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Analysis of Virtual Populations of Small Pelagic Fish Most Caught in Algeria

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ABSTRACT

The biology and dynamics of *sardina pilchardus* and *sardinella aurita* from the east coast of Algeria were studied to compensate the lack of data concerning the exploitation of their stocks in this area. The von Bertalanffy growth equations were as follows: $Lt = 21.58\ [1-e^{-0.39\ (t\ +0.086)}]$ for *S. pilchardus* and $Lt = 26.68\ [1-e^{-0.41\ (t\ +0.085)}]$ for *S. aurita*. The equations of the length - weight relationship were $TW = 0.0039\ TL^{3.236}$ for *S. pilchardus* and $TW = 0.005\ TL^{3.134}$ for *S. aurita.* The lengths at first maturity (L_{m50}) were 11.61 and 13.54cm for *S. pilchardus* and *S. aurita*, respectively. The natural mortalities (M) were 0.46 $year^{-1}$ for both species, while those of fishing mortality coefficients (F) were 1.49 $year^{-1}$ for *S. pilchardus* and 1.41 $year^{-1}$ for *S. aurita*. The results of the virtual population analysis (VPA) showed the existence of an overfishing status for both species. To limit the risk of stock collapse, we recommended adjusting the $F_{current}$ fishing effort factor to $F_{0.1}$, it should be reduced by 65% for *S. pilchardus* and 60% for *S. aurita*; this would allow for resources renewal. as well as increasing the exploitable biomass of both stocks.

INTRODUCTION

The sardine *Sardina pilchardus* (Walbaum, 1792) and the round sardinella *Sardinella aurita* (Valenciennes, 1847) (Clupeidae) are consistently ranked among the most caught small pelagic fish in Algeria, representing respectively 26 and 25% of the total national production of pelagic fish according to the Algerian Directorate General of Fisheries and Aquaculture in 2022.

Several studies have already been carried out to address the biology and dynamic of both species in Algeria, specifically in the central region **(Brahimi *et al*., 1998; Bouaziz *et al*., 2014)** and the western region **(Handjar *et al*., 2019)**. Additionally, research has been conducted in the Atlantic Ocean **(Chesheva, 1998; Silva, 2003; Baali *et al*., 2021)**, and the Mediterranean **(Gaamour *et al*., 2004; Tsikliras *et al*., 2005; Antonakakis *et al*., 2011)**. In our study area, investigations were limited to the biology of *S. pilchardus* and *S. aurita* **(Dahel *et al*., 2016)**, but never before developed the state of fish stocks (excepted **Bedairia and Djebar (2009)** for *S. pilchardus*). Based on these findings, we believe that it was important to expand the study on the population dynamic and provide available updates on the current status of stocks of those species in this zone. To do this, we used the virtual population analysis (VPA) method, which seemed to be most appropriate for the Mediterranean stock evaluation assessment by adjusting the production of both species to fishing effort $F_{0.1}$ (F_{targ} target reference point), much more advantageous than the maximum sustainable yield (MSY), to provide a safety margin for stock renewal and ensure rational and sustainable management.

MATERIALS AND METHODS

From November 2021 to October 2022, 1146 sardine (*S. pilchardus*) and 1033 round sardinella (*S. aurita*) were monthly sampled from four Algerian ports (Fig. 1): Chetaïbi, Annaba, El Kala (the old and the new fishing ports) (located in northeastern Algeria between Cap Takouch 37°04’04’’N – 07° 83’03’’E and Ain B’Har 36°56’45’’N – 8°36’57’’E).

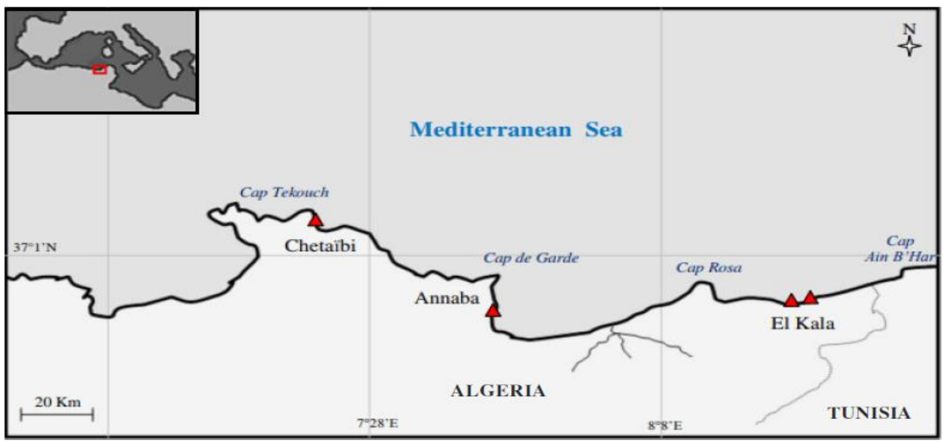

Fig. 1. Map showing study area (the triangles represents the fishing ports)

Each specimen was measured to the nearest mm for total length (TL_ and weighed to the nearest g for total weight (TW). Individuals were then dissected in order to determine sex and assign maturity staging by macroscopic observation **(Fontana, 1969)**.

The age determination was carried out by the indirect Bhattacharya method using the FiSAT II software, a fish stock assessment tool whose application protocol was slightly modified by **Gayanilo *et al*., (2005)**. Concerning the study of linear growth parameters of the von Bertalanffy equation, we used the New VONBIT for Excel:
$L_t = L\infty\ [1 - e^{-k(t-t0)}]$, where L_t: Total length at time t; K: Growth coefficient; L∞: Asymptotic length, and t_0: Theoretical age at length 0.

The length- weight relationship that interprets shape changes in fish length was determined by the equation of **Ricker (1973)**: $TW = a\ TL^b$, where TW: Total weight of the fish; TL: Total length; a: Constant, and b: Allometric coefficient that provides information on the type of fish growth. The value b is statistically compared to $b_0 = 3$ at the $\alpha = 5\%$ threshold using dtudent's t-test **(Dagnelie, 1975)**.

The length at first sexual maturity (L_{m50}) is the length at which 50% of fish are mature; the proportion of mature individuals in each length class was calculated by fixing the threshold of maturity stage from stage III, corresponding to the early developmental state of the gonad **(Fontana, 1969)**. The percentage- length pairs of mature individuals were fitted to a logistic curve of the sigmoid type using Microcal Origin Software (version 6.0).

With the help of a linearized length converted catch curve as defined by **Pauly (1984)** and **Gayanilo *et al*. (2005)**, the total mortality coefficient (Z) was calculated using the FiSAT II software. The coefficient of natural mortality (M) was estimated from two empirical methods: The equation of **Djabali *et al*. (1994)**: Log_{10} M = 0.0278 – 0.1172 Log_{10} L∞ + 0.5092 Log_{10} k (based on growth parameters and mortality of 56 fish stocks living in the Mediterranean Sea; k and L∞ are the constants in the von Bertalanffy equation) and the equation of **Pauly (1980)**: Log_{10} M= - 0.0066 - 0.279 Log_{10} L∞ + 0.6543 Log_{10} k +0.4634 Log_{10} T , where T is mean annual temperature, estimated in study area at 19°C. According to **Pauly (1980)**, fishing mortality (F) is the subtraction of the natural mortality from the total instantaneous mortality: F = Z - M.

The virtual population analysis (VPA) and yield per recruit and biomass per recruit were performed by the introduction of data on the annual production of *S. pilchardus* and *S. aurita* fished in the East coast between November 2021 and October 2022 (4865.31 and 1942.84 tons, respectively) and the biological data previously obtained (age– length key, growth parameters, first maturity and mortality) constitute entry data in the program VIT Software 1.2 **(LIeonart & Salat, 1997)**. The software, recommended by FAO has the advantage of working with pseudo-cohorts, that is to say, it only requires knowledge of the catches in one year instead of a long historical series of ten years.

RESULTS

Composition of samples

The length frequency distribution of the 1146 *S. pilchardus* studied ranged from 8.3 to 19.5cm of total length (3.71≤ TW≤ 54.73g) with a mean length of 14.33± 1.39cm. The dominant length groups were between 13.5 and 15.5cm, while those smaller than 10 and greater than 18cm were very negligible (Fig. 2a). *S. aurita* was represented by 1033 individuals, the length frequency distribution oscillated from 8 to 25.5cm (3.70≤ TW≤ 140.27g), with a mean length of 16.06± 1.10cm. Dominant length groups were between 14 and 19cm, while those smaller than 10 and larger than 23cm were quite negligible (Fig. 2b).

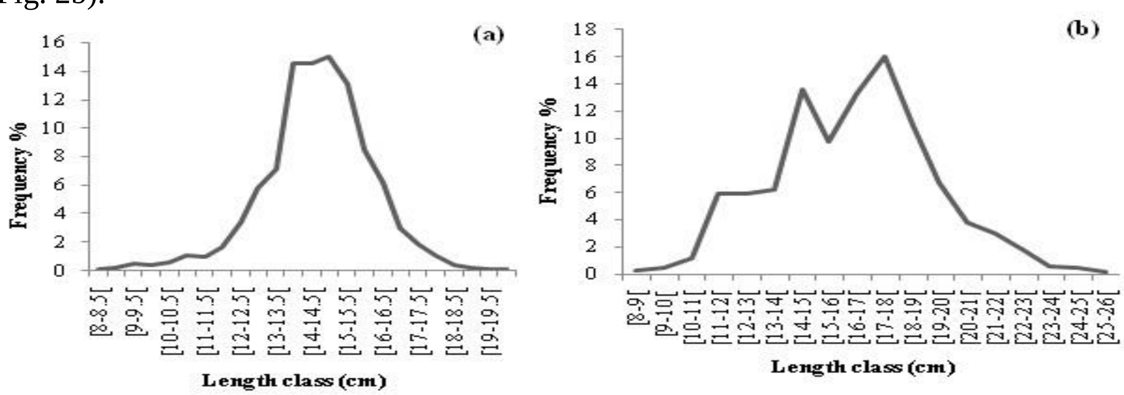

Fig. 2. Length- frequency distribution of **(a)** *S. pilchardus* and **(b)** *S. aurita* fished of the Algerian East coast

The application of the **Bhattacharya (1967)** method allowed us to obtain 5 cohorts, corresponding to the mean lengths 9.5, 10.99, 14.38, 16.60, and 19.62cm for *S. pilchardus*, with ages 3 and 4 years dominating. The minimum catch (0.34%) was observed in 5 years old fish (Table 1).

The same findings were observed for *S. aurita*, where the mean lengths were as follows: 12, 14.75, 17.47, 20.96, and 24.83cm, with dominance of 2 and 3 years old fish. The least captured individuals were those aged 5 (1.25% of catch) (Table 1).

The von Bertalanffy growth model was expressed for the two populations as follows: $L_t = 21.58 [1 - e^{-0.39 (t +0.086)}]$ for *S. pilchardus* and $L_t = 26.68 [1 - e^{-0.41 (t +0.085)}]$ for *S. aurita*.

Table 1. Key age-length of *S. pilchardus* and *S. aurita* obtained by Bhattacharya's method

Species	Age (yr)	Mean length (cm)	Population		Separation index	Growth rate
			N	%		
S. pilchardus	1	9.50	12	1.05	n.a.	-
	2	10.99	30	2.62	2.37	1.49
	3	14.38	539	47.03	3.97	3.39
	4	16.60	239	20.85	2.12	2.22
	5	19.62	4	0.34	4.95	3.02
S. aurita	1	12.00	134	12.97	n.a.	-
	2	14.75	305	29.52	3.33	2.75
	3	17.47	415	40.17	2.64	2.72
	4	20.96	95	9.19	2.74	3.49
	5	24.83	13	1.25	4.14	3.87

N: Number of fish, yr: Years, n.a: not affiched.

Length- weight relationship

The length-weight relationships were calculated as : $TW = 0.0039\ TL^{3.236}$ (R^2= 0.906) for *S. pilchardus* and $TW = 0.005\ TL^{3.134}$ (R^2= 0.879) for *S. aurita*, indicating positive allometry for both species in the study area (Fig. 3).

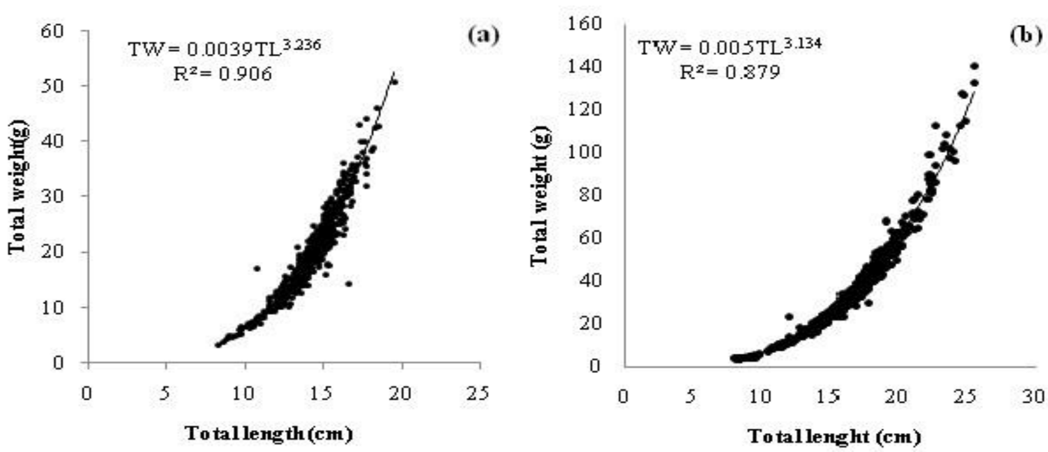

Fig. 3. Length- weight relationship of **(a)** *S. pilchardus* and **(b)** *S. aurita* fished in the waters of the Algerian East coast

Lengths at first maturity

The lengths at first sexual maturity (L_{m50}) were 11.61cm for *S. pilchardus* (Fig. 4a) and 13.54cm for *S. aurita* (Fig. 4b).

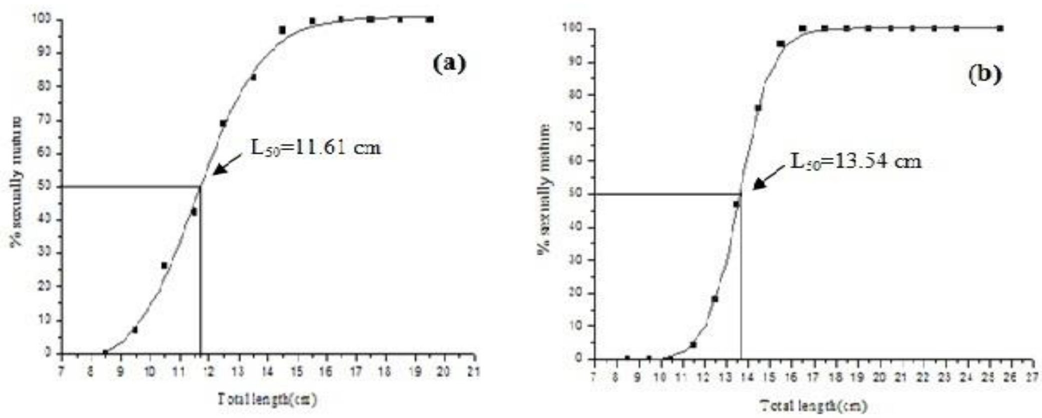

Fig. 4. Length at first sexual maturity (L_{m50}) of **(a)** *S. pilchardus* and **(b)** *S. aurita* fished in the waters of the Algerian East coast

Mortality

The total mortality coefficients (Z) of *S. pilchardus* and *S. aurita* were estimated at 1.95 and 1.87yr^{-1}, respectively. The natural mortality coefficients (M) estimated using the formula of **Pauly (1980)** for *S. pilchardus* and *S. aurita* were 0.88 and 0.86yr^{-1}, respectively, while those calculated via the equation of **Djabali (1994)** were 0.46 $year^{-1}$ for both species. The fishing mortality coefficients (F) according to the equation of **Djabali (1994)** were 1.49yr^{-1} for *S. pilchardus* and 1.41yr^{-1} for *S. aurita* (Fig. 5).

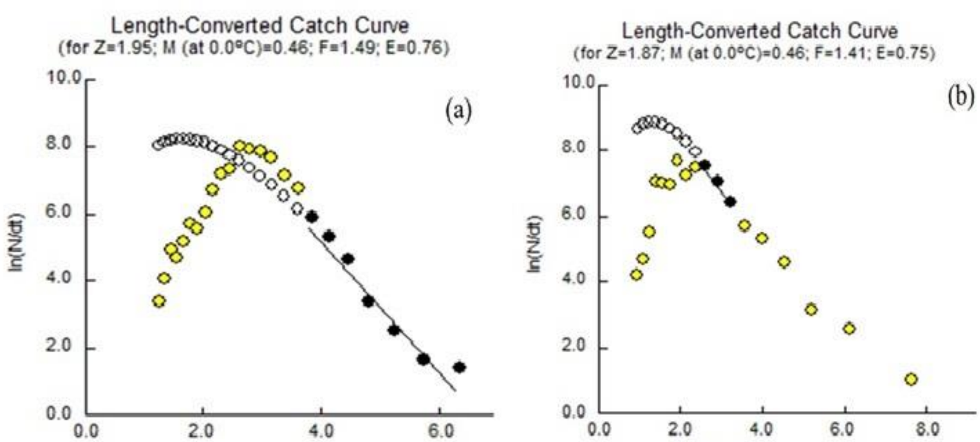

Fig. 5. Length- converted catch curve for **(a)** *S. pilchardus* and **(b)** *S. aurita* fished in the waters of the Algerian East coast

Catches by number and weight

The analysis of catches by number and weight of all individuals by class center showed that the exploitation of *S. pilchardus* was mainly done on individuals belonging to the center class of 14.5cm total length; their total mean weight was 1408493013g (1408.49 tons), corresponding to a catch of 63.5 million individuals. The mean length of the catch was estimated at 14.37cm, corresponding to a mean age of 2.78 years (Table 2). On the other hand, this exploitation was mainly done on the individuals of the class center equal to 17.5cm for *S. aurita*. Their total mean weight was 345433680g (345.43 tons), corresponding to a catch of about 8.8 million individuals. Their mean length and age of capture were about 16.35cm and 2.34 years, respectively (Table 2).

Table 2. Catches by number and weight of individuals by length of *S. pilchardus* and *S. aurita* caught in the waters of the eastern Algerian coast

Class (cm)	***S. pilchardus***		***S. aurita***	
	Catch (in number)	**Catch (in weight g)**	**Catch (in number)**	**Catch (in weight g)**
8.5	563885.19	2247007.01	160359.96	658467.92
9.5	1691655.56	9652622.68	267266.6	1553906.11
10.5	3571272.85	28150753.61	641439.85	5100030.64
11.5	5638851.87	59626670.68	3260652.57	34439964.5
12.5	19735981.6	272919623.2	3260652.57	44709785.6
13.5	46802470.6	827558480	3421012.53	59683973.6
14.5	63531064.4	1408493013	7483464.91	163080583
15.5	46426547.1	1270905821	5398785.4	145033244
16.5	19735981.6	659558728.3	7323104.95	238997730
17.5	6202737.06	250122731.5	8819797.93	345433680
18.5	1127770.37	54685781.8	6040225.25	281514561
19.5	375923.46	21393766.5	3688279.14	202775687
20.5			2084679.51	134128324
21.5			1657052.94	123599003
22.5			1015613.1	87247746.6
23.5			320719.92	31647015.9
24.5			267266.6	29904780.9
25.5			106906.64	13331516.1
Total	215404142	4865315000	55217280.4	1942840000
Mean age (yr)	2.78		2.34	
Mean length (cm)	14.37		16.35	

Virtual population analysis

VPA analysis of the exploitable biomass (Table 3) showed that the mean biomass (B_{mean}) of the current stock of *S. pilchardus* was estimated at 6656.17 tons including 4449.93 tons (67%) of spawning stock biomass (SSB). The mean age of the current stock was 1.94 years, corresponding to a mean length of 11.52cm. The critical age of the current stock was equal to 2.28 years old, corresponding to a length of 13cm. While, the virgin stock (B_0), estimated at 23207 tons was characterized by respective critical age and length of 3.38 years and 16cm. For S. *aurita*, the exploitable B_{mean} of the current stock was estimated at 2829.60 tons and the SSB at 2093.80 tons (74% of the stock). The mean age of the stock was 1.70 years, corresponding to a mean length of 13.28cm. The critical age and length of the current stock were estimated at 2.14 years and 16cm, respectively. The virgin stock (B_0 = 12618.62 tons) was characterized by a critical age and length of 3.29 years and 20cm, respectively.

Table 3. Results of the VPA methods of *S. pilchardus* and *S. aurita* fished in the waters of the Algerian East coast

VPA	*S. pilchardus*	*S. aurita*
Current stock mean age (year)	1.94	1.70
Current stock critical age (year)	2.28	2.14
Virgin stock critical age (year)	3.38	3.29
Current stock mean length (cm)	11.52	13.28
Current stock critical length(cm)	13	16
Virgin stock critical length (cm)	16	20
Number of recruits, R	438458159	109818612
Mean biomass, B_{mean} (tons)	6656.17	2829.60
Spawning Stock Biomass, SSB (tons)	4449.93	2093.80
Virgin biomass, B_0(tons)	23207	12618.62
Biomass balance, D (tons)	7561.72	3074.67
Turnover, D/B_{mean} (%)	113.60	108.66

Yield and biomass per recruit

The current yield per recruit ($Y_{current}$ / R = 11.09g), corresponding to the current fishing mortality ($F_{current}$= 1yr^{-1}) of *S. pilchardus*, was slightly below the maximum sustainable yield threshold (MSY or Y_{MSY}/ R = 11.161g), corresponding to the fishing mortality rate factor that maximizes equilibrium yield per recruit (F_{MSY}= 0.77yr^{-1}). In terms of catch, it was at this effort threshold that the available recruitment was used to its maximum.

The current biomass per recruit ($B_{current}$ /R = 15.181g), expressing the mean annual biomass of survivors as a function of fishing mortality, was relatively lower than the maximum biomass balanced (B_{MSY} / R = 17.2g). The yield per recruit ($Y_{0.1}$ / R) and biomass by recruit ($B_{0.1}$ / R) values correspond to target or optimal fishing effort ($F_{0.1}$ = 0.35 yr^{-1}) were 10.244 and 25.441g, respectively (Table 4 & Fig. 6a). For *S. aurita*, $Y_{current}$ / R evaluated at 17.691g for $F_{current}$ =1yr^{-1} was lower than MSY or Y_{MSY} / R which was equal to 17.83g for F_{MSY} = 0.8 $year^{-1}$. The value of $B_{current}$ / R was 25.766g, it remained much lower than the B_{MSY} / R estimated at 30.701g. The values $Y_{0.1}$ / R and $B_{0.1}$ / R were 16.46 and 49.755g, respectively, for $F_{0.1}$ = 0.40yr^{-1} (Table 4 & Fig. 6b).

Table 4. Yields and biomasses per recruit based on fishing mortality (F) of *S. pilchardus* and *S. aurita*

	S. pilchardus					***S. aurita***				
Type of F	**F (yr^{-1})**	**Y/R (g)**	**B/R (g)**	**Y (t)**	**B (t)**	**F (yr^{-1})**	**Y/R (g)**	**B/R (g)**	**Y (t)**	**B (t)**
F_0	0	0	52.929	0	23207.151	0	0	114.904	0	12618.597
$F_{current}$	1	11.096	15.181	4865.131	6656.233	1	17.691	25.766	1942.801	2829.586
$F_{0.1}$	0.35	10.244	25.441	4491.565	1.1154.814	0.40	16.46	49.755	1807.614	5464.025
F_{MSY}	0.77	11.161	17.2	4893.631	7541.480	0.80	17.83	30.701	1958.658	3371.541
	Number of recruits (R): 438458159					**Number of recruits (R) :** 109818612				

F: Fishing mortality; Y/R: Yield per recruit; B/R: Biomass per recruit; Y = Total yield; B = Total biomass F_0= Factor of no fishing; $F_{current}$ = Factor of current effort fishing; $F_{0.1}$ = Factor of fishing mortality rate at which the marginal yield-per-recruit is only 10 percent of the marginal yield per-recruit on the unexploited stock; F_{MSY} = Factor of fishing mortality rate that maximizes equilibrium yield per recruit, g: Grams, and t: tons.

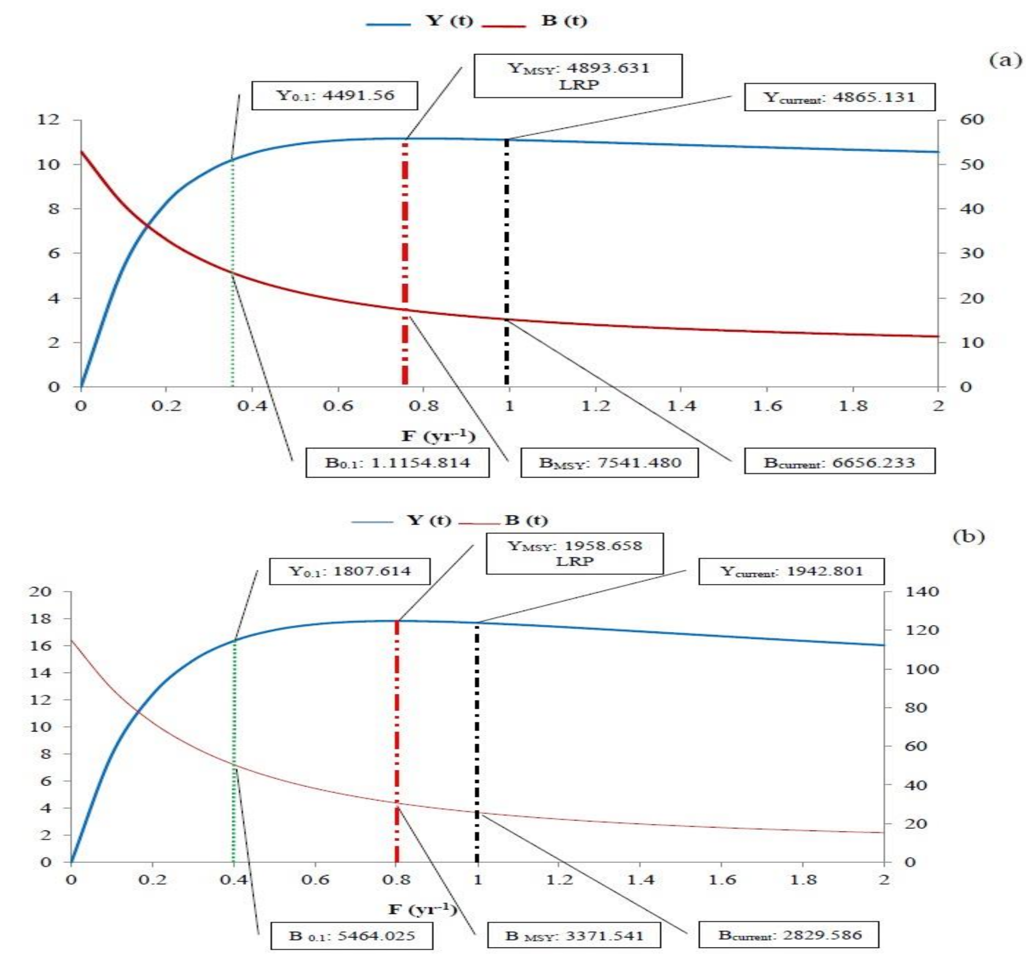

Fig. 6. Schematic representation of the evolution of the yield (Y) and biomass (B) of **(a)** *S. pilchardus* and **(b)** *S. aurita* of the Algerian east coast. $Y_{0.1}$: Optimum yield corresponding to fishing mortality ($F_{0.1}$), $B_{0.1}$: optimum biomass corresponding to fishing mortality ($F_{0.1}$), $y_{current}$: Current yield corresponding to current fishing mortality ($F_{current}$), $B_{current}$: Current biomass corresponding to current fishing mortality ($F_{current}$), B_{MSY}:

Maximum balanced biomass corresponding to maximum fishing mortality (F_{MSY}), and LRP: Limit reference points

DISCUSSION

This study investigated the biological and dynamic characteristics of the two highly targeted small pelagic species of the Algerian littoral; the sardine *S. pilchardus* and the round sardinella *S. aurita*; it provides necessary information for their rational exploitation.

The maximum total lengths were 19.62 and 24.83cm for *S. pilchardus* and *S. aurita*, respectively (during an annual cycle). Our results are different from those obtained by the different authors, with the exception of **Tsikliras *et al.* (2005)**, who worked on sardinella in the Aegean Sea and found a maximum size close to ours (Table 5). The difference in values found in different regions of the Mediterranean and the Atlantic could be explained mainly by the divergence of the sampling methods, as well as the length of the sample collected. Maximum longevity calculated by indirect method was 5 years for both species. Similar results were found in *S. pilchardus* in the extreme Algerian East, as reported by **Brahmi *et al.* (1998)** in the Algerian center. For *S. aurita*, **Tsikliras *et al.* (2005)** and **Baali *et al*. (2021)** found the same results. However, the longevity of both species remains well below those obtained in the Atlantic (Table 5). The difference in the number of age groups may be related to differences in the length of samples collected, the method and components used for age determination **(Bariche, 2005)**. In the Atlantic, the high longevity of both species compared with those of the Mediterranean is due to the habitat of those species characterized by cold waters of upwelling areas that influences the growth of these two clupeids (**Stanichny *et al*., 2005)**. The age groups most frequently caught in *S. pilchardus* and *S. aurita* are of age 3. This indicates that in the eastern Algerian coast, sardine and round sardinella become fully recruited beyond the age of one year, which reassures their ability to reproduce and regenerate despite the pressure of fishing on these two species.

The parameters of von Bertalanffy equation show that both species had a fast growth, which confirms the theory of **Sparre and Venema (1998)**, who concluded that small pelagic fish are characterized by high growth and low longevity. Thus, most of their growth is achieved during the first year of life. Indeed, we obtained for *S. pilchardus*: $L\infty = 21.58$cm, $K = 0.39$ year^{-1}, and $t_0 = -0.086$ year, while for *S. aurita*: $L\infty = 26.68$cm with $K = 0.41$ year^{-1}, and $t_0 = -0.085$ year. The results of $L\infty$ and K of *S. pilchardus* are close to those of **Bedairia and Djebar (2009)** in the same study area. For *S. aurita*, our results differ from the other authors (Table 5).

Length- weight relationships are important for estimating biomass from length estimates, as pointed out by **Pauly and Gayanilo (1996)**. Our results on the allometry of sardine and round sardinella of the Algerian east coast are in perfect agreement with the majority of the results reported in various regions of the Mediterranean and the Atlantic. We are in the presence of a positive allometry for the two species, the weight increases faster than the cube of the length. However, for *S. pilchardus*, the value of b = 3.236 differs from those of **Bedairia and Djebar (2009)** and **Handjar *et al*. (2019)**, who reported an isometric allometry. For *S. aurita*, the value of b = 3.134 differs from that recorded in the study of **Abd El Hakim *et al*. (2010)** in Egypt, who reported a negative allometry (Table 5). The disparity of results may be closely related to environmental conditions and biological phenomena, such as the richness of the environment in nutrients, feeding behavior, seasons, maturity stages, sex, and age **(Sparre & Venema, 1998)**.

Table 5. Various growth parameters of *S. pilchardus* and *S. aurita* in different geographical area

Area	Sex	L_∞ (cm)	K (yr^{-1})	t_0 (yr)	T_{max} (yr)	L_{max} (cm)	a	B	Author
S. pilchardus									
					Mediterranean				
North Aegean Sea	Σ	19.50	0.39	- 0.480	4 (IM)	18.50	-	-	Antonakakis *et al*. (2011)
Center of Algeria	♀	22.58	0.46	-	5 (IM)	18.64	0.0038	3.201(+)	Brahmi *et al*. (1998)
	♂	18.91	-	-	-	-	0.0048	3.104(+)	
East of Algeria	Σ	22.56	0.31	-	6 (IM)	18.72	0.0078	2.930(=)	Bedairia and Djebar (2009)
Center of Algeria	Σ	25.12	0.45	- 0.028	4 (IM)	21.79	0.0069	3.013(+)	Bouaziz *et al.* (2014)
West of Algeria	Σ	23.38	0.18	- 2.50	4 (O)	17.55	0.0089	2.920(=)	Handjar *et al.* (2019)
East of Algeria	Σ	21.58	0.39	- 0.086	5 (IM)	19.62	0.0039	3.236(+)	Present study
					Atlantic				
Bay of *Biscay*	Σ	-	-	-	8 (S)	25.50	-	-	Guerault (1980)
North Atlantic	Σ	-	-	-	10 (O)	24.70	-	-	Silva (2003)
S. aurita									
					Mediterranean				
Aegean Sea	Σ	24.86	0.51	- 0.880	5 (S)	24.80	-	-	Tsikliras *et al.* (2005)
Egypt	Σ	28.37	0.23	- 0.980	4 (S)	22.90	0.0160	2.611(-)	Abd El *Hakim et al.* (2010)
East of Algeria	Σ	26.68	0.41	- 0.085	5 (IM)	24.83	0.0050	3.134(+)	Present study
					Atlantic				
Mauritania	Σ	41.63	0.26	- 0.870	8 (S)	39.10	-	-	Chesheva (1998)
Morocco	Σ	36.24	0.42	- 0.38	5 (IM)	32.4	0.0040	3.270(+)	Baali *et al*.(2021)
	Σ	34.74	0.42	- 1.03	5 (O)	32			

♂, ♀, Σ= male, female, total population, L_∞: Asymptotic length (cm); K: Growth constant (1/ year); t_0: Age at zero length (year); L_{max}: Maximum recorded length (cm); T_{max}: Maximum recorded age (yr); (S): Age determined by scalimetry; (O): Age determined otolithometry; (IM): By indirect methods; (+): Positive allometry; (-): Negative allometry; (=): Isometric allometry.

Lengths at first maturity (L_{m50}) are attained at 11.61cm for *S. pilchardus* and 13.54cm for *S. aurita*. Our results are in accordance with the findings of other studies on the Mediterranean. For *S. pilchardus*, **Bedairia and Djebar (2009)** reported a similar result (11.6 cm) in the same study area. However, our results remain slightly lower than those of **Gaamour *et al*. (2004)** (12.50cm) in Tunisia and **Bouaziz *et al*. (2014)** (12.3cm) in Algeria. For *S. aurita*, our results are lower than those of **Tsikliras and Antonopoulou (2006)** in Greece (16.83 for females and 15.5cm for males). In the Atlantic, we have noticed that the first sexual maturity is reached at a greater length than in the Mediterranean. For instance, in Morocco (Laâyoune), **Amenzoui *et al*. (2006)** found that sardines reach their first maturity at 15.80cm. Fishing may also affect this situation since fishing pressure reduces length at first maturity, and smaller individuals may be recruited to breed; it may be due also to the hydro dynamism, food quality and/or availability environmental conditions,etc **(Sparre & Venema, 1998)**.

Mortality and growth rate of fish are closely correlated, **Pauly (1980)** considered that in fish, natural mortality is linked with length, the more they grow up, the less they are vulnerable to predators. He added that there is also a correlation with a 2^{nd} factor, which is the temperature (T°). Indeed, in hot waters, fish feed more, increasing the likelihood of encountering hungry predators than satiated ones resulting in a higher mortality **(Pauly, 1980)**. The formula of **Pauly (1980)**, as described by **Sparre and Venema (1998)**, can lead to errors because if during the year, the ambient water heats up, natural mortality increases and inversely. From this observation, we opted for the method of **Djabali *et al*. (1994)** that is better adapted to the study of the Mediterranean fish, which according to **Bouaziz *et al*. (2014)** allows calculating precisely the natural mortality coefficient (M). In addition, the mortality coefficients were Z = 1.95, M = 0.46 and F = 1.49 $year^{-1}$ for *S. pilchardus* and
Z = 1.87, M = 0.46 and F = 1.41 $year^{-1}$ for *S. aurita*. Concerning *S. pilchardus*, **Voulgaridou and Stergiou (2003)**, **Bedairia and Djebar (2009)**, **Bouaziz *et al*. (2014)** and **Handjar *et al*. (2019)** found: Z = 1.88, M = 0. 80 et F =1.08 $year^{1}$, Z = 3.52, M = 0.49 and F = 3.03 $year^{-1}$, Z = 0.87, M = 0.33 and F = 0.54 $year^{-1}$, and Z = 5.65, M = 1.34 and F = 4.31 $year^{-1}$ in our study area, in the Algerian center and west, and in Greece, respectively. For S. *aurita*, **Amponsah *et al*. (2017)** in Ghana found that Z = 3.17; M = 0.76, and F = 2.41 $year^{-1}$. The majority of the studies on *S. pilchardus* and *S. aurita* revealed fishing mortality relatively higher than natural mortality, **Amponsah *et al*. (2017)** explained this phenomenon due to fish being more vulnerable to gears fishing than naturally victims of the sea.

The average ages of capture of *S. pilchardus* and *S. aurita* (2.78 and 2.34 years respectively) obtained by VPA are close to critical ages of the current stocks (2.28 and 2.14 years, respectively) for which cohorts attain their maximum biomasses. The approximation of both ages was signaled by **Bedairia and Djebar (2009)** and **Bouaziz *et al*. (2014)** for *S. pilchardus*. According to **Alvaro (1995)**, if we want to draw a high production of stocks, it is desirable that the catch age would be close to critical age; which concords perfectly with our results.

Results relating to yield (Y/ R) and to biomass per recruit (B/ R) of *S. pilchardus* and *S. aurita* showed that the current fishing effort ($F_{current}$ = $1yr^{-1}$) exceeds to both target, optimum effort ($F_{0.1}$), and effort of maximization of yield per recruit (F_{MSY}). In terms of catch, it is in this threshold of effort F_{MSY} that available recruitment is supposed to be maximum, which puts the stocks of *S. pilchardus* and *S. aurita* caught in Algerian East coast in state of overfishing.

According to **Cadima (2002)**, the fishing effort $F_{0.1}$, considered as target reference point TRP, is F value for which the marginal increase of yield per recruit (Y/ R) is of 10 % of its value in the absence of fishing (F = 0). Therefore, to attain $Y_{0.1}$, it is necessary for *S. pilchardus* to adjust $F_{current}$ (equal to 1) at $F_{0.1}$ estimated at 0.35, representing a reduction of fishing effort of about 65%. In the long term, this would lead to an increase in the spawning biomass, resulting in an increase in exploitable biomass from 6656.23 to 11154.8 tons. Concerning *S. aurita*, $F_{current}$ =1 should be adjusted at $F_{0.1}$=0.40 that represents a reduction of effort of around 60% that would also increase the exploitable biomass from 2829.58 to 5464.02 tons.

In conclusion, the VPA allowed us to evaluate the exploitable biomass, yield per recruit, and $F_{0.1.}$ The findings revealed the existence of a state of an overexploitation of the stocks of *S. pilchardus* and *S. aurita* of the eastern coast of Algeria. In order to limit the risk of stock collapse, we suggest adjusting the fishing effort factor from $F_{current}$ to $F_{0.1}$. The selection of reference point $F_{0.1}$ as the target point for fisheries management, rather than F_{MSY} (F_{max}), would ensure for stock stability and prevent negative impact on fishing effort.

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