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AGE, GROWTH AND MORTALITY OF SURF CLAM *MACTRA STULTORUM* IN THE GULF OF GABES, TUNISIA

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ABSTRACT

The population dynamics of surf clam *Macra stultorum* from the Gulf of Gabes was investigated monthly for the first time during a one-year period (2017), including population age, growth, and mortality rate. The allometric relationships between body sizes and length were determined; the shell length/total weight indicated a negative allometric growth relationship that is expressed as $TW = 0.002 SL^{2.314}$. The length frequency data were analyzed for estimation of population parameters. The asymptotic length (L_{∞}) was found to be 46.80 mm, the growth co-efficient (K) 0.71 yr⁻¹. The longevity (T_{max}) and the growth performance indices (ϕ') were 5.42 yr⁻¹ and 3.19, respectively. Total mortality (Z) and natural mortality (M) were estimated by length-converted catch curve at 0.63 yr⁻¹. The findings of the current study suggest that the most intensive growth occurred during the first two years. The data presented herein are essential for an appropriate fisheries management and conservation of surf clams.

Key words: *Macra stultorum*, population dynamic, growth, mortality rate, age, south Tunisia

ETÀ, CRESCITA E MORTALITÀ DI *MACTRA STULTORUM* NEL GOLFO DI GABES, TUNISIA

SINTESI

La dinamica di popolazione della madia bianca *Macra stultorum* del Golfo di Gabes è stata studiata mensilmente per la prima volta durante un periodo di un anno (2017), includendo l'età della popolazione, la crescita e il tasso di mortalità. Sono state determinate le relazioni allometriche tra le dimensioni corporee e la lunghezza; il rapporto lunghezza della conchiglia/peso totale ha indicato una relazione di crescita allometrica negativa, espressa come $TW = 0,002 SL^{2,314}$. I dati sulla frequenza delle lunghezze sono stati analizzati per stimare i parametri della popolazione. La lunghezza asintotica (L_{∞}) è risultata essere di 46,80 mm, il coefficiente di crescita (K) di 0,71 annui. La longevità (T_{max}) e gli indici di performance di crescita (ϕ') sono risultati rispettivamente 5,42 e 3,19 anni. La mortalità totale (Z) e la mortalità naturale (M) sono state stimate dalla curva di cattura convertita in base alla lunghezza a 0,63 per anno. I risultati dello studio suggeriscono che la crescita più intensa si verifica durante i primi due anni. I dati qui presentati sono essenziali per un'appropriata gestione della pesca e per la conservazione della specie.

Parole chiave: *Macra stultorum*, dinamica di popolazione, crescita, tasso di mortalità, età, Tunisia meridionale

INTRODUCTION

The surf clam *Macra stultorum* (Linnaeus, 1758) is a dominant species of the sandy beach macrofauna in the lower infra-littoral zone. It is widely distributed from Norway in the north of Europe to Senegal in West Africa, as well as in the Mediterranean and Black Seas (Conroy et al., 1993). *M. stultorum* is also extensively utilized as seafood and raw material for animal feed production at various aquaculture farms (Hou et al., 2006). Although an important commercial bivalve in many countries, this clam is still unexploited in Tunisia and has yet to be commercialized for the Mediterranean market.

Even with the socio-economic and ecological importance of invertebrate fisheries increasing, the scientific knowledge of the biology of commercial species is frequently insufficient (Anderson et al., 2011). In addition, invertebrate fisheries often operate without regulation, monitoring, and assessment (FAO, 2009). In Tunisia, commercial bivalve fisheries constitute a cultural, social and economic resource for numerous coastal communities. Therefore, further research on the cultivation of commercial species is required before adequate management measures promoting a sustainable exploitation of shellfish resources can be implemented.

In Tunisia, the surf clam *M. stultorum* is particularly abundant in the southern coast; however, the Tunisian clam fisheries seem to focus exclusively on the clam *Ruditapes decussatus* (Linnaeus, 1758) and regard *M. stultorum* as a discard, while in many countries this and other similar species are considered target species and are economically important in terms of employment and exportation. New initiatives in the shellfish fisheries sector include diversification into other exploitable species. Therefore, new projects dealing with the biology of potential shellfish species have been conducted in most production areas. One such species is also the surf clam *M. stultorum*.

The surf clam *M. stultorum* has often attracted considerable research attention because of its economic potential. Previous studies on *M. stultorum* in Tunisia has primarily focused on various aspects of the clam found in the north, including its occurrence (Zamouri et al., 2001; Charef et al., 2011), biology and biochemistry (Chetoui et al., 2018, 2019), and genetics (Chetoui et al., 2012; Chetoui, 2016). However, no data are currently available on the growth and age parameters of the *M. stultorum* from the south of Tunisia. The existing knowledge on this species is limited to the contribution of Derbali et al. (2021), which focuses on the species' stocks.

Given the frequent occurrence of *M. stultorum* in this region, it is essential to gather appropriate information about its growth to manage its exploitation more efficiently and propose regulatory measures to the fisheries authorities (e.g., establishing closed seasons for fishing). Understanding the species' population dynamics is crucial to determining its present status in the southern coastal areas. Therefore, the overall goal of the present study is to provide new data on several population parameters of *M. stultorum*

in the coastal zone of the Gulf of Gabes, such as estimates of the species' age, growth, mortality, and performance index. With such data on the surf clam species it might be possible to commercially exploit it and generate economic activity in southern Tunisian waters.

MATERIAL AND METHODS

Sampling and laboratory procedure

Monthly samples of the surf clam *M. stultorum* ($\approx$ 90 specimens) were collected from the primary shellfish production area of Sfax, southern Tunisia (Fig. 1), from January to December 2017. During each collection, sea-water temperature and salinity were recorded. Initially, the *M. stultorum* individuals were measured for shell length (SL, mm) and shell height (SH, mm) using a digital caliper (with a precision of 0.01 mm), and weighed for total weight (TW, g) on a top-loading digital balance (with a precision of 0.001 g).

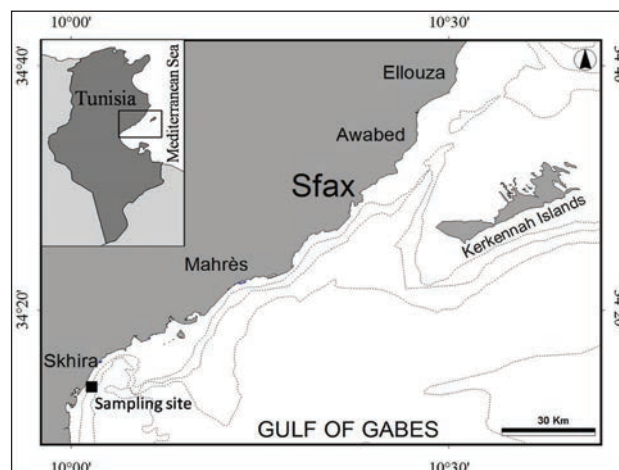


Fig. 1: Map of the study area indicating the sampling location in the south of Tunisia.

Sl. 1: Zemljevid obravnavanega območja z vzorčevalno lokaliteto v južni Tuniziji.

Data analysis

Relative growth

The relationship between total weight (TW, g) and anterior-posterior shell length (SL, mm) was described by the following allometric equation: $\log TW = \log a + b \log SL$, where $\log a$ and b are intercept (initial growth coefficient) and slope (relative growth rate of variables) of the linear regression line, respectively. The deviation of the b value of the regression function from the isometric hypothetical value ($b = 3$) was analyzed by means of a Student's t-test. Significant deviation indicated a negative ($b < 3$) or positive ($b > 3$) allometric relationship.

Tab. 1: Allometric relationships between body sizes and shell length of the *Macra stultorum* collected from the littoral zone of Sfax (south Tunisia) (NS = not significant, S = significant for $p < 0.05$).**Tab. 1: Alometrična razmerja med telesnimi velikostmi in dolžino lupine pri vrsti *Macra stultorum*, nabranih v obrežnem pasu v Sfaxu (južna Tunizija) ((NS = ni statistično značilno, S = statistično značilno na nivoju $p < 0,05$).**

Allometric relation	a	b	Determination coefficient (R^2)	Significance	Relationship (t-test)
SH/SL	0.895	0.970	0.970	S	negative allometry
SW/SL	0.468	1.011	0.944	NS	isometric
TW/SL	0.002	2.314	0.953	S	negative allometry

Age and absolute growth

The age growth parameters were determined using FiSAT II software (Gayaniilo et al., 2005). The asymptotic shell length (L_∞ , mm) and the growth coefficient (K , yr^{-1}) of the von Bertalanffy Growth Function (VBGF) were estimated from these data by means of ELEFAN-I (Electronic Length Frequency Analysis; Pauly & David, 1981). The VBGF is defined by the equation:

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

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

L_∞ and K were used to calculate the growth performance index Φ' (Pauly & Munro 1984) using the equation:

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

Growth performance is a relevant parameter that is closely related to population dynamics of benthic macro-invertebrates (Brey, 1999). This index makes it possible to compare the growth of populations and species allowing for species-specific features to be identified. In this study, growth performance index (ϕ) was used to compare the growth parameters obtained in this work with data from the literature on surf clam populations. The theoretical maximum age ($T_{\max}$) was calculated for each population by solving for t in the von Bertalanffy equation, then setting $SL_t = L_\infty$ and using the equation constructed by Michaelson & Neves (1995):

$$T_{\max} = \frac{h L_\infty + K_o}{K}$$

Mortality rate

Mortality is an important aspect of the population dynamics of bivalve species. The total mortality (Z , yr^{-1}) was estimated from the slope of the right descending arm of a length-converted catch curve according to the method by Pauly (1990) using FiSAT II, which calculates Z year $^{-1}$ as

well as the 95% confidence intervals surrounding the Z based on the goodness of fit of the regression. The natural mortality rate (M , yr^{-1}) was estimated using the empirical relationship developed by Pauly (1980):

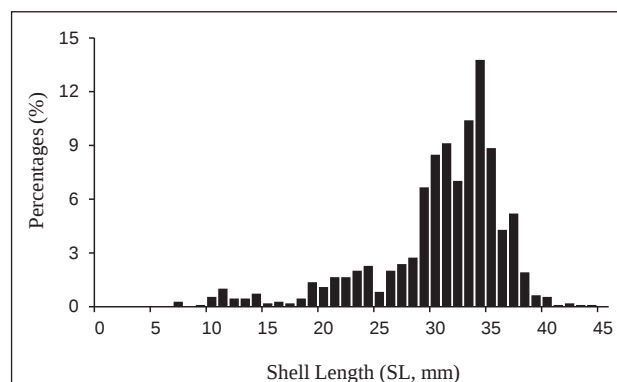
$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T$$

where T = mean annual temperature ($^{\circ}\text{C}$). Once the Z and M were obtained, the fishing mortality (F , yr^{-1}) was estimated using the relationship: $F = Z - M$. The exploitation rate (E), which represents the portion of total mortality due to fisheries, was obtained with the formula proposed by Gulland (1971):

$$E = F/Z = F/(M+F)$$

RESULTS**Relative growth**

The biometric data of the surf clam *M. stultorum* from the littoral zone of Sfax (Tab. 1) showed a strong significant correlation between shell length (SL, mm)/total weight (TW,

**Fig. 2: Shell length frequency distributions of *Macra stultorum* in the south of Tunisia.****Sl. 2: Velikostna porazdelitev lupin školjke *Macra stultorum* na jugu Tunizije.**

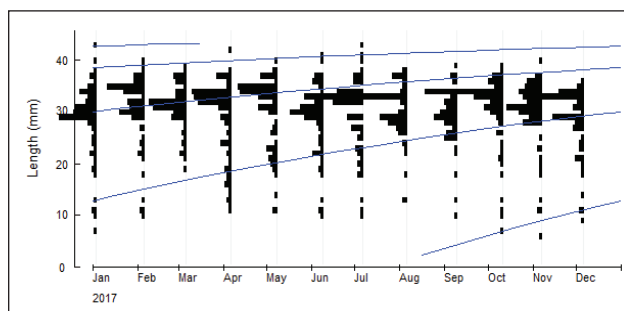


Fig. 3: Length frequency plot of *Mactra stultorum* with superimposed growth curves estimated by ELEFAN 1 ($L_{\infty} = 46.80$ mm, $K = 0.71$ yr⁻¹).

Sl. 3: Velikostna porazdelitev vrste *Mactra stultorum* s superponiranimi krivuljami rasti, ocenjenimi z ELEFAN 1 ($L_{\infty} = 46,80$ mm, $K = 0,71$ leto⁻¹).

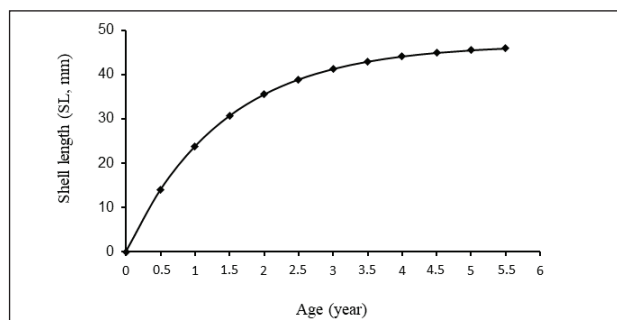


Fig. 4: The von Bertalanffy growth curves in terms of size at determinate age for *Mactra stultorum* based on growth parameters estimated by ELEFAN-I.

Sl. 4: Von Bertalanffyjeve rastne krivulje glede na velikost pri določeni starosti primerkov vrste *Mactra stultorum* na podlagi rastnih parametrov, ocenjenih z ELEFAN-I.

g) and shell length (SL, mm)/shell height (SH, mm) ($R^2 > 0.95$; $p < 0.001$) indicating negative allometric growth patterns; however, an isometric pattern was also recorded in the relation: shell length/shell width (SW, mm) ($p > 0.05$).

Population structure

During the study period, a total of 1096 individuals of *M. stultorum* were studied, with a size range from 6.82 to 43.60 mm. A peak was observed in the population corresponding to individuals with a shell length of 34 mm. The majority of the clam population (73.81%) belonged to the size classes between 29 and 37 mm (Fig. 2). Conversely, the smallest (6.82–28 mm) and the largest (38–43.60 mm) size classes were less represented, accounting for only 22.63% and 3.56% of the total sample, respectively.

Absolute growth and age

Based on the von Bertalanffy Growth Function (VBGF) estimated by ELEFAN-I, the asymptotic length (L_{∞}) and growth coefficient (K) stood at 46.80 mm and 0.71 yr⁻¹ for the surf clam population collected from the littoral zone of Sfax in southern Tunisia. The length frequency distribution and the superimposed growth curves for *M. stultorum* are shown in Figure 3. The growth performance index (Φ') and the theoretical maximum age (T_{max}) were 3.19 and 5.42 yr⁻¹, respectively. The *M. stultorum* population attained sizes of 23, 35, 41, 44, and 45 mm at the end of 1st, 2nd, 3rd, 4th and 5th years of age (Fig. 4).

Mortality rate

The length-converted catch curve analysis using $L_{\infty} = 46.80$ mm and $K = 0.71$ yr⁻¹ showed a low rate mortality ($Z = 0.63$ yr⁻¹). The darkened circles shown in Figure

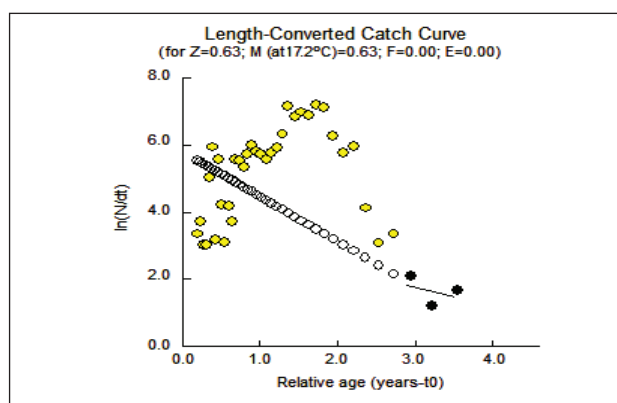


Fig. 5: Length-converted catch curve of *Mactra stultorum* in the south of Tunisia.

Sl. 5: Krivulja ulova za vrsto *Mactra stultorum* na jugu Tunizije, pretvorjena po dolžini.

5 represent the points used in calculating Z via linear regression analysis. The estimated value of natural mortality (M) as per Pauly's empirical formula was 0.63 yr⁻¹, and the fishing mortality was estimated to be zero.

During the sampling period, the salinity remained almost stable throughout the year (29–45.5). The temperature of the seawater ranged between 12.2°C (winter) and 25.6°C (summer).

DISCUSSION

The present study provides, for the first time, data about the population structure, growth, age, and mortality of the surf clam *M. stultorum* from the south of Tunisia. These findings can serve as a baseline for sustainable stock management prior to exploitation. The population parameters are useful bases for evaluating the status of exploited resources as they provide

valuable information on how exploitation affects the population (Pauly, 1984).

The von Bertalanffy growth model has been found to be a good description of bivalve growth (Vakily, 1992), and this is confirmed in the present study of *M. stultorum* from the Gulf of Gabes. The strong correlation between the shell length and total weight observed in the studied surf clam population is similar to that reported for other bivalves (Derbali et al., 2020, 2022; Gaspar et al., 2001).

The biometric characteristics of the shell form showed a negative allometric relationship between shell length and total weight and between shell length and shell height, indicating that the shell was elongated in shape. Similar events were observed for some bivalve species in Algeria (Bensaad-Bendjedid, 2017), Egypt (Mohammad et al., 2014), and Italy (Costa et al., 2008). The authors suggested that this form was the result of an improved burrowing efficiency, which reduced the surf clam's risk of dislodgement by hydrodynamics and predation. In general, variations in the allometry of bivalves have been associated with latitude, species, physiological traits, and local environmental conditions (Caill-Milly et al., 2012; Bensaad-Bendjedid et al., 2017; Derbali, 2011; Derbali et al., 2020, 2022). An isometric relationship was observed between shell length (SL) and shell width (SW), indicating a proportional growth of size and width. The same sequence of events has been reported for *Macrura stultorum* and *Donax semistriatus* from other investigated area in the southern part of Tunisia (Derbali et al., 2018).

The VBGF parameters L_{∞} and K obtained from the length-frequency distribution data were 46.80 mm and 0.71 y^{-1} , respectively. The negative correlation between the asymptotic shell length (L_{∞}) and growth coefficient (K) invalidated a comparison based on individual parameters (Pauly & Munro, 1984). As a result, the comparison of the growth performance of bivalve populations was better fitted by the growth index phi prime (Φ'). This criterion was used to characterize not only similar species (Pauly & Munro, 1984), but also related ones, as was the case of scallops (Del Norte, 1988). When our results were compared with those recorded for *M. stultorum* in previous studies from other Mediterranean regions, the asymptotic shell length ($L_{\infty} = 46.80$), for example, appeared lower than that from the eastern Catalan coast (64.76 mm), the value of the growth performance index (Φ') was higher (3.19) than that from the Catalan coast (3.51) (Solis et al., 2021) – most likely a result of favorable environmental conditions (mainly temperature and food availability) in the Gulf of Gabes – but consistent with those obtained for the clam *Ruditapes decussatus* from the eastern Adriatic Sea (Jurić, 2012) and the cockle *Cerastoderma glaucum* in the south of Tunisia (Derbali et al., 2022), while the theoretical maximum age ($T_{\max} = 5.42 \text{ yr}^{-1}$) was much higher than that reported for the same species (4 yr^{-1}) along the Catalan coast (Solis et al., 2021). In addition,

the specific growth rate of the *M. stultorum* population in the present study was fast in the organisms' first year of life but became progressively slower with their age. All these differences can be explained by the different methods used to determine age, as well as different survival strategies, and ecological factors present at different latitudes.

The low mortality rate ($Z = 0.63 \text{ y}^{-1}$) found in the present study can be only attributed to natural causes, such as predation, pathogens, or other environmental factors, as there is currently no fishing activity for the surf clam *M. stultorum* in the study area. However, research by Park & Zhang (2008) suggests that mortality rates in *Macrura chinensis*, especially in natural beds, may be influenced by a complex interaction of biotic and abiotic factors. In fact, the relatively low natural mortality for *M. stultorum* in the south of Tunisia could be attributed to habitat degradation resulting from runoff and pollution from drainage water. Robinson & Richardson (1998) discovered that the small-sized individuals of *Ensis magnus* (Schumacher, 1817) (= *Ensis arcuatus*) that were returned to the seabed were slow to re-bury and became highly vulnerable to predation by crabs.

The population dynamics of bivalves is also influenced by abiotic factors such as salinity, temperature, immersion time, water velocity, and sediment dynamics (Derbali et al. 2020, 2022). Salinity may be the main factor affecting macrobenthos abundance. Solis et al. (2021) reported that food availability can affect growth and aspects of population dynamics such as production, reproduction, recruitment, and mortality. Seawater temperature and salinity may be the primary factors governing *R. decussatus* densities in the intertidal area (Derbali et al., 2021). The same authors also indicated that densities varied substantially according to strata. It appears that clam populations can be influenced by various strong impacts (e.g., physicochemical, edaphic, and hydrological factors). Previous surveys highlighted the role of seawater temperature and food potential as important factors contributing to phenotypic differences in growth patterns and maximum sizes in a variety of marine organisms.

In conclusion, the present work provides valuable insights into the population dynamics of the surf clam *M. stultorum* in Tunisia, which can be used as a baseline for sustainable and profitable exploitation in the future. It is essential to adopt and implement rules that limit the size of surf clams or catch levels in order to regulate surf clam ranching and thus ensure the protection of this new exploitable fishery resource.

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STAROST, RAST IN SMRTNOST KORITNICE *MACTRA STULTORUM* V GABEŠKEM ZALIVU (TUNIZIJA)

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POVZETEK

Avtorji poročajo o prvi raziskavi populacijske dinamike koritnice vrste *Macra stultorum* v Gabeškem zalivu, v kateri so v mesečnih presledkih v enoletnem obdobju (2017) raziskovali še starost, rast in delež smrtnosti. Določili so alometrični odnos med telesnimi dimenzijami in dolžino. Odnos med dolžino lupine in celokupno težo je pokazal negativno alometrično rast, ki je izražena z enačbo $TW = 0.002 SL^{2.314}$. Analizirali so tudi podatke velikostne porazdelitve za oceno populacijskih parametrov. Asimptotična dolžina (L_{∞}) je bila 46,80 mm, rastni koeficient (K) pa 0,71 na leto. Dolgoživost (T_{max}) je bila 5,42 na leto, rastni indeksi (ϕ') pa 3,19. Celokupno smrtnost (Z) in naravno smrtnost (M) so ocenili iz krivulje ulova, pretvorjene iz dolžine in je bila 0,63 na leto. Izsledki pričujoče raziskave kažejo, da je najbolj intenzivna rast značilna za prvi dve leti. Predstavljeni podatki so ključni za pripravo primerne ribiškega menedžmenta in ohranjanje koritnice.

Ključne besede: *Macra stultorum*, populacijska dinamika, rast, smrtnost, starost, južna Tunizija

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