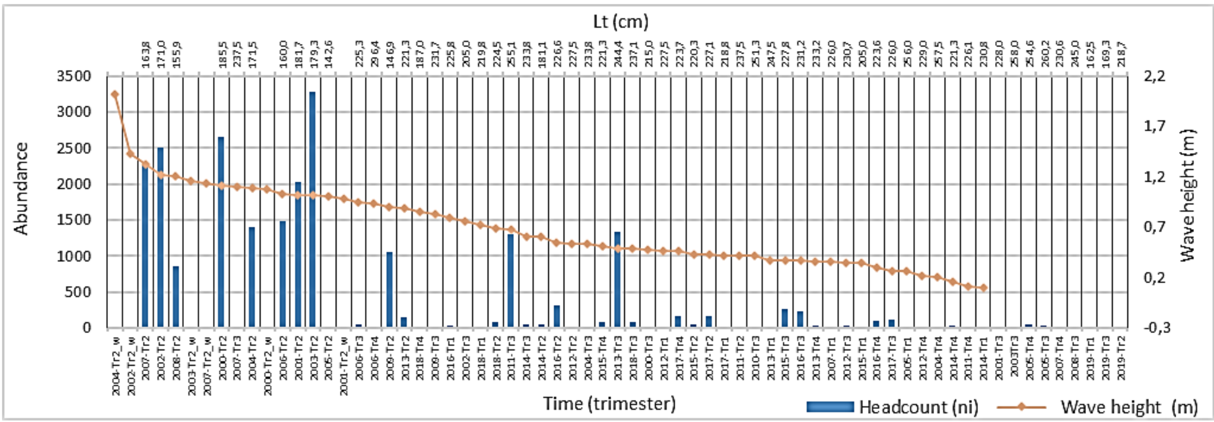


Fig.11. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factor, wave height.

2.2. Chemical factors

Table (5) shows the link between the chemical and physical factors of the marine environment and the biotic parameters of the species (size and weight).

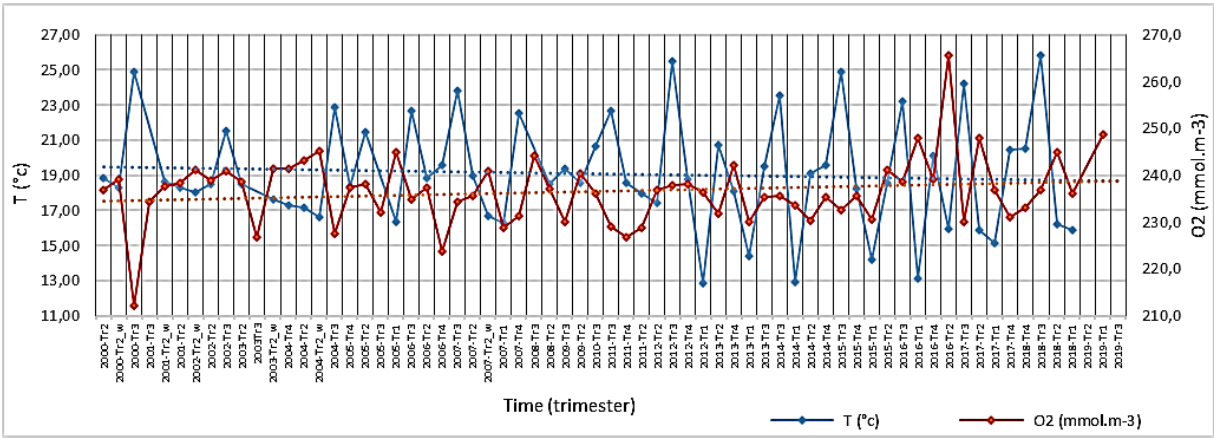


Fig.12. Seasonal variation of the two factors: Temperature and dissolved oxygen

Fig. (4) and Table (5) show that dissolved oxygen in seawater is correlated with temperature and salinity with correlation coefficients (r =-0.64, $p<0.0001$), and (r = -0.652, $p<0.0001$) respectively, as well as with chlorophyll (a) a, at a correlation coefficient of (r = 0.86, $p<0.0001$). Fig. (12) illustrates well the seasonal variation of the two factors: temperature and dissolved oxygen; it shows the inverse relationship between these two parameters during the seasons; the two curves are in opposite direction, oxygen decreases with increasing temperature, the opposite is true.

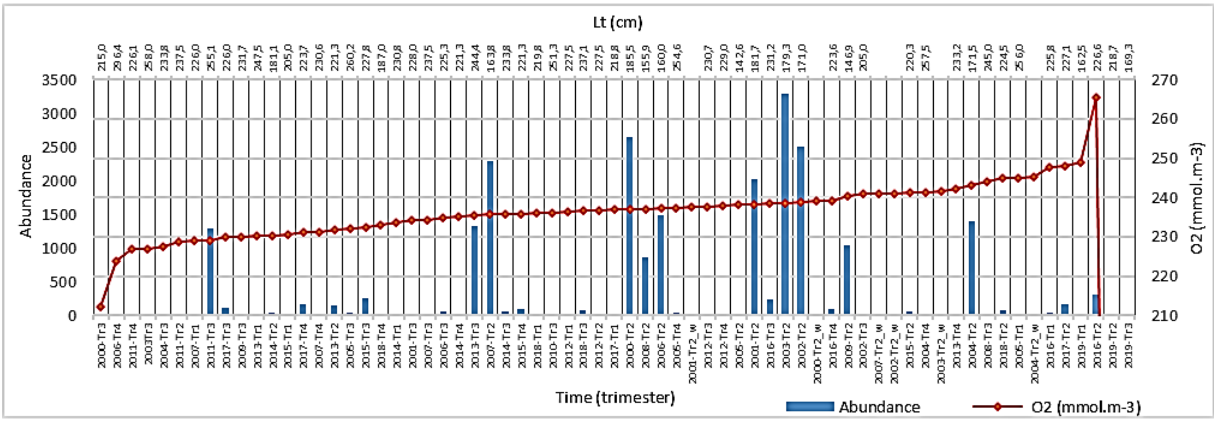


Fig. 13. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factors, dissolved oxygen

The temporal distribution of dissolved oxygen in bluefin tuna catch areas is homogeneous, as the coefficient of variation in these areas is 0.038. O2 concentrations in areas of high bluefin tuna catches vary from 235.6 to 243 $mmol.m^{-3}$ in the spring season and from 229 to 235.4 $mmol.m^{-3}$in the summer season (Fig.13). The temporal distribution of oxygen in seawater is a function of the biological activity and/or ventilation of the water mass **(Lefèvre *et al*., 2012)**.

The BFT has a high aerobic capacity **(Royer, 2005)**, which would allow it to ensure gill ventilation and compensate for its negative buoyancy **(Magnuson (1973, 1978))**; meet the needs of the type I muscles (red muscles); guarantee a high endurance and sustained

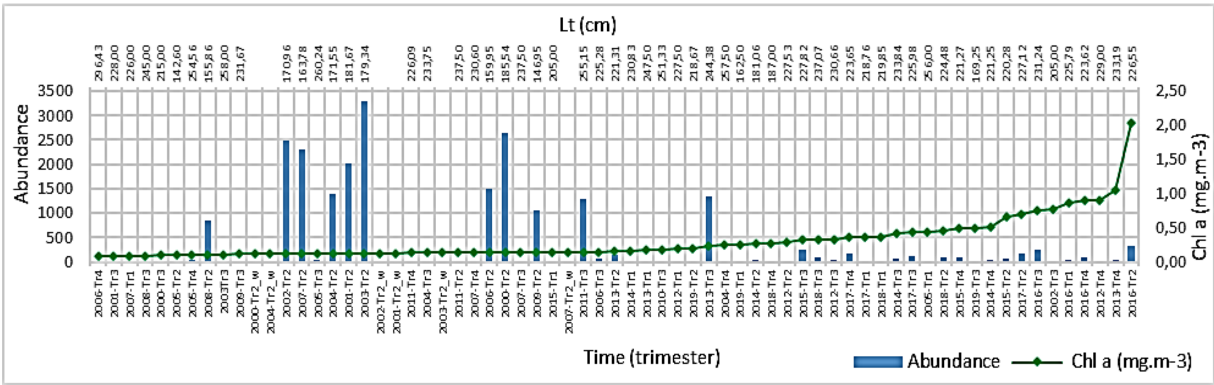


Fig. 14. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factors, chlorophyll (a).

Swimming **(Lutcavage *et al*., 2000; Brill *et al*., 2002; Royer, 2005)**; and to limit energy conflicts. The seasonal variation in surface chlorophyll (a) concentration for the fishing areas is presented in Figs. (14& 9) as a seasonal average. The search for areas of chlorophyll (a) concentration, which is the first link in the food chain, makes it possible to identify schools of fish that are prey to bluefin tuna such as: mackerel, herring, sardines, anchovies and krill. Moreover, **Marie-louise (1957)** and **FURNESTIN (1963)** explained that the third link in the foodchain, that of the Chaetognaths: *Sagitta serratodentata* and *Sagitta elegans*, are indicators of mackerel and herring respectively. Moreover, sardines and anchovies use two feeding behaviours: filtration (they consume phytoplankton), or predation (planktonic prey) **(Plounevez & Champalbert, 2000; Palomera *et al.*, 2007; Chouvelon *et al.*, 2014; Ganias, 2014).**

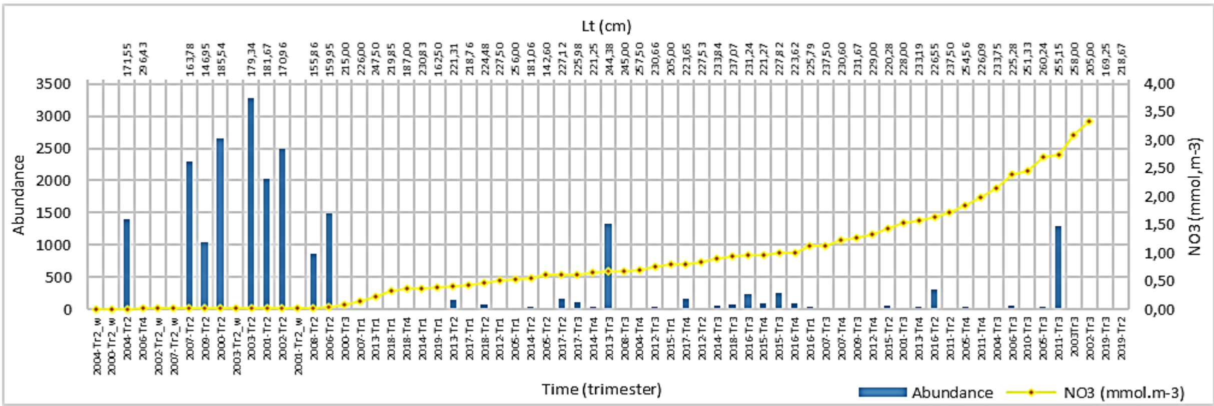


Fig. 15. Seasonal variations in bluefin tuna abundances and mean lengths in relation to environmental factor nitrate (NO3)

Chlorophyll (a) concentrations in fishing areas were found to vary from 0.06 to 6.59mg. m-3 (Table 1). Average chlorophyll (a) concentrations in areas of bluefin tuna overabundance are low, ranging from 0.11 to 0. 14mg.m-3 in spring seasons, and 0.15 to 0.23 mg. m-3 in summer seasons (Fig. 14). According to **(Teo *et al*., 2007)**, tagged adult BFT were located in areas with relatively low surface chlorophyll concentrations (0.10 to 0.16 mg.m-3).figs.12, 9 PCA showed that nitrate (NO3) levels in the fishing area are strongly related to the total length of bluefin tuna ($r = 0.717$, $p < 0.0001$). The limits of nitrate concentrations recorded in the biotope of this species vary between 0.005 and 8.15 mmol.m-3 (Table 1). The nutrient element such as nitrate is important in plankton production **(Tham, 1998)**. Figs. (9& 15) show the average nitrate levels in areas of high bluefin tuna catches; these concentrations are seasonally delineated. Moreover, in spring seasons, the average NO3 concentrations vary between 0.01 and 0.04 mmol.m-3 and in summer seasons they are higher,varying between 0.68 and 2.75 mmol.m-3.The nitrate factor can play the role of an indirect indicator of the presence of bluefin tuna, as nitrate is a primordial nutrient in the development of the first link in the trophic chain; phytoplankton populations**(Tham, 1998; Abboud-Abi Saab *et al*., 2005)**.

CONCLUSION

The distribution of bluefin tuna along the Algerian coast is seasonal and governed by several physical and chemical factors. Indeed, the high abundances of bluefin tuna have been noticed in water masses with a seasonal variation in physical and chemical factors. The BFT has a high aerobic capacity, the O2 concentrations in areas of high bluefin tuna catches vary from 235.6 to 243 mmol.m-3 in the spring season and from 229 to 235.4 mmol.m-3 in the summer season. Chlorophyll (a) is the first link in the food chain and is used to indirectly identify BFT schools. Average chlorophyll (a) concentrations in areas of bluefin tuna overabundance are low, ranging from 0.11 to 0.14 mg.m-3 in spring and 0.15 to 0.23 mg.m-3 in summer. The nitrate factor can play the role of an indirect indicator of the presence of bluefin tuna, as nitrate is a primordial nutrient in the development of the first link in the trophic chain, phytoplankton populations; Thunnus thynnus has the ability to swim in waters of high energy variability. Wave height in areas of high catch averages 0.9-1.33m in spring and 0.49-0.62m in summer.Environmental factors, namely: Temperature, Salinity, Chlorophyll a, Current speed, Wave height, Dissolved oxygen, and Nitrate, are the determining factors of bluefin tuna distribution along the Algerian coast. All in all, it is important to carry out this research on an adequate spatio-temporal scale, which can be applied to different stages of studies: data, analyses, modeling, projections and forecasts. Therefore, other variables must be taken into account in the model to explain variations in the total length of the species studied.

ACKNOWLEDGEMENTS

The authors would like to thank the researchers of the Laboratory of Biological Oceanography and Marine Environment, Faculty of Biology, Houari Boumediene University of Science and Technology and the researchers of the National School of Marine and Coastal Sciences, Algiers, Algeria.

REFERENCES

Abboud-Abi Saab, M.; Fakhri, M.; Kassab, M.T. and Mattar, N. (2005). Les sels nutritifs et le phytoplancton sur la côte sud du Liban: évaluation d'indices écologiques. Leban. Sci. J., 6:27–43.

Abdelhadi, B.; Pilar, H. H. and Aitor Forcada. (2011). Étude de la distribution spatio temporelle de la pêcherie du thon rouge (Thunnus thynnus) en Algérie avec l'utilisation du système d'information géographique (SIG). *Mediterránea. Serie de Estudios Biológicos* (ESP-1). https://doi.org/10.14198/mdtrra2011.esp.04

Alheit, J. and Hagen, E. (2001). The Effect of Climatic Variation on Pelagic Fish and Fisheries, in: Jones, P.D., Ogilvie, A.E.J., Davies, T.D., Briffa, K.R. (Eds.), History and Climate: Memories of the Future? Springer US, Boston, MA, pp. 247–265. https://doi.org/10.1007/978-1-4757-3365-5_12

Amarouche, K.; Akpınar, A.; Bachari, N.E.I.; Çakmak, R.E. and Houma, F. (2019). Evaluation of a high-resolution wave hindcast model SWANS for the West Mediterranean basin. *Appl. Ocean Res*, 84:225–241.

Amarouche, K.; Akpınar, A.; Çakmak, R. E.; Houma, F. and Bachari, N.E.I. 2020. Assessment of storm events along the Algiers coast and their potential impacts. *Ocean Engineering*, 210:107432. https://doi.org/10.1016/j.oceaneng.2020.107432

Aminot, A. and Kérouel, R. (2004). Hydrologie des écosystèmes marins : paramètres et analyses. Editions Quae.

Arena, P. (1959a). Notes on a recent experimental tuna fishing campaign around the Aeolian Islands and in the Straits of Messina. Presented at the General Fisheries Council for the Meditemmean, Rome, pp. 429–432.

Bakun, A. (1996). Patterns in the ocean: Ocean processes and marine population dynamics.

BARTLETT, M.S. (1966). An introduction to stochastic processes. Math. Gaz. 50: b1–b11. https://doi.org/10.1017/S0025557200243313

Block, B.A.; Dewar, H.; Blackwell, S.B.; Williams, T.D.; Prince, E.D.; Farwell, C.J.; Boustany, A.; Teo, S.L.; Seitz, A.; Walli, A. and Fudge, D. (2001). Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. *Science*, 293:1310–1314. doi: https://doi.org/10.1126/science.1061197

Block B.A.; Whitlock, R.; Schallert, R.J.; Wilson, S.; Stokesbury, M.J.W.; Castleton, M. and Boustany, A. (2019). Estimating Natural Mortality of Atlantic Bluefin Tuna Using Acoustic Telemetry. *Sci. Rep.*, 9:4918. https://doi.org/10.1038/s41598-019-40065-z

Brill, R.; Lutcavage, M.; Metzger, G.; Bushnell, P.; Arendt, M.; Lucy, J.; Watson, C. and Foley, D. (2002). Horizontal and vertical movements of juvenile bluefin tuna (Thunnus thynnus), in relation to oceanographic conditions of the western North Atlantic determined with ultrasonic telemetry. *Fish. Bull.*, 100:155–167.

Caill-Milly, N.; Suquet, M. and Arrizabalaga, H. (2002). Fattening of Bluefin Tuna (Thunnus thynnus) caught by the French and Spanish bait boats in the Bay of Biscay. Domest. Thunnus – DOTT Proceeding First Int. *Symp. Held Univ.*Cartagena 194.

Chouvelon, T. ; Chappuis, A. ; Bustamante, P. ; Lefebvre, S. ; Mornet, F. ; Guillou, G. ; Violamer, L. and Dupuy, C. (2014). Trophic ecology of European sardine Sardina pilchardus and European anchovy Engraulis encrasicolus in the Bay of Biscay (north-east Atlantic) inferred from δ13C and δ15N values of fish and identified mesozooplanktonic organisms. *J. Sea Res.,* 85 :277–291.

Collette, B.B. and Nauen, C.E. (1983). FAO species catalogue. Vol.2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date, *FAO Fisheries Synopsis*. ed.

Cort, J. (1990). Biología y pesca del atún rojo,"*Thunnus thynnus*"(L.), del mar Cantábrico. XF2006303440 4.

D'Ortenzio, F. and Ribera d'Alcalà, M. (2009). On the trophic regimes of the Mediterranean Sea: a satellite analysis. *Biogeosc*., 6 :139–148.

Da, N. ; Ouédraogo, R. and Ouéda, A. (2018). Relation poids-longueur et facteur de condition de Clarias anguillaris et Sarotherodon galilaeus pêchées dans le lac Bam et le réservoir de la Kompienga au Burkina Faso. *Int. J. Biol. Chem. Sci.,* 12:1601. https://doi.org/10.4314/ijbcs.v12i4.8

Dickson, R.R. and Brander, K.M. (1993). Effects of a changing windfield on cod stocks of the North Atlantic. *Fish. Oceanogr*., 2:124–153. https://doi.org/10.1111/j.1365-2419.1993.tb00130.x

Durrieu de Madron, X.; Guieu, C.; Sempéré, R.; Conan, P.; Cossa, D.; D'Ortenzio, F.; Estournel, C.; Gazeau, F.; Rabouille, C.; Stemmann, L.; Bonnet, S.; Diaz, F.; Koubbi, P.; Radakovitch, O.; Babin, M.; Baklouti, M.; Bancon-Montigny, C.; Belviso, S.; Bensoussan, N.; Bonsang, B.; Bouloubassi, I.; Brunet, C.; Cadiou, J.-F.; Carlotti, F.; Chami, M.; Charmasson, S.; Charrière, B.; Dachs, J.; Doxaran, D.; Dutay, J.-C.; Elbaz-Poulichet, F.; Eléaume, M.; Eyrolles, F.; Fernandez, C.; Fowler, S.; Francour, P.; Gaertner, J.C.; Galzin, R.; Gasparini, S.; Ghiglione, J.-F.; Gonzalez, J.-L.; Goyet, C.; Guidi, L.; Guizien, K.; Heimbürger, L.-E.; Jacquet, S.H.M.; Jeffrey, W.H.; Joux, F.; Le Hir, P.; Leblanc, K.; Lefèvre, D.; Lejeusne, C.; Lemé, R.; Loÿe-Pilot, M.-D.; Mallet, M.; Méjanelle, L.; Mélin, F.; Mellon, C.; Mérigot, B.; Merle, P.-L.; Migon, C.; Miller, W.L.; Mortier, L.; Mostajir, B.; Mousseau, L.; Moutin, T.; Para, J.; Pérez, T.; Petrenko, A.; Poggiale, J.-C.; Prieur, L.; Pujo-Pay, M.; Pulido-Villena, R. P.; Rees, A.P.; Ridame, C.; Rontani, J.-F.; Ruiz Pino, D.; Sicre, M.A.; Taillandier, V.; Tamburini, C.; Tanaka, T.; Taupier-Letage, I.; Tedetti, M.; Testor, P.; Thébault, H.; Thouvenin, B.; Touratier, F.; Tronczynski, J.; Ulses, C.; Van Wambeke, F.; Vantrepotte, V.; Vaz, S. and Verney, R. (2011). Marine ecosystems' responses to climatic and anthropogenic forcings in the Mediterranean. *Prog. Oceanogr*., 91: 97–166. https://doi.org/10.1016/j.pocean.2011.02.003

Fréon, P. and Misund, O. (1999). Dynamics of pelagic fish distribution and behaviour: Effects on fisheries and stock assessment, *Science*.

Ganias, K. (2014). Biology and ecology of sardines and anchovies. CRC Press.

García, A.; Alemany, F.; Velez-Belchi, P.; López-Jurado, J.; González-Pola, C. and Rodriguez, J. (2003). Bluefin tuna and associated species spawning grounds in the oceanographic scenario of the Balearic archipelago during June 2001. *Collect. Vol. Sci. Pap. Int. Counc. Conserv. Atl*. Tunas 55pp.

Garcia, H.E. and Gordon, L.I. (1992). Oxygen solubility in seawater: better fitting equations. Limnol. *Oceanogr*. 37:1307–1312.

Gushing, D.H. and Dickson, R.R. (1977). The Biological Response in the Sea to Climatic Changes. In: "Advances in Marine Biology" Russell, F.S. & Yonge, M. (Eds.). Academic Press, pp. 1–122. https://doi.org/10.1016/S0065-2881(08)60446-0

ICCAT·CICTA·CICAA [WWW Document], 2019. URL https://www.iccat.int/fr/ (accessed 2.16.21).

Kacemi, M. (2013). Protection et valorisation du littoral en Algérie : législation et instruments : Le cas des communes littorales d'Oran. *Études Caribéennes*. https://doi.org/10.4000/etudescaribeennes.5959

Labidi, N. and Nouar, A. (2013a). Quelques indices de la biologie du thon rouge (Thunnus thynnus) en Algerie. *Collect Vol Sci Pap ICCAT*., 69 :603–620.

Labidi, N.; Nouar, A. (2013b). Evaluation Du Stock De Thon Rouge (Thunnus Thynnus) En Algerie. *Collect Vol Sci Pap ICCAT.*, 69:621–630.

Le Cren, E.D. (1951). The Length-Weight Relationship and Seasonal Cycle in Gonad Weight and Condition in the Perch (Perca fluviatilis). *J. Anim. Ecol.*, 20 :201–219. https://doi.org/10.2307/1540

Lefèvre, D.; Bentley, T.; Lafont, M.; Coppola, L. and Mousseau, L. (2012). Etat Physique Et Chimique Caractéristiques chimiques 11.

Lehodey, P.; Bertignac, M.; Hampton, J.; Lewis, A. and Picaut, J. (1997). El Niño Southern Oscillation and tuna in the western Pacific. *Nature.*, 389:715–718.

Lutcavage, M.E.; Brill, R.W.; Skomal, G.B.; Chase, B.C.; Goldstein, J.L. and Tutein, J. (2000). Tracking adult North Atlantic bluefin tuna (*Thunnus thynnus*) in the northwestern Atlantic using ultrasonic telemetry. *Mar. Biol.*, 137:347–358. https://doi.org/10.1007/s002270000302

MacKenzie, B.R. and Mariani, P. (2012). Spawning of Bluefin Tuna in the Black Sea: Historical Evidence, Environmental Constraints and Population Plasticity. *PLoS ONE 7*, e39998. https://doi.org/10.1371/journal.pone.0039998

Magnuson, J. (1973). Comparative study of adaptations for continuous swimming and hydrostatic equilibrium of scombroid and xiphoid fishes. *Fish Bull*., 71:337–356.

Magnuson, J.J. (1978). Locomotion by Scombrid Fishes: Hydromechanics, Morphology and Behavior. In: "Fish Physiology". Elsevier, pp. 239–313. https://doi.org/10.1016/S1546-5098(08)60166-1

Magnuson, J.J.; Block, B.A.; Deriso, R.B.; Gold, J.R.; Grant, W.S.; Quinn II, T.J.; Saila, S.B.; Shapiro, L. and Don Stevens, E. (1994). An Assessment of Atlantic Bluefin Tuna. The National Academies Press, Washington, DC. https://doi.org/10.17226/4801

Marie-louise, F. (1957). Chaetognathes et zooplancton du secteur atlantique marocain. Rev. Trav. *Inst. Pêch. Marit.*, 0035-2276 ISTPM 1957-0321 N 1-2 P 1-356 21.

Marine | Copernicus [WWW Document], n.d. URL https://www.copernicus.eu/en/copernicus-services/marine (Accessed 2.16.21).

Micha, J.C. (1973). Etude des populations piscicoles de l'Ubangui et tentatives de sélection et d'adaptation de quelques espèces à l'étang de pisciculture [WWW Document]. URL http://agritrop.cirad.fr/344065/ (accessed 9.26.20).

Millot, C. (1989). La circulation générale en Méditerranée occidentale : Aperçu de nos connaissances et projets d'études. *Ann. Géographie*., 98. https://doi.org/ 10.3406/geo.1989.20925

Mylonas, C.C. ; Bridges, C. ; Gordin, H. ; Ríos, A.B. ; García, A. ; De La Gándara, F. ; Fauvel, C. ; Suquet, M. ; Medina, A. ; Papadaki, M. ; Heinisch, G. ; De Metrio, G. ; Corriero, A. ; Vassallo-Agius, R. ; Guzmán, J.-M. ; Mañanos, E. and Zohar, Y. (2007). Preparation and Administration of Gonadotropin-Releasing Hormone Agonist (GnRHa) Implants for the Artificial Control of Reproductive Maturation in Captive-Reared Atlantic Bluefin Tuna (*Thunnus thynnus*). *Rev. Fish. Sci*., 15:183–210. https://doi.org/10.1080/10641260701484572

Neghli, N. and Nouar, A. (2014). Estimation de l'age des spécimens de thon rouge (thunnus thynnus) pêchés sur les côtes algériennes. *Collect Vol Sci Pap ICCAT*., 70 :232–240.

Nouar, A. and Labidi, N. (2009). Croissance du Thon Rouge *Thunnus Thynnus* (Linnaeus, 1758) Des Côtes Algeriennes.

Ottersen, G.; Alheit, J.; Drinkwater, K.; Friedland, K.; Hagen, E. and Stenseth, N.C. (2004). The Responses of Fish Populations to Ocean Climate Fluctuations, Marine Ecosystems and Climate Variation the North Atlantic a Comparative Perspective. https://doi.org/10.1093 /acprof:oso/9780198507499.003.0006

Palomera, I. ; Olivar, M.P. ; Salat, J.; Sabatés, A.; Coll, M.; García, A. and Morales-Nin, B. (2007). Small pelagic fish in the NW Mediterranean Sea: An ecological review. Prog. Oceanogr., Ecological Functioning of the Iberian Seas: A synthesis of GLOBEC Research in Spain and Portugal 74:377–396. https://doi.org/10.1016/ j.pocean.2007.04.012

Plounevez, S. and Champalbert, G. (2000). Diet, feeding behaviour and trophic activity of the anchovy (*Engraulis encrasicolus L*.) in the Gulf of Lions (Mediterranean Sea). *Oceanol. Acta.*, 23 :175–192.

Royer, F. (2005). Contribution à l'étude de la dynamique du thon rouge atlantique : Approches écologiques et océanographiques (These de doctorat). Rennes, Agrocampus Ouest.

Saporta, G. (2006). Probabilités, Analyse Des Données et Statistique. Httplst-Iiepiiep-Unescoorgcgi-Binwwwi32exeinepidoc1int2000010208100.

Searcy, S.P.; Eggleston, D.B. and Hare, J.A. (2007). Is growth a reliable indicator of habitat quality and essential fish habitat for a juvenile estuarine fish? *Can. J. Fish. Aquat. Sci*., 64:681–691. https://doi.org/10.1139/f07-038

Southward, A.J.; Boalch, G.T. and Maddock, L. (1988). Fluctuations in the herring and pilchard fisheries of Devon and Cornwall linked to change in climate since the 16th century. *J. Mar. Biol. Assoc. U. K.*, 68:423–445.

Teo, S.; Boustany, A. and Block, B. (2007). Oceanographic preferences of Atlantic bluefin tuna, Thunnus thynnus, on their Gulf of Mexico breeding grounds. *Mar. Biol*., 152 :1105–1119. https://doi.org/10.1007/s00227-007-0758-1

Tham, D.-H. (1998). Déplacements verticaux des thons et contraintes liées à la profondeur dans l'océan Pacifique sub-tropical : approche de la gestion des gaz dissous.