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Population Structure and Growth Patterns of Anchovy and Sardine in the Safi Fishing Area on the Moroccan Atlantic Coast

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ABSTRACT

This study explored the growth dynamics of anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*) in the Safi fishing zone, a biologically productive area along the Moroccan Atlantic coast influenced by persistent upwelling. Over a two-year period (2018–2019), biological data on size, age, and growth patterns were collected and analyzed using the von Bertalanffy growth model. The results indicated that sardines exhibit stable growth patterns, with asymptotic lengths ($L\infty$) ranging from 22.58 to 23.20cm and growth coefficients (K) between 0.36 and 0.40. In contrast, anchovies displayed greater variability in size-at-age, with an average $L\infty$ of 17.33cm and a wide range of K values (0.250–0.818), reflecting their adaptability to fluctuating environmental conditions. The growth-performance index (ϕ) for anchovies (1.88–2.40) was notably higher than values reported in other regions, suggesting enhanced growth efficiency in the nutrient-rich Safi upwelling zone. Length-weight relationships further revealed species-specific strategies: sardines exhibited a shift toward isometric growth (b = 3.007–3.190), while anchovies maintained positive allometric growth (b = 3.134–3.261), indicating faster weight gain relative to length. These findings underscore the distinct metabolic rates and ecological adaptations of the two species, providing valuable insights for refining stock assessment models and supporting sustainable fisheries management in the region.

INTRODUCTION

The Moroccan Atlantic coast, particularly the Safi fishing area, is influenced by a persistent upwelling system that sustains a thriving marine ecosystem **(Mounir *et al.*,**

2022a). This region is especially significant for species such as anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*), which represented 49% of small pelagic fish landings and 16% of global capture fisheries in 2016 **(MAFRDWF, 2018)**. The Safi region is recognized as a biodiversity hotspot, with anchovies and sardines being key ecological and economic species **(Amenzoui, 2010; Mounir *et al.*, 2022b)**. These fish play vital roles in marine food webs by bridging energy transfer from plankton to higher trophic levels, including commercially valuable predators **(Benazzouz *et al.*, 2014; Hilmi *et al.*, 2021)**. Additionally, they are critical resources for aquaculture feed, industrial oil, health supplements, and direct human consumption **(Barange, 2018)**.

Anchovy and sardine play a crucial role as primary forage for marine predators such as fish, squid, marine mammals, and seabirds **(Cardona *et al.*, 2015)**. Despite their significant ecological and economic value, the growth dynamics of these species are still poorly understood. This knowledge gap is particularly concerning as they now face climate change impacts of unprecedented scale, occurring at a pace equivalent to or greater than changes observed over decades or centuries **(Checkley *et al.*, 2017)**.

Sardines have historically dominated Morocco's pelagic fisheries, accounting for 73% of the total small pelagic catch in 2017, with an average annual catch of 728,000 tonnes between 1990 and 2017 and a notable increase after 2011, reaching 1 million tonnes in 2017. In contrast, anchovy catches declined significantly, from 150,000 tonnes in 2011 to approximately 20,000 tonnes in 2017 **(MAFRDWF, 2018; Alahyane *et al.*, 2022)**. Despite the dominance of sardines, current stock assessments in the Central East Atlantic rely on broad models that fail to capture the specific population structures of sardines and anchovies, highlighting the need for species-specific research **(Sánchez-Garrido *et al.*, 2021)**. The sharp decline in anchovy populations underscores the importance of studying their population dynamics, while sardines, despite their fluctuating catch volumes, remain the predominant species **(Mounir *et al.*, 2022a)**.

Dynamic population models, essential for managing fishery resources and conducting biological studies, require age data to determine the composition of catches based on age and growth rates **(Ricker, 1973)**. Age determination is traditionally performed by examining seasonal growth marks in calcified tissues such as scales, bones, fin rays, and otoliths **(Williams & Bedford, 1974)**. Understanding the growth patterns and age structures of both species is essential for developing effective conservation strategies and maintaining the resilience of these economically significant fisheries in the face of environmental changes **(Cortés, 2004)**.

The growth dynamics of marine species are heavily influenced by environmental factors such as nutrient availability, temperature, and upwelling. In the Moroccan Atlantic region near Safi, a biologically rich area characterized by persistent upwelling, understanding how these environmental factors affect the growth patterns of *E. encrasicolus* and *S. pilchardus* remains an important yet underexplored issue. Specifically, the study aimed to investigate how these species respond to such conditions, with a focus on the variability in their growth rates and adaptability. The main objective of this study was to analyze the size, age, and growth patterns of both species over a two-year period (2018–2019) using the von Bertalanffy growth model, as well as assessing their ecological adaptations and metabolic rates. By examining these growth dynamics, the study aimed to provide insights that can inform stock assessment models and contribute to sustainable fisheries management in this ecologically significant region.

MATERIALS AND METHODS

1. Study site

The Safi fishing area lies along Morocco's mid-Atlantic coast, stretching from Essaouira in the South (31°29’N, 9°45’W) to El Jadida in the North (32°47’N, 8°58’W). Situated in central-western Morocco, it is approximately 150km northwest of Marrakesh and 250km south of Casablanca, providing strategic access to productive fishing grounds (Fig. 1). The region is part of the larger Moroccan Atlantic fishing zone, known for its nutrient-rich waters due to the upwelling system that supports a diverse and productive marine ecosystem. This area is particularly important for the fishing of small pelagic species such as *S. pilchardus* and *E. encrasicolus*, making it a significant hub for Morocco’s fishing industry.

The upwelling currents in this region, which the Canary current drives, bring cold, nutrient-rich waters from the deep ocean to the surface, creating favorable conditions for plankton growth. This, in turn, supports a thriving fish population. Safi's proximity to this natural phenomenon contributes to the area’s prominence in pelagic fishing.

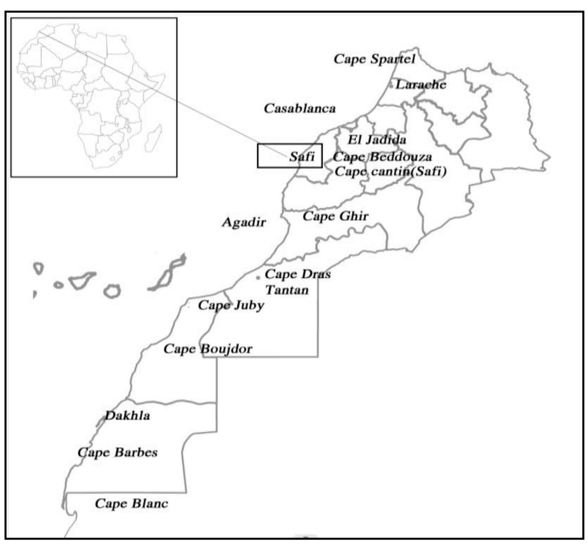

Fig. 1. Map of the study area

2. Sampling and analytical methods

Systematic biological sampling of sardines and anchovies was carried out monthly in 2018 and 2019 from the active fishing fleet off Safi. A stratified sampling approach was employed for each catch, with approximately 3kg of fish randomly selected from each size stratum to accurately represent the size composition of the haul. Given that the catches are stored in bulk within the holds, a systematic random sampling method was performed to minimize bias and ensure the integrity of the samples. Samples were immediately frozen on board the vessel to preserve their quality.

2.1. Morphometric measurements and length-weight relationship

Upon retrieval, morphometric measurements were conducted on each fish, including total length (in millimeters) and body weight (to the nearest 0.01g), and sex was determined through dissection, providing essential data for subsequent analyses. To establish the length-weight relationship (LWR) for sardines and anchovies, data were collected from commercial catches between 2018 and 2019, specifically from boats operating in the Central Atlantic region with landings at the port of Safi. A total of 798 sardines and 743 anchovies were analyzed to explore the relationship between their lengths and body weights (Table 5).

The LWR was calculated using the equation $P = aL^b$ **(Ricker, 1980)**, where 'P' is body weight, 'L' is total length, 'a' is the constant of proportionality, and 'b' is the growth coefficient. This relationship is critical for converting measured lengths into weight data, facilitating the understanding of fish growth patterns.

2.2. Otoliths extraction and reading of sardines and anchovies

To investigate size-dependent variations in population structure, subsamples of different size classes, with a 0.5cm granularity, were collected at random intervals. These subsamples were used to collect "sagitta" otoliths, essential for precise size/age determinations. The collected otoliths were carefully preserved for subsequent analysis to maintain their integrity for accurate size/age determination studies (Fig. 2).

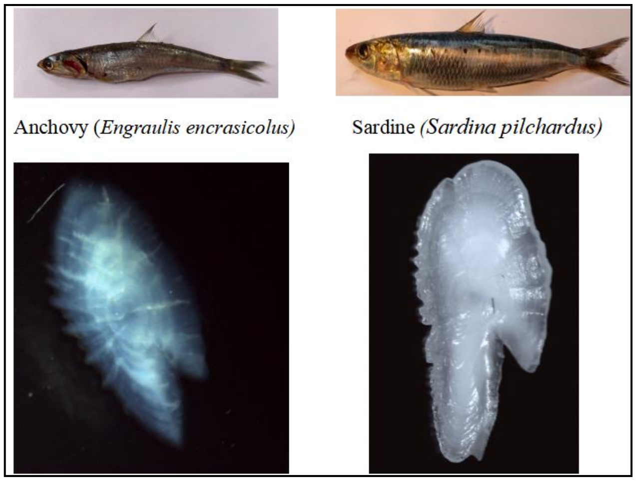

Fig. 2. Otoliths of *E. encrasicolus* and *S. pilchardus*

The age of sardines and anchovies was determined by examining "Sagitta" otoliths, calcified structures within the inner ear. Otoliths were carefully extracted by cutting the head near the upper edge of the operculum or by removing the gill apparatus and perforating the capsules. After extraction, the otoliths were thoroughly cleaned with water to remove impurities, ensuring clear visibility of the growth rings. The cleaned otoliths were then mounted on dark-bottomed plates using resin for easier storage when illuminated, the otoliths displayed alternating light and dark rings, corresponding to limestone deposits from the fish's annual growth cycle (Fig. 2). Age was determined by counting the opaque or translucent (hyaline) rings, visible under reflected light.

To enhance precision in age determination, a stereoscopic magnifying glass equipped with a camera system connected to a computer with image analysis software was employed. This sophisticated setup enabled the accurate measurement of individual growth rings, ensuring a reliable estimation of the age structure within the studied fish populations.

2.3. Linear growth model

The growth in length was modeled using the von Bertalanffy growth function **(von Bertalanffy, 1938)**, which is expressed as:

$$Lt=L\infty(1-e^{-K\,(t-t0)})$$

Where, Lt is the length of the fish at age t (years), L∞ is the length of the fish if it continues to grow indefinitely, K is a specific growth coefficient, t is the age of the fish in years and t0 is the theoretical age at which the fish would have a length of zero.

3. Statistical analysis

The chi-squared goodness-of-fit test was used to assess the interannual variations in the von Bertalanffy growth parameters for the two species. The significant difference between the observed size-weight relationships for each species in 2018 and 2019 and the expected model. To assess the size-weight relationship for *S. pilchardus* and *E. encrasicolus*, a regression analysis was carried out, using the power regression model.

RESULTS AND DISCUSSION

1. Population structure of sardines and anchovies

Fig. (3) illustrates the size composition of sardines and anchovies sampled in the Safi region during 2018 and 2019, revealing distinct size distributions and frequency peaks for both species. Sardines predominantly range from 12.5 to 21.5cm, with a frequency peak around 14-16cm, indicating a stable population dominated by medium to large-sized individuals, likely reflecting consistent growth and recruitment conditions **(Mounir *et al.*, 2022a)**. In contrast, anchovies show a smaller size range (11 to 16.5cm), with a frequency peak around 12-13cm, suggesting a significant recruitment of young individuals and potential sensitivity to environmental or fishing pressures **(Mounir *et al.*, 2022b)**. The broader size distribution of sardines compared to the narrower peak in the anchovy highlights differences in life strategies and growth rates, with sardines exhibiting faster growth or better survival of young individuals **(Benazzouz *et al.*, 2014)**. The stability in sardine size distribution between 2018 and 2019 suggests resilience to environmental changes, while the slight variability in anchovies may indicate greater vulnerability **(Checkley *et al.*, 2017)**. These findings emphasize the importance of species-specific management strategies to ensure the sustainability of sardine and anchovy stocks, particularly in the context of fluctuating environmental conditions and fishing pressures in the Moroccan Atlantic region **(MAFRDWF, 2018; Sánchez-Garrido *et al.*, 2021; Mounir *et al.*, 2021)**.

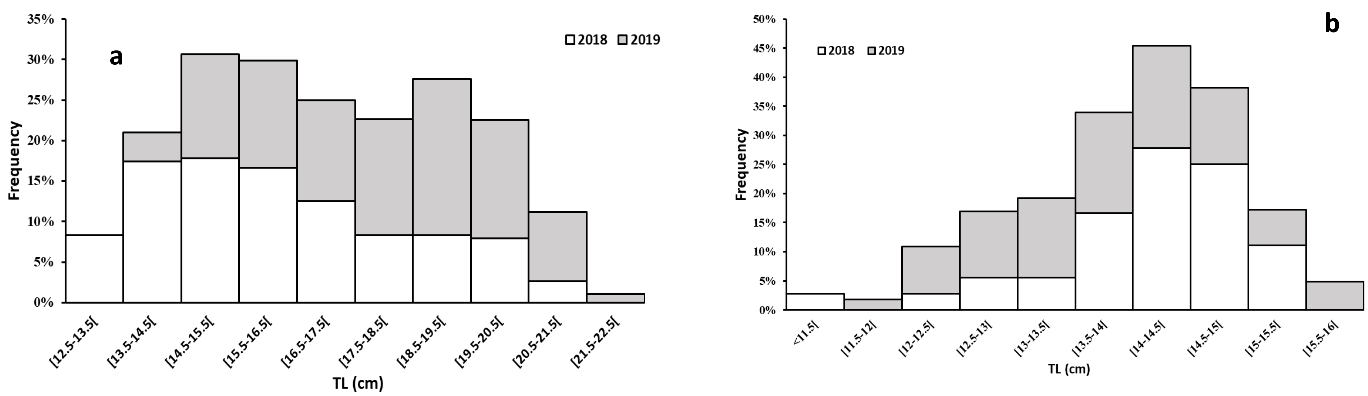

Fig. 3. Size composition of **(a)** *S. pilchardus* and **(b)** *E. encrasicolus* sampled in the Safi region during 2018 and 2019

2. Rate of legible and non-legible otoliths

The legibility of otoliths, crucial for age determination in fish populations, varied between *E. encrasicolus* and *S. pilchardus* in 2018 and 2019 (Table 1). For *E. encrasicolus*, otolith legibility improved significantly from 93.51% in 2018 to 98.41% in 2019, with non-legible otoliths decreasing from 6.5 to 1.59%. This improvement may reflect advancements in extraction, preparation, or environmental conditions enhancing otolith clarity. In contrast, *S. pilchardus* experienced a slight decline in legibility, from 98.15% in 2018 to 96.24% in 2019, with non-legible otoliths increasing from 1.85 to 3.76%, possibly due to sampling or environmental factors **(Proctor *et al.*, 2021)**. Despite this, sardine otolith legibility remained high overall. The greater variability in anchovy otolith legibility compared to the relatively stable sardine results highlights species-specific differences in otolith morphology and environmental influences. These findings emphasize the importance of rigorous quality control in otolith processing to ensure reliable age estimation, supporting sustainable management of these ecologically and commercially significant species **(Reis-Santos *et al.*, 2023)**.

Table 1. Rate of legible and non-legible otoliths by species

Species	***Engraulis encrasicolus***		***Sardina pilchardus***	
	2018	**2019**	**2018**	**2019**
Legible otoliths (%)	93.51	98.41	98.15	96.24
Non-legible otoliths (%)	6.50	1.59	1.85	3.76

3. Location of growth rings from the nucleus

Age reading was conducted on 644 sardine and 322 anchovy otolith pairs collected in 2018 and 2019 at Safi region, identifying four distinct age groups for both species (Table 2). The analysis provided detailed insights into the age structure and growth dynamics of these populations. For *S. pilchardus*, the distances between the nucleus and growth rings were measured as follows: Ring I (1.02–1.57mm), Ring II (1.16–1.61mm), and Ring III (1.23–1.65mm), with Ring IV not detected. In contrast, *E. encrasicolus* exhibited larger distances: Ring I (1.48–1.77mm), Ring II (1.23–1.91mm), Ring III (1.73–1.93mm), and Ring IV (1.84–2.02mm) (Table 2). These differences reflect species-specific otolith morphology and growth patterns, likely influenced by ecological factors such as habitat, feeding behavior, and life history traits **(Takasuka *et al.*, 2008)**.

Table 2. Distances of the growth rings from the nucleus

Species	**Ø (min)**	**Ring I**	**Ring II**	**Ring III**	**Ring IV**
Sardina pilchardus	Ø min.	1.02	1.16	1.23	**
	Ø max.	1.57	1.61	1.65	**
	Ø moy.	1.26	1.4	1.45	**
Engraulis encrasicolusus	Ø min.	1.48	1.23	1.73	1.84
	Ø max.	1.77	1.91	1.93	2.02
	Ø moy.	1.64	1.81	1.89	1.93

The variability in growth ring distances underscores the importance of considering ontogenetic development in otolith-based age analysis **(Lewis *et al.*, 2021)**. These findings provide critical insights into the demographic composition and growth dynamics of sardines and anchovies in the Safi region, supporting sustainable management and conservation efforts for these ecologically and economically vital fish populations.

4. Length-weight relationships

The length-weight relationship (LWR) for *S. pilchardus* and *E. encrasicolus* in 2018 and 2019 shows positive allometric growth ($b > 3$), indicating that weight increases faster than length for both species (Table 3). *E. encrasicolus* exhibited slightly higher growth coefficients (b = 3.134–3.261) compared to *S. pilchardus* (b = 3.007–3.190), suggesting a stronger weight gain relative to length. The R^2 values (0.961–0.976) confirm a strong correlation between length and weight, with *E. encrasicolus* in 2019 (R^2 = 0.976) displaying the most consistent LWR model. While *S. pilchardus* in 2019 (b = 3.007, R^2 = 0.968) showed a slightly lower allometric coefficient and correlation, all values remain statistically significant ($P< 0.05$), confirming the reliability of the growth models for both species across both years.

The length-weight relationship for *Sardina pilchardus* and *Engraulis encrasicolus* in 2018 and 2019 demonstrates that weight increases at a greater rate than length for both species. The obtained growth coefficients are consistent with previous research on small pelagic fish, where *b* values generally fall within the range of 2.8 to 3.3 **(Froese, 2006)**. The R^2 values (0.961–0.976) confirm a strong correlation between length and weight, consistent with findings from similar studies in the Mediterranean and Northeast Atlantic **(Stergiou & Moutopoulos, 2001)**. The slightly higher *b* values for *E. encrasicolus* suggest a stronger weight gain relative to length, which has been reported in other studies attributing such trends to environmental factors, prey availability, and population density **(Şenbahar *et al.*, 2020)**. While *S. pilchardus* in 2019 (b = 3.007, R^2 = 0.968) showed a slightly lower allometric coefficient, it remains within the expected range for pelagic fish, indicating that growth patterns are largely consistent with global references **(Mounir *et al.*, 2022b)**.

Table 3. Length–weight relationship calculated for *S. pilchardus* and *E. encrasicolusus*

Species	Year	No.	Equations	R^2	Growth type	*P*-value
Sardina pilchardus	2018	1320	$TW = 0.0050 \times TL^{3.190}$	0.974	+ allometry	0.032*
	2019	1400	$TW = 0.0089 \times TL^{3.007}$	0.968	+ allometry	0.026*
Sardina pilchardus	2018	1200	$TW = 0.0034 \times TL^{3.261}$	0.961	+ allometry	0.028*
	2019	2646	$TW = 0.0048 \times TL^{3.134}$	0.976	+ allometry	0.033*

TW: Total weight (g), TL: Total length (cm), No: Number of samples, R^2: coefficient of determination.

5. Age-length relationships

The age-length relationship and growth trends of *S. pilchardus* and *E. encrasicolus* were modeled using the von Bertalanffy Growth Function (VBGF), a standard method in fisheries biology for describing growth patterns. Figs. (5, 6) illustrate the growth trajectories of sardines and anchovies in the Safi region during 2018 and 2019, providing valuable insights into their life history strategies.

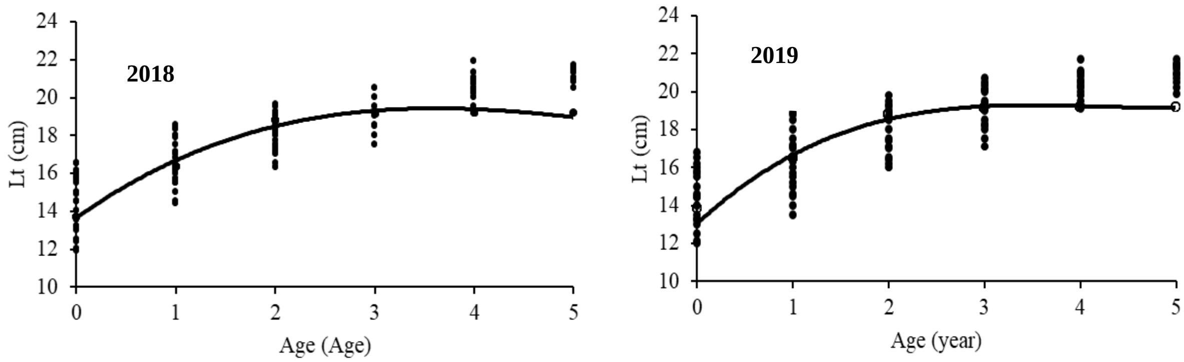

Fig. 5. Age-length relationship of *S. pilchardus* sampled during 2018 and 2019

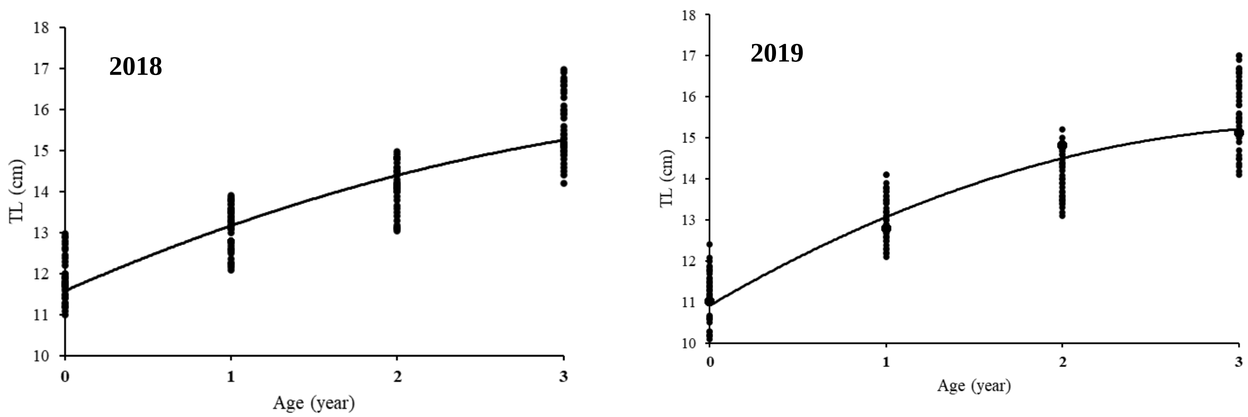

Fig. 6. Age-length relationship of *E. encrasicolus* sampled during 2018 and 2019

On the one hand, *S. pilchardus* in 2018, sardines exhibited rapid growth during their first year, increasing from approximately 12cm at age 0 to around 16cm at age 1, a critical phase for early survival **(García *et al.*, 2020)**. Growth slowed between ages 1 and 3, reaching about 18cm by age 3, and plateaued at around 20cm by age 5, indicating that sardines reach their maximum size by ages 3–4 **(Murua *et al.*, 2021)**. In 2019, the growth pattern was similar, with sardines growing rapidly in the first year (~12 to ~16cm), slowing between ages 1 and 3 (~18cm), and stabilizing near 20cm by age 5 (Fig. 6). The consistent growth trajectory across both years suggests stable environmental conditions and favorable recruitment for sardines in the region **(Albo-Puigserver *et al.*, 2022)**.

On the other hand, *Engraulis encrasicolus* in 2018, anchovies displayed rapid growth in their first year, growing from approximately 11cm at age 0 to 13cm at age 1.

Growth continued steadily through age 2, reaching around 14.5cm, and slightly slowed between ages 2 and 3, reaching 16cm by age 3. In 2019, anchovies followed a similar growth pattern, confirming the species' growth characteristics **(López *et al.*, 2019)**. This pattern suggests that anchovies exhibit steady growth during the first three years, after which growth slows but continues at a slower rate **(Freire *et al.*, 2020)**. The consistent growth observed in both years highlights the species' relatively stable life history characteristics and development in the region.

Sardines and anchovies exhibit distinct growth patterns, with sardines reaching larger sizes and plateauing earlier than anchovies. For instance, sardines display rapid early growth followed by a slowdown, while anchovies show a more gradual growth trajectory but with a similar pattern of slower growth after age 3. These findings underscore the importance of early life stages in the development of both species and suggest that stable environmental conditions in the Safi region support these growth trends. Effective fisheries management must consider these life history traits to ensure sustainable exploitation of these key marine species.

6. Growth Parameters of Sardines and Anchovies

The growth parameters for *S. pilchardus* and *E. encrasicolus* in 2018 and 2019 reveal distinct growth patterns between the two species (Table 4). *Sardina pilchardus* exhibited a higher asymptotic length ($L\infty$ = 22.58–23.20cm) compared to *E. encrasicolus* (17.33cm in both years), indicating that sardines grow to a larger maximum size. The growth rate (K) for anchovies was notably higher in 2018 (0.818 year^{-1}) than in sardines (0.400 year^{-1}), suggesting faster growth. However, in 2019, anchovy growth declined sharply (K = 0.250 year^{-1}), whereas sardine growth remained relatively stable. The growth performance index (ϕ) for anchovies also dropped significantly from 2.3904 in 2018 to 1.8755 in 2019, indicating a decline in overall growth efficiency, while sardines showed a more consistent ϕ (2.2638–2.3293). The more negative t_0 values for sardines (-2.987 to -5.31) compared to anchovies (-3.91 to -4.456) suggest differences in early developmental stages, with sardines potentially experiencing slower initial growth but achieving larger sizes over time.

These results align with previous studies, where $L\infty$ values for sardines typically range from 20 to 25cm in the Mediterranean and Northeast Atlantic **(Silva *et al.*, 2008; Mounir *et al.*, 2022a)**. Similarly, *E. encrasicolus* showed $L\infty$ values (~17cm) consistent with findings in Iberian and Moroccan waters **(Somarakis & Nikolioudakis, 2007)**. The K values for sardines (0.360–0.400 year^{-1}) fall within the expected range (0.35–0.45 year^{-1}) **(Silva *et al.*, 2008)**. On the other hand, the drastic decline in K for anchovies (0.818 to 0.250 year^{-1}) deviates from the typical 0.5–1.2 year^{-1} reported in previous studies **(Basilone *et al.*, 2004)**. This reduction in growth rate and performance index for anchovies could be linked to environmental changes, food availability, or increased fishing pressure, which disproportionately affect species with shorter lifespans and higher metabolic rates. The observed fluctuations highlight the need for further monitoring of anchovy populations and their response to ecological shifts in Moroccan waters.

Table 4. Growth parameters ($L\infty$, K, t_0) of *S. pilchardus* and *E. encrasicolus* in the Moroccan Atlantic Ocean

Species	Year	L¥ (cm)	K (year^{-1})	t_0 (years)	ϕ
Sardina pilchardus	2018	23.20	0.400	-2.987	2.3293
	2019	22.58	0.360	-5.31	2.2638
Engraulis encrasicolus	2018	17.33	0.818	-3.91	2.3904
	2019	17.33	0.250	-4.456	1.8755

CONCLUSION

This study provides a detailed examination of the population structure and growth patterns of anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*) in the Safi fishing area along the Moroccan Atlantic coast, a region renowned for its high biological productivity driven by persistent upwelling. By analyzing biological data collected over two years (2018–2019) and applying the von Bertalanffy growth model, the research highlights distinct growth dynamics between the two species. Sardines exhibited stable growth patterns, with consistent asymptotic lengths ($L\infty$) and growth coefficients (K), while anchovies displayed greater variability in size-at-age, reflecting their adaptability to environmental conditions. The higher growth-performance index (ϕ) for anchovies in the Safi upwelling zone suggests enhanced growth efficiency compared to other regions, likely due to the area's rich nutrient availability. Additionally, length-weight relationships revealed species-specific strategies, with sardines shifting toward isometric growth and anchovies maintaining positive allometric growth, indicating faster weight gain relative to length.

These findings underscore the importance of understanding species-specific growth dynamics and ecological adaptations, particularly in the context of environmental changes and their impacts on small pelagic fish populations. The study addresses critical knowledge gaps in the growth patterns of these ecologically and economically vital species, providing essential insights for refining stock assessment models and guiding sustainable fisheries management. Given the significant role of anchovies and sardines in marine food webs and their contribution to Morocco's fisheries, this research highlights the need for targeted conservation strategies to ensure the resilience of these populations in the face of climate change and other anthropogenic pressures. By integrating these findings into fisheries management practices, stakeholders can work toward maintaining the ecological balance and economic viability of the Safi region's marine resources.

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