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Research Article

Growth and Morphological Trends of the Keystone Species *Patella rustica* Linnaeus, 1758 (Mollusca: Gastropoda) in a Protected Mediterranean Lagoon

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Abstract: The purpose of this paper is to provide for the first time data on a hard substratum macroinvertebrate species inhabiting El Mellah, the unique coastal lagoon in Algeria, and to increase knowledge on limpet species in South Mediterranean protected areas. Between the summer 2019 and the spring 2020, several biological and population dynamics aspects of the high-shore limpet *Patella rustica* were investigated. Based on length-frequency distribution analysis using the FiSAT II software, the age of sampled limpets ranged from one to five years old, and the estimated growth parameters were identified as $L\infty = 40.55$ mm, $K = 0.39$ year^{-1}, with a growth performance index (Φ') of 2.81. Morphometric analysis revealed significant positive allometric relationships indicating variations in body proportions during ontogenesis. Condition index exhibited strong seasonality, with the highest value (41.27±3.27) recorded during winter. Overall, this study revealed that *P. rustica* from El Mellah lagoon follows similar morphological and physiological patterns to other populations in the range of the species across oceanic and marine coastal waters.

Key words: Limpet, growth parameters, shell form, lagoon, South Mediterranean.

Introduction

Patellid limpets are one of the most widespread invertebrates inhabiting the rocky shores of the intertidal area from the supratidal to the subtidal (Ridgway et al. 1998, Henriquez et al. 2017). Their geographical distribution is essentially anti-tropical limited mainly to southern Africa and the North-eastern Atlantic (Koufopanou et al. 1999). Limpets are generalist herbivorous grazers (Keasar & Safriel 1994). They are considered key species in rocky coastal ecosystems through their fundamental role in the ecology and biodiversity of these habitats (Hawkins & Hartnoll 1983, Branch 1985, Menge et al. 1994, Espinosa & Rivera-Ingraham 2017). Thereby, limpet's grazing activity impacts not only algal abundance, density and growth but this process is essential in structuring intertidal communities by influencing the establishment of other organisms such as barnacles (Boaventura et al. 2002, Jenkins et al. 2005, Coleman et al. 2006, Borges et al. 2015). Consequently, any change or removal of limpets feeding behaviour may have cascading effects on the ecosystem in which they live (Raffaelli & Hawkins 1996, Prusina et al. 2014).

In the Mediterranean Sea, the literature mentions that the family Patellidae is represented by two genera, *Cymbula* H. Adams & A. Adams, 1854

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Fig. 1. Location and boundaries of Ramsar site El Mellah.

and *Patella* Linnaeus, 1758 (Ridgway et al. 1998, Espinosa et al. 2011, Espinosa & Rivera-Ingraham 2017, Henriquez et al. 2017); the Algerian coastline hosts representatives belonging to both genera. Four species at least have been recorded and their presence recently confirmed: *Patella ferruginea* Gmelin, 1791, *Patella caerulea* Linnaeus, 1758, *Patella rustica* Linnaeus, 1758 and *Cymbula safiana* (Lamarck, 1819) (Kallouche et al. 2018, Bouzaza & Mezali 2019). These patellids have been the subjects of numerous studies dealing with various aspects of their biology and ecology such as occurrence, distribution, morphometric characteristics, reproduction, phylogeny and ecotoxicology (Boumaza & Semroud 2001, Espinosa 2009, Beldi et al. 2012, Kallouche et al. 2014, 2018, Maatallah et al. 2014, Zegaoula et al., 2016, Bouzaza & Mezali 2018a, 2018b, 2019, Ait Mohamed Amer et al. 2018). However, most of these studies have been conducted on the Oran coast (northwest Algeria) and mainly focused on *P. caerulea* and *P. ferruginea*. The particular attention put on these two species has probably been linked to their endemic status in the Mediterranean and to the fact that *P. ferruginea* is an endangered species at risk of extinction (Espinosa 2009 and literature therein). On the other hand, relatively little is known about the remaining species of the family Patellidae occurring along Algerian shores.

El Mellah is the only coastal lagoon in Algeria; it is a Ramsar site and a part of the UNESCO Biosphere Reserve of El-Kala National Park located in the northeast of the country. This paralic ecosystem is far from any sources of pollution; although maintaining fishing and aquaculture activities, El Mellah remains slightly affected by anthropogenic disturbance and may be recognised as a reference to south Mediterranean lagoons (Draredja et al. 2019). El Mellah has been the subject of many scientific studies that have looked at both applied and ecological aspects. Among the latter, research works focusing on macrozoobenthic fauna received much attention (Bakalem & Romano 1979, Guelorget et al. 1989, Draredja & Bakalem 2004, Draredja 2005, Draredja et al. 2012, Magni et al. 2015, Bensaâd-Bendjedid et al. 2018). However, to date, none of these studies covered hard substratum macro-invertebrates and all of them have taken into account only soft-bottom communities.

Against this background, the aim of the present study was to provide basic information on the biology of patellogastropod limpet *Patella rustica* as a first contribution to the knowledge of rocky shore communities inhabiting El Mellah lagoon. We also

contribute additional data on patellid limpets resident in the South Mediterranean protected areas. In this work, we analyse age structure, growth, shell form and seasonal variations in the condition index of the population under study.

Materials and Methods

Study area

El Mellah lagoon is situated at the extreme north-east of Algeria (36°53' N, 8°19' E) (Fig. 1). This protected transitional water ecosystem (Ramsar site No. 1424) covers an area of 865 ha. It communicates with the Mediterranean Sea to the north by a long and narrow channel (900 m long, 10 m wide). El Mellah sediment is sand with shell debris along the shore and mud in the central area of the lagoon (Magni et al. 2015). Its rocky banks consist of shelly sandstone blocks (Guelorget et al. 1989). El Mellah is characterised by its rich biodiversity; it provides an adequate habitat for a wide range of wildlife species – water birds, fish, invertebrates and plants. Besides its ecological significance, the lagoon plays an important socio-economic role as it maintains artisanal fisheries activities.

Sampling

Patella rustica specimens were collected along El Mellah lagoon rocky intertidal area near the mouth, where the species is most abundant. Field sampling was performed randomly at low tide on a seasonal basis from summer 2019 to spring 2020 (Table 1). Limpets were hand-collected using a knife and then transferred to the laboratory for processing. Only individuals with minimum or free of epibionts were retained for the study. Once brushed and rinsed, six parameters were measured on each individual: shell length (SL, mm), shell width (SW, mm), shell height (SH, mm), distance from apex to anterior end (AA, mm), distance from apex to posterior end (AP, mm) (Fig. 2) and total weight (TW, g). Linear and weight measurements were performed using a Vernier calliper and digital scale with respective accuracies of 0.1 mm and 0.01 g.

Table 1. Sampling periods and number of *Patella rustica* sampled individuals.

Season – Month	Number of individuals
Summer – July 2019	450
Autumn – October 2019	307
Winter – January 2020	241
Spring – April 2020	402

Age structure and growth parameters

The shell length dataset was divided into size classes of 2 mm intervals. Based on the analysis of the length-frequency distribution (LFD), age groups were determined through the Bhattacharya procedure (1967) incorporated in the FiSAT II software (Gayanilo et al. 2005). This approach assumes the normal distribution of cohorts. Subsequently, from the resulting mean sizes for each age, asymptotic length ($L\infty$, mm) and growth coefficient (K, yr^{-1}) of the von Bertalanffy growth formula (VBGF) were also estimated via FiSAT II. Note that by default, FiSAT considers t_0, the third parameter of VBGF equal to zero. Obtained $L\infty$ and K were used to compute the growth performance index according to Pauly & Munro (1984) equation as: $\Phi' = \log10\ K + 2\ \log10\ L\infty$.

Relative growth and shell morphology

Length-length and length-weight relationships between pairs of measured parameters (SL vs SW, SH, AA, TW) were determined by regression equations according to the logarithmic form Log Y = Log a + bLog X (Sokal & Rohlf 1987), which was converted from the original equation $Y= a*X^b$; where Y is the dependent and X the independent variables, "a" the intercept and "b" the slope of the regression line. Both constants a and b were calculated by the least-squares method. The determination coefficient "R^2" was used to assess the association degree between variables. All regression analyses were performed on

Table 2. Summary statistics on measured variables of *Patella rustica* from El Mellah lagoon.

Variables	N	Mean	SE	Min	Max
SL (mm)	1400	22.72	0.13	12	38.1
SW (mm)	1294	18.78	0.13	7.1	32.3
SH (mm)	1294	8.99	0.08	3	22.2
AA (mm)	1195	12.51	0.10	4	24.1
AP (mm)	1195	16.38	0.11	7.3	29.5
TW (g)	1384	2.45	0.05	0.12	10.56

N = Number of specimens; SE = Standard Error of mean; min = minimum; max = maximum

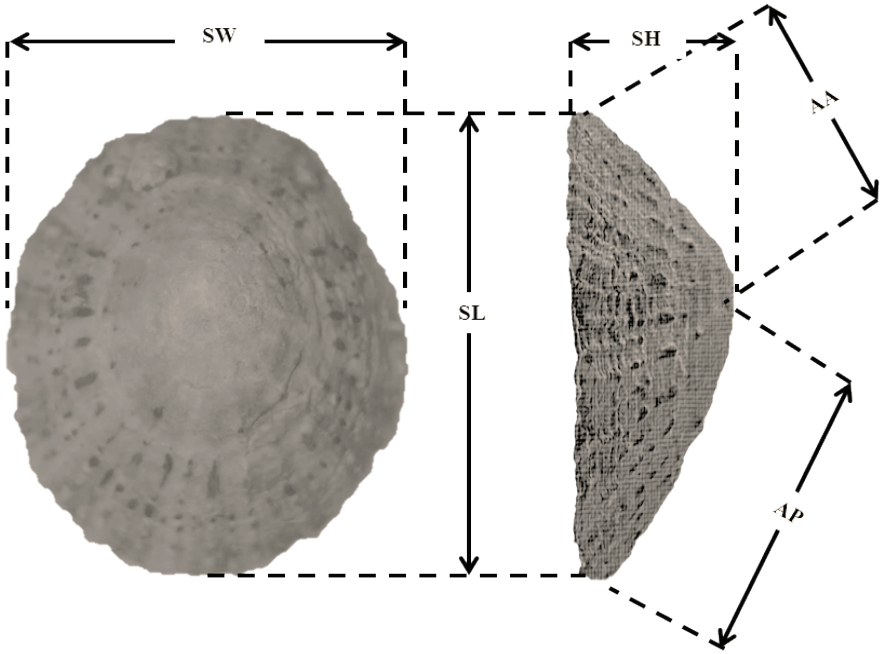

Fig. 2. Measured shell dimensions on *P. rustica* shells.

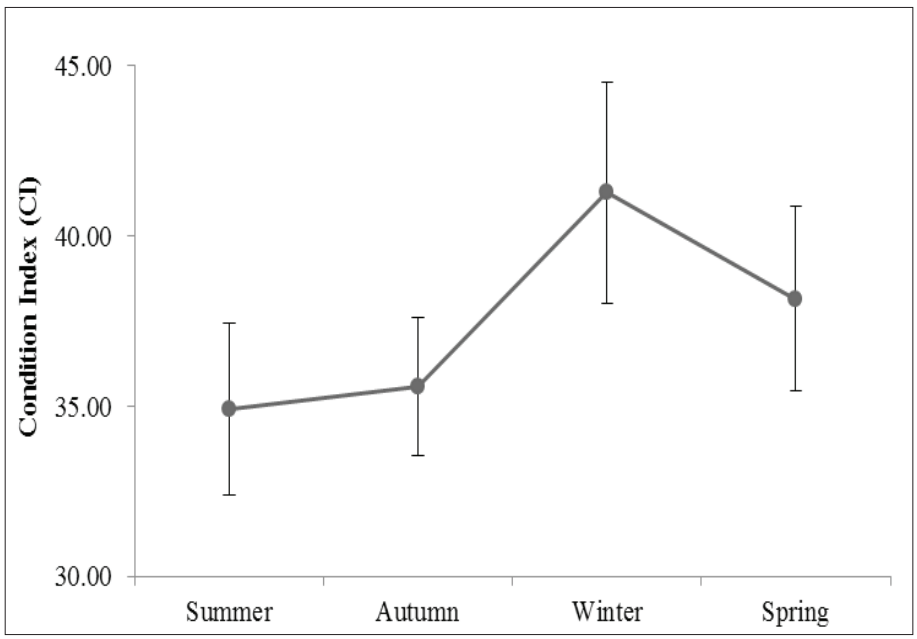

Fig. 3. Seasonal changes in mean values of condition index with standard deviation (vertical bars) for *P. rustica* from El Mellah Lagoon.

log-transformed data using R software, version 3.1.2 (R Development Core Team, 2014). To determine the nature of growth (isometry vs allometry), a Student's t-test (Sokal & Rohlf 1987) was applied to calculate the deviation of the slope b from isometric values one or three; 1: in the case of the same type of variables (length-length relationships) and 3: in case of a distinct type of variables (length-weight relationship). For all tests, statistical significance level was accepted at $P<0.05$. Besides, to deeply analyse shell patterns, metric measures were also used to calculate the means of 3 classic morphometric descriptors SW/SL, SH/SL, and AA/AP. According to Cabral (2007), those ratios provide respectively information on shell base form (circular/ oval), conicity (hight/ flattened cone), and cone eccentricity (centered/ eccentric apex) depending on whether their values are equal or lower than 1.

Table 3. Age-length key of *Patella rustica* from El Mellah lagoon.

Age (year)	Mean length (mm) ± SD	% of population	SI
1	15.67 ± 1.73	15.14	-
2	21.84 ± 1.12	40.14	2.54
3	26.66 ± 1.27	33	2.20
4	31.82 ± 2.18	9.29	2.32
5	36 ± 2.40	2.43	1.83

SD= standard deviation; SI= Separation index

characters are presented in Table 2.

Age structure and growth parameters

Length-frequency distribution analysis suggested that *P. rustica* population from El Mellah lagoon is divided into five age groups ranged from 1 to 5 years, with the dominant cohorts in the second and third age-classes which together represented about 73% of overall sampled individuals. Data on mean lengths assigned to each identified age group are presented in table 3. Values of von Bertalanffy growth parameters obtained from age-length key were $L\infty$ = 40.55 mm, K = 0.39 year^{-1}. The growth performance index was equal to 2.81.

Table 4. Morphometric relationships and type of growth of *Patella rustica* from El Mellah lagoon.

X	Y	N	Log a	b	SE b	R^2	*P*	Relationship t-test
Log SL	Log SW	1294	- 0.2091	1.0909	0.0002	0.96	<0.001	+ allometry
Log SL	Log SH	1294	- 0.8308	1.3076	0.0005	0.81	<0.001	+ allometry
Log SL	Log AA	1195	- 0.5203	1.1943	0.0003	0.91	<0.001	+ allometry
Log SL	Log TW	1384	- 4.1787	3.3109	0.0005	0.95	<0.001	+ allometry

Table 5. Morphometric ratios of *Patella rustica* from El Mellah lagoon.

Descriptor	Calculation	N	Mean	SD	Shape tendency
Base ellipticity	SW/SL	1294	0.82	0.05	The closer the value is to 1, the closer the shell base to the circular form
Conicity	SH/SL	1294	0.39	0.06	The greater the ratio, the higher the cone.
Cone eccentricity	SAA/SAP	1195	0.76	0.08	The closer the ratio is to 1, the more symmetrical the apex".

Condition index

A conventional condition index (CI) as an indicator of molluscs physiological status was calculated seasonally for 50-60 individuals of similar sizes (20-30 mm shell length), following Lucas & Beninger (1985) as:

$$CI = \frac{\text{Flesh wet weight (g)}}{\text{Total weight (g)}} * 100$$

CI seasonal values were expressed as mean ± standard deviation (SD). The Kruskal-Wallis non-parametric test (5% level of significance) performed under R software was used to investigate significant differences between seasonal CI values.

Results

Specimen sizes and weights

In the present study, specimens of *P. rustica* ranged respectively in shell length and total weight from 12 to 38.1 mm (Mean ± SE: 22.72 ± 0.13 mm), and 0.12 to 10.56 g (Mean ± SE: 2.45 ± 0.05 g). Data on descriptive statistics of measured morphometric

Relative growth and shell morphology

The morphometric relationships relating SL to linear and weight characteristics (Table 4) were significant (P<0.001) and showed high determination coefficients with values ranged between 0.81 and 0.96. Positive allometries prevailed in all relationships indicating that: SW, SH, AA, and TW growth occurs at a faster rate than shell length; this implies that during ontogenesis, individuals of *P. rustica* from El Mellah tend to become heavier and their shell bases more circular with relatively higher cones. These results were supported by ratios analysis (Table 5) indeed, base ellipticity and cone eccentricity showed values close to one when the conicity ratio was slightly below 40%.

Condition index

Variation in the condition index of *P. rustica* is presented in Figure 3. Values were low in summer

(34.91±2.54), increased in autumn (35.56±2.03), peaked during winter (41.27±3.27), and once again declined in spring (38.15±2.71). The Kruskal-Wallis analysis showed significant differences between CI mean values among seasons ($P < 0.001$).

Discussion

The maximum shell length registered in *P. rustica* from El Mellah lagoon was 38.1 mm. Comparing our results with previous studies, it appears that this value is higher than what was observed for the species in the Algerian western coast (36 mm, Ait Mohamed Amer et al. 2018), in the southeastern Adriatic Sea (33.6 mm, Prusina et al. 2015) and, in Sardinia shores where Marra et al. (2017) report that individuals larger than 35 mm were extremely rare. However, it is lower than the maximum shell lengths registered in *P. rustica* populations from Viranşehir (Turkey, Deniz 2010) and Mindelo shores (Portugal, Sousa et al. 2012) where the largest specimens reached respectively 42.5 mm and 51 mm. Several authors have attributed the difference in limpet maximum sizes to the effects of environmental factors such as primary productivity, sea-water temperature, and influence of the latitude (Bosman et al. 1987, Espinosa & Rivera-Ingraham 2017, Henriques et al. 2017). Otherwise, numerous studies have demonstrated that limpets reach higher sizes in Marine Protected Areas in contrast with non-protected and easily accessible zones where limpets' largest specimens remain the preferential target of human collection (Lasiak 2006, Espinosa et al. 2014, Marra et al. 2017, Sousa et al. 2020). However, it is worth noting that in El Mellah lagoon, Ramsar site of ornithological importance (Samraoui & Samraoui 2008), avian predation pressure should be taken into account as a factor that can impact limpets' population structure. In a survey on El Mellah waterbirds assemblage, Telailia et al. (2017) counted no less than 11 piscivorous bird species among which *Larus michahellis*, *Larus fuscus*, *Ichthyaetus audouinii* and *Phalacrocorax carbo*. According to Espinosa (2009) and Tlig-Zouari et al. (2010), birds especially gulls are significant predators which might seriously affect the population dynamics of limpets.

In the present study, age composition revealed a maximum age of five years, with an abundance of second and third-year-old individuals. Our results suggest that *P. rustica* from El Mellah lagoon is a relatively short-living species; this is in line with previous studies. Indeed, Prusina et al. (2015) estimated the mean age at approximately 2.9 years, while Marra et al. (2017) reported that the species rarely exceed two years of life. Nevertheless, Lima et al. (2006) had given a conservative estimate of 4 to 6 years as maximum longevity of *P. rustica*. Moreover, the calculated asymptotic length, growth coefficient, and growth performance index of the studied population were 40.55 mm, 0.39 $year^{-1}$, and 2.81 respectively. Compared to the little available literature documenting the growth of *P. rustica*, our findings fall between results obtained in the Adriatic sea (Prusina et al. 2015) and those from the Sardinia coast (Marra et al. 2017). According to Henriques et al. (2017) who reviewed the published literature on the biology of patellid limpets, growth variability within this family would be mostly related to local environmental factors such as seawater temperature (resulting from geographical latitude), availability of food, wave action, and vertical distribution on the shore. However, other factors such as hydrodynamics, desiccation, immersion period, predation and competition were also considered as having a significant impact on the growth rate among limpet species (Espinosa & Rivera-Ingraham 2017, Sousa et al. 2017).

The shell shape analysis showed that *P. rustica* from El Mellah lagoon has an overall positive allometric growth reflecting a more rapid increase in shell height and width than shell length; this means that as individuals grow, shell bases tend to become progressively more circular, and the cones higher. Our findings are consistent with the general morphology pattern observed in *P. rustica* (Deniz 2010, Prusina et al. 2014) as well as several other *Patella* living at high shore levels (Cabral 2007, Telig-Zouari et al. 2011, Batelli 2016, Bouzaza & Mezali 2018b). In previous literature, this growth profile is described as an adaptive phenotypic response of molluscs to dry habitats, allowing them to store a greater amount of water and minimize its loss due to high temperature, desiccation and salinity stress (Branch 1981, Öztürk & Ergen 1999, Boukhicha et al. 2010, Belkhodja & Romdhane 2012). Several authors (Cabral 2007, Cabral & Natal Jorge 2007) highlighted that patellid limpets developed efficient adaptations to overcome certain environmental factors, which would be responsible for their specific morphological patterns and genetic variability (Branch 1981, Mauro et al. 2003, Faria et al. 2017). Nevertheless, among limpet species, *P. rustica* appears to be particularly well adapted to life in harsh environments and resist remarkably to heterogeneous conditions that characterize the coastal intertidal habitats (Prusina 2015). This observation is fully supported by the findings of Tlig-Zouari et al. (2010). These authors reported that along the

Tunisian coastline, even though *P. rustica* occurred higher than all other limpet species, it seemed to be the more tolerant to the stresses caused by the duration of air exposure and dehydration.

Condition indices reflect general physiological states of organisms, they are closely related to both intrinsic (gametogenic and nutrient storage cycles) and extrinsic factors (water temperature and availability of food); thereby, these indicators represent practical and easy tools to monitor molluscs reproductive activity as well as environmental conditions of their habitats (Vasconcelos et al. 2008, Fernández et al. 2015). Seasonal variations in the condition index of *P. rustica* from El Mellah lagoon were in full agreement with results obtained in previous works. Indeed, some authors have indicated that the significant increase of soft parts recorded in *Patella* spp. during winter could be due to the frequent water splashes that facilitate limpets grazing, contrary to summer, in which high temperature and desiccation reduce their foraging activity (Santini & Chelazzi 1995, Prusina et al. 2015). On the other hand, the CI peak detected in January may also correspond to the ripening phase of the reproductive cycle, when most individuals are at their best physiological status just before spawning. Under this scenario, the study population would likely follow the reproductive pattern previously observed in other *P. rustica* populations from the Atlantic and Mediterranean coastal waters, describing a spawning event occurring in the cold season (Ribeiro et al. 2009, Prusina et al. 2014, Zegaoula et al. 2016).

Conclusion

This work focused on some morphological and physiological traits of the keystone species *P. rustica*, a limpet known for its ability to adapt to high shore environments where molluscs are left dry and exposed to waves and currents actions (Cabral & Natal Jorge 2007, Prusina et al. 2015). The main finding drawn from this study is that the age structure, growth patterns, and condition index of *P. rustica* from El Mellah lagoon showed values and trends similar to those obtained elsewhere in the range of the species across oceanic and marine coastal waters. These results could reflect a successful adaptation of the studied population against the unstable and stressful environmental conditions that characterize coastal lagoons. Our findings can be a good starting point for further and more detailed studies necessary to establish effective conservation measures for this species.

Reference

Ait Mohamed Amer L., Benali I., Dermeche S. & Bouderbala M. 2018. Seasonal variations of the biometric indices of *Patella rustica* Linnaeus, 1758 (Gastropoda Patellidae) from contrasted sites of the western Algerian coast. Biodiversity Journal 9 (3): 205–212.

Bakalem A. & Romano J. C. (1979). The benthic populations of Lake Mellah. Rapport de la mission sur le lac Mellah, Rapport du Centre de Recherche Océanographique et de la Pêche (CROP). pp. 13–22. (In French).

Battelli C. 2016. Morphometric characteristics, vertical distribution and density of the limpet *Patella caerulea* L. in relation to different substrata of the bay of Koper (Gulf of Trieste, northern Adriatic). Annales, Series Historia Naturalis 26 (2): 145–156.

Beldi H., Boumaza F. Z., Draredja B. & Soltani N. 2012. Biodiversity of Patellidae (Gastropoda, Prosobranchia) in the Gulf of Annaba (Algeria). Bulletin de la Société Zoologique de France 137 (1–4): 121–132. (In French).

Belkhodja H. & Romdhane M.S. 2012. Morphometric study of the Gastropod mollusc *Patella caerulea* Linnaeus, 1758 from the northern coasts of Tunisia. Bulletin de l'Institut National des Sciences et Technologies de la Mer 39: 15–23. (In French).

Bensaâd-Bendjedid L., Belhaoues S., Kerdoussi A., Djebbari N., Tahri M. & Bensouilah M. 2018. Age structure, growth and shell form of *Cerastoderma glaucum* (Bivalvia: Cardiidae) from El Mellah lagoon, Algeria. AACL Bioflux 11 (3): 894–904.

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

Boaventura D., Alexander M., Della Santina P., Smith N. D., Ré P., Cancela da Fonseca L. C. & Hawkins S. J. 2002. The effects of grazing on the distribution and composition of low-shore algal communities on the central coast of Portugal and the southern coast of Britain. Journal of Experimental Marine Biology and Ecology 267: 185–206.

Borges C. D. G., Hawkins S. J., Doncaster C. P. & Crowe T. P. 2015. Effects of simulated human exploitation of a key grazer, *Patella vulgata*, on rocky shore assemblages. Marine Ecology Progress Series 533: 163–176.

Bosman A. L., Hockey P. A. R. & Siegfried W. R. 1987. The influence of coastal upwelling on the functional structure of rocky intertidal communities. Oecologia 72: 226–232.

Boukhicha J., Tlig S. Z. & Ben Hassine O. K. 2010. Morphometric diversity of *Patella caerulea* (Linnaeus, 1758) from the rocky coastline of the Tunisian coast. Rapport du Congrès de la Commission Internationale Pour l'Exploration Scientifique de la Mer Méditerranée 39: 722. (In French).

Boumaza S. & Semroud R. 2001. Inventory of the population of *Patella ferruginea* Gmelin, 1791 of the Habibas islands (West of Algeria). Rapport du Congrès de la Commission Internationale pour l'Exploration Scientifique de la Mer Mediterranée 36: 361. (In French).

Bouzaza Z. & Mezali K. 2018a. Evolution and Pattern of connectivity in some species of the genus *Patella* from the Algerian coast. Advances in Bioresearch 9 (5): 46–53.

Bouzaza Z. & Mezali K. 2018b. Discriminant-based study of the shell morphometric relationships of *Patella caerulea* (Gastropoda: Prosobranchia) of the western Mediterranean

Sea. Turkish Journal of Zoology 42: 513–522.

Bouzaza Z. & Mezali K. 2019. On the presence of *Cymbula safiana* (Gastropoda: Patellidae) on the Algerian coast (SW Mediterranean): Population structure and new record stations. Ecologia Mediterranea 45 (1): 5–13. (In French).

Branch G. M. 1981. The biology of limpets: Physical factors, energy flow, and ecological interactions. Oceanography and Marine Biology: An Annual Review 19: 235–380.

Branch G. M. 1985. Limpets: their role in littoral and sublittoral community dynamics. In: Moore P.G. & Seed R. (Ed.). The ecology of rocky coast. New York: Columbia University Press, pp: 97–116.

Cabral J. P. 2007. Shape and growth in European Atlantic *Patella* limpets (Gastropoda, Mollusca). Ecological implications for survival. Web Ecology 7: 11–21.

Cabral J. P. & Natal Jorge R. M. 2007. Compressibility and shell failure in the European Atlantic *Patella* limpets. Marine Biology 150: 585–597.

Coleman R. A., Underwood A. J., Benedetti-Cecchi L., Aberg P., Arenas F., Arrontes J., Castro J., Hartnoll R. G., Jenkins S. R., Paula J., Della Santina P. & Hawkins S. J. 2006. A continental scale evaluation of the role of limpet grazing on rocky shores. Oecologia 147: 556–564.

Deniz A. 2010. Distribution and morphometric characteristics of *Patella* species (Archaeogastropoda) in Mersin-Viranşehir region of the Northeastern Mediterranean Sea. Journal of FisheriesSciences.com 4: 171–176.

Draredja B. 2005. Structure and organization of the benthic macrofauna of the Mellah lagoon (South-Western Mediterranean, Algeria). Journal de Recherche Océanographique 30: 24–33. (In French).

Draredja B. & Bakalem A. 2004. Biomass of macrobenthic populations of the Mellah lagoon (Northern Algeria) in the spring period. Sciences et Technologie 21: 61–65. (In French).

Draredja B., Melouah K., Beldi H. & Benmarce S. 2012. Benthic macrofauna diversity of the Mellah lagoon (El-Kala National Park of northeast Algeria). Bulletin de la Société Zoologique de France 137 (1–4): 73–86. (In French).

Draredja M. A., Frihi H., Boualleg C., Gofart A., Abadie E. & Laabir M. 2019. Seasonal variations of phytoplankton community in relation to environmental factors in a protected meso-oligotrophic southern Mediterranean marine ecosystem (Mellah lagoon, Algeria) with an emphasis of HAB species. Environmental Monitoring and Assessment 191: 603.

Espinosa F. 2009. Population status of the endangered mollusk *Patella ferruginea* Gmelin, 1791 (Gastropoda, Patellidae) on Algerian islands (SW Mediterranean). Animal Biodiversity & Conservation 32 (1): 19–28.

Espinosa F., Nakano T., Guerra-García J. M. & García-Gómez J. C. 2011. Population genetic structure in a temperate Northern hemisphere region: of the endangered limpet *Cymbula nigra* influence of palaeoclimatic events?. Marine Ecology 32 (1): 1–5.

Espinosa F. & Rivera-Ingraham G. 2017. Biological Conservation of Giant Limpets: The Implications of Large Size. Advances in Marine Biology 76: 105–155.

Espinosa F., Rivera-Ingraham G., Maestre M., González A., Bazairi H. & García-Gómez J. 2014. Updated global distribution of the threatened marine limpet *Patella ferruginea* (Gastropoda: Patellidae): An example of biodiversity loss in the Mediterranean. Oryx 48 (2): 266–275.

Faria J., Martins G., Pita A., Ribeiro P., Hawkins S., Presa P. & Neto A. I. 2017. Disentangling the genetic and morphological structure of *Patella candei* complex in Macaronesia (NE Atlantic). Ecology and Evolution 7 (16):6125–6140.

Fernández N., Alborés I. & Acena-Matarranz S. 2015. Characterization of the reproductive cycle and physiological condition of *Patella vulgata* in the NW of the Iberian Peninsula: Relevant information for a sustainable exploitation. Fisheries Research 164: 293–301.

Gayanilo F. C. Jr., Sparre P. & Pauly D. 2005. FAO-ICLARM Stock Assessment Tools II: User's Guide. FAO Computerized Information Series (Fisheries) 8: 1–126.

Guelorget O., Frisoni G. F., Ximenes M. C. & Perthuisot J. P. 1989. Biogeological expression of confinement in a Mediterranean lagoon: Lake Mellah (Algeria). Revue d'Hydrobiologie Tropicale 22:87–99. (In French).

Hawkins S. & Hartnoll R. 1983. Grazing of intertidal algae by marine invertebrates. Oceanography and Marine Biology 21: 195–282.

Henriques P., Delgado J. & Sousa R. 2017. Patellid Limpets: An Overview of the Biology and Conservation of Keystone Species of the Rocky Shores. In: Ray S. (Ed.). Organismal and Molecular Malacology. Croatia: InTech, pp: 71–95.

Jenkins S. R., Coleman R. A., Burrows M. T., Hartnoll R. G. & Hawkins S. J. 2005. Regional scale differences in determinism of limpet grazing effects. Marine Ecology Progress Series 287: 77–86.

Kallouche M. M., Acevedo I., Ghalek M., Bouras D. & Machordom A. 2018. Filling the limpet gap: molecular characterization of the genus *Patella* (Patellidae, Gastropoda) in the Algerian coasts of Oran. Acta Zoologica Academiae Scientiarum Hungaricae 64 (2): 161–184.

Kallouche M. M., Bouras D. & Hussein K. B. 2014. Faunal composition, distribution and richness of the Oran's intertidal coastal zone (Mediterranean Sea, Algeria). Journal of Biodiversity and Environmental Sciences 5 (4): 122–132.

Keasar T. & Safriel U. N. 1994. The establishment of a territory: effects of food and competitors on movement patterns in *Patella caerulea* limpets. Ethology Ecology & Evolution 6: 103–115.

Koufopanou V., Reid D. G., Ridgway S. A. & Thomas R. H. 1999. A molecular phylogeny of the patellid limpets (Gastropoda: Patellidae) and its implications for the origins of their antitropical distribution. Molecular Phylogenetics and Evolution 11 (1): 138–156.

Lasiak T. 2006. Spatial variation in density and biomass of patellid limpets inside and outside a marine protected area. Journal of Molluscan Studies 72 (2): 137–142.

Lima F. P., Queiroz N., Ribeiro P. A., Hawkins S. J. & Santos A. M. 2006. Recent changes in the distribution of a marine gastropod, *Patella rustica* Linnaeus, 1758, and their relationship to unusual climatic events. Journal of Biogeography 33: 812–822.

Lucas A. & Beninger P. G. 1985. The use of physiological condition indices in marine bivalve aquaculture. Aquaculture 44:187–200.

Maatallah R., Cheggour M., Louadi K. & Djebar A. B. 2014. Gastropods Patellidae and their use in assessment of the pollution on the coastline of Skikda (North East Algeria). Revue CAMES 2: 15–29. (In French).

Magni P., Draredja B., Melouah K. & Como S. 2015. Patterns

of seasonal variation in lagoonal macrozoobenthic assemblages (Mellah lagoon, Algeria). Marine Environmental Research 109: 168–176.

Marra S., Coppa S., Camedda A., Massaro G. & De Lucia G. 2017. The exploitation of limpets in a Mediterranean Marine Protected Area: assessing the effectiveness of protection in the intertidal zone. Mediterranean Marine Science 18 (3): 406–423.

Menge B. A., Berlow E. L., Blanchette C. A., Navarrete S. A. & Yamada S. B. 1994. The keystone species concept: variation in interaction strength in a rocky intertidal habitat. Ecological Monographs 64 (3): 249–286.

Öztürk B. & Ergen Z. 1999. *Patella* species (Archeogastropoda) distributed in Saros Bay (Northest Aegean Sea). Turkish Journal of Zoology 23 (2): 513–519.

Pauly D. & Munro J. L. 1984. Once more on the comparison of growth in fish and invertebrate. ICLARM Fishbyte 2 (1): 21.

Prusina I., Ezgeta-Balić D., Ljubimir S., Dobroslavić T. & Glamuzina B. 2014. On the reproduction of the Mediterranean keystone limpet *Patella rustica*: histological overview. Journal of the Marine Biological Association of the UK 94 (8): 1651–1660.

Prusina I., Peharda M., Ezgeta-Balic D., Puljas S., Glamuzina B. & Golubic S. 2015. Life-history trait of the Mediterranean keystone species *Patella rustica*: growth and microbial bioerosion. Mediterranean Marine Science 16 (2): 393–401.

Raffaelli D. & Hawkins S. 1996. Intertidal Ecology. London: Chapman & Hall. 356 p.

Ribeiro P. A., Xavier R., Santos A. M. & Hawkins S. J. 2009. Reproductive cycles of four species of *Patella* (Mollusca: Gastropoda) on the northern and central Portuguese coast. Journal of the Marine Biological Association of the UK 89 (6): 1215–1221.

Ridgway S. A., Reid D. G., Taylor J. D., Branch G. M. & Hodgson A. N. 1998. A cladistics phylogeny of the family Patellidae (Mollusca: Gastropoda). Philosophical Transactions: Biological Sciences 353 (1375): 1645–1671.

Samraoui B. & Samraoui F. 2008. An ornithological survey of Algerian wetlands: Important Bird Areas, Ramsar sites and threatened species. Wildfowl 58: 71–96.

Santini G. & Chelazzi G. 1995. Glycogen content and rates of depletion in two limpets with different foraging regimes. Comparative Biochemistry and Physiology Part A: Physiology 111 (2): 271–277.

Sokal R. R. & Rohlf F. J. 1987. Introduction to biostatistics, 2nd edn. New York: W.H.Freeman and Co Ltd. 363 p.

Sousa L. L., Seabra R., Wethey D. S., Xavier R., Queiroz N., Zenboudji S. & Lima F. P. 2012. Fate of a climate-driven colonisation: Demography of newly established populations of the limpet *Patella rustica* Linnaeus, 1758, in northern Portugal. Journal of Experimental Marine Biology and Ecology 438: 68–75.

Sousa R., Delgado J., Pinto A. R. & Henriques P. 2017. Growth and reproduction of the north-eastern Atlantic keystone species *Patella aspera* (Mollusca: Patellogastropoda). Helgoland Marine Research 71: 8.

Sousa R., Henriques P., Vasconcelos J., Pinto A. R, Delgado J. & Riera R. 2020. The protection effects of marine protected areas on exploited molluscs from an oceanic archipelago. Aquatic Conservation – Marine and Freshwater Ecosystems 30 (4): 717–729.

Telailia S., Boutabia L., Khemis El-Hak M. D., Elafri A. & Djebbari N. 2017. Multi-annual and seasonal patterns of waterbird assemblages in a Mediterranean coastal lagoon (El Mellah lagoon) of Northeastern Algeria. Ekológia (Bratislava) 36 (2): 146–157.

Tlig-Zouari S., Rabaoui L., Fguiri H., Diawara M. & Ben Hassine O. K. 2010. Spatial diversity of rocky midlittoral macro-invertebrates associated with the endangered species *Patella ferruginea* (Mollusca: Gastropoda) of Tunisian coastline. Estuarine, Coastal and Shelf Science 87: 275–283.

Tlig-Zouari S., Rabaoui L., Fguiri H. & Ben Hassine O. K. 2011. Morphometric characterization of the limpet *Patella ferruginea* along the Tunisian coasts. Cahiers de Biologie Marine 52: 269–278.

Vasconcelos P., Lopes B., Castro M. & Gaspar M. 2008. Comparison of indices for the assessment of reproductive activity in *Hexaplex trunculus* (Gastropoda: Muricidae). Marine Biology Research 4: 392–399.

Zegaoula B., Beldi H., Draredja B. & Soltani N. 2016. Reproduction of *Patella rustica* (Mollusca, Gastropoda) in the gulf of Annaba (Algeria, Mediterranean South Western). Advances in Environmental Biology 10: 42–50.

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