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Population Characteristics of the Atlantic Chub Mackerel (*Scomber colias* Gmelin, 1789) in the Northwestern Atlantic Coast of Morocco

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ABSTRACT

The Atlantic chub mackerel (*Scomber colias*) is a pelagic fish species which strongly supports fisheries along the Moroccan Atlantic coasts. However, despite commercial landings which have increased over the last decades in Morocco, biological information on this species remain scarce at the national scale. The present study was therefore conducted to examine the reproductive biology of *S. colias* in the Atlantic coasts of Morocco. A total of 432 specimens were collected from Safi fishing harbor between March 2023 and February 2024, including 207 females and 225 males. The results showed that gonadosomatic index peaked during the colder months, while the spawning season occurred between December and March. Maximum hepatosomatic index values were recorded in June, at 1.13 ± 0.41 for females and 1.33 ± 1.32 for males. The overall body condition factor ranged from 0.71 to 0.91 in both sexes. Finally, size at first maturity was estimated at 18.26cm for males and 19.31cm for females. These preliminary findings provide crucial baseline data that may inform sustainable management practices and support conservation efforts of the Atlantic chub mackerel populations in the Moroccan marine waters.

INTRODUCTION

The Atlantic chub mackerel *Scomber colias* (Gmelin, 1789) is a pelagic fish species belonging to the Scombridae family, characterized by a fast-growing and early maturing of individuals. Specimens can reach a maximum length of 50cm and an age of 13 years **(Castro & Santana, 2000)**. This species colonizes the warm and temperate Atlantic coastal waters and surrounding seas, including the Mediterranean, Black and Adriatic Seas, generally on the continental shelf at depths between 0 and 300m **(Collette & Nauen, 1983; Castro & Santana, 2000)**. Its geographical range extends from the Bay of Biscay in the northern part of the eastern Atlantic to South Africa. However, this species is also located along the U.S. coast from Massachusetts to Florida, in the Bahamas, the Gulf of Mexico, and in southern Venezuela, Brazil, Uruguay, and Argentina **(Castro & Santana, 2000)**.

The central and southern regions of Morocco are identified as key areas for the concentration of the Atlantic chub mackerel along the northwest African coast. In Moroccan waters, *S. colias* is a significant fishery resource, with fishing activities carried out using capture seiners, artisanal fleets, and commercial trawling vessels, including refrigerated sea water vessels. The Atlantic chub mackerel fishery has significant socioeconomic importance in Morocco, being one of the most valued commercial fish throughout its habitat, and providing food and job opportunities for many locals. Indeed, catches were 380 000 tons, representing about 16% of the overall catch of small pelagic fish within the country **(ICES, 2020)**. However, the fishing pressure directed at this species in Morrocan waters negatively affect the biomass, resulting in the stock on populations being extensively exploited **(Derhy *et al.*, 2022)**. For instance, despite the increasing demand by consumers, the annual catches of key small pelagic fish species in the region decreased from 2.8 million tons in 2019 to 2.6 million tons in 2020 **(FAO, 2020)**. This reduction is primarily associated with fishing activities during the spawning season, which result in unintended juvenile mortality and consequently contribute to the decline in the stock biomass of *Scomber colias*. Despite the species' significant economic importance and the vast extent of Morocco's marine coastline, studies on its biological characteristics and spatial variability remain limited. To date, scientific efforts concerning the Atlantic chub mackerel at the national level have been restricted in both temporal and geographical scope and fall short of reflecting the species' socio-economic and nutritional significance. Only a limited number of studies have explored specific aspects of its biology—such as diet, age, growth, reproduction, morphometry, and exploitation rates—revealing differences between Mediterranean and Atlantic populations **(Bouzzammit & El Ouizgani, 2019; Techetach *et al.*, 2021; Bouzzammit *et al.*, 2022)**.

More precise and up-to-date biological data are essential for evaluating the status of *S. colias* populations and understanding their life-history traits, thereby supporting the implementation of more appropriate and adaptive management strategies across temporal and spatial scales.

The present study aimed to investigate a broad set of biological parameters of *S. colias*, including sex ratio, size at first maturity, spawning season, and maturity stages along the northwestern coast of Morocco. Specimens were collected from the central zone of the Atlantic stock, extending from Safi (32°19′N, 9°00′W) to Cap Boujdour (26°07′N, 14°30′W). By providing updated data, this study contributes to a better understanding of the seasonal population dynamics and biological characteristics of *S. colias* in northwestern Moroccan waters.

MATERIALS AND METHODS

1. Sampling

A total of 432 individuals of the Atlantic chub mackerel, caught by purse seine, were collected from commercial catches landed at the port of Safi City from March 2023 to February 2024 (Fig. 1). 36 specimens were sampled three times a month. The fish were transported to the laboratory in isothermal containers filled with ice. In the laboratory, morphometric data were recorded for each individual, such as total length (TL, cm) and total weight (TW, g). After dissection, the sex was identified macroscopically while the gonad weight (GW, g) and liver weight (LW, g) were measured to the nearest 0.01g.

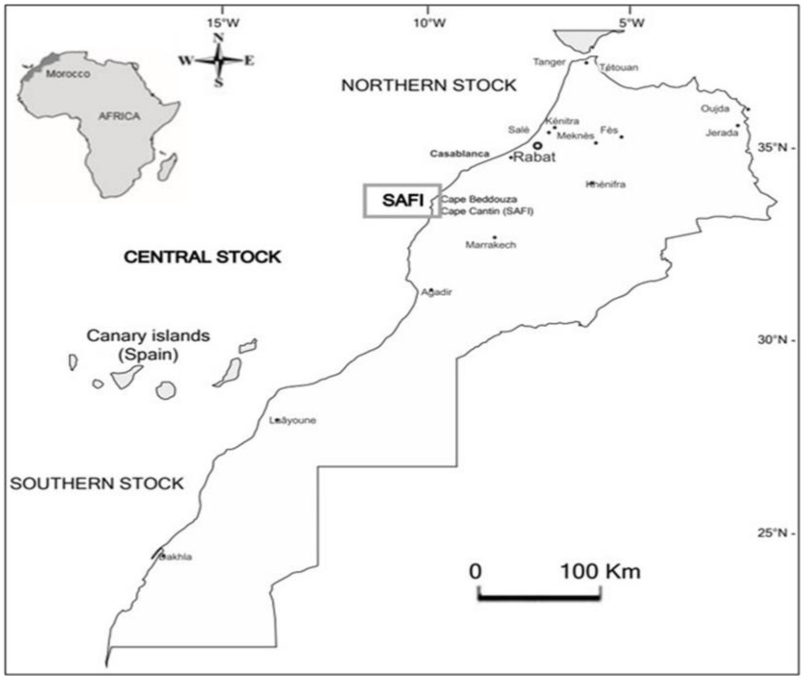

Fig. 1. Geographic location of the sampling area of *S. colias* in the Atlantic coast of Morocco

2. **Length-weight relationship**

The majority of fish exhibit an allometric correlation between size and weight. Estimating the morphological changes induced by growth is highly beneficial in fisheries biology. It is converted into a species equation **(Le Cren, 1951)**:

$$TW = a \times TL^b,$$

Where, a: constant, and b: allometry coefficient.

3. **Sex ratio**

The sex ratio was determined using the following equation:

$$SR = M/F,$$

Where, F: number of females, and M: number of males.

4. **Stages of sexual maturity**

Sexual maturity stages were determined by direct observation of the gonads using various morphological parameters including size, color, and the volume they occupied within the abdominal cavity. According to **Arriaga *et al.* (1983)**, the macroscopic maturity scale includes five stages recognized in both males and females: stage I (immature), stage II (maturing virgin or recovering spent), stage III (maturation), Stage IV (spawning), and stage V (post-spawning).

5. **Biological index**

To assess the maturity of *S. colias* and the condition of specimens sampled, three indices were calculated: The gonadosomatic index (GSI), hepatosomatic index (HSI) and condition factor (K). The GSI serves as a dependable measure of reproductive activity in fish. It assesses fluctuations in gonadal weight relative to factors like body length, total body weight, or somatic weight, enabling the identification of the reproductive period. The GSI is determined by analyzing changes in gonad weight throughout the sexual cycle and is represented by the following formula:

$$GSI = (GW/TW\text{-}GW) \times 100$$

Where, GW: gonads weight, and TW-GW: total weight-gonads weight. The gonado-somatic index is used to determine the timing and duration of spawning **(Lahaye, 1980)**. All the energy required for gonad maturation comes from the lipid reserves stored in the liver. The HSI indicates the liver's energy reserves, essential for sexual maturation. It illustrates the fluctuations in liver mass during the sexual cycle, offering insights into energy distribution and physiological readiness for reproduction. The index is computed applying the subsequent formula:

$$HSI = (LW/TW\text{-}LW) \times 100$$

Where, LW: liver weight, and TW-LW: total weight-liver weight.

The K value was calculated using the formula **(Bouhali *et al.*, 2015)**:

$$K = (Wgt/TL^3) \times 100$$

Where, Wgt: gutted body weight, and TL: total length.

6. **Size at first maturity**

The size at which 50% of individuals are sexually mature is known as the size at first sexual maturity (TL_{50}). To determine this size, samples were taken from the 1cm size class, and the number of individuals was recorded. The proportion of mature individuals (stages III, IV, and V) was subsequently determined for each size class. The correlation between size and the proportion of mature individuals was represented by a sigmoid logistic curve, mathematically expressed as follows **(King, 1995)**:

$$P = 1/ (1 + e^{(-a(TL-TL_{50}))}),$$

Where, P is the proportion of mature fish for the total length, and a is a parameter of the model.

7. **Data analysis**

The sex ratio, GSI, and HSI data were analyzed using the Chi-Square test ($\chi 2$) to determine potential differences in the proportions of each sex. Variations in size during first maturity were evaluated applying Z values **(Gunderson, 1977)**. The differences were considered significant at $P< 0.05$. The statistical software SPSS version 20.0. was used for the data analysis.

RESULTS

1. Population structure

The study population consisted of 207 female and 225 male individuals of *S. colias*. The overall length of the individuals varied between 15.5 and 26cm, with an average of 20.55 ± 1.63cm. Specifically, the length distribution for males ranged from 16.5 to 26cm, with a mean of 20.55 ± 1.63cm, while for females, it extended from 15.5 to 25cm, with a mean of 20.5 ± 1.63cm (Fig. 2). A statistical analysis revealed no significant difference in the total length distribution between the sexes ($P > 0.05$), indicating similar size distributions for males and females. Regarding weight, the total body mass for males ranged from 35 to 132g, with a mean of 71.39 ± 21.21g, whereas for females, it ranged from 38 to 156g, with a mean of 71.61 ± 21.36g. Although there was a slight variation in the range of weights between the sexes, the means were closely aligned, suggesting that body mass did not differ substantially between males and females in this population.

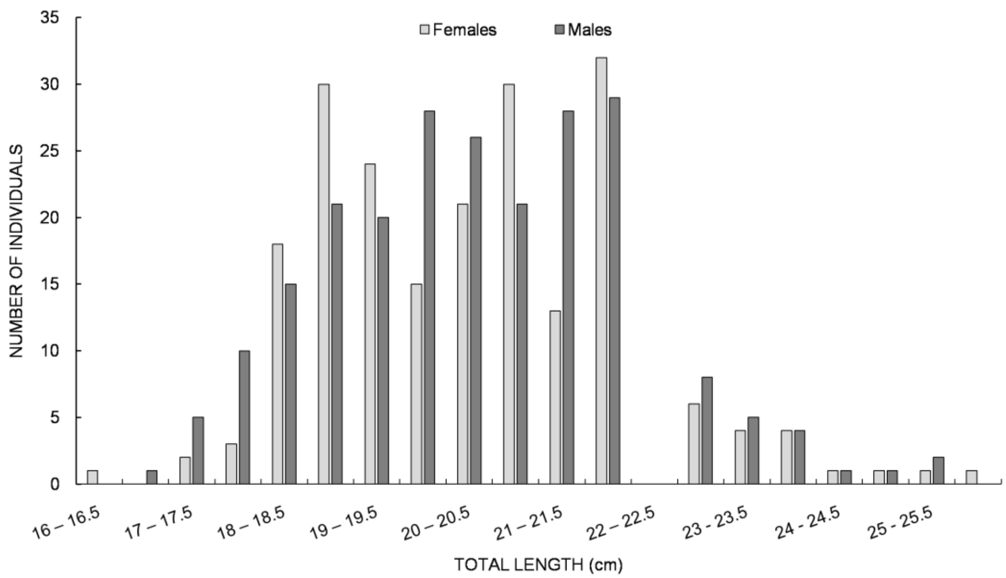

Fig. 2. Distribution frequency of the total length (TL) in *S. colias* on the Atlantic coast of Morocco

2. Length-weight relationship

A significant relationship between length and weight was observed ($P < 0.05$) (Fig. 3). The correlation coefficient was 89 and 91% for males and females. respectively, indicating a strong correlation between weight and size of *S. colias* in Safi area. The allometric coefficient (b) was significantly greater than 3 for both sexes, indicating a positive allometric growth in *Scomber colias*, meaning the species tends to become heavier relative to its length as it grows (Table 1).

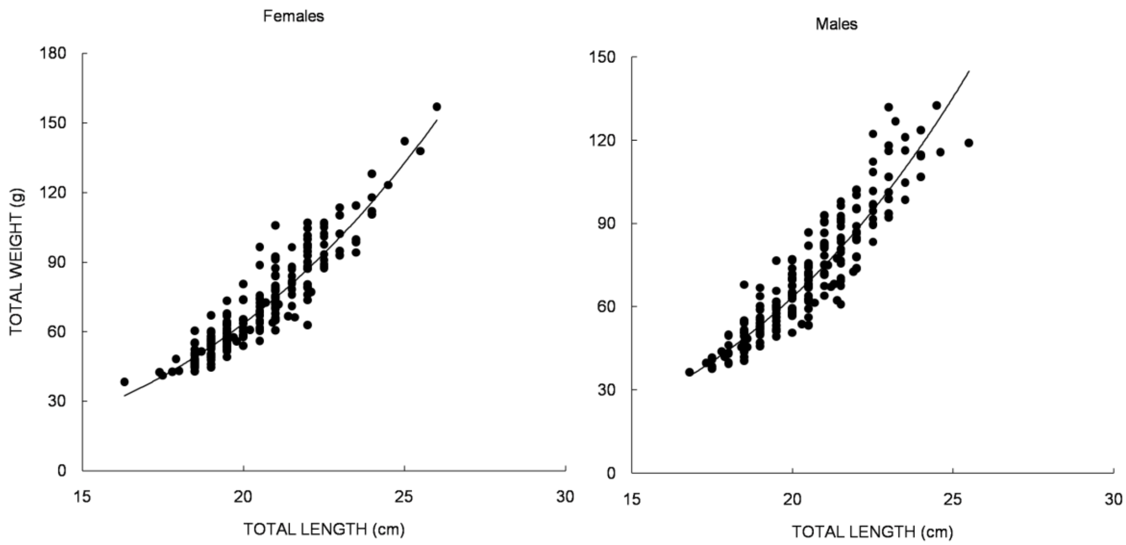

Fig. 3. Length-weight relationship in females and males of *S. colias* along the Atlantic coast of Morocco

Table 1. Parameters of length-weight relationship for *S. colias* (N = number of fish; a = scaling coefficient; b = allometry coefficient; r = correlation coefficient)

Sex	N	a	b	r	Allometry
Males	207	0.0032	3.3055	0.89	
Females	225	0.0035	3.2751	0.91	Positive
All fish	432	0.0033	3.2910	0.90	

3. Sex ratio

The sex ratio of *S. colias* was 1:1.08 (females to males), which approaches a ratio of 1:1 ($\chi^2 = 0.75$, $P > 0.05$). On a monthly basis, the sex ratio was especially near parity in June and July (1:0.1), as well as in October (1:0.80). For monthly changes in sex ratio according to the studied months, no significant differences between the males and females populations were noticed throughout all months, apart from the month of May in which statistically significant differences emerged ($\chi^2 = 4$, $P < 0.05$) (Table 2). The seasonal analysis of the ratio of female-to-male appearance showed little fluctuation in the ratio of females to males throughout the year. Conversely, spring was also noted for a clear male bias ($P < 0.05$), with a significantly higher representation of males across the season (Fig. 4).

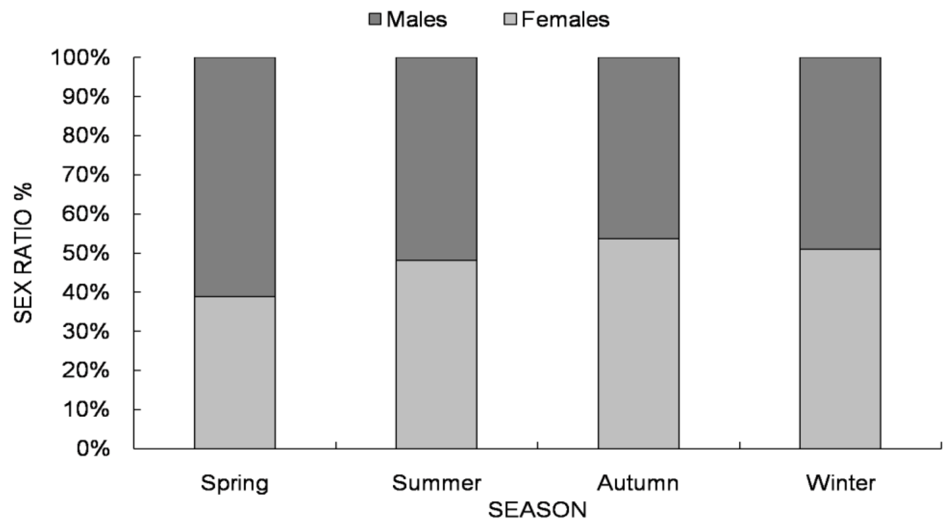

Fig. 4. Seasonal evolution of the sex ratio of *S. colias* on the Atlantic coast of Morocco

Table 2. Monthly variation of the sex ratio, mean total length (TL), mean total weight (TW) of *S. colias*. * Significant difference *P*< 0.05

Month	Number of specimens			SR	χ²	TL (cm)	TW (g)
	Females	Males	Total				
Mar	16	20	36	1.25	0.44	21.48 ± 1.81	73.07 ± 20.82
Apr	14	22	36	1.57	1.77	19.63 ± 1.72	58.14 ± 14.04
May	12	24	36	2.00	4.00*	21.18 ± 2.17	81.27 ± 27.73
Jun	13	23	36	1.77	2.77	21.83 ± 0.83	95.68 ± 12.08
Jul	21	15	36	0.71	1.00	21.39 ± 0.90	84.69 ± 16.87
Aug	18	18	36	1.00	0.00	20.04 ± 1.02	66.06 ± 11.96
Sep	16	20	36	1.25	0.44	20.21 ± 1.34	74.58 ± 21.05
Oct	20	16	36	0.80	0.44	21.04 ± 1.46	80.62 ± 18.39
Nov	22	14	36	0.64	1.77	20.39 ± 1.15	67.07 ± 14.72
Dec	18	18	36	1.00	0.00	21.15 ± 1.40	73.41 ± 17.85
Jan	21	15	36	0.71	1.00	19.07 ± 0.89	50.54 ± 5.49
Feb	16	20	36	1.25	0.44	19.01 ± 0.89	51.06 ± 9.71

4. Stages of sexual maturity

Through macroscopic examination of the gonads of *S. colias*, five different stages of sexual maturity were identified (Fig. 5). The seasonal distribution of these stages revealed that both sexes predominantly remained in stage I (immature) and stage II (maturing virgin) for the majority of the year (Fig. 5). There was a particularly high proportion of females in stage I during the summer months, with a striking 71 % (July), 72 % (August) and 88 % (September) of the population in stage I. Lowest proportion of immature females (11% in December) indicated progression to more mature stages during this period. Stage II, representing maturing virgins, exhibited smaller proportions but showed significant peaks in November (45%) and April (36%), reflected a period of growth in the cycle immaturity. A similar high percentage of stage I in males was observed between May and August, 83 % to 78 %, with 93 % peak in November. It indicates a lengthy period of immaturity behavior during these months. For females, stage III (mature virgin) occurred from February to March while for males it occurred from November to March. With respect to sex and stage, Stage IV (fully mature), which is indicative of reproductive readiness, only occurs in February for females and males in March. This period corresponds to the peak of reproductive activity, as evidenced by the highest rates of maturity and spawning stages for both sexes, particularly in February and March.

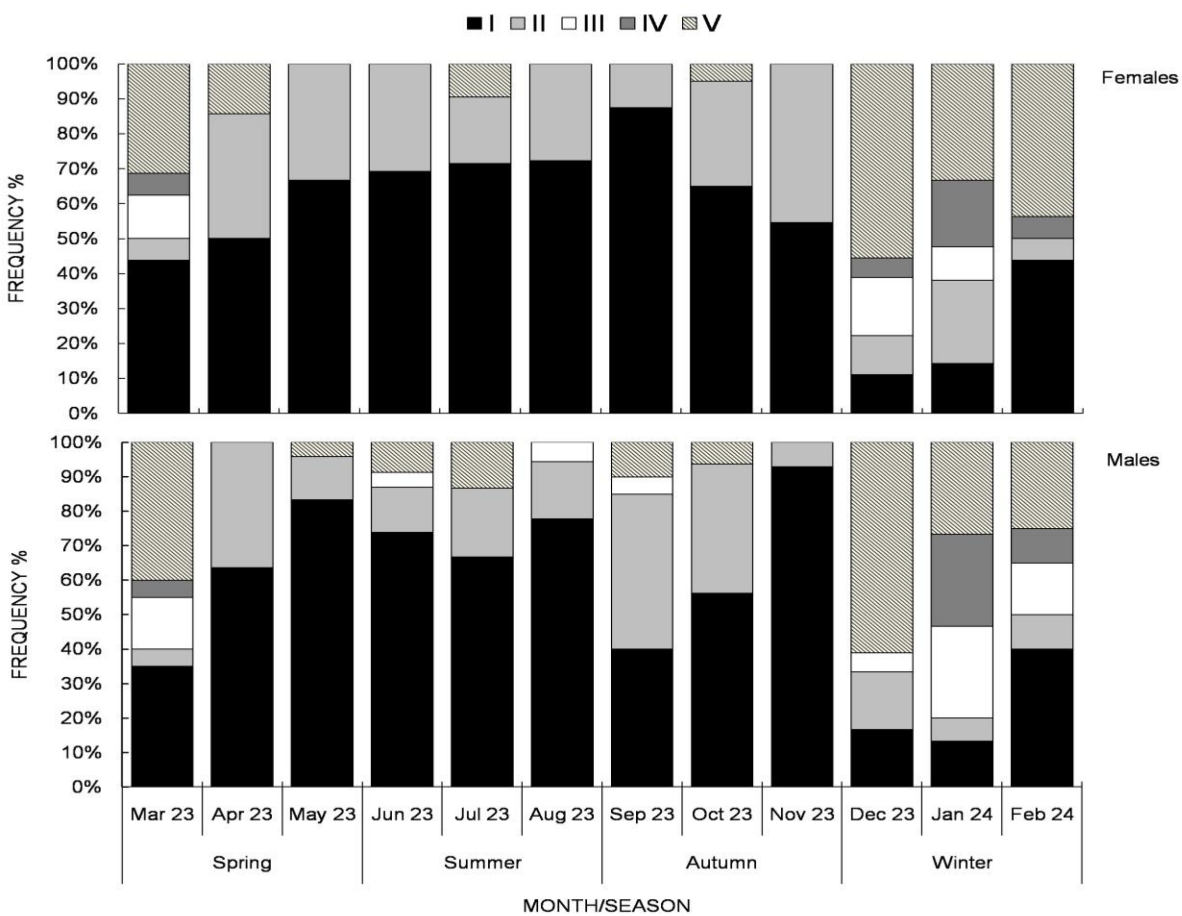

Fig. 5. Monthly variation of sexual maturity stages for females and males of *S. colias* along the Atlantic coast of Morocco

5. Biological index

Both sexes demonstrated a comparable pattern in the evolution of the GSI (Fig. 6). The monthly variations in the mean GSI ranged from 0.29 ± 0.14 to 1.28 ± 1.57 in females and from 0.30 ± 0.19 to 1.36 ± 1.60 in males (Fig. 6). The GSI began increasing in November, reaching its peak in February for both males and females. Afterward, it gradually declined from March onward, hitting its lowest levels in June. Similarly, the HSI followed a comparable pattern, with elevated values observed during two distinct periods: May to June and September to October. The highest recorded HSI values occurred in September, measuring 1.18 ± 0.29 for females and 1.33 ± 1.32 for males. In contrast, the lowest values were observed in April, with females at 0.52 ± 0.14 and males at 0.54 ± 0.17 (Fig. 6). After summer, the HSI showed a gradual decline but remained relatively stable, indicating a depletion of energy reserves following the spawning season. Statistical analysis using the χ^2 test found no significant differences in the monthly trends of GSI and HSI between males and females ($P > 0.05$). Both indices exhibited a consistent and synchronized pattern across sexes, highlighting the shared physiological and reproductive dynamics of *S. colias* (Fig. 6). The condition factor ranged from 0.72 to 0.92 in females and from 0.71 to 0.91 in males. The highest values were observed in June, while the lowest occurred in March. Temperature fluctuations likely play a role in influencing reproductive cycles and energy storage. Warmer summer temperatures may contribute to improved body condition (as indicated by higher K values) and increased energy reserves (HSI), whereas colder winter temperatures could stimulate spawning, leading to a rise in GSI.

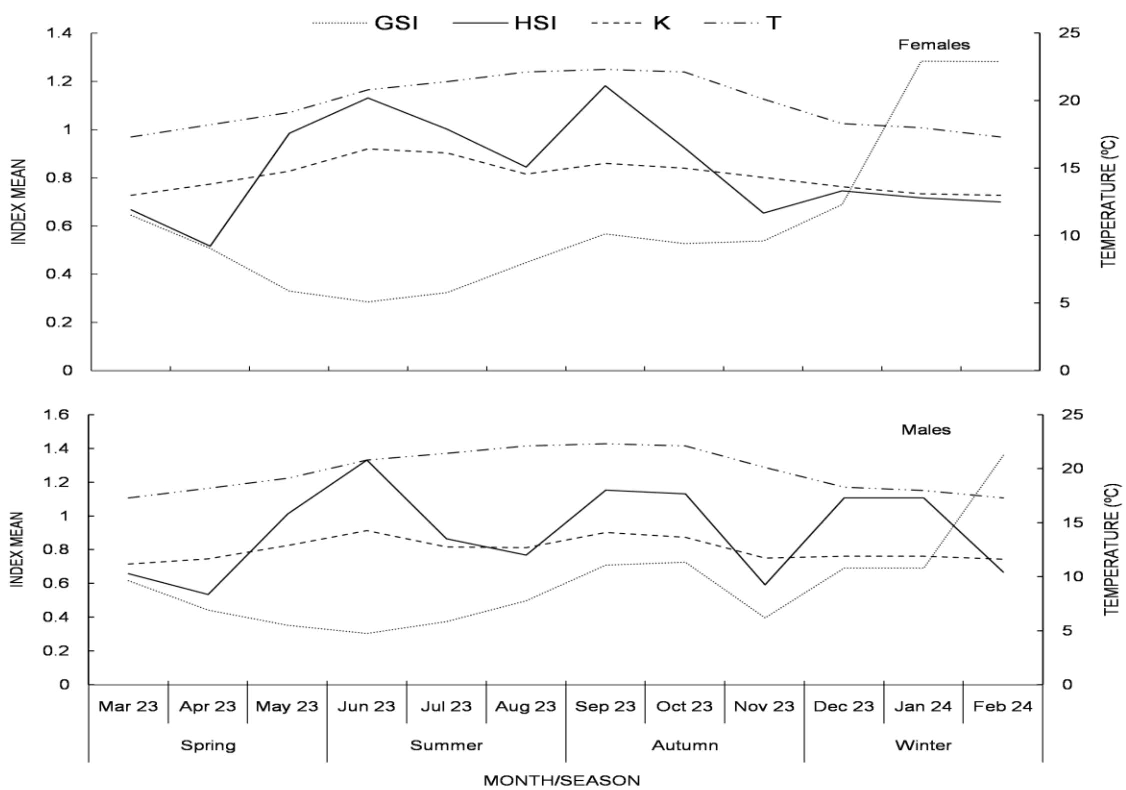

Fig. 6. Monthly variation of GSI, HIS and K for females and males of *S. colias* and evolution of water temperature along the Atlantic coast of Morocco

6. Size at maturity estimates

The maturity curve showed a significant fit to the observed data ($\chi2 = 3.89$, $P< 0.05$ for males; $\chi2 = 39.86$, $P< 0.001$ for females; $\chi2 = 15.51$, $P< 0.001$ for the whole sample). The smallest mature specimens measured 17.5cm for both sexes. The size at first maturity was 18.26cm for males, 19.31cm for females, and 18.98cm for the combined sexes (Fig. 7), with no significant difference between sexes of the Atlantic chub mackerel ($Z = 0.72$; $P> 0.05$).

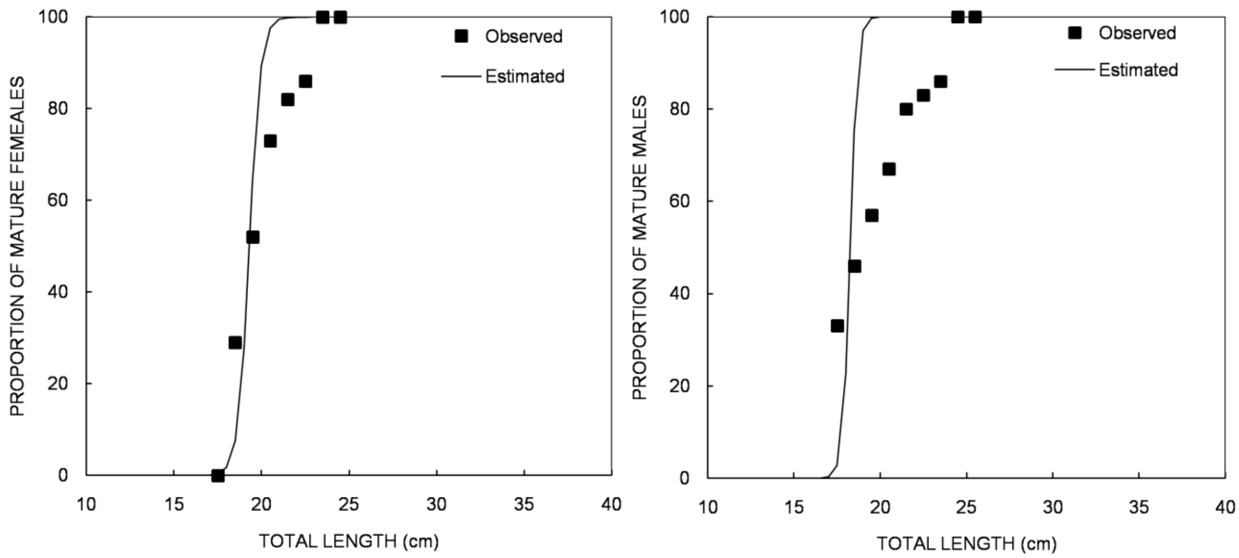

Fig. 7. Maturity ogive for females and males of *S. colias* along the Atlantic coast of Morocco

DISCUSSION

Length–weight relationships (LWRs) are widely used to describe the growth patterns of fish species **(Pauly, 1984)**. In fisheries science, LWRs are essential as they allow the estimation of biomass from commercial length-frequency data **(Anderson & Gutreuter, 1983)**. In this study, the LWR analysis indicated a positive allometric growth pattern for all samples of *Scomber colias*, meaning that weight increased at a faster rate than length. The coefficient b exceeded 3, reflecting that the fish become proportionally heavier with growth, potentially due to favorable environmental conditions and food availability. A strong correlation between length and weight was observed, with correlation coefficients $(r) \geq 0.8$.

These findings are consistent with previous studies on the Moroccan Mediterranean coast **(Techetach *et al.*, 2021)**, as well as in other parts of the Mediterranean, including the Hellenic Seas **(Kiparissis *et al.*, 2000)**, the Aegean Sea **(Moutopoulos & Stergiou, 2002)**, Izmir Bay **(Bayhan *et al.*, 2007)**, the Alboran Sea **(Velasco *et al.*, 2011)**, and Saros Bay **(Cengiz, 2012)**. However, isometric growth (where $b \approx 3$) has been reported in Izmir Bay **(Özaydın & Taşkavak, 2006)**, Tunisian waters **(Allaya *et al.*, 2013)**, and the

Adriatic Sea **(Čikeš Keč & Zorica, 2013)**. Such variation in LWR parameters may be attributed to differences in geographic location, sampling methods, diet, sex, sexual maturity, body condition, and individual physiology **(Tesch, 1971; Ricker, 1975)**.

Sex ratio

Sex ratio can vary by population, size class, season, and year. In this study, the overall sex ratio was 1:1.08 (females to males), closely approaching the expected 1:1 ratio typical of most fish species **(Nikolsky, 1963)**. This balance is ecologically important, as future recruitment relies heavily on the proportion of females in the population. However, our results contrast with those of **Techetach *et al.* (2010)**, who reported a male-biased sex ratio (0.79:1) on Morocco's northern Atlantic coast. Other studies, such as **Techetach *et al.* (2019)** and **Bouzzammit *et al.* (2022)**, observed female-biased ratios of 1:0.49 and 1:0.86, respectively. A slight dominance of females was also reported in the Canary Islands **(Lorenzo & Pajuelo, 1996)**. According to **Murua and Saborido-Rey (2003)**, a female-biased sex ratio may offer reproductive advantages and play an important role in population dynamics and reproductive success.

Spawning season and reproductive cycle

Our results show that gonadosomatic index (GSI) values and the frequency of gonadal maturity stages are reliable indicators of the spawning period of *S. colias* along the northwest Atlantic coast of Morocco. The reproductive cycle is characterized by a well-defined spawning season from November to March. This conclusion is supported by a high proportion of mature individuals and elevated GSI values during this period **(Rizzo & Bazzoli, 2020)**.

Notably, the hepatosomatic index (HSI) peaked prior to the GSI, suggesting a mobilization of liver energy reserves to support gonadal development and vitellogenesis **(Garcia-Diaz *et al.*, 2006)**. This inverse HSI–GSI relationship is a strong indicator of energy transfer from the liver to the gonads and has also been documented in other species **(Nunes *et al.*, 2011; Teichert *et al.*, 2014)**. These findings reinforce the role of the liver in supporting reproductive processes in *S. colias*, aligning with the view that HSI serves as a reliable indicator of hepatic contribution to reproductive energy demands **(Rizzo & Bazzoli, 2020)**.

Our findings pinpoint the spawning season from December to March. This matches observations from the southwest coast of Gran Canaria, where spawning occurs from December to March with a peak in December and January **(Lorenzo & Pajuelo, 1996)**. On the northern Moroccan coast, two spawning peaks have been recorded: December–March and June–July **(Techetach *et al.*, 2010)**. In the Madeira Archipelago, spawning spans from January to April with a peak in February–March **(Vasconcelos *et al.*, 2012)**. In Portuguese waters, the peak has been reported between February and March, extending to June **(Nunes *et al.*, 2019)**. In contrast, the Azores reported a spawning period from March to July–August **(Carvalho *et al.*, 2002)**, while **Navarro *et al.* (2021)** noted a shorter season peaking in June.

These regional variations suggest a latitudinal gradient in spawning activity, influenced by environmental factors such as temperature, ocean currents, upwelling, and food availability **(ICES, 2020)**. Temperature, in particular, is recognized as a key driver of reproductive timing, with optimal spawning temperatures for *S. colias* ranging between 15– 20°C **(Collette & Nauen, 1983; Wootton, 1990)**.

Length at first maturity

Our results for length at first maturity (TL_{50}) are presented in Table (3). TL_{50} was estimated at 18.26cm for males and 19.31cm for females. These values are slightly lower than those observed in M'diq Bay **(Techetach *et al.*, 2019)** but are in close agreement with estimates from central Moroccan coastal waters **(Bouzzammit *et al.*, 2022)**. In general, TL_{50} values for *S. colias* range from 18.26 to 25.59cm **(Navarro *et al.*, 2014)**.

Variations in TL_{50} between regions may be attributed to factors such as food availability, temperature, genetic makeup, fishing pressure, selectivity, and differences in methodology, including the type of maturity scale used **(Trippel & Harvey, 1991)**. It is important to note that macroscopic staging without histological validation, as used in some studies, can introduce bias in TL_{50} estimates **(Hunter *et al.*, 1992)**.

Our findings also reveal that males attain sexual maturity at smaller sizes than females, a trend commonly reported in many fish species. This difference is often explained by sex-specific energy allocation, with males investing more in growth and females in reproduction **(Wootton, 1990)**.

Table 3. Size at first sexual maturity (TL_{50}, cm) of *S. colias* in different areas

Area	References	Males	Females	Combined	Gonad evaluation
Safi	Present study	18.26	19.31	18.98	Macroscopic
M'diq Bay	Techetach et al. (2019)	-	19.19	-	Microscopic
Larache	Techetach et al. (2010)	22.88	23.01	22.83	Macroscopic
Agadir	Bouzzammit et al. (2022)	20.82	21.08	-	Macroscopic
Bay of Biscay	Navarro et al. (2014)	24.73	25.59	25.54	Macroscopic
Portugal	Nunes et al. (2019)	19.15	22.64	20.57	Microscopic
Iberian waters	Navarro et al. (2021)	-	22.90	-	Macroscopic
Canary Islands	Jurado-Ruzafa et al. (2021)	18.79	19.44	19.00	Macroscopic

The size at first sexual maturity (TL_{50}) provides important insight into the impact of fisheries on stock dynamics **(ICES, 2012)**. An increase in fishing mortality can alter the size structure of the exploited population by reducing the proportion of larger, mature individuals **(Lappalainen *et al.*, 2016)**. In this study, TL_{50} analysis revealed a downward trend, which is often associated with declining stock biomass—a typical outcome of intensive fishing pressure. Such reductions in size at maturity have been reported as consequences of heavy exploitation **(Lojo *et al.*, 2022)**.

The estimation of TL_{50} is particularly useful for informing fisheries management, as it can guide the establishment of a minimum landing size. Ideally, the legal minimum size should exceed TL_{50} to ensure that individuals have the opportunity to reproduce at least once before capture. However, current Moroccan fisheries legislation does not impose a minimum landing size for *Scomber colias*, a regulatory gap that has direct negative implications for the sustainability of this fishery.

Regional differences in TL_{50} and other biological traits of *S. colias* populations may be attributed to a combination of genetic, environmental, and ecological factors. From a genetic standpoint, limited gene flow between populations can result in local adaptations, which manifest as differences in size, maturation timing, and other phenotypic traits. Environmentally, variables such as water temperature, salinity, and oxygen concentration can significantly influence metabolic and reproductive processes in fish.

Additionally, food availability and quality—both of which vary across marine ecosystems—play a fundamental role in shaping growth and reproductive strategies. In Morocco, differences between the Atlantic and Mediterranean coasts are largely driven by distinct geographic and hydroclimatic conditions. Even within the Atlantic coast, substantial variations in biological responses have been observed between northern, central, and southern zones, likely reflecting localized environmental conditions and food resource distributions.

CONCLUSION

This study highlights the importance of understanding the reproductive biology of *S. colias* and its temporal patterns on the Morocco Atlantic caost. As the current Moroccan legislation lacks specific regulations on minimum landing size, the availability of basic biological data becomes even more critical to prevent over exploitation of the stock. These findings are crucial for the effective management of fishery resources, as they fill an important gap by providing valuable information for decision-makers to develop sustainable management plans for *S. colias* fishery resources in the region.

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