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STATUS OF THE EXPLOITED CLAM *RUDITAPES DECUSSATUS* IN THE LITTORAL ZONE OF SFAX, TUNISIA

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ABSTRACT

The natural populations of Ruditapes decussatus *in Tunisia are heavily harvested. The clam harvesting sector is of paramount importance for the local fishing industry. This study was performed to estimate stocks and provide a management plan for natural populations along the Sfax coasts, as the area prepares to resume operations after a 3-year hiatus from exploitation. The results have revealed significant density fluctuation of this bivalve in the study area, which was roughly divided into six sites. The stock density ranged from 0 to 8 ind m^{-2}, and biomass values varied from 0 to 54 g m^{-2}. The total biomass amounted to 115.4 tons, with abundance levels exceeding 22.45 million individuals across an area of 3,867 hectares. The sampled individuals ranged in size from 2 to 59 mm. It was observed that the spread of the species was strongly affected by several abiotic parameters. In order to sustainably exploit this resource, guidelines are necessary to prevent overfishing and restore the stock to sustainable levels.*

Key words: *Ruditapes decussatus*, stock assessment, cartography, population structure, Sfax coasts, Tunisia

STATO DELLO SFRUTTAMENTO DELLA VONGOLA VERACE *RUDITAPES DECUSSATUS* NELLA ZONA LITORALE DI SFAX, TUNISIA

SINTESI

Le popolazioni naturali di Ruditapes decussatus *in Tunisia vengono pesantemente sfruttate. Il settore della raccolta delle vongole è di fondamentale importanza per l'industria della pesca locale. Questo studio è stato condotto per stimare gli stock e fornire un piano di gestione per le popolazioni naturali lungo le coste di Sfax, mentre l'area si prepara a riprendere le attività dopo una pausa di 3 anni dallo sfruttamento. I risultati hanno rivelato una significativa fluttuazione della densità di questo bivalve nell'area di studio, suddivisa approssimativamente in sei siti. La densità dello stock variava da 0 a 8 ind m^{-2} e i valori di biomassa variavano da 0 a 54 g m^{-2}. La biomassa totale ammontava a 115,4 tonnellate, con livelli di abbondanza superiori a 22,45 milioni di individui su un'area di 3.867 ettari. Gli individui campionati avevano dimensioni comprese tra 2 e 59 mm. È stato osservato che la diffusione della specie è fortemente influenzata da diversi parametri abiotici. Per sfruttare in modo sostenibile questa risorsa, sono necessarie linee guida per prevenire la raccolta eccessiva e riportare lo stock a livelli sostenibili.*

Parole chiave: *Ruditapes decussatus*, valutazione dello stock, cartografia, struttura della popolazione, coste di Sfax, Tunisia

INTRODUCTION

The grooved carpet clam *Ruditapes decussatus* (Linnaeus, 1758) is a commercially valuable bivalve mollusk. In Tunisia, only the native populations of this clam have been targeted for shellfish exploitation, representing an important economic resource that is mostly exported to Europe. They are exclusively collected in the southern part of the country. Fishery plays a major socio-economic role in Tunisia. It is fundamental to supporting rural and vulnerable communities, particularly clam collectors, in their struggle for survival. *R. decussatus* has been extensively exploited for two decades, but since 2017, a gradual depletion of the resource has been observed, inducing the cessation of fishing activities in 2021. The main reasons for stock depletion included overexploitation, inappropriate fishing methods, pollution, deterioration of water quality, climate change, and inadequate management of fishing practices (Gharbi *et al*., 2023). Unfortunately, the most productive coastal areas are characterized by significant industrial activity. To prevent further stock decline and sustain this sector, Tunisian authorities have established a relatively comprehensive institutional and regulatory framework compliant with international standards, as well as overseeing and regularly monitoring the harvest season, and launching several development projects. Accordingly, they resolved that future exploitation should be carefully planned, starting with a proper study on *R. decussatus* in the present study area. But while extensive work has been done on ecotoxicology, reproductive biology, and pollution along the Sfax coasts (Hamza-Chaffai *et al*., 2003; Smaoui-Damak *et al*., 2003; Banni *et al*., 2009; Derbali *et al*., 2018; Dammak Walha *et al*., 2021), and although the knowledge of stock assessment is considered essential for a dynamic management and conservation of marine bivalve populations, there has been only one study on the occurrence of the *R. decussatus* clam (Derbali *et al*., 2017). The overall goal of the present study is therefore to update information and provide new data on the current status of *R. decussatus* along the Sfax coasts focusing on the population structure, geographical distribution, and stock size in relation to the effects of specific abiotic factors.

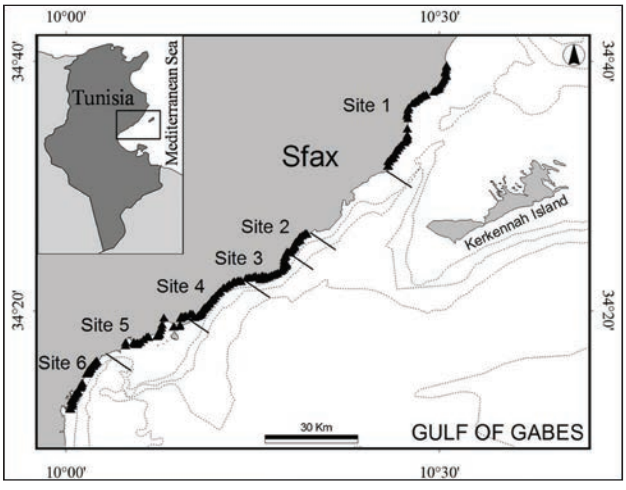

Fig. 1: Map of the study area indicating the locations of sampling transects.
Sl. 1: Zemljevid obravnavanega območja z označenimi lokalitetami vzorčevalnih transektov.

MATERIAL AND METHODS

Study area

The Sfax region, located in the Gulf of Gabes (southern Tunisia), spans 135 km in length (Fig. 1). The seabed is gradually sloping, reaching a depth of 60 m at a distance of 110 km from the coast (Ben Othman, 1973). The predominant substrates in the shellfish production area are muddy sands, with some areas covered by the seagrasses *Cymodocea nodosa* (Ucria) Ascherson and *Nanozostera noltei* (Hornemann) Tomlinson & Posluszny. The local climate is dry due to hot winds (sirocco). The sampling area exhibits the highest tidal ranges in the Mediterranean Sea. The tide is semidiurnal, with the spring tide reaching a high of +1.60 m and a low of +0.30 m (Zaghden *et al*., 2014). The intertidal zone is an important source of natural resources harvested both by professional and recreational fishers. During spring tides, the expansive intertidal sand and mudflat zone is exploited for clam harvesting, primarily targeting *R. decussatus*.

Field sampling and processing

Field sampling was carried out over a two-year period (2022–2023) along the Sfax coasts (southern Tunisia). The sampling area was roughly divided into six sites based on clam occurrence (Fig. 1). Transects were systematically conducted during low tides. Samples were collected every 50 m along the transect lines extending from the extreme high tide to the extreme low tide. Along each transect, 4–10 replicates were taken in quadrats (0.25 m^2) using a shovel. The samples were preserved in a 7% formaldehyde solution and then transferred to the laboratory for processing. During the sampling activities, seawater temperature and salinity were measured near the bottom immediately after sampling, using a multi-parameter kit (Multi 340 i/ SET). To enhance the study on clam distribution, specific interactions between abiotic and biotic factors affecting the spatial distribution of the *R. decussatus* population

were investigated by analyzing granulometric characteristics recorded during the sampling activities. Sediment samples were collected from each site to a depth of 5 cm. Samples weighing 300 g each were pooled for each site, treated with an H_2O_2 solution, and then dried at 40 °C. The dried samples were sieved using AFNOR mesh-type sieves ranging from 2 mm to 63 µm. The Shepard (1954) grain size classification was followed.

Data analysis

In the laboratory, shell length (SL, mm; maximum anteroposterior distance considered as reference length), shell height (SH, mm; maximum distance from hinge to ventral margin), and shell width (SW, mm; maximum distance between the closed shell valves) were measured using a digital caliper to the nearest 0.01 mm. Additionally, the specimens were weighed on a top-loading digital balance (with a precision of 0.001 g) to determine total fresh weight (TW). The obtained dataset was registered, and maps were drawn using ArcGIS 10.8 software. Furthermore, the data were pooled at sampling sites to calculate mean densities (ind. m^{-2}) and mean biomass (g. m^{-2}) per site, and assessed across sampling sites using the following equation (Gulland, 1969): Bi = Ni × Ai/ai × 1/Xi, where Bi represents the total biomass of clams, Ni is the mean abundance of all quadrat samples in each site, Ai is the site area surface, ai is the quadrat swept area, and Xi is the proportion retained.

For statistical analysis, data were tested for homogeneity of variance and normality using Levene's and Kolmorogov–Smirnov tests, respectively. The Kruskal–Wallis median test was used to compare densities, while similarities between sites in terms of abundance and biomass were investigated using cluster analysis (group average method). In addition, the harmonic Spearman correlation coefficient was applied to identify any significant correlations between density and biomass of clams at each site. The results are presented as means ± standard error (SE), and the significance level used for the tests was set at $p < 0.05$.

RESULTS

Environmental parameters

The sediment parameters at all sites predominantly indicated silty-sandy substrates, except for site 5 (Tab. 1). Most of the sampled sites were covered with the seagrassess *C. nodosa* and *N. noltei* (> 50%). During the sampling period, the highest temperature values were recorded in July (31 °C), the lowest in February (14.9 °C). Salinity ranged between 37 in winter and 47 in summer.

Tab. 1: Sediment type recorded in the littoral zone of Sfax (Tunisia).
Tab. 1: Tip sedimenta na obalnem območju Sfaxa (Tunizija).

Sites	%Gravel	%Sand	% Silt/clay
Site 1	1.42	97.21	1.37
Site 2	0	98.50	1.50
Site 3	0.25	94.67	5.08
Site 4	0	95.57	4.43
Site 5	0.30	90.31	9.39
Site 6	0.45	99.26	0.29

Occurrence and distribution

Ruditapes decussatus was found in all sampling zones (sites 1 to 6) at depths between 0 and 1 m. A total of 184 transects were made from the extreme high water tide point to the extreme low water tide point. In total, 796 replicates were collected during sampling, covering a total area of 3,867 ha.

In general, there were significant fluctuations in the distribution of clams across the sites, with densities ranging from 0 to 8 ind. m^{-2} and biomass from 0 to 54 g m^{-2} (Figs. 2–3). Densities did not exhibit normal distribution (Kolmorogov–Smirnov test, $p < 0.05$) and were not homogeneous (Levene's test, $p < 0.05$). Furthermore, pairwise comparisons indicated that abundance and biomass levels obtained for sites (1–6) were significantly different (Kruskal–Wallis median test, $p < 0.05$).

Stock assessment

The total stock of the species under study was estimated at 115.4 ± 32.5 t (total fresh weight), with abundance levels exceeding 22.45 ± 8.4 million individuals. The mean biomasses and densities estimated from all sites were 2.98 ± 0.6 g m^{-2} and 0.58 ± 0.1 ind. m^{-2}, respectively.

Significant variations in mean stock levels were recorded across all sites (Fig. 4). At site 5, the results were significantly higher than those from the remaining sites ($p < 0.05$). On the other hand, no significant variations were found between values from sites 1 and 2 and those from sites 3 and 4 ($p > 0.05$). Regarding abundance, biomasses levels showed significant variations among the surveyed sites, with values at sites 3, 4, and 5 being higher than those from sites 1, 2, and 6 ($p < 0.05$). Similar differences were observed between site 6 and sites 1 and 2. Cluster analysis (group average) applied to assess similarities between the sites identified a core

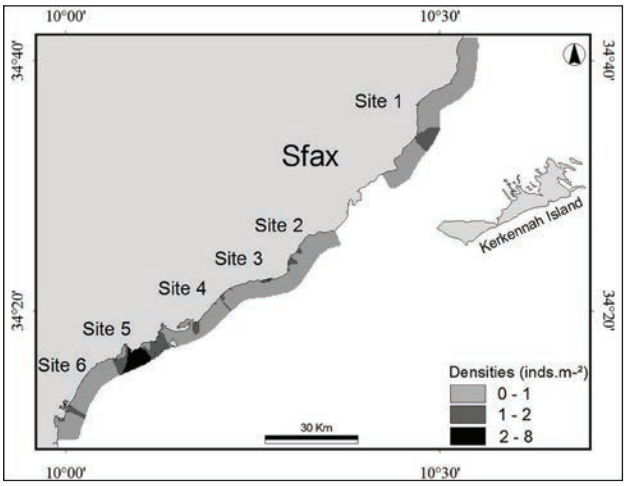

Fig. 2: *Ruditapes decussatus****: spatial distribution of densities in the littoral zone of Sfax (Tunisia).***
Sl. 2: *Ruditapes decussatus****: prostorska porazdelitev gostot v obrežnem območju Sfaxa (Tunizija).***

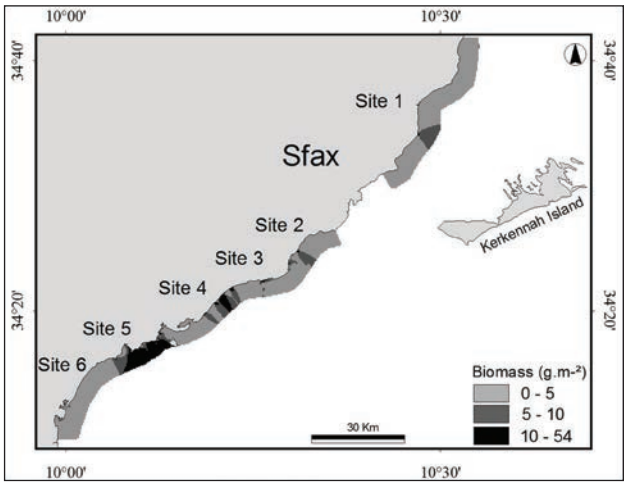

Fig. 3: *Ruditapes decussatus****: spatial distribution of biomass in the littoral zone of Sfax (Tunisia).***
Sl. 3: *Ruditapes decussatus****: prostorska porazdelitev biomase v obrežnem območju Sfaxa (Tunizija).***

group that spanned all sites (Fig. 5). The analysis of similarity tests revealed significant difference between the aforementioned group and site 5 (global R greater than 0.9; $p < 0.05$). This discrepancy was primarily attributed to *R. decussatus* stocks being most abundant at site 5 compared to the remaining sites.

Population size structure

The size structure analysis combines data from all sites hosting the clam *R. decussatus*. The distribution of clams was analyzed with respect to their sizes, which varied markedly between the sites. The clam population exhibited a non-uniform distribution: while larger specimens displayed a relatively heterogeneous distribution throughout the study area, smaller ones were more geographically restricted to sites 1 and 6. In general, the specimens' sizes ranged from 2 to 59 mm SL. The majority of the population fell into size classes ranging from 2 to 35 mm, representing 83% of all samples. Larger sizes (> 35 mm) only accounted for 17% of the population. In addition, two peaks were observed in size distribution: one at 9 mm and another at 29 mm, possibly indicating the presence of at least two cohorts (Fig. 6).

DISCUSSION

The current study establishes a wide informative baseline of the status of the grooved carpet clam *Ruditapes decussatus* along the Sfax coasts, providing essential groundwork for sustainable stock management as the area prepares to resume operation after more than 3 years of discontinuation. The species was found at depths ranging from 0 to 1 m. Based on our biomass estimates, this area supports a stock of 115.4 ± 32.5 tons of total fresh weight, with density levels exceeding 22 ± 8.4 million individuals. The available information on *R. decussatus* stock levels is deficient. Data about clam stocks are limited to preliminary studies conducted only in the southern part of the Sfax region, where the total biomass was estimated at about 891 tons, with relative abundance levels exceeding 261 million individuals (Derbali *et al*., 2016). The main factors to have contributed to stock depletion include an increase of fishing activities, climate change, and characteristics of soft bottoms (Gharbi *et al*., 2023). In fact, *R. decussatus* population stocks

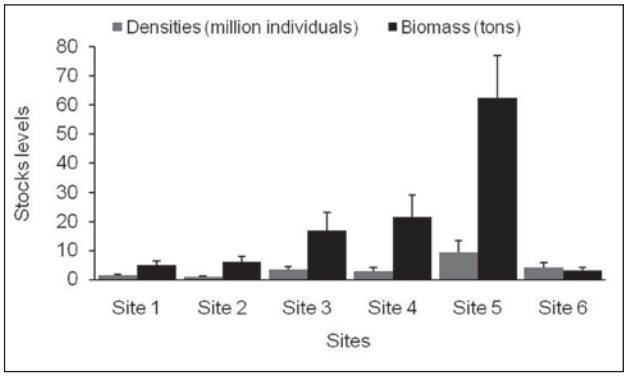

Fig. 4: *Ruditapes decussatus* ***stock levels in the colonized sites and their standard errors (± SE) in the littoral zone of Sfax (Tunisia).***
Sl. 4: Ocena staleža vrste *Ruditapes decussatus* ***v naseljenih lokalitetah in standardna napaka (± SE) v obrežnem območju Sfaxa (Tunizija).***

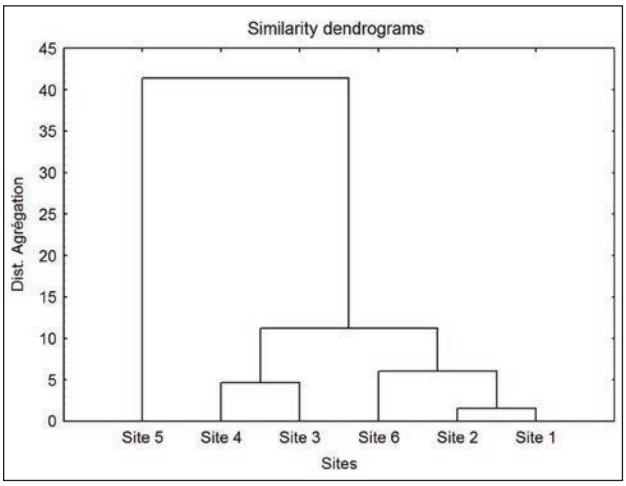

Fig. 5: *Ruditapes decussatus****: similarity dendrograms for the colonized zones (average group) in the littoral zone of Sfax (Tunisia).***
Sl. 5: *Ruditapes decussatus****: podobnostni dendrogrami v naseljenih lokalitetah (povprečne skupine) v obrežnem območju Sfaxa (Tunizija).***

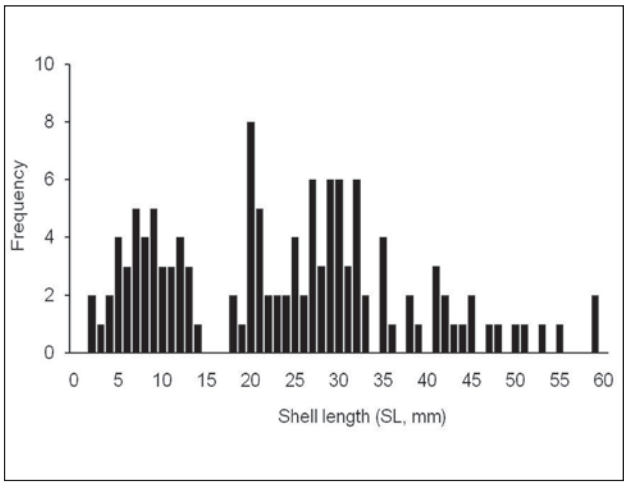

Fig. 6: *Ruditapes decussatus****: length–frequency distribution along the Sfax coastline (Tunisia).***
Sl. 6: *Ruditapes decussatus****: frekvenčna porazdelitev dolžine vzdolž obalne črte Sfaxa (Tunizija).***

varied within and between sampling sites, as well as compared to other geographic areas characterized by diverse seabed characteristics, vegetation cover, and physicochemical factors. The population seems to have been influenced by strong interaction at different levels (e.g., between physicochemical factors and soft bottom features characterizing the study area).

All sampling sites are located in rural zones that are facing several complex challenges, including socio-economic problems (low income from artisanal fishing or fish farming activities, high illiteracy rates), ecological concerns (stock depletion and closure of the clam-fishing season), climate change impacts, and a lack of measures to improve the residents' living conditions. The present investigation revealed variable distribution of *R. decussatus* populations within and among sites despite similar hydrodynamic conditions across the study area. The key factors in structuring bivalve populations include soft bottom and climate change (Derbali & Jarboui, 2021; Derbali *et al*., 2021). The distribution of clams appears to be inversely correlated with the muddy-sand fraction. There is some evidence suggesting that a high degree of gravel in the seabed may deter clam settling, which, in turn, suggests that muddy-sand seabed may encourage higher densities. However, further studies involving sampling sediments and clams in each quadrat, for instance, are needed to support this hypothesis.

The dramatic decline in stocks could also be attributed to overexploitation in most shellfish production areas. Several incentive mechanisms have been implemented to promote sustainable fisheries management, including limiting fishing efforts, strengthening the legislative and institutional framework, and establishing biological rest periods. The authorities have been supporting this sector by establishing a relatively comprehensive institutional framework, by overseeing and regularly monitoring the harvest season, strengthening control and awareness raising measures, and launching several development projects. Despite all these efforts, clam production has witnessed a severe decline over the past five years, dropping by 95% from 1,825 tons in the 2016 season to just 84 tons in the 2020 season (DGPA, 2020).

R. decussatus appears to have been strongly affected by abiotic factors. During the present study, hydrodynamic conditions were found consistent within the sampling area, suggesting that relative population growth is influenced by other environmental parameters such as sediment type, organic matter content, the clams' burrowing behavior, and their subsequent strategies to counter dislocation and avoid predation. In fact, some interesting connections were detected between environmental conditions and bivalve behavior. The clam population seems to peak in areas sheltered by seagrasses *C. nodosa* and *N. noltei* where these cover more than 50% of the site (i.e., about 1,935 ha in total). The clam distribution was found to be significantly correlated with the abundance of the two seagrasses. This positive correlation could rest on: i) detrital organic source offered by these seagrasses, and/or ii) the fact that the presence of seagrasses reduces bottom scour and allows accumulation of organic matter. Vilela (1950) reported that among the dominant organic sources in the diet of *R. decussatus* is the organic matter from *C. nodosa*. Sarà (2007)

reached the same conclusion for cockles in Italy. Additional mechanisms structuring clam populations include soft bottoms, with *R. decussatus* showing a particularly strong association with silty-sandy substrates (site 5).

The grooved carpet clam *R. decussatus* is extensively fished in the study area. The high exploitation rate (E = 0.51) indicates serious overexploitation of the stock. Derbali *et al*. (2024) reported that the fishing mortality (F) of *R. decussatus* (F = 1.02 yr^{-1}) exceeded the natural mortality (M = 0.90 yr^{-1}) in this area. Beck *et al*. (2015) suggested that harvesting activity targeting *R. decussatus* during high tide creates strong disturbances and has a negative effect on clam populations. The depletion of *R. decussatus* stocks can be attributed to direct and indirect mortality (e.g., destruction of tubes, exposure to predators, and loss of specimens due to unstable sediments and water currents) (Munari *et al*., 2006; Carvalho *et al*., 2013). According to Aranguren *et al*. (2014) mortality rates in *R. decussatus*, especially in natural beds, may result from a complex synergy of biotic and abiotic factors. Similarly, Robinson and Richardson (1998) clarified that individuals of *Ensis magnus* (Schumacher, 1817) that were returned to the seabed were slow to re-bury, becoming highly vulnerable to predation by crabs.

Water temperatures and salinities recorded during the sampling period were much higher than those recorded in 2015 (Derbali *et al*., 2016). Several authors have suggested that increased temperature and salinity can have a significant impact on fauna composition and reduce the standing crop (Fishar, 2000; El-Shabrawy, 2001). They have also noted that temperature spikes during summer are associated with adverse effects on marine organisms. It can be inferred that these unfavorable conditions also contribute to the mortality of *R. decussatus* individuals. Furthermore, this mortality rate appears to be correlated with the increase in size of adult individuals. It is likely that clams, as they grow larger, have difficulties in burying themselves in substrates, thereby increasing the chances of mortality. Moreover, our results indicate that the shellfish production area is subject to phytoplankton blooms (diatoms, dinoflagellates, etc.). For years, dinoflagellate blooms have occurred during summer, causing mass mortalities among bivalve species. Among these, *R. decussatus* is particularly negatively impacted by the blooms. The clam disappears from the large central area likely due to anoxia, re-colonizing it in autumn as the temperatures cool down. In our survey, we found that larger individuals almost disappeared in summer. The population structure of this species is also seriously affected by the extensive and continuous removal of seagrasses, as these serve as the main area for larval settlement.

To ensure the sustainable commercial exploitation of *R. decussatus*, it is imperative to implement guidelines that prevent recruitment overfishing. These guidelines should include imposing closed seasons during months of peak spawning activity, monitoring fishing efforts to determine adequate clam fishing technologies, adopting rules to avoid disturbing grass bed, and enforcing limits on clam sizes, as well as regulating catch levels. Implementation of these guidelines could restore the stock to sustainable levels. Further studies are necessary to determine the precise technological requirements for establishing profitable exploitation and long-term farming of this resource.

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STANJE KOMERCIALNO IZKORIŠČENE BRAZDASTE VONGOLE *RUDITAPES DECUSSATUS* V LITORALNEM OBMOČJU SFAX, TUNIZIJA

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POVZETEK

*Naravne populacije brazdaste vongole (*Ruditapes decussatus*) so v Tuniziji hudo zdesetkane. Sektor nabiranja školjk je izjemno pomemben za lokalno ribištvo. Namen raziskave je bil oceniti stalež teh školjk in pripraviti načrt upravljanja naravnih populacij vzdolž obale Sfaxa, ko se na območju pripravljajo, da bi po triletnem premoru izkoriščanja spet začeli z delovanjem. Rezultati so obelodanili znatna nihanja v gostoti školjk na obravnavanem območju, ki je bilo v grobem razdeljeno na šest lokalitet. Gostota školjk se je gibala med 0 in 8 osebkov* m^{-2}*, biomasa pa med 0 in 54 g* m^{-2}*. Celokupna biomasa je bila 115,4 ton, število školjk pa je na površini 3867 hektarjev presegalo 22,45 milijonov primerkov. Vzorčeni primerki so merili med 2 in 59 mm. Ugotovili so, da je na širjenje vrste vplivalo več abiotskih dejavnikov. Da bi trajnostno izkoriščali ta vir, je potrebno vzpostaviti smernice za preprečevanje prelova in obnovitev staleža na trajnostno raven.*

Ključne besede: *Ruditapes decussatus*, ocean staleža, kartografija, struktura populacije, obale Sfaxa, Tunizija

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