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Growth dynamics of the common sole *Solea solea*, in the Morroccan Atlantic coastal waters

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Abstract

This study investigated the growth parameters, mortality and exploitation rate among the common sole *Solea solea* in the waters off the Moroccan Atlantic coast. Monthly samples were obtained from commercial bottom trawl fishing operations in the Safi fishing area, from January to December 2022. A total of 847 specimens were examined, ranging from 13 to 33 cm total length. The length-weight relationships were determined as $W= 0.0097\ L^{3.012}$ for females and $W= 0.01089\ L^{2.969}$ for males. The von Bertalanffy formula was applied to estimate growth parameters, revealing L_∞, K, and t_0 values for males (L_∞=23.98 cm, K= 0.945 year^{-1}, t_0=-0.001 years) and females (L_∞=23.71 cm, K= 0.884 year^{-1}, t_0=-0.002 years). The estimated age ranged from 0 to 8 years. The total mortality (Z), natural (M) and fishing mortality (F) rates were estimated as Z=4.48, M=1.84 and F=2.64 respectively. The estimated exploitation rate (E=0.59), indicated overexploitation of *S. solea* in the studied fishing area. Based on these results, it is essential to formulate sustainable management strategies to safeguard this marine resource and support the development of fishery plans.

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Introduction

Flatfishes are an exceptionally diverse group of teleost fishes. Although, approximately 1,820 flatfish species have been reported, only 1,073 are currently recognised as valid (Eschmeyer and Fong, 2017). Within this group, the Soleidae family comprises about 281 species, of which 181 are considered valid and 56 species hold commercial significance (Ulutürk, 2012). In Morocco, several flatfish species, including the Senegalese sole, Atlantic sole, and largescale sole, play a crucial role in commercial fisheries (MAFRDWF, 2023). The common sole *Solea solea* is particularly valuable, being a key commercial species along the Moroccan coast (MAFRDWF, 2023) as well as in other regions worldwide (Teixeira, 2007; Munoz-Cueto *et al.,* 2019).

Ecologically, *S. solea* is a demersal species found in the North-east Atlantic, from Norway and Iceland to Mauritania (Mollet *et al.*, 2013), and extending to the Eastern Atlantic and Mediterranean Sea. Its economic value makes it a prime target during specific fishing periods, highlighting the need for effective stock management strategies. Consequently, numerous studies have examined its stock structure in the North-east Atlantic, Mediterranean, and Eastern English Channel (Rolland *et al.,* 2007; Cuveliers *et al.,* 2012; Du Pontavice *et al.,* 2018, Corti *et al.,* 2025), as well as its growth (Cerim and Ateş, 2020; Carbonara *et al.,* 2023) and population parameters (Türkmen, 2003). However, research on *S. solea* in African regions remains lacking.

Otolith-based age estimation remains one of the most accepted methods for identifying the age of *S. solea*, emphasising the need for further growth studies on its populations along the Atlantic and Mediterranean coasts (Merigot *et al.,* 2007; Tanner *et al.,* 2011; Yedier *et al.,* 2018; Başusta *et al.,* 2020). Age data are now routinely utilised in fish population studies to analyse the population dynamics of both exploited and non-exploited natural populations (Berkeley *et al.,* 2004; Hichami *et al.,* 2025). However, there appears to be no comprehensive source that summarises the earliest literature on age comparisons of flatfish, particularly the common sole, within a broader historical framework.

Age data plays a crucial role in fisheries, helping to understand the chronology of life stages in individuals and populations, making them essential for stock analysis. Growth parameters serve as key biological indicators and are vital for studying the stock dynamics of common sole in Moroccan waters. However, research on the age and growth of *S. solea* along the Moroccan coast remains limited. In this context, the present study aims to determine the age and growth of *S. solea* in the Safi fishing area while identifying the most suitable methodology for its management and to assess the current status of this resource. This work seeks to contribute to the sustainable management of one of the most heavily exploited demersal species in the Moroccan Atlantic.

Materials and methods

Sampling

Common sole specimens were collected monthly through random sampling, ensuring representation of all length variations by obtaining samples before commercial size sorting. Sampling was conducted aboard trawlers operating in the central Moroccan Atlantic (Fig. 1), covering fishing grounds from Essaouira to El Jadida, with Safi Port serving as the departure and arrival point. Between January and December 2022, a total of 429 males, 418 females, and 91 undetermined individuals (excluded from the total specimen count) were collected. Total length (TL) and total weight (TW) were recorded with a precision of 0.5 cm and 0.01 g, respectively. Sex and maturity stages were determined macroscopically following Brown-Peterson *et al*. (2011).

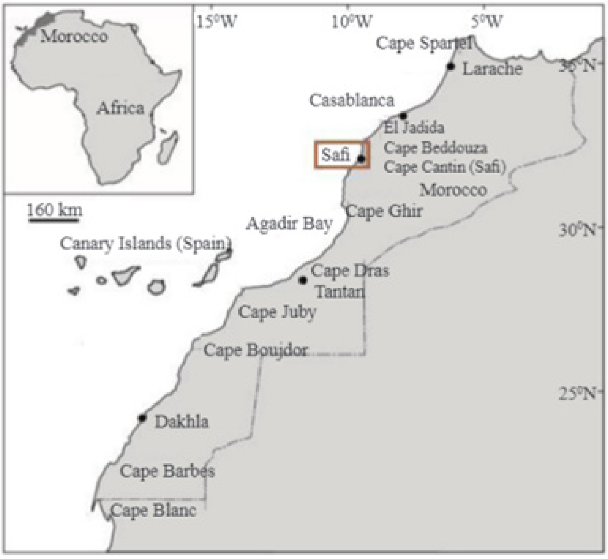


Fig. 1. Study area on the Atlantic coast of Morocco (Mounir *et al.,* 2022).

For age estimation, sagittal otoliths were carefully extracted using fine forceps to prevent breakage, and only intact otoliths without anomalies were analysed. Age determination was performed by counting annuli under a dissecting microscope, with two independent readings per specimen. If discrepancies occurred between readings, the data were excluded from further analysis. Ultimately, 278 individuals (155 females and 123 males) were successfully aged.

Length-weight relationship

The length-weight relationships for females, males, and the combined sexes were determined using the formula $W=a\times L^b$ (Ricker, 1973), where L represents total length, W denotes total weight, 'a' is the intercept of the regression curve, and b is the regression coefficient. The constants 'a' and 'b' were estimated using the least-squares method through regression analysis of total length (TL) and total weight (TW) in an Excel spreadsheet. A b value less than 3 indicates negative allometry, equal to 3 signifies isometry, and greater than 3 suggest positive allometry. A t-test was performed to evaluate whether the b values significantly differed from 3.

Age and growth performance

Estimates of theoretical growth in length were obtained by fitting length-at-age data to the von Bertalanffy growth equation:

$L_t = L_\infty\ (1-e^{-k(t\ -\ t0)})$,

where L_t is the total length, L_∞ is the asymptotic length, k is the growth coefficient, and t_0 is the theoretical age at zero length. The values of L_∞ and K were calculated using ELEFAN in FAO-ICLARM Stock Assessment Tools (FiSAT II) package program (Gayanilo *et al.,* 2005). The growth parameters of this model were estimated iteratively using the least squares method in Excel software. This analysis was performed separately for males and females.

Growth performance was assessed using the formula proposed by Pauly and Munro (1984), calculated as:

$Ø' = \mathrm{Log}_{10}\ K+2\ \mathrm{Log}_{10}\ L_\infty$,

where: Ø ' = Phi-prime, *i.e*, a length-based index of growth performance.

Mortality parameters and exploitation

The total mortality (Z) was determined utilising the length-converted catch curve methodology established by Pauly (1993). The natural mortality (M) was estimated using the empirical equation developed by Pauly (1984):

$\mathrm{Log}_{10}M = 0.0066 - 0.279\mathrm{Log}_{10}\ (L_\infty) + 0.6543\mathrm{Log}_{10}(K)+0.4634\mathrm{Log}_{10}(T)$

where, M is the natural mortality, L_∞ is the asymptotic length, K is the growth coefficient and T is the average surface temperature of the water (°C).

The fishing mortality rate (F) was calculated using the equation described by Pauly and Munro (1984), which states that the total mortality rate is the sum of natural mortality and fishing mortality (F), expressed as: $F = Z - M$

The exploitation rate (E) was determined using the equation outlined by Pauly and Munro (1984), which states that it is equal to the ratio of fishing mortality (F) to total mortality (Z), expressed as: $E = F/Z$

Statistical analysis

The data were collected, arranged, summarised and then analysed using SPSS software to detect the mean and standard deviation of length and weight of the fish and otoliths. The relationships of the total length and weight with the body length and weight of fish were estimated using the Pearson correlation coefficients.

Results

Population structure

Out of 938 specimens sampled, the number of males, females and immature fishes were, 429 (45.73%), 418 (44.56%) and 91 (9.7%) respectively (Fig. 2).

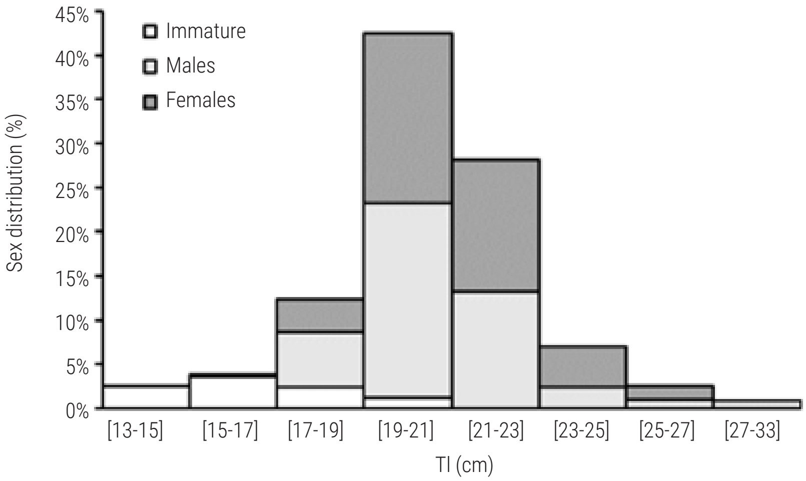


Fig. 2. Length frequency distribution of immature males and females of *S. solea*.

Monthly variation in length-frequency distributions

Fig. 3. shows the monthly variation in length-frequency distributions of the species over calendar year, reflecting dynamic changes in population structure. During January to March, the population is dominated by a mix of smaller and mid-sized individuals, indicating the presence of both juveniles and subadults. A notable peak of small individuals (<15 cm) in March suggests a significant recruitment event, possibly linked to spawning earlier in the year. From June to September, a clear progression in size is evident, with modal classes shifting steadily upward (15–25 cm), consistent with seasonal growth. October and November reveal a peak in larger size classes (25–30+ cm), implying that many individuals have reached maturity. The bimodal patterns seen in certain months (*e.g.*, February, October) may reflect overlapping cohorts, possibly due to multiple spawning events or continuous recruitment. The absence or scarcity of data in April, May, and December was due to sampling gaps or lower catchability.

Length-weight relationship

A total of 429 males were analysed, with total lengths ranging from 13.5 to 33.5 cm and weights varying between 28.50 and 317.1 g. Similarly, 418 females were included, with lengths ranging from 14.4 to 34.1 cm and weights between 30.4 and 472 g, for the estimation of the length-weight relationships (Fig. 4). The values of a and b ranged from 0.0094 to 0.0109 and from 2.969 to 3.012, respectively, for both sexes as well as for the combined sample. The coefficient of determination (R^2) varied between 0.9203 and 0.9205, indicating a strong correlation between length and weight of the common sole.

The statistical analysis results, summarised in Table 1 , reveal that females exhibit significant positive allometric growth, while males display negative allometric growth.

Table 1. Length–weight relationships derived for *S. solea*

Sex	Sample size (Nos,)	Equations	R^2	Growth type	p Value
Female	418	$TW = 0.0097\ xTL^{3.012}$	0.9203	+ Allometry	0.021*
Male	429	$TW = 0.0109\ xTL^{2.969}$	0.9204	- Allometry	0.034*
Combined	847	$TW = 0.0094\ xTL^{3.004}$	0.9205	+ Allometry	0.031*

*Significantly different from 3 ($p < 0.05$); TL: Total length (cm), TW: Total weight (g); R^2: Coefficient of determination

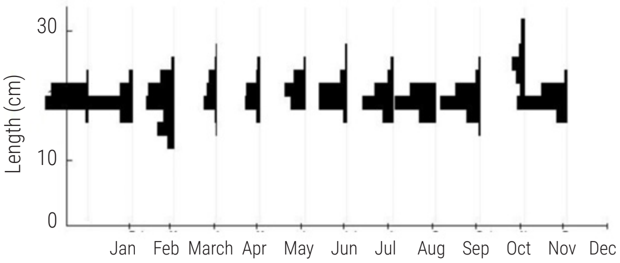
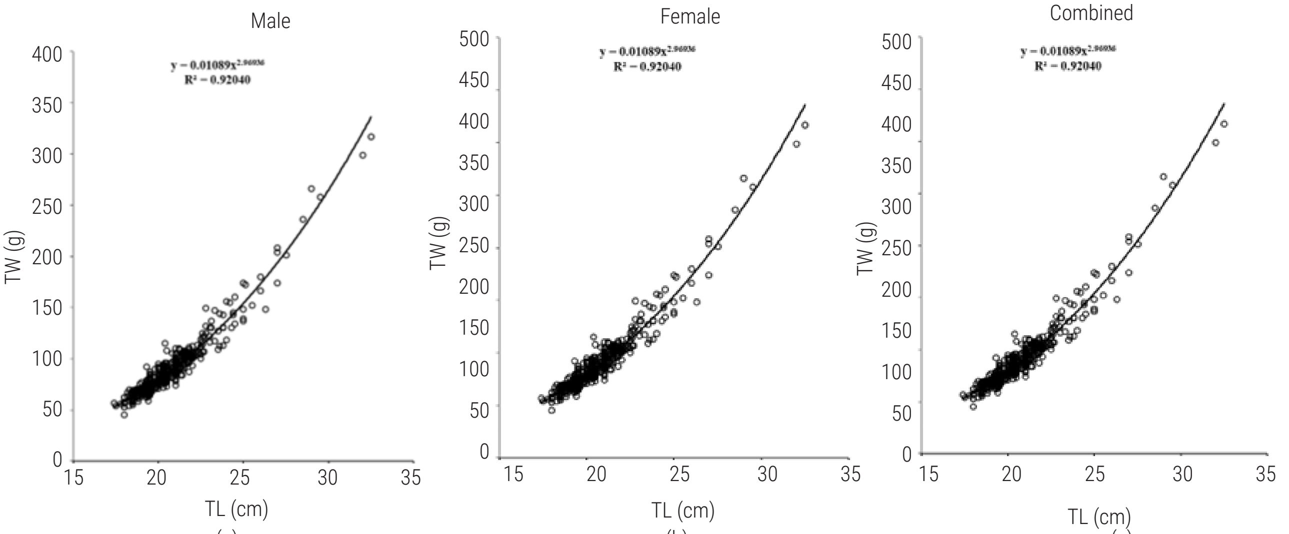


Fig. 3. Seasonally oscillating growth curve generated from length–frequency distribution for *S. solea*

It was observed that females of *S. solea* in the study area are characterised by a high growth rate than males.

Mortality and exploitation

Based on the length-converted catch curve analysis (Fig. 6), the total mortality rate (Z) was estimated at 4.48 yr^{-1}. The natural mortality rate (M) was estimated at 1.84 yr^{-1} at 18°C. Fishing mortality rate (F) was then calculated as 2.64 yr^{-1}, indicating that fishing plays a significant role in overall mortality. Additionally, the Z/K ratio was calculated at 1.83, while the exploitation rate (E) was 0.59, suggesting a moderately high level of exploitation and substantial fishing pressure on the stock.



(a) (b) (c)

Fig. 4. Length-weight relationship of *S. solea* (a) males; (b) females and (c) combined sexes in the Atlantic coasts of Morocco, TW: Total weight (g), TL: Total length (cm)

Age

Intact otoliths without anomalies from 278 individuals (155 females, 123 males) were used to determine and classify various length classes independently of their sexes. The age range spanned from 0 to 8 years for both sexes, as illustrated in Fig. 5.

Growth parameters

The obtained von Bertalanffy theoretical growth in length equations for *S. solea* was as follows:

Males : $L_t = 23.98\ (1 - \exp^{-0.945\ (t+0.001)})$

Females : $L_t = 23.71\ (1 - \exp^{-0.884(t+0.002)})$

The growth parameters estimated in the present study for males and females of *S. solea* from Atlantic Moroccan coast along with those reported by other researchers for the same species are summarised in Table 2 .

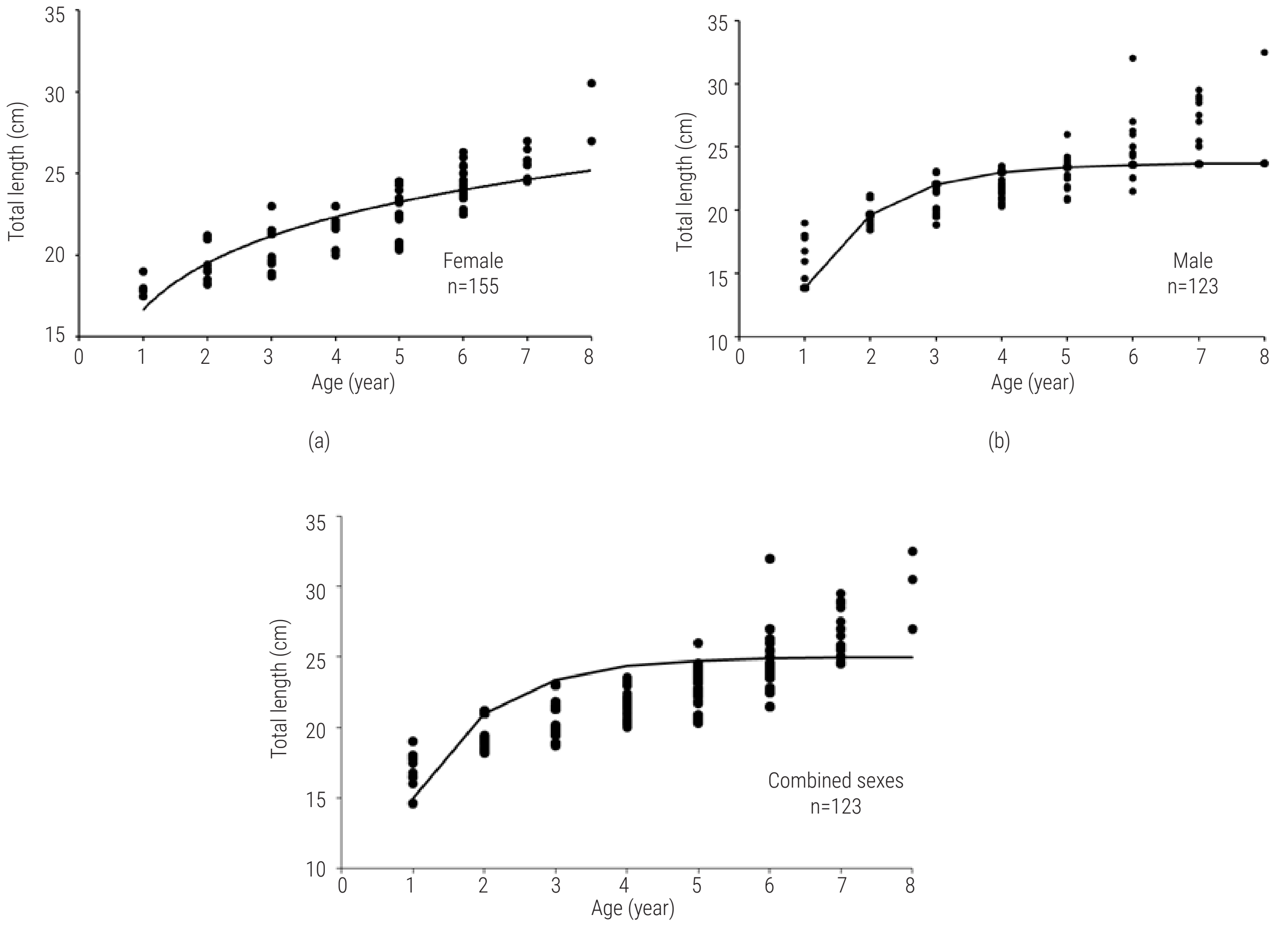
Growth performance index (Ø')

The computed growth performance index for *S. solea* in Safi fishing area was 2.697 and 2.717 for males and females, respectively.

Discussion

Length-weight relationships (LWRs)

The LWRs of *S. solea* have been widely studied across different regions, highlighting notable differences in growth patterns. These variations are influenced by factors such as sex, environmental conditions, and geographic location (Alahyane *et al.,* 2022). In the current study, the LWRs of *S. solea* revealed sex-specific growth patterns. Females exhibited positive allometric growth (b=3.012), indicating that weight increases faster than length as they grow. This finding is consistent with reports from the eastern Mediterranean (El-Aiatt *et al.*, 2019) and may be attributed to increased energy allocation for reproduction and egg production. In contrast, males showed negative allometric growth (b=2.969), suggesting that weight increases at a slower rate relative to length. When both sexes were combined, the growth pattern appeared nearly isometric (b=3.004), indicating weight and length increase proportionately, potentially masking the sex specific differences.These variatons in growth patterns likely reflect differences in energy allocation strategies between sexes (Sardi *et al.,* 2023). These differential growth patterns align with life-history theory, which emphasises



(a)

(b)

(c)

Fig. 5. Age distribution of *S. solea* estimated using otolith ageing for (a) Males; (b) Females and (c) Combines sexes

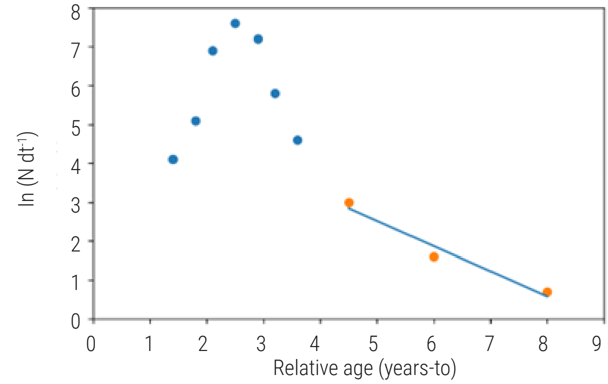


Fig. 6. Estimated Z from the length-converted catch curve of *S. solea* along the North Atlantic coast of Morocco

trade-offs in energy distribution to satisfy physiological and reproductive demands (Roff, 1992; Stearns, 1992). Females invest significant metabolic energy in gonadal maturation and vitellogenesis (El-Aiatt *et al*., 2019), which restricts somatic growth. In contrast, males usually undergo a less energy-intensive gamete production, focusing more on reproductive behaviours, enabling consistent weight gain (Borg, 1994). This trade-off is governed by the neuro-endocrine systems of the hypothalamic-pituitary-gonadal (HPG) and hypothalamic-pituitary-somatic (HPS) axes. Androgens like 11-ketotestosterone promote male somatic growth through insulin-like growth factors, while supporting reproductive functions (Mommsen, 2001). Thus the exponent b serves as a useful phenotypic indicator of sex-specific growth strategies shaped by physiological and evolutionary processes.

Comparisons with previous studies reveal regional variations in LWRs for *S. solea*. In Bardawil Lagoon, Egypt, Desouky (2016) reported LWR equations as, $W= 0.0055\ L^{3.171}$, $W= 0.0047\ L^{3.2334}$ and $W= 0.0048\ L^{3.2215}$ for males, females and combined sexes respectively**.** Similarly, Başaran *et al.* (2008) found a higher exponent (b = 3.3631) in Izmir Bay, Turkey, indicating stronger positive allometry. These differences likely stem from environmental factors like temperature, salinity and food availability, which shape physiological adaptations (Hildrew *et al.,* 2007). For instance, the high b value (3.377) reported from Lake Manzalah's suggests optimal conditions (El-Bokhty and Mehanna, 2023), contrasting with lower b value (2.932) estimated for Lake Qarun, reflecting slower growth (Desouky, 2016). Such disparities underscore how localised ecological conditions influence growth dynamics. The high R^2 values obtained in the present study, confirm

Table 2. Population parameters for selected sole species from different localities.

Authors	Sex	n	K (yr^{-1})	t_0 (yr)	L_∞ (cm)	Ø*	Location
Ramos (1982)	F	179	0.220	-0.749	46.4	2.68	Western Mediterranean
	M	151	0.240	-1.085	38.8	2.56	
Froglia and Gianetti (1985)	F+M	671	0.041	-3.574	38.25	1.78	Adriatic
Vianet *et al.* (1989)	F	287	0.270	-0.41	51.56	2.86	Gulf of Lion
	M	274	1.030	-0.07	48.83	2.76	
	F+M	561	0.240	-0.77	48.83	2.76	
Papaconstantinou*et al.* (1990)	F+M		0.380	-0.41	34.88	2.66	Amvrakikos Gulf
Deniel (1990)	F	558	0.329	0.075	48.2	2.88	France
	M	351	3.970	0.093	42.4	2.85	
Oral (1996)	F+M	523	0.273	-1.166	37.12	2.58	Sea of Marmara
	F	218	0.729	-1.065	35.79	2.97	
	M	206	0.629	-0.911	28.63	2.71	
Stergiou *et al.* (1997)			0.380	-0.41	34.9	2.67	Aegean Sea
Hoşsucu *et al.* (1999)	F+M	340	0.280	-1.109	34.75	2.53	İzmir Bay
	F	184	0.170	-1.956	42.45	2.49	
	M	156	0.330	-1.043	31.14	2.51	
Türkmen (2003)	F	553	0.181	-1.55	29.95	2.21	İskenderun Bay
	M	550	0.221	-1.31	26.03	2.18	
Mehanna and Salem (2012)		2179	0.330	-0.45	44.36	2.81	Egypt
Salman (2014)	F		0.550	0.05	37.23	2.88	Bardawil lagoon
	M		0.470	-0.2	32.72	2.7	
Mehanna *et al.* (2015)	F+M		0.580	-0.003	35.81	2.87	Egypt
	F		0.620	-0.009	36.24	2.81	
	M		0.550	-0.06	34.77	2.82	
Cerim and Ateş (2020)	F+M	1136	0.208	-0.032	33.95	2.38	Güllük Bay
	F	607	0.236	-0.037	31.98	2.38	
	M	529	0.324	-0.03	29.11	2.44	
The present study	F+M	278	0.917	-0.001	23.57	2.707	Atlantic coasts of Morocco
	F	155	0.945	-0.001	23.48	2.717	
	M	123	0.884	-0.002	23.71	2.697	

a strong LWR in *S. solea*. While the observed growth patterns are consistent with some earlier findings (Mehanna *et al.,* 2020), discrepancies among studies (Table 1) highlight growth variability under varying conditions across regions. These differences likely reflect regional environmental influences. Positive allometric growth ($b>3$) has been documented in Bardawil Lagoon and Manzalah Lake (Mehanna and Salem, 2012; Salman, 2014), whereas, near-isometric growth ($b=2.9$-3.0) has been reported from lake Qarun (Mosaad, 1990; Desouky, 2016), demonstrating how habitat conditions shape growth dynamics in flatfish populations. Some studies have also reported near-isometric growth ($b\approx3$) in *S. solea* (Eid, 2015; Mehanna *et al.,* 2015), while others reported stronger allometry ($b=3.092$, 3.222) in Bardawil and Mediterranean waters (El-Aiat *et al.,* 2019; Mehanna and Farouk, 2021), mirroring Manzalah Lake's growth pattern. These contrasting findings highlight how growth strategies vary across populations and environments. These discrepancies in b values in *S. solea* reflect diverse environmental pressures (habitat, food, fishing) and genetic factors (Hildrew *et al.,* 2007). Understanding these growth drivers enables tailored conservation strategies for distinct populations. Future research should clarify environment-growth relationships to ensure sustainable management of this ecologically vital species.

Age and growth parameters

This study examined the age and growth parameters as critical biological indicators for fish stock management in *S. solea* populations. Our findings demonstrated that males exhibit marginally higher asymptotic lengths (L_∞=23.98 cm) than females (23.71 cm), coupled with faster growth rates (k=0.945 year^{-1} for males *vs*. 0.884 year^{-1} for females), Table 2 summarises growth parameters reported for *S. solea* from various geographical regions. These parameters suggest subtle but biologically relevant sex-based growth differences in the studied population. Comparisons with other studies reveal regional differences in growth parameters. For example, examining the Western Mediterranean population (Ramos, 1982), females exhibited a growth rate (K) of 0.220 yr^{-1}, while males demonstrated slightly higher growth rate of 0.240 yr^{-1}. Females attain a larger asymptotic length (L_∞) of 46.4 cm compared to males, indicating sexual dimorphism in growth parameters. Similarly, in the Adriatic Sea, Froglia and Gianetti (1985) reported lower growth rate (K) of 0.041 yr^{-1}, for both sexes, suggesting slower growth compared to the Western Mediterranean population. Notably, the theoretical age at zero length (t_0) is strongly negative (-3.574 yr), indicating that growth is initiated at an early developmental stage.

In the Gulf of Lion, Vianet *et al.* (1989) studied population parameters for sole species. Females exhibited a higher growth rate (K) of 0.270 yr^{-1} compared to males (0.103 yr^{-1}). However, males achieved larger asymptotic length (L_∞) of 48.83 cm compared to females (51.56 cm), reflecting sexual dimorphism in size but not in growth rate. In the Amvrakikos Gulf, Papaconstantinou *et al.* (1990) provided combined population parameters for both sexes. Here, a growth rate (K) of 0.380 yr^{-1} was observed, with an asymptotic length (L_∞) of 34.88 cm. These parameters indicate relatively fast growth and smaller maximum size compared to other populations. Deniel (1990) examined sole populations in France, revealing substantial differences between sexes. Females exhibited a growth rate (K) of 0.329 yr^{-1}, while males demonstrated remarkably higher growth rate of 3.970 yr^{-1}. Moreover, males achieved lower asymptotic length (L_∞) of 42.4 cm compared to females (48.2 cm), indicating pronounced sexual dimorphism in growth parameters. In the Sea of Marmara, Oral (1996) observed population parameters for both sexes and females demonstrated a higher growth rate (K) of 0.273 yr^{-1} compared to males (0.629 yr^{-1}). Additionally, females achieved larger asymptotic length (L_∞) of 37.12 cm compared to males (28.63 cm), reflecting sexual dimorphism in size and growth rate. In İzmir Bay, Hoşsucu *et al.* (1999) provided population parameters for both sexes. Females exhibited a growth rate (K) of 0.280 yr^{-1}, while males demonstrated lower growth rate of 0.170 yr^{-1}. Further, females achieved larger asymptotic length (L_∞) of 42.45 cm compared to males (34.75 cm), indicating sexual dimorphism in growth parameters. Overall, the comparison of population parameters across diverse geographical localities highlights the variability in growth dynamics and sexual dimorphism of the common sole across different locations. These findings provide valuable understanding into the adaptive strategies and ecological interactions shaping sole populations in different marine environments.

In comparison to the aforementioned studies, our findings reveal notable differences in population parameters for the common sole. Specifically, the growth rates (K) observed in our study for males (0.945) and females (0.884) surpassed many of the reported values across different localities. These reflect sex-specific growth strategies shaped by energy allocation and reproductive trade-offs. Females divert substantial energy to gonad development, ovary maturation, and prolonged egg production, slowing somatic growth and delaying approach to their asymptotic length, whereas males produce sperm at lower metabolic cost, allowing faster growth even after reaching sexual maturity (Carbonara *et al.*, 2023). Females also mature later than males and experience extended spawning seasons, further constraining growth, while males maintain rapid growth despite earlier maturation (Kahraman *et al.,* 2021). Despite lower k values, females typically achieve larger asymptotic lengths, investing conservatively in growth but maximising total body mass and fecundity, illustrating a trade-off between growth rate and reproductive potential that causes sexual dimorphism in this species. This also suggests that the sole population in the studied area experiences relatively rapid growth compared to other regions. Additionally, the similarity in growth rates between males and females in our population contrasts with some of the observed sexual dimorphism in other studies, where males often exhibit either faster or slower growth rates compared to females. The higher growth rates observed in our population may reflect favourable environmental conditions, such as ample food availability or optimal habitat suitability. Furthermore, the absence of pronounced sexual dimorphism in growth rates within our population underscores the importance of considering local environmental factors in understanding the variability of growth dynamics among sole populations. These comparative insights contribute to a deeper understanding of the factors influencing population dynamics and growth patterns in sole species across diverse marine ecosystems (Denechaud *et al.,* 2020). The variations in growth parameters among populations may reflect differences in resource availability, predation pressure, and genetic factors.

The growth performance index (Ø') further confirms our population's robust growth, with values of 2.697 for males and 2.717 for females, surpassing many Mediterranean counterparts. This metric, integrating both growth rate and maximum size, suggests particularly favourable conditions in the Safi fishing area, especially for females who may benefit from optimal resource allocation for reproduction and growth. Similar high-performance indices in Egyptian lagoons (Mehanna *et al.,* 2020) indicate certain environments consistently support enhanced productivity for the species. Future research should focus on mechanistic links between environmental variables (temperature, salinity, prey availability) and the observed growth parameters. Further research is needed to distinguish genetic influences from phenotypic plasticity in growth variation and to evaluate the potential impacts of climate change. The substantial variability documented across populations emphasises the necessity of region-specific stock assessments and management plans in this ecologically and commercially important flatfish species.

Mortality and exploitation

Mortality and exploitation rates serve as essential indicators for assessing the sustainability of fish populations. The natural mortality rate (M) was calculated at 1.84 yr^{-1}, reflecting background losses due to predation, disease, and senescence. Total mortality (Z), encompassing both natural and fishing-related causes, was estimated at 4.48 yr^{-1}, while fishing mortality (F) was determined to be 2.64 yr^{-1}, indicating substantial anthropogenic pressure. The corresponding exploitation rate (E) was 0.59, suggesting that approximately 59% of the stock is harvested annually. This value exceeds the precautionary threshold and indicates a state of overexploitation that could compromise the long-term sustainability of the stock if management strategies are not adequately implemented (Gebremedhin *et al.,* 2021).

Furthermore, the ratio of total mortality to the von Bertalanffy growth coefficient (Z/K) was 1.83, suggesting that fishing pressure is high relative to the species' intrinsic growth potential (Boddington *et al.,* 2021). Elevated exploitation rates such as this can diminish stock resilience, hinder recruitment success, and heighten the risk of population collapse. These findings collectively underscore the need for immediate and effective fisheries management interventions to mitigate overfishing and safeguard the viability of *S. solea* populations (Farella *et al.,* 2020).

Implications for fisheries management

The findings of this study have important implications for the management and conservation of *S. solea* populations. The observed differences in growth patterns and mortality rates across regions highlight the need for region-specific management strategies. For example, in areas with high exploitation rates, such as the Atlantic Moroccan Coast, measures such as size limits, catch quotas, and gear restrictions may be necessary to reduce fishing pressure and ensure sustainable harvests (Cabral *et al.,* 2019). The sex-specific growth patterns observed in this study underscore the importance of considering sexual dimorphism in fisheries management. For instance, protecting larger females, which contribute disproportionately to reproductive output, can help maintain population stability (Sardi *et al.,* 2023). Research in the northern and central Adriatic Sea has highlighted the importance of implementing effective management measures to prevent overfishing and ensure the long-term sustainability of *S. solea* populations (Masnadi, 2023). Similarly, habitat protection and restoration efforts can enhance food availability and reduce natural mortality, supporting healthier fish populations (Lourenço *et al.,* 2023).

This study on *S. solea* along the Atlantic Moroccan Coast offers key insights into its population dynamics by analysing growth parameters, mortality, exploitation, and length–weight relationships. The von Bertalanffy growth model revealed subtle sexual dimorphism, with males showing slightly higher asymptotic lengths and both sexes demonstrating rapid growth, reflecting environmental and fishing pressures. Allometric growth patterns and variability in length–weight relationships further highlight the impact of local environmental factors and feeding ecology. Moderate natural and fishing mortality rates, coupled with a notable exploitation rate, suggest risks of overexploitation, emphasising the need for size-specific management. Overall, the findings support the development of sustainable management strategies to ensure the long-term conservation of *S. solea* fisheries.

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