Age, growth and exploitation of *Chamelea gallina* (Linnaeus, 1758) on the eastern Mediterranean coast of Morocco

[1]Amira Kharkhache, [1,2]Souad Abdellaoui, [1]Douaa Slimani, [1]Imane El Khamlichi, [1]Rajae Mouedden, [3,4]Nassir Kaddouri, [1]Mohammed ElYakoubi, [1]Youssef Smiri

[1] Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco; [2] Fishing Laboratory, Regional Center of the National Institute of Fisheries Research, 2, Bd Sidi Abderrahman, Ain Diab, 20180 Casablanca, Casablanca-Settat region, Morocco; [3] Department of Biology, Biodiversity, Ecology and Genomics Laboratory, Faculty of Sciences, Mohammed V University, Rabat, Avenue Ibn Battouta, B.P. 1014, 10000, Rabat, Rabat-Salé-Kénitra Region, Morocco; [4] Fishing Laboratory, Regional Center of the National Institute of Fisheries Research, 13, Boulevard Zerktouni, BP 493, Nador, Oriental Region, Morocco. Corresponding author: A. Kharkhache, amira.kharkhache@ump.ac.ma

Abstract. The present study aimed to estimate the age, and to evaluate the biometric relationships of the *Chamelea gallina* saltwater clam along with its condition index and exploitation level. To this end, growth parameters were measured, including shell length, thickness, height, total weight, and flesh and shell weights. Samples were taken along the Cap de l'Eau (Ras el Ma) coastline in Saïdia (Moroccan Mediterranean) between December 2023 and November 2024. Environmental parameters were simultaneously recorded in the sampling area. Results indicate that physico-chemical parameters, notably dissolved oxygen and temperature, significantly influence the condition index. The growth of this bivalve was described as isometric, meaning that weight increases proportionally to the cube of length. Age estimation identified three age classes using the Bhattacharya method. Asymptotic length ($L\infty$), growth rate (k) and theoretical age at zero size (t_0) were estimated at 44.23 mm, 0.39 years^{-1} and -0.38 years, respectively. Mortality analysis revealed a total instantaneous mortality (Z) of 1.60 years^{-1} and a natural mortality (M) of 0.74 years^{-1}. Fishing mortality (F = 0.86 years^{-1}) exceeded both the optimum fishing mortality rate (F_{opt}=0.30 years^{-1}) and the limit mortality (F_{limit} = 0.19 years^{-1}). Furthermore, the current exploitation rate ($E_{current}$ = 0.54 years^{-1}) exceeds the sustainable exploitation level (E_{50} = 0.27 years^{-1}) and slightly exceeds the maximum allowable exploitation threshold (E_{max} = 0.42 years^{-1}), indicating that *C. gallina* exploitation is reaching its maximum sustainable yield and is experiencing overfishing. Urgent management measures are therefore needed to protect the *C. gallina* stock.
Keywords: age estimation, Bhattacharya method, biometric relationships, bivalve, environmental factors.

Introduction. Artisanal fishing in the Moroccan Mediterranean is important to local populations (Benouahmane & El Alaoui 2024). This activity plays a crucial role in maintaining and developing the socioeconomic fabric of fishing communities, standing out as one of the most important in the region (Bouzaidi et al 2021). The Cap de l'Eau-Saïdia littoral zone, located in the northeast of Morocco's Mediterranean coastline, was, until 1998, one of the main shellfish production regions on a national scale (Layachi et al 2014). It was home to large natural shellfish beds, including small prairies, cockles, sea beans and varnishes. In this region, artisanal fishing activity developed particularly well thanks to the exploitation of *Chamelea gallina* (Linnaeus, 1758), a species of clam prized for its commercial value. This fishery, important to local populations, was an essential means of subsistence and largely predominated in the eastern littoral region (Layachi et al 2014).

Chamelea gallina is an infaunal bivalve species in the Veneridae family. It lives buried in sandy and muddy sediments in coastal areas, mainly in the Mediterranean (Bargione et al 2021), the Black Sea and along the western Atlantic coast. This species is a filter feeder of microorganisms suspended in water. It plays an important ecological role due to its sensitivity to environmental variations, making it a biological indicator of coastal habitat quality. Many aspects of the biology of *C. gallina* have been studied, including its distribution and general ecology (Kisseleva 1981; Scarlato & Starobogatov 1972; Chukhchin 1965). However, in several regions, there are still gaps concerning essential parameters such as the longevity, age and growth rate of this species (Boltacheva & Mazlumyan 2003). These elements need to be studied in greater depth to gain a better understanding of population dynamics.

This keystone species colonizes coastal areas to a depth of 20 meters, with a marked preference for sandy bottoms (Deval & Oray 1998). Its range covers a vast area along the coasts of the eastern Atlantic, including the British Isles, Norway, Portugal, Morocco and the Canary Islands, as well as the maritime regions of the Adriatic, Black and Mediterranean seas (Fischer et al 1987; Deval 2001).

In the Moroccan Mediterranean, *C. gallina* populations face increasing pressure from fishing and environmental change, making it crucial to study their dynamics. The study of *C. gallina* growth provides a better understanding of the factors influencing its development. This knowledge is fundamental to establishing sustainable management models and preserving this species in the context of potential overexploitation. In this context, the present study aims to analyze the growth and age of *C. gallina* in Moroccan Mediterranean waters, considering environmental parameters and fishing practices. The results will contribute to a better understanding of the species' biology and provide relevant data to guide conservation and sustainable management strategies.

Material and Method

Description of the study sites. The Cap de l'Eau-Saïdia area, located in northeastern Morocco in the western Mediterranean basin (35°5' N, 2°13' W), has a coastline stretching for more than 20 km, from the mouth of the Oued Kiss to the port of Cap de l'Eau (Figure 1). This sandy coastline, oriented generally along an ESE-WNW axis, is characterized by a gently sloping beach, varying in width from 150 to 200 m in places, and a concave-shaped foreshore (Layachi et al 2014).

The study area is characterized by fine sandy-muddy bottoms and a temperate climate, with an average annual temperature of 18°C. The region's climate is marked by high inter-annual and intra-seasonal precipitation variability and a summer dry season (Lasgaa 2018). In recent years, the area has experienced an intensification of prolonged drought periods, exacerbating the already marked characteristics of a Mediterranean climate.

Biological sampling. A total of 1687 individuals of Chamelea gallina were collected along the Cap de l’Eau-Saïdia coast between December 2023 and November 2024. Of these, 360 individuals were selected for detailed biometric analysis, while the full sample was used for size structure and age-frequency analyses. Samples were taken using a hull dredge at depths ranging from 5 to 10 m.

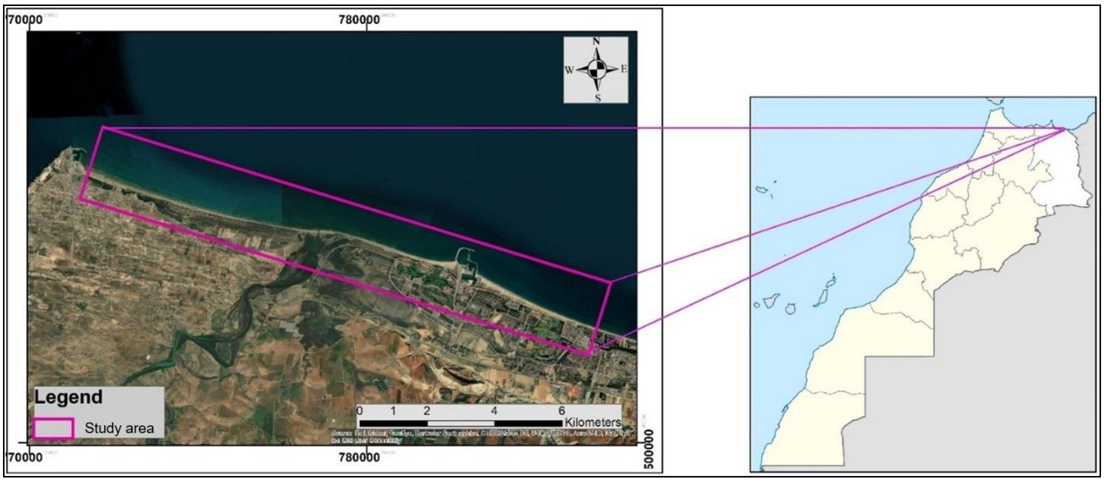

Figure 1. Study area location on Morocco's Mediterranean coast (map generated using ArcGIS 8.1).

Biometric study. In the laboratory, all individuals collected were measured and weighed. Length (L), height (H) and thickness (E) were measured with an electronic calliper to the nearest 0.01 mm, while weight measurements: total weight (Pt), wet weight (Pds Ch H) and shell weight (Pds coq) were recorded with a 0.1 mg precision balance (RADWAG, Poland).

Biometric relationships between the different dimensions of the specimens studied were established to characterize their growth. The following relationships were analyzed: length-weight, length-thickness, length-height. The degree of association between the variables was assessed using the coefficient of determination (R^2) to measure the model's goodness of fit.

The relationship between height and weight was modelled using the following equation (Ricker 1975):

$$Pt = aL^b$$

Where Pt is the total weight of the bivalve (g), L is the total length (cm), a is a constant of proportionality, and b is the coefficient of allometry.

Condition index (CI). This index was calculated according to the following equation (Simon et al 2013):

$$CI = \frac{Flesh\,weight}{Total\,weight}\,x\,100$$

Age and linear growth. Age was determined using length frequency data and applying Bhattacharya's (1967) method in FISAT II software. In population dynamics, von Bertalanffy's (1938) model is used to express linear growth mathematically, according to the equation:

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

where Lt is the length at age t, L_∞ is the maximum asymptotic length the organism would reach under ideal conditions, K is the growth coefficient (years^{-1}), represents the rate at which an organism approaches its maximum asymptotic length, t_0 is the theoretical age at which length is zero (the curve intersects the x-axis).

Based on the size-frequency distribution, the L_∞ and K parameters were obtained using the ELEFAN (Electronic Length Frequency Analysis) method, integrated into the FISAT II software. The logarithmic form of von Bertalanffy's growth equation enables us to calculate the theoretical age at zero length (t_0) using the asymptotic size (L_∞) and growth rate (k) according to the following equation (Pauly 1979):

$$\log(-t_0) = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$$

The growth performance index (Φ) is expressed as follows (Pauly & Munro 1984):

$$Ø = \log K + 2 \log L_\infty$$

Instantaneous mortality rate and exploitation ratio. Instantaneous natural mortality (M) was estimated using the following empirical equation (Pauly 1983):

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$$

where L_∞ and K are the von Bertalanffy growth parameters; T is the mean water temperature at the sampling site, considered here to be equal to 20°C, because the majority of biological activity and shellfish growth occurs during the warmer months, when water temperatures are typically higher than the annual mean. This approach allows for a more accurate estimation of natural mortality during the main growth period, as recommended in previous studies (Pauly 1983).

The following formula was used to calculate the instantaneous fishing mortality rate (F) (Beverton & Holt 1957):

$$F = Z - M$$

where Z is total mortality, and M is natural mortality.

The current exploitation rate ($E_{current}$) was estimated as F/Z, according to Gulland (1970).

Maximum fishing effort (F_{max}), precautionary reference point (F_{limit}) and optimal fishing rate (F_{opt}) were estimated using the following expressions (Hoggarth et al 2006; Patterson 1992; Pauly 1983), where LC 50 is the length at first capture.

$$F_{max} = \frac{0.67K}{0.67 - Lc}$$

$$Lc = \frac{LC50}{L_\infty}$$

$$F_{limit} = \frac{2}{3}\, x\, M$$

$$F_{opt} = 0.4\, x\, M$$

Relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R). They were analysed using the net-cut option used to calculate E_{max} known as the maximum exploitation rate, $E_{0.1}$ known as the exploitation rate that does not exceed 10% of the original stock, and $E_{0.5}$ representing the exploitation rate below which the stock is reduced to half of its original biomass.

Environmental data collection. The environmental parameters analyzed monthly in this study include pH, water temperature (T°C), chlorophyll-a (Chl-a), salinity, dissolved oxygen (O), nitrate (NO_3), and ammonium (NH_4). All data were retrieved from the Copernicus Marine Environment Monitoring Service (https://data.marine.copernicus.eu/products), ensuring spatial and temporal consistency with the biological sampling. For each month and sampling site, average values for each parameter were extracted and used in the analysis. This approach guarantees that the environmental variables precisely match the periods and areas studied for the biological component.

Statistical analysis. All statistical analyses were performed using SPSS version 25 software. For the study of allometry, the allometric coefficient b was considered a source of variation. Means were compared using the t-test, with statistical significance set at $p < 0.05$. Principal component analysis (PCA), integrating the curve of the first two principal components, and linear regression were used to compare the environmental parameters.

Results. The measurements recorded for the study population are presented in Table 1. The analyzed specimens had a total shell length between 19.97 and 39.98 mm, with a mean of 28.57 mm, and a total weight between 2.30 and 207.32 g, with a mean of 8.23 g (Table 1) .

Table 1
Morphometric parameters measured for *Chamelea gallina* between December 2023 and November 2024

Morphometric parameters	*Min - Max*	*Mean ± SD*
Length L (mm)	19.97 - 39.98	28.57 ± 3.87
Height H (mm)	16.84 - 33.95	23.93 ± 3.22
Thickness E (mm)	10.56 - 22	15.98 ± 2.28
Total weight Pt (mm)	2.30 - 207.32	8.23 ± 3.45
Flesh weight Pch (g)	0.11 - 5.188	1.37 ± 0.88
Shell weight Pcoq (g)	1.97 - 15.075	6.01 ± 2.35

Biometric relationships. Figure 2A shows the relationship between total length (mm) and total weight (g) for all individuals sampled. A strong correlation was observed, with a high coefficient of determination ($R^2 = 0.89$). The t-test applied at the 5% significance level indicates that the difference between the estimated value of b (= 2.9307) and the theoretical value of 3 is insignificant. This qualifies the relative growth as isometric, i.e., weight increases proportionately to the cube of length. A good linear correlation was also observed between height and length ($R^2 = 0.95$) and between shell thickness and length ($R^2 = 0.85$), as shown in Figure 2 B, C.

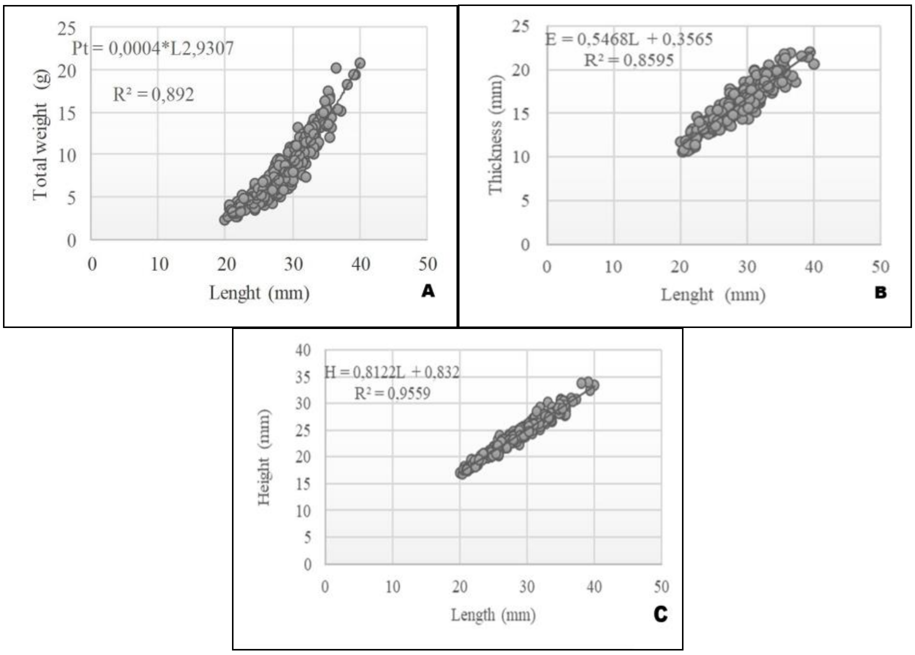

Figure 1. Biometric relationships in *Chamelea gallina* in the Cap de l'Eau-Saidia area. A: Correlation between length L (mm) and total weight Pt (g), B: Correlation between thickness E (mm) and length L (mm), C: Correlation between height H (mm) and length L (mm).

Weight gain. Figure 3a shows a seasonal variation in shell weight throughout the year, with a marked peak in January and a minimum in August. Relative stability can be observed during specific periods, particularly in spring, when shell weights reach relatively high levels, whereas in summer, these values are significantly lower. The wet weight of the flesh shows a clear seasonal variation, with a marked decrease in summer and autumn (Figure 3b). This decrease reaches its lowest point in summer, especially in July and August. The winter months (mainly January) and spring correspond to increased flesh tissue growth or maintenance. In contrast, the warmer months may be associated with reduced growth or weight loss.

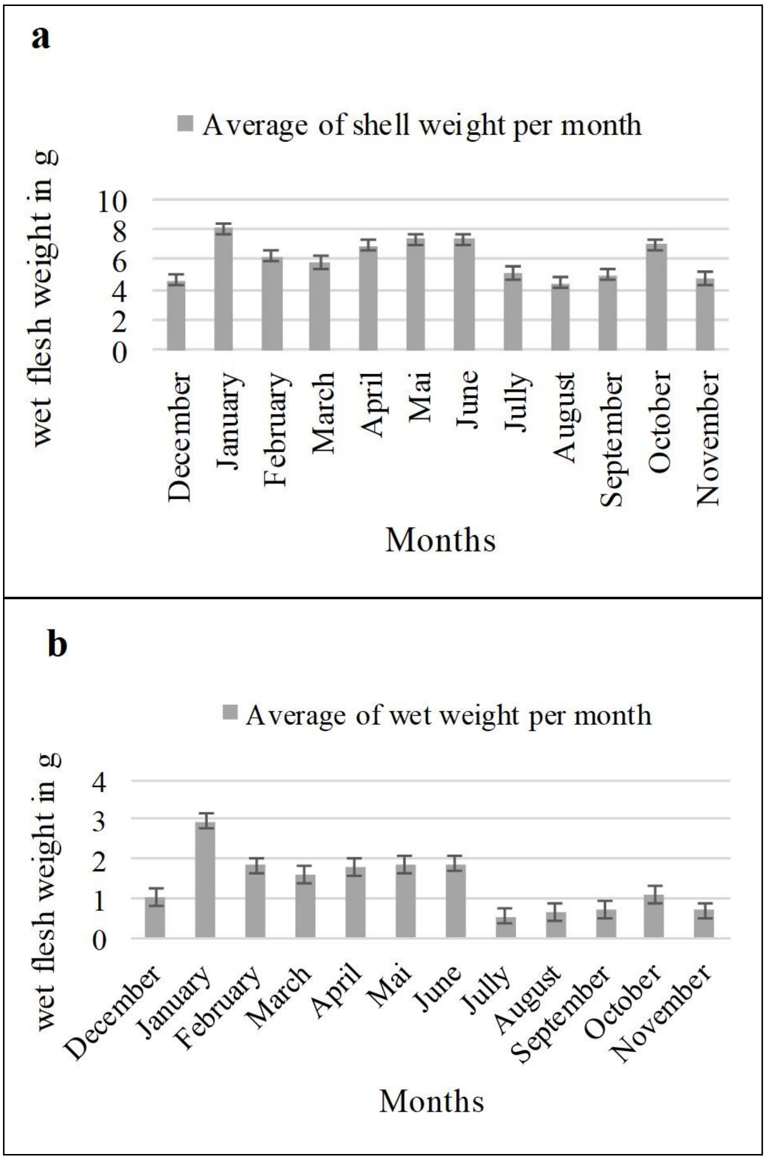

Figure 2. Monthly trends in *Chamelea gallina* shell and meat weight (mean ± SD) at the Cap de l'Eau-Saidia coastline from December 2023 to November 2024.

Condition index. The monthly evolution of the condition index (or condition factor) reveals interesting fluctuations throughout the year. The highest values of this index are recorded in winter and spring, particularly in January, when it peaked at 26.60. Conversely, the lowest values were recorded in summer and autumn, with a minimum of 9.38 in July (Figure 4).

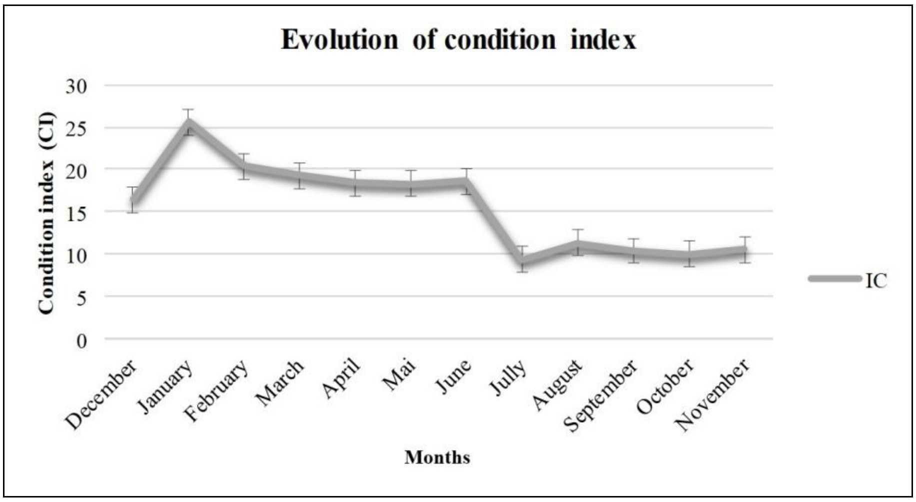

Figure 4. Evolution of the *Chamelea gallina* condition index (mean ± SD) at the Cap de l'Eau-Saidia coastline from December 2023 to November 2024.

Size structure. A total of 1,687 individuals were analyzed to characterize the size distribution of *Chamelea gallina*. Figure 5 shows the size frequencies, expressed as percentages, for classes ranging from 18.5 mm to 39.5 mm. Sizes between 20 mm and 30 mm dominate, reflecting their importance in the population and their high exploitation.

The size distribution of *C. gallina* shows a polymodal structure, indicating the coexistence of several cohorts within the population. A first mode is observed around 21-23 mm, corresponding to young individuals. A second mode, between 24 and 28 mm, reflects growing adults, while a third mode, between 30 and 33 mm, represents older, mature individuals.

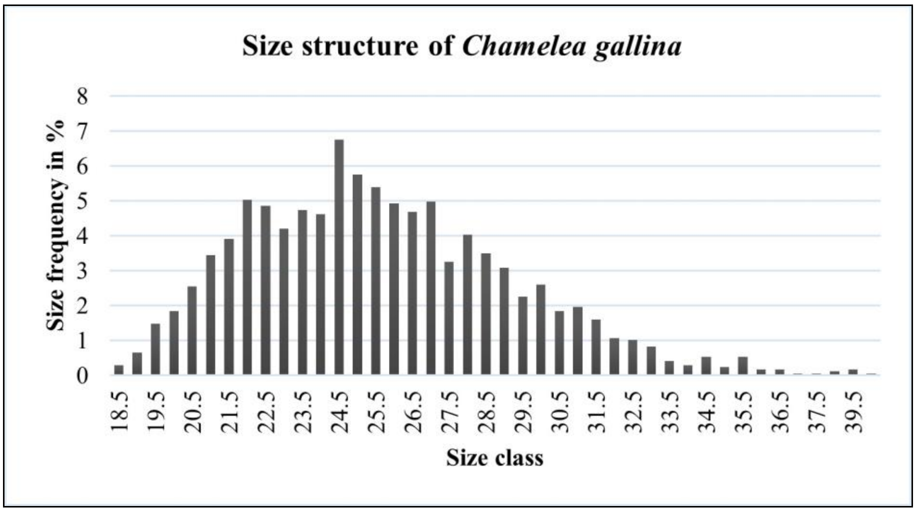

Figure 5. Size structure of *Chamelea gallina* in the eastern part of the Moroccan Mediterranean coast from December 2023 to November 2024.

Age and linear growth. Using Bhattacharya's (1967) method, we identified three cohorts corresponding to three different age groups at the study site. Based on the analysis of polymodal distributions, this method proved particularly effective in breaking down the frequency data into sizes and highlighting the different cohorts. It also allowed us to establish precise correspondences between the ages of individuals and their mean lengths, providing a solid basis for a better understanding of the species' demographic structure and growth dynamics in its natural environment. In this study, cohort 0 was not observed due to the fishing gear used, which does not allow the capture of pre-recruited individuals (Figure 6). The characteristics of each age group are presented in Table 2.

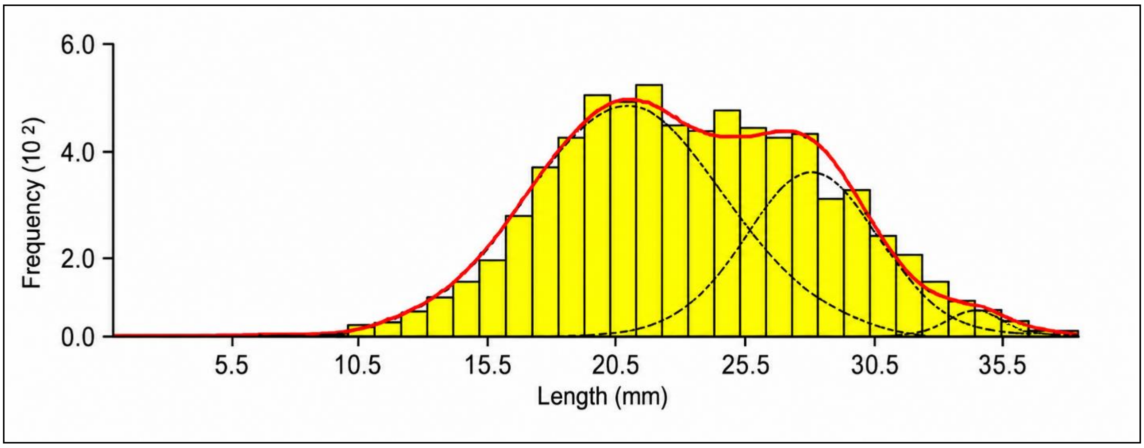

Figure 6. Length frequency distribution for the *Chamelea gallina* population (N= 1687) from December 2023 to November 2024. The curves define the cohorts determined by the Bhattacharya (1967) method.

Table 2
Mean length, standard deviation (SD) and separation index (SI) for each age group of *Chamelea gallina* obtained by the Bhattacharya (1967) method

Age (years)	*Mean length (cm)*	*SD*	*Population*		*SI*
			N	*%*	
1	23.78	2.600	1292.89	76.64	N.A
2	28.94	2.580	377.39	21.41	2.000
3	33.00	2.250	16.79	0.95	1.950

The linear growth parameters calculated for *Chamelea gallina* in the Cap de l'Eau-Saïdia area make it possible to characterize the growth dynamics of this species in the environment studied. The results obtained, which include values for the theoretical asymptotic length (L_∞), the growth coefficient (K) and the theoretical age at zero size (t_0), are detailed in Table 3. These parameters have been used to construct the von Bertalanffy (1938) growth model, which is formulated as follows:

$$Lt = 44.23\ (1 - e^{-0.39(t+0.38)})$$

Table 3
von Bertalanffy (1938) growth parameters calculated for *Chamelea gallina* in the Cap de l'Eau-Saidia area

L_∞ (cm)	*K (year-1)*	*t_0 (year)*	*Performance index (Φ)*
44.23	0.39	−0.38	2.882

Instantaneous mortality and exploitation rate. Analysis of the catch curve (Figure 7), based on length distributions (Pauly 1984), shows that total mortality (Z) is relatively high (Z = 1.60 years^{-1}), indicating significant overall pressure on the population, including fishing and natural mortality.

Natural mortality (M) is lower (M = 0.74 years^{-1}) than that of fishing mortality (F = 0.86 years^{-1}), indicating that fishing is the main cause of mortality in this population.

The exploitation rate (E) of 0.54 exceeds the value of 0.5, which is often used as an indicator of overfishing. This indicates intense exploitation, exceeding levels considered sustainable for this population.

The values for F_{opt} (0.30 years^{-1}), F_{max} (0.45 years^{-1}) and F_{limit} (0.19 years^{-1}) are all lower than the observed fishing mortality (F = 0.86 years^{-1}), confirming an overfished situation that exceeds the precautionary limits recommended to maintain the sustainability of the stock.

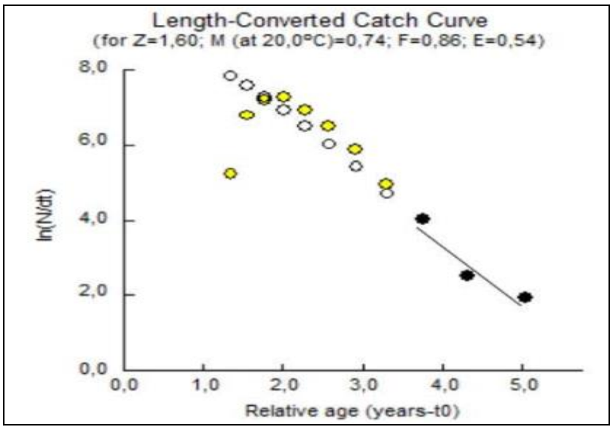

Figure 7. FiSAT II output of linearized length-converted catch curve for *Chamelea gallina* on the eastern Mediterranean coast of Morocco (Cap de l'Eau-Saidia).

Relative yield per recruit (Y'/R). Figure 8 shows the various exploitation rates determined by applying Beverton and Holt's (1957) relative yield per recruit model.

E_{max} representing the maximum yield per recruit is reached at an exploitation rate of 0.421 (E_{max}), lower than the current exploitation rate (0.54). This indicates that the population is being exploited beyond the point of optimum yield, compromising sustainable stock renewal (Figure 7).

$E_{0.5}$ estimated at 0.278, corresponds to the level of exploitation that maintains the spawning biomass at 50% of its original level. The current rate (0.54) is almost twice this value, indicating excessive pressure on the population's reproductive capacity.

$E_{0.1}$ calculated at 0.355 represents a marginal exploitation rate that provides a good compromise between yield and stock conservation. Exceeding this value by the current rate (0.54) confirms that the population is being exploited beyond the level considered sustainable and highlights the risks to the sustainability of the species.

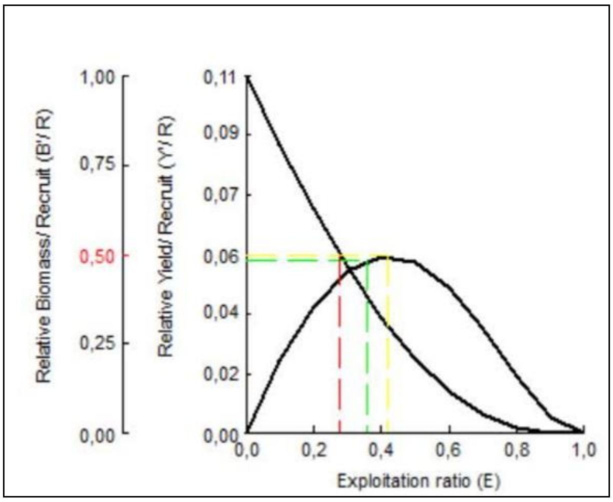

Figure 8. Relative yield (Y'/R) and relative biomass per recruit (B'/R) for *Chamelea gallina* on the Mediterranean coast of eastern Morocco (Cap de l'Eau-Saidia), showing yield index levels (red dashes = $E_{0.5}$, green dashes = $E_{0.1}$ and yellow dashes = E_{max}).

Environmental factors. The pH of the water varies throughout the year, ranging from 8.086 in February to 7.934 in August, with a general tendency to decrease slightly during the summer, especially in July and August, when it falls below 8. The water temperature follows a characteristic seasonal cycle, ranging from 16.91°C in January to a maximum of 26.08°C in August (Table 4). In summer, it favours biological growth and phytoplankton activity, while in winter it decreases, reducing biological activity.

Dissolved oxygen concentrations are relatively high in winter and spring, reaching a maximum of 250 mmol/m³ in March, and lower in summer and autumn, with a minimum of 230 mmol/m³ in August. Chlorophyll-a (Chl-a) concentrations are highest in winter, reaching 0.74 µg/L in February, before decreasing to 0.11 µg/L in September (Table 4), reflecting a significant decrease during the summer period.

Salinity remains relatively stable at around 36 PSU, with minimal seasonal variation, typical of Mediterranean waters where intense evaporation and low freshwater input are dominant factors. Nitrate concentrations are generally low, rising slightly in January and during the summer months, reaching a maximum of 0.3 mmol/m³ in September (Table 4).

Ammonium concentrations are also low, with a slight increase in January, May and July, reaching 0.1 mmol/m³. Ammonium values (Table 4), a product of the decomposition of organic matter and marine excrement, indicates good water quality here, although small seasonal variations can be observed.

Table 4

Monthly values of recorded seawater environmental parameters

	Months	*pH*	*T°C*	*Chl-a µg/L*	*Salinity PSU*	*O mmol/m3*	*NO_3 mmol/m3*	*NH_4 mmol/m3*
2023	December	8.062	18.06	0.63	36.52	242	<0.1	<0.1
2024	January	8.079	16.91	0.68	36.45	249	0.2	0.1
2024	February	8.086	16.94	0.74	36.49	248	<0.1	<0.1
2024	March	8.084	16.94	0.65	36.49	250	<0.1	<0.1
2024	April	8.04	18.36	0.55	36.38	246	<0.1	<0.1
2024	Mai	8.021	19.58	0.28	36.37	243	0.1	0.1
2024	June	8.012	21.97	0.26	36.48	241	<0.1	<0.1
2024	Jully	7.98	24.82	0.17	36.39	231	0.1	0.1
2024	August	7.934	26.08	0.17	36.35	230	0.2	<0.1
2024	September	7.961	24.5	0.11	36.32	223	0.3	<0.1
2024	October	7.998	22.23	0.19	36.29	225	0.1	0.1
2024	November	8.035	20.85	0.37	36.36	236	<0.1	<0.1

Statistical analysis using principal component analysis (PCA). Principal component analysis (PCA) reveals a strong positive correlation between the variables pH, chl-a, salinity and dissolved oxygen on the first axis, while a marked negative correlation is observed between these same variables and temperature. Furthermore, pH, chl-a, salinity and dissolved oxygen show significant positive associations with January, February, March and December (cold season), while pronounced negative correlations are highlighted with October, July, September and August (warm season), suggesting a potential influence of temperature variations. Conversely, temperature shows a strong negative correlation with these same months, indicating a relationship opposite to that of the other variables in the group. On the other hand, the nitrate variable showed a moderate correlation, while no statistically significant relationship was detected between ammonium and all the other parameters analyzed.

The factorial design composed of axes 1 and 2 (Figure 9) explains 84.133% of the total variance (Component 1 represents 68.467% of the total variance, while Component 2 represents 15.666%).

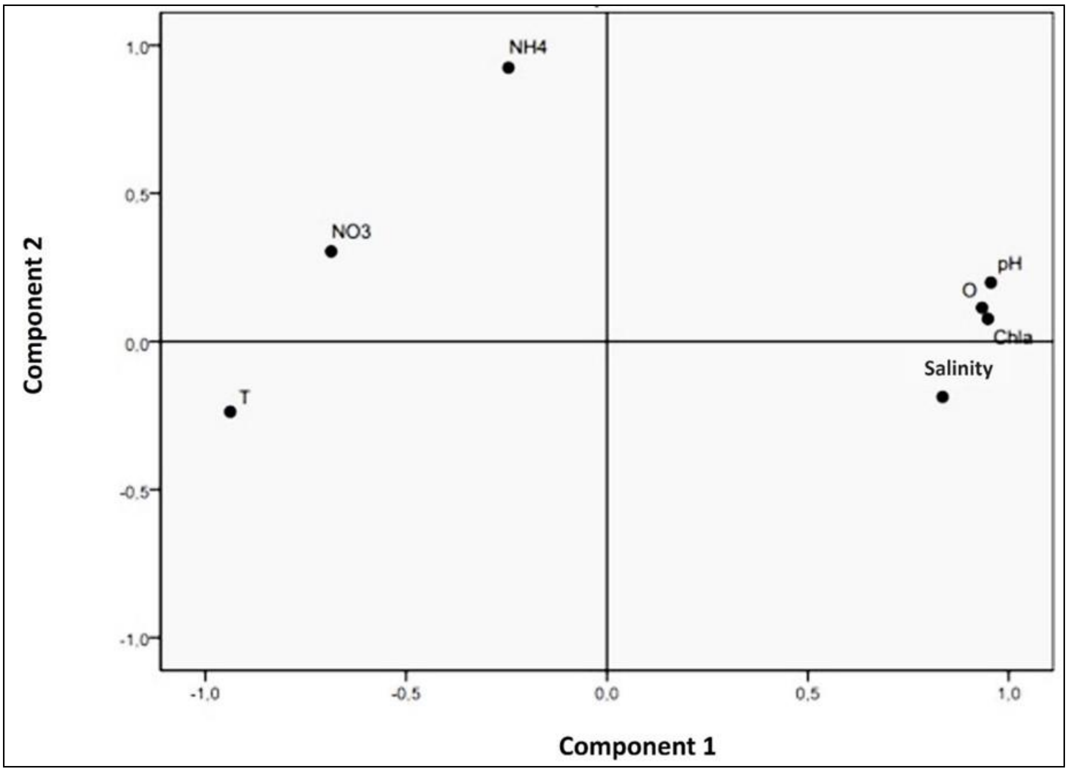

Figure 9. Analysis of environmental parameters studied.

Discussion. The growth parameters, environmental conditions and exploitation rates estimated for *Chamelea gallina* in this study provide essential information for understanding the population dynamics of this species in the eastern Mediterranean region of Morocco.

Relative growth of *Chamelea gallina*. The maximum recorded size of *Chamelea gallina* in the Moroccan Mediterranean is 28.57 mm. However, several studies report remarkable regional variations. On the southern coast of Portugal, a maximum size of 40 mm has been reported (Gaspar et al 2002), while on the Black Sea coast it reaches 31 mm (Boltacheva & Mazlumyan 2003). In the southern Adriatic, the maximum recorded size is 46.5 mm (Marano et al 1982), while in the Gulf of Trieste it is 39.6 mm (Valli & Zecchini-Pinesich 1981).

On the Mediterranean coast of Morocco, the average total weight observed is 8.23 g. Studies in the Black Sea (Turkey) have also shown variability in total weight. For example, specimens from the eastern and central coast of this region have an average weight of 1.95 ± 1.415 g (Kasapoglu & Duzgunes 2014). Similarly, in the western Marmara Sea, the total weights vary considerably, ranging from 0.3g to 21.05g (Çolakoğlu 2010).

The variations in weight and size observed in these different regions can be attributed to several specific environmental factors. Parameters such as water temperature, salinity, pH and nutrient availability play a critical role in the growth and development of bivalves (Lee et al 2024). In addition, substrate characteristics, fishing pressure and gear selectivity also contribute to the observed differences between *Chamelea gallina* populations across its range (Çolakoğlu 2010).

Comparative analysis of the length-weight relationships of *Chamelea gallina* in different regions highlights the biological and ecological variations that influence the growth of this bivalve mollusc. In particular, these variations are reflected in differences in the values of the b coefficient, which reflects the type of growth observed. In the eastern Mediterranean of Morocco, b is estimated to be 2.9307, reflecting isometric growth. Similar values are reported for the Sea of Marmara (b = 2.97) and the Algarve coast of Portugal (b = 2.80). In the Black Sea, on the other hand, the values are lower, with b = 2.37, according to Kasapoglu and Duzgunes (2014). Table 5 presents a comparative summary of length-weight relationship parameters for *Chamelea gallina* from the present study and other regions.

The observation of isometric growth for *C. gallina* in the present study, as well as for the Huelva coast (Spain), according to Delgado et al (2015), is consistent with previous work by Valli and Zecchini-Pinesich (1981), Cano and Hernández (1987). However, these results differ from those reported by Gaspar et al (2002) on the Algarve coast, where a positive allometric relationship was observed, which could be attributed to discrepancies in age assignment methods. Similarly, according to Kasapoglu and Duzgunes (2014), these differences can also be attributed to the ecological conditions specific to each region. In particular, the Black Sea, characterized by lower salinity and high anthropogenic pressure (exploitation by hydraulic dredging), could explain the relatively lower growth of individuals. On the other hand, the Mediterranean and Atlantic Seas offer more stable environmental conditions and greater trophic availability, favouring better growth of *Chamelea gallina*.

Table 5

Length-weight relationship parameters of *Chamelea gallina* estimated from the present study and other areas

Geographical area	*N*	*a*	*b*	*R²*	*References*
Eastern Mediterranean Sea (Morocco)	360	0.0004	2.9307	0.89	Present study
Black Sea (Turkey)	628	0.4520	2.37	0.954	Kasapoglu & Duzgunes 2014
Marmara Sea (Turkey)	91	0.0004	2.97	-	Tunçer & Erdemir 2002
Algarve coast (Portugal)	695	0.0007	2.80	--	Santos et al 2001
Huelva, Atlantic Ocean (Spain)	-	0.0005	2.862	0.993	Delgado et al 2015

Age and linear growth. In the Black Sea, the thin section technique applied to the shell is widely used to determine the age of individuals, providing a direct reading of internal growth rings (Boltacheva & Mazlumyan 2003). Delgado et al (2015) have used several methods in the Atlantic, including acetate fingerprint analysis and length-frequency studies. In the Mediterranean, several approaches have also been used to characterize the growth of *C. gallina*. Among these, surface ring analysis has been used by Deval and Oray (1998) and Gaspar et al (2004), while the use of acetate fingerprints has been studied by Deval (2001) and Ramón and Richardson (1992). Length-frequency analysis has been used by Gaspar et al (2004). These different methodologies (Table 6) , although aimed at the same objective, can lead to discrepancies in the estimates of the growth parameters. These discrepancies highlight the need for a standardized and comparative approach to ensure greater reliability of biological data used in managing and conservating *C. gallina* populations.

A study of growth and longevity parameters of *C. gallina* reveals marked differences between the Black Sea and Mediterranean Sea populations due to environmental factors and the age estimation techniques used. In the Black Sea, individuals grow more slowly, with a growth coefficient (K) ranging from 0.21 to 0.609. In the Mediterranean, on the other hand, growth is faster, K values are higher, reaching 0.737 on the northern Mediterranean coast of Egypt (FAO 2014). Longevity in Mediterranean populations is generally shorter, not exceeding 7 years. Populations in the western Adriatic show intermediate K values between 0.48 and 0.52 (Arneri et al 1995, 1997).

The results obtained in the Moroccan Mediterranean in this study show a high asymptotic size (L_∞ = 44.23 mm), but a reduced longevity to only 3 years, suggesting a more opportunistic life strategy. This trend indicates that Mediterranean populations, which evolved in warmer, more productive waters, favour rapid growth at the expense of longevity. Conversely, the Black Sea's colder, less saline conditions slow down growth but allow individuals to survive longer.

Table 6

Comparison of growth parameters and age estimation with the method used in other studies in different geographical areas

Geographical area	L_∞ *(mm)*	*K (years⁻¹)*	*Age (years)*	*Method used*	*Reference*
Eastern Mediterranean Sea of Morocco	44.23	0.39	3	Bhattacharya (1967)	Present study
Western Marmara Sea (Turkey)	33.05	0.39	-	-	Çolakoğlu 2010
Mediterranean Sea (Egypt)	38.84	0.737	7	-	FAO 2014
Black Sea (Russia)	27.25	0.609	9	Thin sections	Boltacheva & Mazlumyan 2003
Northern Marmara Sea (Turkey)	34.17	0.43	5	Surface rings	Deval & Oray 1998
Northern Marmara Sea (Turkey)	33.46	0.37	7	Acetate peels	Deval 2001
Western Adriatic (Italy)	41.6	0.48	-	Thin sections	Arneri et al 1995
Western Adriatic, Neretva Estuary (Croatia)	39.5	0.52	-	Thin sections	Arneri et al 1997
Western Mediterranean (Spain)	36.12	0.35	4	Acetate peels	Ramón & Richardson 1992
Algarve coast (Portugal)	37.55	0.71	5	Surface rings	Gaspar et al 2004
Algarve coast (Portugal)	38.95	0.47	4	Acetate peels	Gaspar et al 2004
Algarve coast (Portugal)	42.15	0.32	5	Length frequency	Gaspar et al 2004
Huelva, Atlantic Ocean (Spain)	36.11	0.79	5	Acetate peels	Delgado et al 2015
Huelva, Atlantic Ocean (Spain)	44.30	0.38	3	Length frequency	Delgado et al 2015

Weight gain. Comparative analysis of the meat and shell weights of *Chamelea gallina* from different geographical areas reveals marked variations due to various environmental and anthropogenic factors. The data show that *C. gallina* specimens from the eastern Mediterranean coast of Morocco have an average total weight of 8.23 g, including 1.37 g for the meat and 6.01 g for the shell, with an average length of 28.57 mm.

Other studies have reported contrasting values depending on the region studied. In Egypt, *C. gallina* specimens with an average total weight of 7.05 g, a flesh weight of 1.35 g and a shell weight of 5.30 g have an average length of 26.87 mm (FAO 2014). In the Marmara Sea, a previous study recorded specimens with an average length of 25.20 mm, with average flesh and shell weights of 1.56 g and 5.27 g, respectively (Tunçer & Erdemir 2002). On the other hand, the values recorded in the Adriatic Sea are also variable, with average flesh and shell weights of 2.9 g and 5.4 g (Manca Zeichen et al 2002). A comprehensive summary of the comparative data from various regions is provided in Table 7.

Table 7

Comparison of weight parameters with other studies

Geographical area	*Length (mm)*	*Total weight (g)*	*Meat weight (g)*	*Shell weight (g)*	*Reference*
Mediterranean Sea (Morocco)	28.57	8.23 ± 3.45	1.37	6.01	Present study
Mediterranean Sea (Egypt)	26.87	7.05	1.35	5.30	FAO 2014
Eastern and Central Black Sea (Turkey)	17.6	1.95 ± 1.415	-	-	Kasapoglu & Duzgunes 2014
Marmara Sea (Turkey)	25.20	6.84	1.56	5.27	Tunçer & Erdemir 2002
Southern Adriatic Sea (Italy)	46.5	-	-	-	Marano et al 1982
Gulf of Trieste (Italy)	39.6	-	-	-	Valli & Zecchini-Pinesich 1981
Algarve Coast (Portugal)	40	-	3.2	5.6	Gaspar et al 2002
West Marmara Sea (Turkey)	23.9	0.3 - 21.05	-	-	Çolakoğlu 2010
Adriatic Sea (Italy)	-	-	2.9	5.4	Manca Zeichen et al 2002
Black Sea (Turkey)	31	-	-	-	Boltacheva & Mazlumyan 2003

Condition index. This study's condition index (CI) shows a marked seasonal variation. This index reaches its highest values in winter (especially in January), indicating an optimal physiological state for *C. gallina* individuals at the beginning of the year. This period probably corresponds to favourable environmental conditions, particularly an increase in food resources. Indeed, a high chlorophyll-a concentration is recorded during these months, indicating an increased abundance of phytoplankton. The abundance of phytoplankton is an essential food resource for these filter-feeding organisms, promoting growth and the accumulation of body reserves. From March onwards, the CI gradually decreases and stabilizes between May and November. This may be related to higher temperatures during the warmer months, such as July and August. High temperatures can accelerate the metabolism of organisms, reducing their ability to accumulate body reserves. This period is also characterized by a decrease in chlorophyll-a concentration, indicating a reduction in phytoplankton resources. This reduction in food abundance can directly impact individuals' physical condition, limiting their ability to maintain an optimal state.

The seasonal variation in the condition index of *C. gallina* observed in this study is consistent with results reported from different regions. Moschino et al (2006) showed that condition indices of *C. gallina* populations from the Black Sea were highest in winter and decreased significantly during the summer. Similarly, on the Algarve coast of Portugal, higher CI values were observed during colder months (Gaspar et al 2004). Seasonal patterns have also been reported in other Mediterranean and Atlantic regions, typically with lower CI during the spawning season or warmer periods. These authors attributed this trend to the lower metabolic activity of bivalves during this period, favouring body reserves accumulation. The similarities between these studies and the results obtained on the Moroccan Mediterranean coast highlight the importance of considering the seasonal variation of the condition index in fisheries management strategies. A better understanding of these cycles could contribute to the sustainability of stocks by adapting fishing seasons to the optimum state of the population.

Conclusions. This study provides an in-depth analysis of the growth and seasonal variation of the condition index of *Chamelea gallina* along the Cap de l'Eau-Saidia coast in the Moroccan Mediterranean. The results highlight the role of environmental factors such as temperature, dissolved oxygen and phytoplankton availability in determining the growth and physiological condition of the species. These observations provide valuable insights into the ecological mechanisms affecting this species and highlight the importance of appropriate management strategies. The study also provides an analysis of the current state of exploitation of *Chamelea gallina*, the results of which reveal a situation of overexploitation of its stock in this region due to excessive fishing pressure. Given this worrying situation, it is essential to implement stricter management measures to reduce fishing pressure and exploitation rates. These measures are crucial to prevent stock collapse and ensure this fishery's long-term sustainability while helping preserve the ecological balance and local economic activities.

Authors Contributions. Conceptualization: AK, SA. Methodology: AK, SA. Software: AK, SA, DS, NK, ME. Formal Analysis: AK, SA, DS, RM, IE, NK. Review and Editing: AK, SA. Supervision: SA, YS.

Conflict of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding. This research received no external funding.

References

Arneri E., Froglia C., Polenta R., Antolini B., 1997 Growth of *Chamelea gallina* (Bivalvia: Veneridae) in the Eastern Adriatic (Neretva River Estuary). Tisuc´u Godina Prvoga Spomena Ribarstva u Hrvata 597:669–676.

Arneri E., Giannetti G., Polenta R., Antolini B., 1995 Age and growth of *Chamelea gallina* (Bivalvia: Veneridae) in the Central Adriatic Sea obtained by thin sections. Rapp Comm Int Mer Méditerranée 34:1–17.

Bargione G., Donato F., Barone G., Virgili M., Penna P., Lucchetti A., 2021 *Chamelea gallina* reproductive biology and Minimum Conservation Reference Size: implications for fishery management in the Adriatic Sea. BMC Zoology 6:32. https://doi.org/10.1186/s40850-021-00096-4

Benouahmane S., El Alaoui A., 2024 [Adaptation to the impacts of climate change: strategies for artisanal fishers in the Moroccan Mediterranean]. Revue Dossiers De Recherches En Économie Et Management Des Organisations 9(1):41–55. [in French]

Beverton R. J. H., Holt J. S., 1957 On the dynamics of exploited fish populations. Fisheries Investigations, Series II, Vol. 19. Ministry of Agriculture, Fisheries and Food, London. 533 pp.

Bhattacharya C., 1967 A simple method of resolution of a distribution into Gaussian components. Biometrics 23(1):115–135.

Boltacheva N. A., Mazlumyan S. A., 2003 The growth and longevity of *Chamelea gallina* (Mollusca, Veneridae) in the Black Sea. Vestn Zool 37(3):71-74.

Bouzaidi H., Maatouk M., El Moumni B., Haroufi O., Saber M. A., AbouElmaaty E. E., Daoudi M., 2021 Population structure, age and growth of *Callista chione* (Bivalvia: Veneridae) in Martil Coast of the Western Mediterranean. Reg Stud Mar Sci 48:101996. https://doi.org/10.1016/j.rsma.2021.101996

Cano F. V., Hernández J. M., 1987 [Biometrics and reproduction of *Chamelea gallina* L. in the Bay of Mazarrón (SE of the Iberian Peninsula) and some considerations on its fishing]. FAO Fish Rep 395:107–111. [in Spanish]
Chukhchin V. D., 1965 [Reproductive biology of *Venus gallina* L. (Lamellibranchiata) in the Black Sea. In Benthos]. Kiev: Naukova Dumka. 15–23 pp. [in Russian]
Çolakoğlu S., 2010 [Some population parameters of white clam (*Chamelea gallina* L., 1758) in Western Marmara]. Turk J Fish Aquat Sci 27(2):65–71. [in Turkish]
Delgado M., Silva L., Moura P., Sánchez-Leal R. F., Gaspar M. B., 2015 Variation of growth performance of the striped venus clam *Chamelea gallina* (Mollusca: Bivalvia) (Linnaeus, 1758) in relation to environmental variables along the southern part of its geographic range. Vie Et Milieu-Life and Environment 65(4):201-210.
Deval M. C., 2001 Shell growth and biometry of the striped venus *Chamelea gallina* (L.) in the Marmara Sea, Turkey. Journal of Shellfish Research 20:155–159.
Deval M. C., Oray I. K., 1998 The annual shell increments of Bivalvia *Chamelea gallina* L. 1758 in the northern Sea of Marmara. Oebalia 24:93–109.
Fischer W., Bauchot M. L., Schneider M., 1987 [FAO species identification sheets for fisheries purposes (Revision 1), Mediterranean and Black Sea, Fishing Area 37, plants and invertebrates. Publication prepared by FAO, result of an agreement between FAO and the Commission of the European Communities (Project GCP/INT/422/EEC) jointly funded by these two organizations]. Rome, FAO, 1.2:761-1530.
Gaspar M. B., Pereira A. M., Vasconcelos P., Monteiro C. C., 2004 Age and growth of *Chamelea gallina* from the Algarve coast (Southern Portugal): influence of seawater temperature and gametogenic cycle on growth rate. J Molluscan Stud 70(4):371–377.
Gaspar M. B., Chícharo L. M., Vasconcelos P., Garcia A., Santos A. R., Monteiro C. C., 2002 Depth segregation phenomenon in *Donax trunculus* (Bivalvia: Donacidae) populations of the Algarve coast (south- ern Portugal). Scientia Marina 66:111–121.
Gulland J. A., 1970 The fish resources of the ocean. FAO Fisheries Technical Paper No. 97. FAO, Rome. 425 pp.
Hoggarth D. D., Abeyasekera S., Arthur R. I., Beddington J. R., Burn R. W., Halls A. S., Kirkwood G. P., McAllister M., Medley P., Mees C. C., Parkes G. B., Pilling G. M., Wakeford R. C., Welcomme R. L., 2006 Stock assessment for fishery management: A framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP). FAO Fisheries Technical Paper No. 487. FAO, Rome, Italy. 261 pp.
Kasapoglu N., Duzgunes E., 2014 Length-weight relationships of marine species caught by five gears from the Black Sea. Mediterranean Marine Science 15(1):95–100.
Kisseleva M. I., 1981 [The benthos of soft bottom sediment of the Black Sea]. Kyiv: Naukova Dumka. 168 pp. [in Russian]
Lasgaa H., 2018 [Evaluation of longshore-cross-shore sediment transport along the Saidia-Cap de l'Eau coastline (Northeast Morocco)]. Revue Marocaine de Géomorphologie 1:1-17. [in French]
Layachi M., Bouthir F. Z., Benbrahim S., Chiaar A., Chfiri R., El Madani F., Azzaoui Y., 2014 [Study of the bacteriological and chemical health status of the Ras Kebdana-Saïdia coastline (eastern Moroccan Mediterranean coast)]. Environ Sci 5(S1):2176–2183. [in French]
Lee R. P.-T., Lin Y.-R., Huang C.-Y., Nan F.-H., 2024 Effects of nutrient source, temperature, and salinity on the growth and survival of three giant clam species (Tridacnidae). Animals 14(7):1054. https://doi.org/10.3390/ani14071054
Manca Zeichen M., Agnesi S., Mariani A., Maccaroni A., Ardizzone G. D., 2002 Biology and population dynamics of *Donax trunculus* L. (Bivalvia: Donacidae) in the South Adriatic Coast (Italy). Estuarine, Coastal Shelf Science 54(6):971–982.
Marano G., Casavola N., Saracino C., Rizzi E., 1982 [Reproduction and growth of *Chamelea gallina* and *Venus verrucosa* (Bivalvia: Veneridae) in the Lower Adriatic]. Memorie di Biologia Marina e di Oceanografia 12:93–110. [in Italian]

Moschino V., Chicharo L. M. Z., Marin M. G., 2006 Seasonal changes in physiological responses and evaluation of "well-being" in the Venus clam *Chamelea gallina* from the Northern Adriatic Sea. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 145(4):433-440.
Patterson K., 1992 Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish Biology and Fisheries 2:321–338.
Pauly D., 1983 Some simple methods for the assessment of tropical fish stocks. FAO Rome 234. 52 pp.
Pauly D., 1979 Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula. Ber Inst Meereskunde 63. 156 pp.
Pauly D., Munro J., 1984 Once more on the comparison of growth in fish and invertebrates. Fishbyte 2:1–21.
Ramón M., Richardson C. A., 1992 Age determination and shell growth of Chamelea gallina (Bivalvia: Veneridae) in the western Mediterranean. Marine Ecology Progress Series 89:15–23.
Ricker W. E., 1975 Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:1–382.
Santos M. N., Gaspar M. B., Vasconcelos P., Monteiro C. C., 2001 Weight–length relationships of 50 selected fish species of the Algarve coast (southern Portugal). Fisheries Research 50(3):289–295.
Scarlato O. A., Starobogatov Y. E., 1972 [Class Bivalvia. In Keys to the Fauna of the Black and Azov Seas]. Naukova Dumka. 178–249 pp. [in Russian]
Simon K., Mazlan A., Cob Z., 2013 Condition factors of two archerfish species from Johor coastal waters, Malaysia. Sains Malaysiana 42:1115–1119.
Tunçer S., Erdemir C. C., 2002 A preliminary study on some properties for *Chamelea gallina* (L.) (Bivalvia: Veneridae) from Karabiga-Canakkale. Turk J Fish Aquat Sci 2(2):117–120.
Valli G., Zecchini-Pinesich G., 1981 [Some aspects of reproduction and biometry of *Chamelea gallina* (Mollusca: Bivalvia) in Gulf of Trieste]. Nova Thalassia 5:57–73. [in Italian]
von Bertalanffy L., 1938 A quantitative theory of organic growth (inquiries on growth laws II). Human Biology 10:181–213.
*** Copernicus Marine Environment Monitoring Service. Accessed on 31 October 2024. Available at https://data.marine.copernicus.eu/products
*** Food and Agriculture Organization (FAO) EastMed, 2014 A study to investigate the potential exploitation of the Venus clam *Chamelea gallina* in Egypt. Food and Agriculture Organization of the United Nations GCP/INT/041/EC – GRE – ITA/TD-20. 85 pp.

Received: 08 October 2025. Accepted: 11 December 2025. Published online: 22 May 2026.
Authors:
Amira Kharkhache (AK), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: amira.kharkhache@ump.ac.ma
Souad Abdellaoui (SA), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: abdellaoui.souad01@gmail.com
Douaa Slimani (DS), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: douaaslimani2@gmail.com
Imane El Khamlichi (IEK), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: el.imanekhamlichi@gmail.com
Rajae Mouedden (RM), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: mouedden.rajae@gmail.com
Nassir Kaddouri (NK), Department of Biology, Biodiversity, Ecology and Genomics Laboratory, Faculty of Sciences, Mohammed V University, Rabat, Avenue Ibn Battouta, B.P. 1014, 10000, Rabat, Rabat-Salé-Kénitra Region, Morocco, e-mail: kaddouri.nassir@gmail.com
Mohammed ElYakoubi (ME), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: elyakoubimed@gmail.com
Youssef Smiri (YS), Laboratory for the Improvement of Agricultural Production, Biotechnology and the Environment, Faculty of sciences, Mohammed First University, B.P. 717, 60000 Oujda, Oriental Region, Morocco, e-mail: smiriy@yahoo.fr

How to cite this article:
Kharkhache A., Abdellaoui S., Slimani D., El Khamlichi I., Mouedden R., Kaddouri N., ElYakoubi M., Smiri Y., 2026 Age, growth and exploitation of *Chamelea gallina* (Linnaeus, 1758) on the eastern Mediterranean coast of Morocco. AACL Bioflux 19(3):1040-1057.