

UPDATED LIFE HISTORY PARAMETERS AND ESTIMATES OF SPAWNING POTENTIAL RATIO FOR FRIGATE TUNA *AUXIS THAZARD* STOCK IN THE NORTHEAST ATLANTIC

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SUMMARY

The scientific work presents the attempt to estimate the status of Frigate tuna stock in the Northeast Atlantic. Stock status estimates were obtained based on biological data from by-catch of Russian resources studies. Analysis of Frigate tuna length composition allowed to obtain estimates of life history parameters. Bertalanffy equation parameters were calculated using the ELEFAN procedure in R ($L_{\infty} = 48.6$ cm, $k = 0.48$). Lengths where 50% and 95% of the fish are mature were calculated by the FSA package in R ($L_{mat50} = 30.1$ cm; $L_{mat95} = 41.2$ cm). A qualitative assessment of Frigate tuna stock status was performed based on the Length-Based Spawning Potential Ratio (LBSPR) methodology. The spawning potential ratio (SPR) was 0.26 in 2015-2016, which is below the biological target reference point and formally indicates the status of overfishing stock.

RÉSUMÉ

Ce travail scientifique présente une tentative d'estimation de l'état du stock de l'auxide dans l'Atlantique Nord-Est. Les estimations de l'état du stock ont été obtenues à partir des données biologiques provenant des études sur les prises accessoires des ressources russes. L'analyse de la composition par taille de l'auxide a permis d'obtenir des estimations des paramètres du cycle vital. Les paramètres de l'équation de Bertalanffy ont été calculés en utilisant la procédure ELEFAN dans R ($L_{\infty} = 48,6$ cm, $k = 0,48$). Les longueurs où 50 % et 95 % des poissons sont matures ont été calculées au moyen du paquet FSA dans R ($L_{mat50} = 30,1$ cm ; $L_{mat95} = 41,2$ cm). Une évaluation qualitative de l'état du stock de l'auxide a été réalisée sur la base de la méthodologie du ratio du potentiel de reproduction basé sur la longueur (LBSPR). Le ratio du potentiel de reproduction (SPR) était de 0,26 en 2015-2016, ce qui est inférieur au point de référence biologique cible et indique formellement l'état de surpêche du stock.

RESUMEN

El trabajo científico presenta el intento de estimar el estado del stock de melva del Atlántico nordeste. Las estimaciones del estado del stock se obtuvieron a partir de los datos biológicos de los estudios sobre las capturas fortuitas de los recursos rusos. El análisis de la composición por tallas de la melva permitió obtener estimaciones de los parámetros del ciclo vital. Los parámetros de la ecuación de Bertalanffy se calcularon mediante el procedimiento ELEFAN en R ($L_{\infty} = 48,6$ cm, $k = 0,48$). Las tallas en las que el 50 % y el 95 % de los peces son maduros se calcularon con el paquete FSA en R ($L_{mat50} = 30,1$ cm; $L_{mat95} = 41,2$ cm). Se llevó a cabo una evaluación cualitativa del estado del stock de melva basada en la metodología de ratio de potencial de desove basada en la talla (LBSPR). La ratio de potencial de desove (SPR) fue de 0,26 en 2015-2016, lo que está por debajo del punto de referencia del objetivo biológico e indica formalmente el estado de sobrepesca del stock.

KEYWORDS

*Frigate tuna *Auxis thazard*, small tunas, length composition, life history parameters, Bertalanffy equation parameters, SPR*

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1. Introduction

Russian vessels do not engage fishery activities of Frigate tuna although this species occurs as by-catch in trawling small pelagic fish species (horse mackerel, mackerels, sardinella, etc.) and in resources studies of Atlantic branch of VNIRO (AtlantNIRO) mainly in Morocco, Mauritania, and Senegal waters. Despite a wide distribution of this species in Atlantic and its value for regional commercial fisheries in many coastal communities Frigate tuna life history has not been studied properly. The reason of it is a deficit of primary information. For example last values of life history parameters for Frigate tuna of the Northeast Atlantic were calculated in 1986 (Grudtsev and Korolevich, 1986).

At present time the information support of Frigate tuna in the Northeast Atlantic does not allow the use of traditional abundance dynamics models to assess the status of this species stocks. However, attempt to estimate stock status by data-limited assessment methods were initiated in recent years (Pons et al., 2019). According to this scientific work for better understanding of Frigate tuna stock status it is important to use length composition data from different fishery gears in stock assessment.

The study consists of two parts. The first one includes assessment of life history parameters (L_{∞} , k , L_{m50} , L_{m95} , M) for Frigate tuna stock in the Northeast Atlantic. And second one includes stock assessment by calculating SPR values.

2. Material and methods

The research is based on Russian data collected between 2010 and 2019 by Atlantic branch of VNIRO (AtlantNIRO) researchers in the Northeast Atlantic (Morocco, Mauritania, Senegal and Guinea-Bissau waters). Frigate tuna occurred in research trawls as a by-catch from a few individuals or up to several hundred at depths, ranging from 23 to 1350 meters. Number of caught individuals is presented in **Table 1**. Caught individuals were weighted and measured for their total length. Besides, sex and maturity stage were defined for every individual. The difficulty of this research was the age data missing. Overall, the input data included the following parameters: catch date, length, weight, maturity statement «mature» or «immature» and maturity stage of fish.

A total of 1665 Frigate tuna specimens were caught over this period. The total length (TL) was measured for all fish individuals; among them, the fork length (FL) was also determined for 234 individuals. According to the results of regression analysis in Statistica 8.0, $FL = 0.95 TL$. This study used the fork length in all calculations.

The linear growth parameters of the Bertalanffy equation (Bertalanffy, 1964) for Frigate tuna were obtained using the TropFishR package (version 1.6.1) (Mildenberger et al., 2017) in the R software environment. This package allows to use an analysis of the distribution of length values (Electronic length frequency analysis, ELEFAN) of the study object (Pauly and Gaschuetz, 1979; Pauly, 1987) to estimate the theoretical maximum length of an individual (L_{∞}) and growth rate (k). The advantage of the method is the opportunity to estimate these parameters without age data, which is typical for most stocks of small tunas, including Frigate tuna.

The use of ELEFAN implies but is not limited to the following conditions: (1) the size of sample over 1 month should be not less than 50 individuals; (2) the period between catches of individuals under study should be equal. The input data for the ELEFAN procedure included data on the length of individuals captured in 2011 and 2012, but taking into account the ELEFAN conditions further analysis used data obtained also in other years (to have samples more than 50 individuals). An assumption was made about the constancy of the growth parameters of Frigate tuna over the past 10 years. **Table 2** presents size of samples used in ELEFAN.

The maturity ogive of Frigate tuna was built based on the assumption of the logistic dependence using a generalized linear model implemented in the FSA package (version 0.8.24) (Ogle, 2013; Ogle et al., 2018). The input information for constructing the curve and estimating lengths values where 50% and 95% of the fish are mature included the catch date, length, maturity stage and state (“mature” or “immature” stage) according to the AtlantNIRO Guide (Alekseev and Alekseeva, 1996) for each individual.

The natural mortality instantaneous rate (M) of Frigate tuna was calculated by several methods (Alverson, Carney, 1975; Rikhter, Efanov, 1976; Roff, 1984; Jensen, 1996; Jensen, 1997; Zhang, Megrey, 2006; Then et al., 2015) in the Barefoot Ecologist's Toolbox (http://barefootecologist.com.au/shiny_m). Since there are no estimates for the fish age, the value of the maximum age of Frigate tuna in the northeastern Atlantic Ocean that is used in some methods for determining the natural mortality instantaneous rate was taken from the published data (Grudtsev, Korolevich, 1986). The final estimate of the rate was obtained by averaging the resulting values.

The stock status of Frigate tuna was analyzed using the length-based spawning potential ratio (LBSPR) method (Hordyk et al., 2015a; Hordyk et al., 2015b) also in the Barefoot Ecologist's Toolbox (Prince et al., 2015). This approach allows getting of approximate estimate of the stock status based on analyzing the length composition of catches and estimating the spawning potential ratio (SPR). In the international practice of stock assessment with poor information supply, the SPR is used as a biological reference point and reflects changes in the total potential productivity of the population due to catches of aquatic organisms. The ratio value of 40% (or 0.4) is used as an alternative to the $BMSY_{target}$ reference point (a stock biomass value corresponding to the maximum sustainable yield) in cases when stock information is unavailable (Mace and Sissenwine, 1993; Brooks et al., 2010). The fishery strategy aimed at reaching the fishing mortality rate that corresponds to the SPR of 40% is considered effective even for stocks with a very low resistance to external effects (Clark, 2002).

3. Results and discussion

3.1 Assessment of Frigate tuna life history parameters

In ELEFAN calculating the cross method was chosen, the maximum age of Frigate tuna was 4 (Grudtsev, Korolevich, 1986); range of L_{∞} values was from 39 cm (obtained by the Powell-Wetherall method) to 52 cm (borrowed from literature (Grudtsev, Korolevich, 1986)); range of k values was from $\log(0.1)$ to $\log(2)$; number indicating over how many length classes the moving average should be performed (MA) was 7. Thus, the growth curves of Frigate tuna generations were constructed (**Figure 1**). The calculated values of the Bertalanffy equation parameters were: $L_{\infty} = 48.6$ cm, $k = 0.48$. It should be noted that the calculated values of Frigate tuna growth parameters do not contradict the literature data.

The length at which 50% of individuals reach sexual maturity (L_{m50}) was 30.1 cm (at a confidence interval of 29.7 – 30.5 cm); the length at which 95% of individuals reach sexual maturity (L_{m95}) was 41.2 cm (39.9 – 43.0 cm). Obtained estimates are common for both sexes (**Figure 2**). Before these parameters were not calculated for Northeast Atlantic stock except values of total length (Petukhova, 2019).

Results of calculation of the natural mortality instantaneous rate of Frigate tuna using different methods present in **Table 3**. The final estimate of the rate results from averaging the obtained values was 0.76 year^{-1} . Such value is characteristic of short-lived species, which include Frigate tuna.

Estimates of the life history parameters of the North-East Atlantic Frigate tuna which were inputs data for calculating SPR are given in Summary **Table 4**. Also, the results of studies conducted by other researchers are provided. As can be seen from **Table 4**, the calculated estimates of life history parameters of Frigate tuna do not significantly differ from the literature data and could be used in further analysis of the stock status using data limited methods.

3.2 Stock assessment by LBSPR methodology

Figure 3 presents length composition of Frigate tuna by-catches in different years with curves fitted by LBSPR assessment software. In 2013, 2017, 2018 Frigate tuna samples were small for further analysis. Besides (looking ahead), according to LBSPR software estimated F/M were unrealistically high in 2012, 2014, 2017-2019. For these reasons data for 2015–2016 were used in the further analysis.

Selectivity curves of fishing gears that caught Frigate tuna were constructed (**Figure 4**). Also, the length values at which 50% and 95% of the stock were available for fishery gears were calculated. According to calculations part of individuals that did not reach sexual maturity captured. The values of the spawning potential ratios, selectivity parameters, and ratio of the fishing and natural mortality instantaneous rates are given in **Table 5** and represented in **Figure 5**.

Calculated value of SPR (0.26) is below the target reference point (0.4) and formally indicates the status of overfishing stock. Based on research results fishing pressure by trawls should be reduced but it is unlikely because Frigate tuna is not target species and occurs just in by-catch. Conclusion about stock status should be used with caution. According to Hordyk et al. (2015) study it is expected that the LBSPR method overestimates F/M and underestimates SPR when confronted with data from a trawls fishery with dome-shaped selectivity. In order to better understanding the stock status, it is necessary to continue collecting data of Frigate tuna and using other methods (DLM).

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Table 1. Number of caught Frigate tunas in Russian by-catches in the Northeast Atlantic (in Morocco (MAR), Mauritania (MRT), Senegal (SEN), Guinea-Bissau (GNB) waters).

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
<i>Auxis thazard</i>	150 MAR	391 MAR+ SEN	280 MRT	29 MAR+ GNB	138 MAR+ MRT	128 MAR+ MRT	245 MAR+ MRT	83 MAR+ MRT	56 MAR+ MRT	128 MAR+ MRT

Table 2. Size of Frigate tuna samples caught as by-catch in resource studies of AtlantNIRO in the Northeast Atlantic (by month)

Month/ year	1	2	3	4	5	6	7	8	9	10	11	12
2010										100	50	
2011		50		150	50	100	41	50			0+50	
2012		0+154			55	125	75	25+1+50+13			52+30+2+8	27
2013	17								1	11		
2014							40	1		50	52	5
2015						49		50	29			
2016	40	154	1					13		7	30	
2017					21	33	4		17	6	2	
2018	1						26		1	28		
2019	1	2	1		1		7		107		8	1

Samples marked yellow color were used in ELEFAN; numbers marked red color were borrowed for ELEFAN condition implementation: the size of sample over 1 month should be not less than 50 individuals

Table 3. Results of calculation of the natural mortality instantaneous rate of Frigate tuna in the Northeast Atlantic using different methods

Author(s) of method	Calculated value
Alverson, Carney, 1975	0,86
Zhang, Megrey, 2006	0,58
Then, Honeig, Hall, Hewitt, 2015	0,66
Jensen, 1996	0,72
Jensen, 1996	0,76
Roff, 1984	0,89
Jensen, 1997	0,82
Rikhter, Efanov, 1976	0,76
Mean	0,76

Table 4. Estimates of the life history parameters of Frigate tuna in the Northeast Atlantic (data in column «present work» was used for LBSPR analysis)

Parameters	Values	
	present work	literature data
Maximum length (FL), cm	42.3	44.0 (Grudtsev and Korolevich, 1986)
von Bertalanffy asymptotic length (L_{∞}), cm	48.6	51.5 (Grudtsev and Korolevich, 1986)
von Bertalanffy growth coefficient (k), year ⁻¹	0.48	0.32 (Grudtsev and Korolevich, 1986)
Length where 50% of the fish are mature (L_{m50}), cm	30.1	30.0 (Cayre et al., 1993) value borrowed from the Southeast stock
Length where 95% of the fish are mature (L_{m95}), cm	41.2	NA
Maximum age (t_{max}), years	NA	4 (Grudtsev and Korolevich, 1986)
Natural mortality instantaneous rate (M), year ⁻¹	0.76	0.48; 1.01; 1.37 (Pons et al., 2019)

Table 5. Results of indicators assessment for the Frigate tuna stock status in the Northeast Atlantic (SPR - spawning potential ratio; SL_{50} and SL_{95} - lengths at which 50 and 95% of fish, respectively, are available for fishery gears; F/M – relative fishing mortality)

Years	SPR	SL_{50}	SL_{95}	F/M
2015	0.26	30.19	32.48	3.08
	0.24 (0.20 - 0.29)	29.43 (28.72 - 30.14)	31.16 (29.9 - 32.42)	2.92 (1.87 - 3.97)
2016	0.26	30.3	32.64	3.1
	0.29 (0.25 - 0.33)	31.36 (30.59 - 32.13)	34.28 (32.95 - 35.61)	3.3 (2.24 - 4.36)

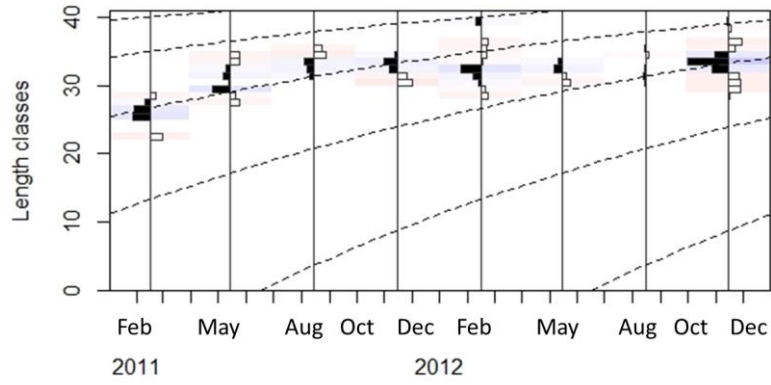


Figure 1. Growth curves (---) of Frigate tuna generations, built in the TropFishR software package.

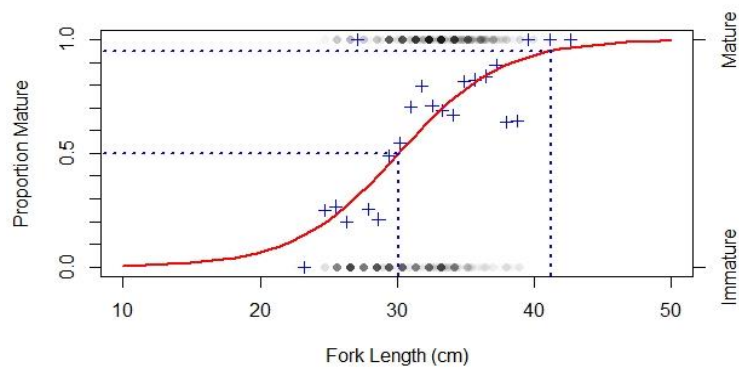


Figure 2. Maturity curve for Frigate Tuna in the Northeast Atlantic.

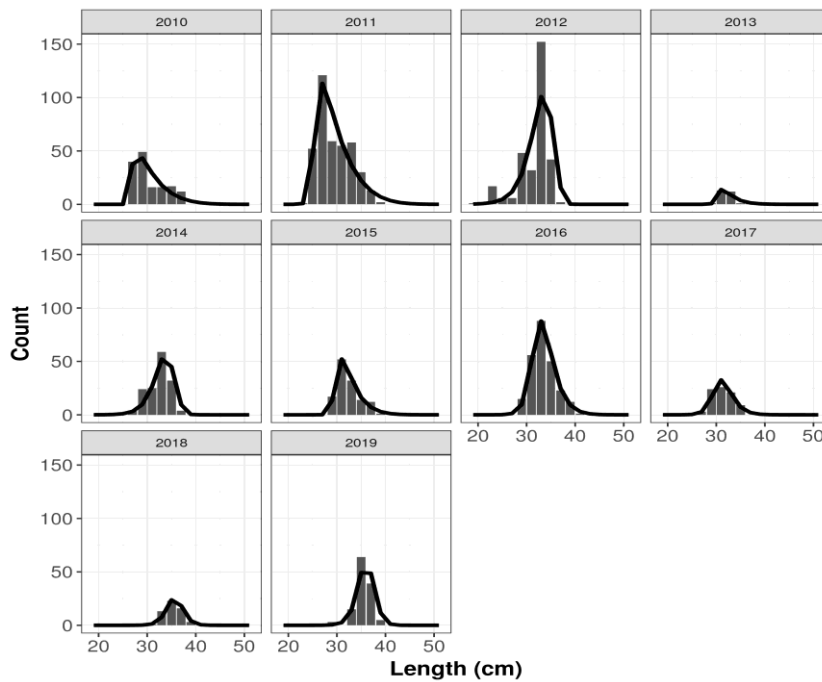


Figure 3. Length composition of Frigate tuna by-catches in different years with curves fitted by LBSPR assessment software.

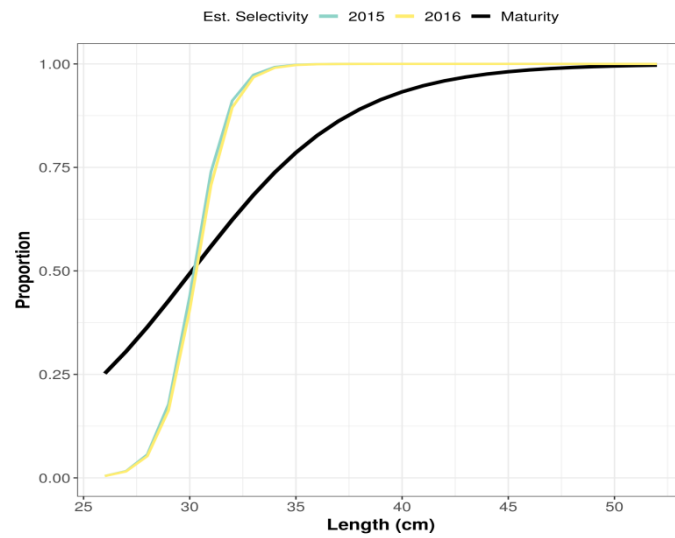


Figure 4. Maturity ogive of Frigate tuna and selectivity curves of mid-water trawls in 2015–2016

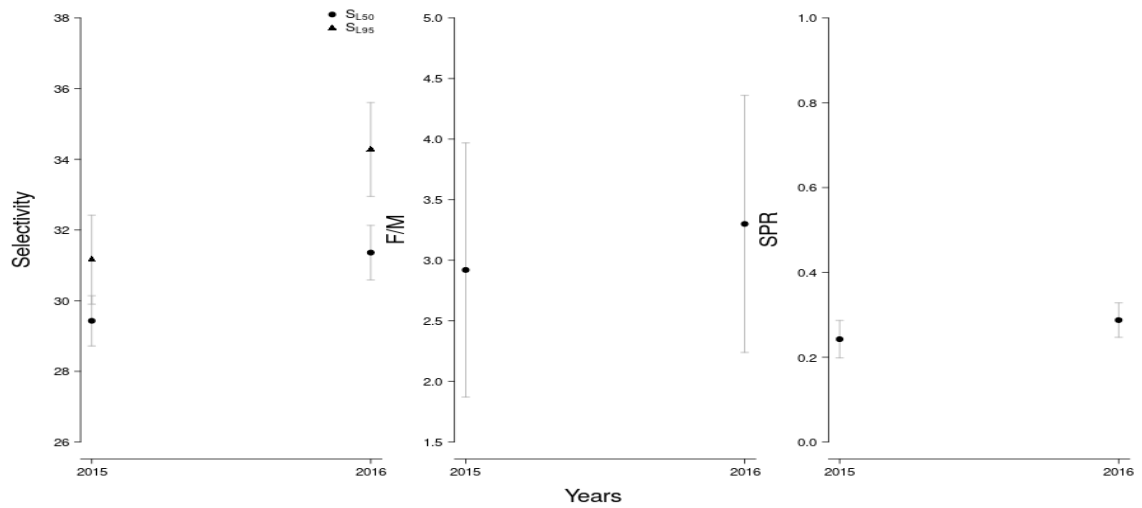


Figure 5. Visual representation of estimates (SPR, SL_{50} , SL_{95} and F/M) by year with 95% confidence intervals