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Age, growth, mortality and population structure of *Polititapes aureus* (Mollusca: Bivalvia) in the Gulf of Gabes, Tunisia

by

Abdelkarim Derbali*

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Institut National des Sciences et Technologies de la Mer (INSTM), Sfax, Tunisia

* *derbali10@gmail.com*

Abstract

The population dynamics of *Polititapes aureus* from Tunisia were investigated monthly during a one-year period (2018). The possible future commercial benefits of the species as a significant resource of artisanal fisheries require better knowledge of its population dynamics. This study provides the first insight into population parameters by investigating its population structure, growth, mortality, and exploitation rate. Allometric relationships between body size and length were determined. The shell length/total weight ratio indicated a positive allometric growth and was expressed as *TW* = 0.0002 SL3.103. Length frequency data were analyzed to estimate population parameters using FiSAT II software. *P. aureus* showed lower growth rate (K = 0.46 yr^{-1}) and asymptotic length (L_∞ = 38.80) compared to those obtained for other bivalve species (mean values: K = 0.61 and L_∞ = 55.02). Longevity (T_{max}) and the growth performance index (φ′) were 7.95 yr^{-1} and 2.84, respectively. Total mortality (Z) was estimated from the length-converted catch curve at 0.85 yr^{-1} and fishing mortality (F) at 0.03 yr^{-1}. Both values of natural mortality (M = 0.82 yr^{-1}) derived from bivalve literature and based on Pauly's (1980) empirical equation (M = 0.83 yr^{-1}) developed for fish were comparable. The most intensive growth occurred during the first three years. The data presented herein are crucial for appropriate fisheries management and conservation of clams.

Key words: *Polititapes aureus*, population structure, age, growth, mortality, Gulf of Gabes

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1. Introduction

The venerid *Polititapes aureus* (= *Venerupis aurea*) (Gmelin 1971) is native to the Mediterranean Sea and occurs throughout Western Europe (World Register of Marine Species; https://www.marinespecies.org). It colonizes the intertidal zone of the Gulf of Gabes, including wide mudflats and sandy beaches favorable for infaunal bivalves (Ben Salem et al. 2002). Populations of *P. aureus* occur in sandy and silty-sandy sediments in estuaries, bays and coastal lagoons from mid-tide to shallow subtidal levels. In areas where the resources are found, the clam *P. aureus* has often attracted considerable attention from researchers because of its economic potential (Kandeel 2013; Fouda M.M. & Abou-Zied M.M. 1990; Kandeel 2018).

Even with the growing socio-economic importance of invertebrate fisheries, knowledge of the biology of commercial species is insufficient (Anderson et al. 2011). Moreover, despite the ecological importance of invertebrates, their harvesting often occur without regulation, monitoring and assessment (FAO 2009). In Tunisia, commercial bivalve fisheries constitute a cultural, social and economic resource for numerous coastal communities. Accordingly, further research on the growth of commercial species is required to implement management measures aimed at promoting the sustainable exploitation of shellfish resources.

In Tunisia, *P. aureus* has not been exploited despite its importance as a major component of the benthic fauna. From the available literature, it appears that several studies were conducted on the clam *P. aureus* in the Mediterranean and Adriatic seas. They focused on various aspects of its biology and ecology, namely reproductive biology, population dynamics, population structure and genetics (Corni & Trentini1990; Fouda & Abou-Zied 1990; Kandeel 2006; 2008; 2013; 2018; Mohammad et al. 2014; Derbali 2022). However, no data are currently available on the growth and age parameters of *P. aureus* from the Gulf of Gabes. In Tunisia, the shellfish trade has so far only been interested in the clam *Ruditapes decussatus* (Linnaeus, 1758), which has been heavily exploited (Gharbi et al. 2023). To avoid a stock decline, the Tunisian shellfish industry seeks to diversify their catch by focusing on other species that are not fished. However, the suitability and resilience of these species to fishing should first be properly assessed. Previous studies have quantified the stock assessment and reproductive biology of *P. aureus* from the southern part of Tunisia (Derbali & Jarboui 2021; Derbali 2022), but individual growth rates and population age structure remain completely unknown. Therefore, the present study is the first attempt to estimate the population structure, age, growth and mortality.

2. Materials and methods

2.1. Study area

The study area is located in the southern Tunisian waters (Fig. 1). The bottom slopes gradually toward the sea, with a depth of 60 m at a distance of 110 km off the coast (Ben Othman 1973). The substrate in the coastal zone of Sfax, covered in some areas by the seagrasses *Cymodocea nodosa* (Ucria) Asch. and *Zostera noltei* Hornemann, 1832, is mostly silty sand (Derbali & Jarboui 2021). The climate is dry, due to the effect of hot winds (Sirocco). Tides are semidiurnal, with a high tide of +1.60 m and a low, spring tide of +0.30 m (Zaghden et al. 2014).

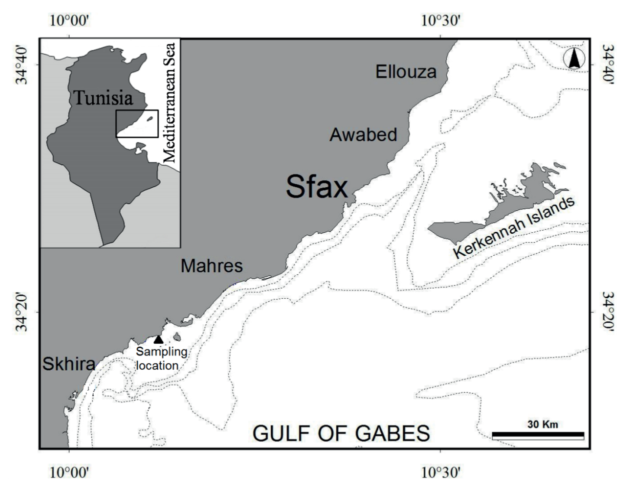

Figure 1

Map of the study area indicating the sampling location in the Gulf of Gabes.

2.2. Sampling and laboratory procedure

Polititapes aureus individuals were collected monthly in the littoral zone of the Gulf of Gabes (southern Tunisia) from January to December 2018. Sampling was performed during low tides. Approximately 110 specimens were sampled monthly in 4 to 10 quadrats (0.25 m^2) using a shovel from the shore to a depth of 1 m. Large and small specimens were collected by hand and using a 2 mm mesh sieve, respectively. Seawater temperature and salinity were recorded at the time of clam collection using a multi-parameter kit (Multi 340 i/SET). Samples were measured in the laboratory for shell length (*SL*, mm), shell height (*SH*, mm) and shell width (*SW*, mm) using a digital caliper (0.01 mm accuracy), and for total weight (*TW*, g) using a top-loading digital balance (0.001 g accuracy).

2.3. Data analysis

2.3.1. Relative growth

Morphometric relationships between shell dimensions and total weight versus shell length of the *P. aureus* population were performed by fitting a linear function to the data:

$$log\ Y = log\ a + b\ log\ X$$

where *Y* (SH, SW, or TW) and *X* (SL) are the dependent and independent variables, respectively; a and b are the intercept (initial growth coefficient) and slope (relative growth rate of the variables) of the linear regression line, respectively. The deviation of the *b* value of the regression function from the isometric hypothetical value was analyzed using Student's t-test. The type of allometry depends on whether the two variables (X, Y) have the same units of measurement (isometric when $b = 1$; negative allometric when $b < 1$; positive allometric when $b > 1$), or different ones (isometric when $b = 3$; negative allometric when $b < 3$; positive allometric when $b > 3$).

2.3.2. Age and absolute growth

Length–frequency data were analyzed using FiSAT II software (Gayanilo et al. 2005). Clams were grouped into shell length classes and divided into cohorts at 1 mm intervals. The asymptotic shell length (L_∞, mm) and the growth coefficient (K, yr^{-1}) of the von Bertalanffy Growth Function (VBGF) were estimated using ELEFAN-I (Pauly & David 1981). The VBGF is defined by the equation:

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right]$$

where L_t = mean length at age *t*, L_∞ = asymptotic shell length, *K* = growth coefficient, *t* = age, and t_0 = hypothetical age at which length is zero (Pauly & David 1981); here $t_0 = 0$.

Growth performance is a relevant parameter closely related to the population dynamics of benthic macroinvertebrates (Brey 1999). In this study, the growth performance index (φ') was used to compare the growth parameters obtained in this work with literature data on *P. aureus* populations.

L_∞ and *K* were used to compute the growth performance index φ' (Pauly & Munro 1984) using the following equation:

$$\Phi' = log\ (K) + 2\ log\ (L_\infty)$$

The equation of Michaelson & Neves (1995) was applied to calculate the theoretical maximum age (T_{max}):

$$T_{max} = \frac{ln\ L_\infty + K\ t_0}{K}$$

2.3.3. Mortality rate

Mortality is an important aspect in the dynamic population of bivalve species. Total mortality (*Z*, yr^{-1}) was estimated from the slope of the right descending arm of the length-converted catch curve (Pauly 1990) using FiSAT II, which calculates *Z* $year^{-1}$, as well as 95% confidence intervals surrounding *Z* based on the goodness of fit of the regression. The estimate of natural mortality (*M*) was obtained by averaging *M/K* values from bivalve literature and multiplying them by the *K* value derived from this study. Once *Z* and *M* were obtained, fishing mortality (*F*, yr^{-1}) was estimated using the relationship: $F = Z – M$. The exploitation rate (*E*) is the portion of total mortality caused by fisheries. It was obtained from the relationship proposed by Gulland (1971):

$$E = \frac{F}{Z} = \frac{F}{(M+F)}$$

3. Results

3.1. Morphometric relationships

Allometric relationships between body size and length of *P. aureus* from the coast of the Gulf of Gabes (Table 1) showed a strong significant correlation between shell length (*SL*, mm) and total weight (*TW*, g), and between shell length (*SL*, mm) and shell width (*SW*, mm) ($R^2 > 0.92$; $p < 0.001$), indicating a positive allometric growth pattern. For the relationship between shell length and shell height, the slope (b) of the linear regression significantly deviated from 1 ($p < 0.05$), indicating a negative allometric growth pattern.

3.2. Population structure

A total number of 1333 specimens of *P. aureus* were harvested from the southern part of Tunisia. The size range of specimens ranged from 4.90 to 35.34 mm *SL*.

Table 1

Allometric relationships between body size and shell length of *Polititapes aureus* collected from southern Tunisia (NS = not significant; S = significant at $p < 0.05$).

Allometric relation	a	b	Determination coefficient (r^2)	Significance	Relationship (*t*-test)
SH/SL	0.743	0.977	0.955	S	negative allometry
SW/SL	0.379	1.027	0.927	S	positive allometry
TW/SL	0.0002	3.103	0.952	S	positive allometry

The mean size of the length distribution was 22.15 ± 0.29 mm *SL*. The majority of the clam population (90%) belongs to size classes between 14 and 30 mm, while the smallest (values) and largest (values) individuals account for only 6.5% and 3.5% of all samples, respectively (Fig. 2).

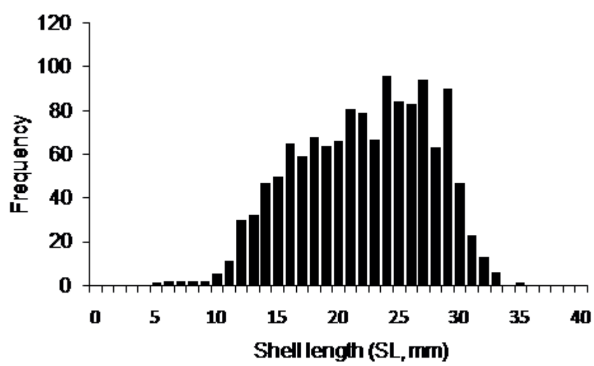

Figure 2

Length–frequency distribution of *Polititapes aureus* shells in the Gulf of Gabes.

3.3. Absolute growth and age

Monthly length–frequency data were entered into FiSAT software and the extreme value theory was used to determine the maximum length (L_∞) from the extreme values. The computed growth curves for *P. aureus* estimated by ELEFAN-I are shown over the restructured length–frequency distribution in Figure 3. Three cohorts were observed in the *P. aureus* population. The estimated asymptotic length (L_∞) and growth coefficient (K) of the von Bertalanffy Growth Formula (VBGF) by ELEFAN-I were 38.80 mm and 0.46 yr^{-1}, respectively. The growth performance index (Φ′) was 2.84 and the theoretical maximum age (T_{max}) was 7.95 yr. The achieved sizes of individuals of the clam population at the end of the 1st, 2nd, 3rd, 4th, 5th and 6th year of life were 14.31, 23.34, 29.04, 32.64, 34.91 and 36.34 mm, respectively (Fig. 4).

3.4. Mortality and exploitation rate

Using the length-converted catch curve, the total mortality (Z) of *P. aureus* was estimated at 0.85

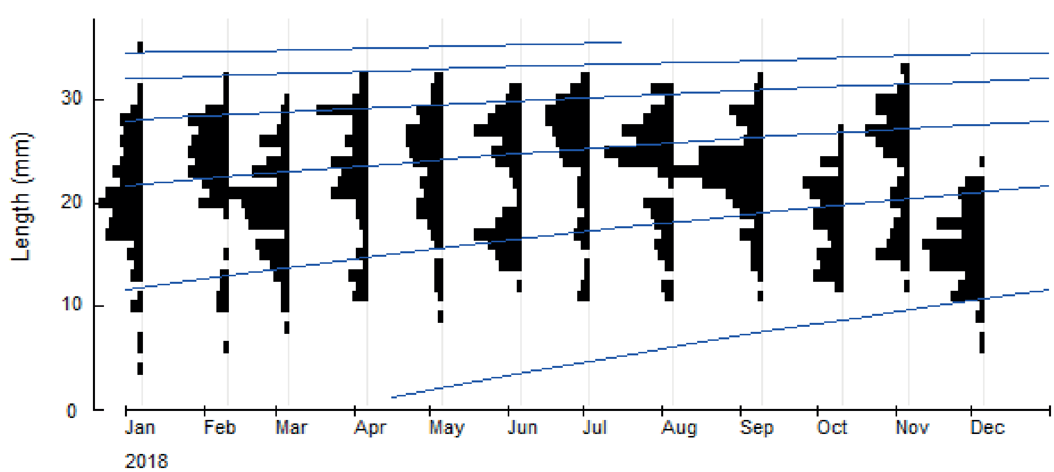

Figure 3

Length–frequency plot for *Polititapes aureus* with superimposed growth curves estimated by ELEFAN 1 ($L\infty$ = 38.80 mm and K = 0.46 yr^{-1}) in all monthly samples, $N > 100$.

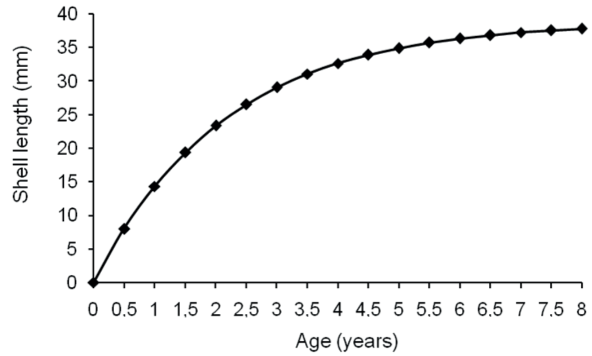

Figure 4

Von Bertalanffy growth curves for Polititapes aureus in terms of size at age based on growth parameters estimated from ELEFAN-I.

yr^{-1} (Fig. 5). The shaded circles represent the points used to calculate Z by linear regression analysis. An estimate of natural mortality (*M*) was obtained by averaging the *M/K* values (average *M/K* = 1.78) from the bivalve literature and multiplying them by the *K* value (*K* = 0.46) derived from the present study. The estimated value of natural mortality (*M*) was 0.82 yr^{-1} and fishing mortality (*F*) was 0.03 yr^{-1}. We can conclude that both values of natural mortality derived from the bivalve literature and based on Pauly's (1980) empirical equation (*M* = 0.83 yr^{-1}) were very close. The rate of exploitation (*E*) for the present study area was estimated at 0.04. During the study period, the lowest mean seawater temperature was recorded in winter (12.2°C), whereas the highest mean value was recorded in summer (25.6°C). In general, the salinity ranged from 29 to 45.5 throughout the year.

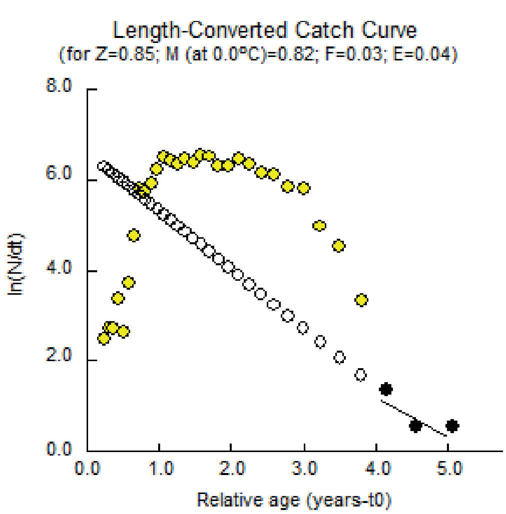

Figure 5

Length-converted catch curve for *Polititapes aureus* from the Gulf of Gabes.

4. Discussion

This work is the first report on the population dynamics of the golden carpet shell *Polititapes aureus* along the southern part of Tunisia. This clam is particularly abundant in heavily fished areas along the Sfax coast. However, clam fisheries in southern Tunisia exclusively target *Ruditapes decussatus*, while *P. aureus* are discarded as bycatch. *P. aureus* is a commercially important bivalve in many countries. The highest abundance of this species (up to 124 ind. m^{-2}) was recorded in the southern region of Sfax (Derbali & Jarboui 2021). The authors reported that soft bottom and organic matter are the main mechanisms structuring the *P. aureus* population in this area. They showed that sediment parameters related mainly to silty-sandy substrates.

In order to properly manage shellfish fisheries for sustainable long-term use, knowledge of various population parameters (growth, recruitment, mortality) and the level of exploitation (*E*) of that population is required. There are many tools for stock assessment. Of these, FiSAT (FAO-ICLARM Stock Assessment Tools) has been most frequently used to estimate population parameters of some venerid bivalve species (Del Norte-Campos & Villarta 2010; Kandeel 2016; Bensaad-Bendjedid et al. 2017; Kandeel 2018), including this study, as it only requires length–frequency data. Population parameters are a useful basis for comparing the status of exploited resources, as they provide valuable information on how exploitation affects the population (Pauly 1984).

The von Bertalanffy growth model was found to be a good description of bivalve growth (Vakily 1992), which was confirmed in the present study for the clam *P. aureus* in southern Tunisia. In the present study, the target species were found to have higher determination coefficients in allometric relationships, indicating that shell growth is less variable. In addition, the prevalence of positive allometric growth between shell length/total weight and shell length/shell width indicates that shell length increases at a lower rate than both total weight and shell width. In practice, this means that during ontogeny, bivalve shells become progressively wider than heavier. These results disagree with those reported for venerid species (Costa et al. 2008; Mohammad et al. 2014; Bensaad-Bendjedid et al. 2017). In general, variations in allometry of bivalves have been linked to latitude, species, physiological traits and local environmental conditions (Derbali 2011; Caill-Milly et al. 2012; Bensaad-Bendjedid et al. 2017; Derbali et al. 2020; 2022).

The growth performance index (φ') was used to compare the growth parameters reported in the present work with those from the published literature on some bivalve species (Table 2). It appears that the value of growth performance (Φ' = 2.84) obtained in the present study is consistent with those obtained for the same species from Lake Timsah, Egypt (Kandeel 2018), but remains lower than the values recorded for other bivalve species (Table 2). In addition, it was observed that the specific growth rate of the *P. aureus* population from the current study area was faster in the first two years of life and slowly decreased as the age of the organisms increased. The same was observed for other bivalve species, such as the cockle *Cerastoderma glaucum* (Derbali et al. 2022) and the surf clam *Mactra stultorum* (Derbali et al. 2023) from the same study area, *C. glaucum* from Egypt (Kandeel et al. 2017) and *Callista chione* from the Gulf of Trieste in Italy (Keller et al. 2002). It can be assumed that the growth of bivalves is strongly affected by biological and environmental factors, and, as suggested in the literature, varies significantly between populations and even within the same species (Vakily 1992; Kandeel et al. 2017; Derbali et al. 2022).

In this study, *P. aureus* showed lower growth rate (K = 0.46 yr^{-1}) and asymptotic length (L_∞ = 38.80) than those obtained for other bivalve species (average values: K = 0.61 and L_∞ = 55.02; Table 2). Our study indicates that the growth parameters K and L_∞ determined in this study are an accurate representation of the considered population, as it has been suggested that the values are different for the same species and genera (Kandeel 2018; Derbali et al. 2022). It seems that differences in the growth parameters, as already reported for *P. aureus* in this study and for other bivalve species (Table 2), may be due to differences in the ecosystems studied and the species' responses to environmental gradients.

The literature data on bivalves used to calculate natural mortality (M) are shown in Table 2. Based on these, the estimated value (M = 0.82 yr^{-1}) was obtained by averaging M/K values and multiplying them by the K value derived from this study. Del Norte-Campos & Villarta (2010) reported that averaged M/K values taken from the bivalve literature are biologically suitable to use as the basis for computing M for the species examined in the present study. As for the low mortality rate obtained in this study (Z = 0.85 yr^{-1}), it can only be related to natural causes (predation, pathogens, anthropogenic activity), since there is no *P. aureus* clam fishery in the Gulf of Gabes. Nevertheless, according to Park et al. (2008), mortality rates in *Mactra chinensis*, especially in natural beds, may result from a complex synergy of biotic and abiotic factors. Similarly, Albert et al. (2014) reported that fishing activity in clam beds was a major factor affecting the dynamics of *Paphia textile* (Gmelin 1792) populations. Moreover, habitat degradation and climate change may be the major cause of natural mortality (M = 0.82 yr^{-1}) for the clam *P. aureus* in southern Tunisia.

During the present study, the highest and lowest water temperature values were recorded in July (26.2°C) and January (13.8°C), respectively. Salinity measurements showed annual variations ranging from 37.2 PSU in winter to 47.8 PSU in summer. Previous studies showed that the progress of gametogenic

Table 2

Natural mortality (M, yr^{-1}), growth coefficient (K, yr^{-1}), asymptotic length ($L\infty$) and growth performance indices (φ') obtained for different bivalve species. Age determination method: LF – length–frequency, MR – mark and recapture. Literature estimates of M and K used to compute M values for the clam *Polititapes aureus* in the present study. Reported values obtained from different methods were averaged.

Species	M	K	M/K	L_∞	Φ'	Method	Study area	References
Venus antiqua	0.33	0.18	1.83	80.0	3.07	MR	Isla de Chiloé, Chile	Glasing et al. (1994)
Ruditapes decussatus	1.28	0.81	1.58	50.4	3.31	LF (FiSAT)	Lake Timsah, Egypt	Kandeel (2016)
Paphia textile	1.98	1.0	1.98	67.9	3.69	LF (FiSAT)	Manukan, Zamboanga Del Norte, Philippines	Albert et al. (2014)
Paphia textile	1.98	1.0	1.98	69.9	2.69	LF (FiSAT)	Roxas, Zamboanga Del Norte, Philippines	Albert et al. (2014)
Paphia undulata	1.57	1.0	1.57	79.0	-	LF (FiSAT)	Southern Negros Occidental	Del Norte-Campos & Villarta (2010)
Ruditapes decussatus	0.65	0.38	1.71	63.92	3.61	LF (FiSAT)	El Mellah lagoon, Algeria	Bensaad-Bendjedid et al. (2017)
Polititapes aureus	0.70	0.28	2.5	36.57	2.58	LF (FiSAT)	Taawen site, Lake Timsah, Egypt	Kandeel (2018)
Polititapes aureus	0.76	0.36	2.11	36.57	2.69	LF (FiSAT)	Etap site, Lake Timsah, Egypt	Kandeel (2018)
Cerastoderma glaucum	0.90	0.48	1.87	32.55	2.71	LF (FiSAT)	Gulf of Gabes, Sfax Tunisia	Derbali et al. (2022)
Cerastoderma glaucum	0.81	0.42	1.93	36.75	2.75	LF (FiSAT)	Gulf of Gabes, Gabes Tunisia	Derbali et al. (2022)
Mactra stultorum	0.63	0.71	0.89	46.80	3.19	LF (FiSAT)	Gulf of Gabes, Tunisia	Derbali et al. (2023)
Ruditapes decussatus	0.99	0.70	1.41	59.95	3.40	LF (FiSAT)	Gulf of Gabes, Tunisia	Derbali et al. (2024)
1.78 Mean M/K								
Polititapes aureus	0.82	0.46		38.8	2.84	LF (FiSAT)	Gulf of Gabes, Tunisia	present study

activity in the *P. aureus* population and other bivalve species was accompanied with an increase in water temperature (e.g. Derbali 2011; 2022; Derbali et al. 2023). For many bivalve species, several environmental factors are known to affect shell morphology and relative proportions, such as latitude, depth and sediment type (e.g. Newell & Hidu 1982; Solis 2019). Thereafter, Derbali et al. (2020; 2022; 2023) based on research conducted in Tunisia argued that these parameters are potentially related to environmental conditions and vary accross bivalve species and between localities.

A previous study conducted in the same area (Derbali & Jarboui 2021) also showed that the abundance of *P. aureus* clams was controlled by strong interactions at different levels (e.g. physicochemical, edaphic and hydrological factors operating in the study area). In this regard, temperature and food resources are the most important factors affecting phenotypic differences in growth patterns and maximum size in different marine organisms (Stergiou et al. 1997). Increased water temperatures and phytoplankton levels can promote rapid growth rates in bivalve species (Derbali & Jarboui 2021).

Finally, this study provides new information on the population dynamics of the clam *P. aureus* in Tunisia. It may contribute to the introduction of sustainable and profitable exploitation. In addition, the adoption and implementation of rules limiting the species size will be required to regulate and protect this new exploitable fishery resource.

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