Pinna nobilis in the south Marmara Islands (Sea of Marmara); it still remains uninfected by the epidemic and acts as egg laying substratum for an alien invader

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Abstract

A total of 12 Pinna nobilis beds were found and studied at depths varying between 2 and 6 m in the south Marmara Islands (Sea of Marmara). Fan mussel individuals in the beds were healthy with a few old dead specimens, indicating that the epidemic, which has devastated P. nobilis populations in the Mediterranean Sea, has not reached the Sea of Marmara, making the region a refuge area for the species. The average density of P. nobilis in the area varied between 0.6 ind.10 m-2 and 24 ind.10 m-2. The P. nobilis shells overall provided substrata or refuge for 14 species (10 sessile and 4 motile organisms), from macroalgae to fish. Shells of juvenile and adult specimens had different species assemblages. Four distinct assemblages were detected on shells, primarily formed by the red alga Gracilaria bursa-postaris, egg cocoons of the invasive alien Rapana venosa, the gastropod Bittium reticulatum and the serpulid polychaete Spirobranchus polytrema.

Keywords: Fan mussel; healthy individuals; critically endangered species; associated biota; Sea of Marmara; Haplosporidium pinnae.

Introduction

The fan mussel Pinna nobilis Linnaeus, 1758, endemic to the Mediterranean Sea, widely occurs in the shallow-water sandy environments (with or without seagrasses) of the Mediterranean Sea, but rarely in rhodolith and boulders beds, and lives as deep as 60 m (Butler et al., 1993; Kersting & García-March, 2017). It is the largest bivalve species in the region, reaching a shell length of up to 120 cm and a life span that can exceed 45 years (Rouanet et al., 2015). It plays important ecological functions in the benthic ecosystem, i.e. filtering seawater, removing suspended particulate matter and enhancing water transparency (Trigos et al., 2014); providing a suitable substratum by its wide-surface shells for a large number of species belonging to different taxonomic groups (Addis et al., 2009; Rabaoui et al., 2009). This species has also a commensal relationship with the pea crabs Nepinotheres pinnotheres and Pinnotheres pisum, and the shrimp Pontonia pinnophylax (Rabaoui et al., 2008; Becker & Türkyay, 2017).

As Pinna nobilis forms beds in the shallow-water benthic environments where several human activities (i.e. fishing, recreation) take place, populations of the species have drastically declined over the last decades (Katsanevakis, 2006; Acarli et al., 2011; Hendriks et al., 2013). Consequently, it has been listed as an endangered species and is under protection according to the EU Habitats Directive 92/43/EEC (Annex IV), the Protocol for Specially Protected Areas and Biological Diversity in the Mediterranean (Barcelona Convention, Annex II) and national legislations of most Mediterranean countries, including Turkey.

Since the late 2016, mass mortalities of P. nobilis have been described in the western Mediterranean and Aegean Seas, due to a suddenly developed disease, which was primarily caused by a sporozoan parasite, Haplosporidium pinnae, or by a set of pathogens including different bacteria and H. pinnae (Vázquez-Luis et al., 2017; Cantanese et al., 2018; Cabanellas-Reboredo et al., 2019; Katsanevakis et al., 2019; Panarese et al., 2019; Carella et al., 2020; Scarpa et al., 2020). Even in the Çanakkale Strait, which constitutes the southern gate of the Sea of Marmara, mass mortality of P. nobilis has been recently reported (Özalp & Kersting, 2020). This epidemic is seriously threatening the existence of P. nobilis in the region,
therefore, IUCN has recently categorized it as a critically endangered species (Kersting et al., 2019).

The Sea of Marmara’s two layered-water system provides a suitable environment for *P. nobilis*, due to its special characters such as high productivity and low salinity in surface waters (Özsoy & Altiok, 2016). The Black Sea-originated surface water layer (between 0-25 m depth) has lower salinity (around 18 psu near the İstanbul Strait and becoming more saline (22-24 psu) towards the Çanakkale Strait), but the Aegean Sea-originated deep water layer (>25 m depth) has high salinity (37-38 psu) across the Sea of Marmara (Özsoy & Altiok, 2016). *Pinna nobilis* has been sporadically recorded in the region since the first report by Forsskål (1775), but data on its population and health status have not been documented, except for a recent study by Öndes et al. (2020b), who mentioned a healthy, uninfected *P. nobilis* population around Erdek, which is close to the south Marmara Islands.

During an expedition with a completely different purpose (assessing alien species), we were able to dive and observe several sites in the south Marmara Islands. *Pinna nobilis* beds were frequently encountered in the shallow waters of certain areas and information about its population, health status, and shell-associated biota were gathered during the study.

Materials and Methods

Within the scope of the MARIAS project (Addressing Invasive Alien Species Threats at Key Marine Biodiversity Areas Project), a scientific cruise was organized between 05.09.2020-09.09.2020 to assess the composition and distribution of alien species (especially *Rapana venosa* and *Asterias rubens*) along the coasts of the south Marmara Islands. For this purpose, 17 stations were selected from different parts of the region (Fig. 1), and the depths 0-25 m (if possible) were swept by SCUBA divers. The selection of stations was random, but attention was paid to put at least one station in all large islands and to put stations in different geographic directions of islands.

At each station where a continuous (covering large area, i.e. at least 50 m on a horizontal line) *P. nobilis* bed existed (at around 3 m depth), five replicate plots, each with an area of 10 m² (5 m x 2 m), were considered to count living and dead *P. nobilis* individuals. The replicates were randomly deployed and set at least 20 m apart from each other. The adult and juvenile specimens, which differ from each other in having different shell length (juvenile <20 cm) and morphology (thick raised scales on shell in juveniles), were counted separately. The species settled on shells of *P. nobilis* were identified by under-water observations and examinations of photographs taken at 7 stations (1, 3, 5, 9, 11, 15 and 17). The coverage of species (both sessile and motile) on shells was estimated using the photoQuad software (Trygonis & Sini, 2012; freely available at: http://www.mar.aegean.gr/sonarlab/photoquad/index.php). For the assessment of the species’ percentage coverage, 100 points were uniformly applied over each shell.

In order to assess the species assemblages on *P. nobilis* shell surfaces, coverage values of species were considered, and the average coverage values derived from replicates were square-root transformed prior to the analysis. The Bray-Curtis index (Bray & Curtis, 1957) was applied to construct the triangular resemblance matrices. The assemblage multivariate pattern was explored and visualized using the Principal Coordinate Analysis (PCoA) (Torgerson, 1958) applied on the Bray-Curtis resemblance matrices at the species level.

**Fig. 1:** Map of the investigated area (south Marmara Islands) with the locations of sampling sites. The black triangle shapes indicate the *Pinna nobilis* beds in the region.
Permutational Analysis of Variance (PERMANOVA) was applied to check 1) if the density of P. nobilis differed among stations (Euclidian distance matrix) and 2) if shells of adult and juvenile individuals of P. nobilis possessed different epibiotic communities (Bray-Curtis distance matrix). In the first PERMANOVA design, stations (12 levels) where P. nobilis was found, were selected as a fixed factor. In the second design, only one factor (the shell size) was considered (two levels, fixed).

Results

Density of Pinna nobilis

Continuous Pinna nobilis beds were found at 12 out of 17 stations in the study area. The depth range distribution of the bed was between 2-6 m depths, but some solitary individuals were observed at 12 m (max depth range of the species in the area). It largely inhabited sandy substrata with shell fragments, but specimens were also observed in Cymodocea nodosa beds (Fig. 2). The P. nobilis populations were mainly composed of adult specimens, but juvenile individuals (almost 5-10% of the populations) were also encountered. The density of the species differed among the sampled stations (PERMANOVA, P<0.01) (Table 1). The highest density of the species (40 ind.10 m-2) was detected at station 3. The average density of the species ranged from 0.6 ind.10 m-2 (±0.54 SD, station 11) to 24 ind.10 m-2 (±11 SD, station 2) (Fig. 3). At four stations (1-3 and 9), the average density of the species was higher than 10 ind.10 m-2.

Dead individuals of Pinna nobilis

Individuals in the P. nobilis beds in the region showed no signs of the disease. Dead individuals were very rare, observed only at stations 3 (five individuals) and 5 (one individual). However, dense epibiotic settlements on shells indicated that they were old dead individuals. No apparent human impact (e.g. anchorage) was detected in the P. nobilis beds, except for station 17 where a ghost net completely covered 5-6 P. nobilis individuals (Fig. 2B).

Epibiotic communities of Pinna nobilis

The large surface area of P. nobilis shells attracted many species, from algae to fish. A total of 14 species (10 sessile (see Fig. 4) and 4 motile (Bittium reticulatum, Gibbula adansoni, Paracentrotus lividus and Trigonyma tripterenotus)) were observed on shells. The species occupying large areas on shells differed among stations

Table 1. Overall PERMANOVA tests applied on the density of Pinna nobilis at locations (based on Euclidian distance) and the epibiotic assemblages (based on Bray-Curtis similarity) on shells of different growth stages of P. nobilis (juvenile and adult).

|                      | Degree of Freedom | Sum of Squares | Mean Squares | Pseudo-F | P(perm) |
|----------------------|-------------------|----------------|--------------|----------|---------|
| Station              | 11                | 2848.8         | 258.9        | 17.8     | 0.001   |
| Residual             | 46                | 669.07         | 14.5         |          |         |
| Total                | 57                | 3517.9         |              |          |         |
| Growth stage         | 1                 | 3078.4         | 3078.4       | 2.68     | 0.04    |
| Residual             | 5                 | 5737.1         | 1147.4       |          |         |
| Total                | 6                 | 8815.5         |              |          |         |

Fig. 2: General view of a Pinna nobilis bed at station 9 (Ekinlik Island) (upper picture) and fishing net-covered P. nobilis individuals in a Cymodocea nodosa bed at station 17 (Kapıdağ Peninsula) (lower picture).
The red alga *Gracilaria bursa-postaris* had the highest percent coverage on shells (coverage: 58-75%) at three stations (1, 3 and 9), whereas the serpulid *Spirobranchus triqueter* covered the majority of shell surface (90%) at station 17. At only station 5, the alien invader gastropod *R. venosa* densely laid eggs on shells of *P. nobilis*, occupying almost 60% of the total shell surface.

In this small spatial scale, four different epibiotic communities were assessed, based on the Bray-Curtis similarity value higher than 50% (Fig. 5). The first two axes of the PCoA graph explained 77% of the total variance. Shells of adult and juvenile (at stations 11 and 15) individuals of *P. nobilis* possessed significantly different epibiotic communities (Table 1, Permanova, *P*<0.05). Shell surfaces of adult *P. nobilis* were densely occupied by alga, *R. venosa* egg cocoons or serpulid polychaetes (Figs 5, 6), with almost no empty surfaces available, whereas the majority of shell surfaces of juvenile *P. nobilis* were empty, with only 16-18% of surface area being covered, mainly by filamentous algae (10%), *Bittium reticulatum* and serpulid polychaetes (4-5%).

**Fig. 3:** Mean population densities of *Pinna nobilis* at stations (Bar indicates ± standard deviation).

**Fig. 4:** The mean percent coverages of the species associated with *Pinna nobilis* shells.

**Fig. 5:** Principal Coordinate Analysis (PCoA) showing the similarity among stations based on coverages of species associated with *Pinna nobilis* shells. Vectors represent the species that are responsible for dissimilarity among different assemblages. Stations 11 and 15 had juvenile *Pinna nobilis*. 
Discussion

*Pinna nobilis* occurs widely in the shallow-water bare sand or sea-grass occupied sandy habitats along the coasts of Turkey with the exception of the Black Sea. Its first record in the region was given by Forsskål (1775) from the Sea of Marmara and the Aegean Sea. The northern distribution boundary of the species in the region was determined in the Istanbul Strait; between Kızkulesi and Tophane (cited as *Pinna pectinata* var. *fragilis* by Marión, 1898). In the following years, mainly in the Aegean Sea, data on its distribution (Geldiay & Kocataş, 1972; Pergent & Pergent, 1985; Okuş et al., 2007; Gönülal & Güreşen, 2014), growth (Demirci & Acarli, 2019), commensal relationship with other species (Acarli et al., 2019), and culture and growth (Acarli et al., 2011; 2018) have been acquired.

Little has been published about the density of *P. nobilis* in the region. In the cartography study carried out by Pergent & Pergent (1985) near Urla Harbour (Aegean Sea), it was indicated on the map that the *P. nobilis* density among *Posidonia oceanica* meadows reached up to 4 ind.10m$^{-2}$. The mean density of *P. nobilis* was estimated as 1.1 individuals.10m$^{-2}$ (highest density as 10 individuals.10 m$^{-2}$) in the middle Aegean Sea (from Şakran to Özbek) (Öndes et al., 2020a), and as 2.4 ind.10m$^{-2}$ in the Sea of Marmara (Erdek) (Öndes et al., 2020b). The present study indicated that this species formed beds at different parts of the south Marmara Islands and built up a mean density from 0.6 to 24 ind.10m$^{-2}$, with a maximum of 40 ind.10m$^{-2}$. Such a high density (90 ind.10 m$^{-2}$) was also reported from the Çanakkale Strait (Özalp & Kersting, 2020). In the Greek coasts of the Aegean Sea, the density of the species locally exceeded 2 ind.10m$^{-2}$ in Souda Gulf (Crete) (Katsanevakis & Thessalou-Legaki, 2009), 1 ind.10m$^{-2}$ in Gera Gulf (Lesvos) (Tsaridis et al., 2018), and 0.7 ind.10m$^{-2}$ (with a mean estimate of 0.3 ind.10m$^{-2}$) in the southern Aegean Islands (Vafidis et al., 2014). In the other sub-regions of the Mediterranean Sea, the average population density of this species was estimated as 2 ind.10m$^{-2}$ in the Adriatic Sea (Šiletić & Peharda, 2003), and 0.1 ind.10m$^{-2}$ in the western Mediterranean Sea (Coppa et al., 2010).

Across the Mediterranean Sea, the *P. nobilis* populations have been subjected to a mass mortality event first appearing on the Spanish coast in Autumn 2016 (Vázquez-Luis et al., 2017), possibly due to the sporozoan parasite *Haplosporidium pinnae* (Catanese et al., 2018) or a mix of pathogens including *Vibrio* spp., *H. pinnae*, *Mycobacterium* sp. and *Perkinsus* sp. (Lattos et al., 2020; Carella et al., 2020). The pathogens seem to be host-specific as they do not infect the congeneric species *P. rudis*. The death rate is very high, reaching up to 90%-100% in the western Mediterranean (Vázquez-Luis et al., 2017), 36%-100% in the Adriatic Sea (Cizmek et al., 2020), 75%-100% in the Aegean Sea (Katsanevakis et al., 2019; Øndes et al., 2020b), 99% in the Çanakkale Strait (Özalp & Kersting, 2020). It seems that only two

![Fig. 6: Different species assemblages on shells of Pinna nobilis in the south Marmara Islands. A. Gracilaria bursa-pastoris dominated assemblage, B. Bittium reticulatum dominated assemblage, C. Rapana venosa egg cocoon dominated assemblage, D. Spirobranchus triqueter dominated assemblage.](image-url)
years later, this epidemic reached from the Spanish coast to the north Aegean Sea (Katsenavakis et al., 2019). The summer marine current system in the Mediterranean (Catanese et al., 2018), an intermediate host (planktonic species) (Cabanellas-Reboredo et al., 2019) or the movement of vessels (through ballast water) (Šarić et al., 2020) might help these pathogens to spread across the Mediterranean. There has been evidence that the disease is closely related to the environmental variables, being active in temperatures above 13.5°C and in a salinity range between 36.5–39.7 PSU (Cabanellas-Reboredo et al., 2019). It seems that the mortality is now at the gate of the Sea of Marmara (Özalp & Kersting, 2020). Nevertheless, the low mortality rate found in Erdek (10%, Öndes et al., 2020b) and the southern Marmara Islands (<1%, old dead, present study) indicated that this severe epidemic has not reached the region. The low salinity (around 22 PSU in the southern Marmara Islands) (Çinar et al., 2020) in the Sea of Marmara due to influx by the Black Sea water seems to act as a barrier for these pathogens. However, to reach a reliable conclusion, the P. nobilis populations in the region should be monitored. Kersting et al. (2020) indicated the importance of unaffected population of P. nobilis on its survival in the Mediterranean Sea, which would act as a source population through which larvae are dispersed to affected areas via sea currents, a golden chance for its recovery.

The first data presented here regarding the biota associated with P. nobilis shells from the Sea of Marmara exerted very interesting results. The juvenile and adult P. nobilis shells included different epibiotic compositions. Unlikely, surfaces of juvenile shells were largely bare and occupied (especially on posterior margin) by the herbivorous Bittium reticulatum, which was assumed to feed on filamentous algae newly growing on shells. Contrary to other studies (Cosentino & Giacobbe, 2007; Rabauoi et al., 2009), this study clearly indicated that the size of P. nobilis shells played an important role in the structure of the associated biota. In accordance with the present study, Banach-Esteve et al. (2015) postulated that juvenile and adults presented different species composition aggregat ed to shells. The shells in the present study had different species assemblages mainly characterized by abundant occurrence of; 1) Gracilaria bursa-pastoris, 2) Bittium reticulatum, 3) Rapana venosa egg cocoon, 4) Spirobranchus triqueter. These assemblages seem to be developed in specific biotic and abiotic conditions. The availability of reproducing individuals of R. venosa (present at station 5), the development stage of the species (juvenile or adult) and different environmental conditions (especially at station 17, high turbidity) at stations might have contributed in shaping the epibiotic communities.

It is important to note that shells of P. nobilis acted as egg laying substrata of the invasive gastropod R. venosa. Although the gastropod attaches its egg cocoons to every available hard substrata (including the shells of other R. venosa individuals, pers. obser.), it seems that its preferential substratum at station 5 was shells of P. nobilis. The availability of adult gastropod species seemed to be responsible for this dense settlement, but if any environmental variable played a role in this phenomenon is unknown at this stage and it needs further investigation. On these shells, other sessile species such as S. triqueter were represented by low percent coverages. Egg cocoons formed a layer of 5-6 cm thickness on shell surfaces. The effect of dense egg cocoon aggregations on the feeding activity of P. nobilis and the epibiot is unknown at this stage. Cabanellas-Reboredo et al. (2010) reported the invasive alga species Lophocladia lallemandii on shells of P. nobilis and proved that the alga slightly decreased the trophic level of P. nobilis. Kersting & García-March (2017) found that the reduction in growth of juveniles of P. nobilis in the Columbretes Islands over the years co-occurred with the spread of L. lallemandii.

Contrary to the south Marmara Islands, Pinna nobilis shells were almost completely covered by S. triqueter in the Kapıdağ Peninsula (station 17), where dense human settlements occurred. Though not measured, relatively dense suspended material that diminished underwater visibility were observed in this area and it might have drastically affected the species composition associated with P. nobilis. Spirobranchus triqueter, a serpulid polychaete species, is known to densely settle on bottoms with shell fragments in the Sea of Marmara (Çinar et al., 2015). It is considered as an opportunistic species, making use of available space quickly (Riley & Ballerstedt, 2005), occurring predominantly in stressed environments such as harbors (Çinar, 2006). It was also reported on P. nobilis shells, but with a low cover percentage (<%4) (Šiletić & Peharda, 2003; Plečaš, 2017).

The epibiotic communities of P. nobilis were rarely a subject of study in Turkey. Çinar et al. (2001) and Çinar (2003) reported relatively dense populations of Platyneiris dumerilii (88% of total number of nereidid individuals), and Salvatoria clavata, Haplosyllis spongicola and Syllis prolifera (36% of total syllid individuals) on shells collected from the east coast of the Aegean Sea.

Conclusions

The present study indicated that the Pinna nobilis individuals in the south Marmara Islands were healthy and have not been affected by the rapidly spreading disease occurring in the Mediterranean and Çanakkale populations. It is very crucial to protect the populations from any anthropogenic impacts, as they would possibly act as a source population for the recovery of this species in the Mediterranean Sea. Therefore, the south Marmara Islands, which represent an important reservoir of P. nobilis, should be declared as a marine protected area and a monitoring program should be implemented. The reasons why P. nobilis populations in the Sea of Marmara (at least in the south Marmara Islands) have not been affected by the disease would be an interesting subject of study. Is it a matter of time or a matter of environmental conditions of the Sea of Marmara?
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References

Acarli, S., Vural, P., Öktener, A., 2019. Association between the English of the final version of the paper.

Acarli, S., Lok, A., Acarli, D., Kirtik, A., 2018. Reproductive cycle and biochemical composition in the adductor muscle of the endangered species fan mussel Pinna nobilis (Linnaeus, 1758), from the Aegean Sea, Turkey. Alimenti Journal of Agriculture Science, 34, 169-174.

Acarli, S., Lok, A., Yigitkurt, S., Palaz, M., 2011. Culture of fan mussel (Pinna nobilis, Linnaeus 1758) in relation to size on suspended culture system in Izmir Bay, Aegean Sea, Turkey. Kafkas Universitesi Veteriner Fakultesi Dergisi, 17 (6), 995-1002.

Acarli, S., Lok, A., Acarli, D., Kirtik, A., 2018. Reproductive cycle and biochemical composition in the adductor muscle of the endangered species fan mussel Pinna nobilis, Linnaeus 1758 from the Aegean sea, Turkey. Fresenius Environmental Bulletin, 27, 6506-6518.

Addis, P., Secchi, M., Brundu, G., Manunza, A., Corrias, S. et al., 2009. Density, size structure, shell orientation and epibiontic colonization of the fan mussel Pinna nobilis L. 1758 (Mollusca: Bivalvia) in three contrasting habitats in an estuarine area of Sardinia (W Mediterranean). Scientia Marina, 73, 143-152.

Banach-Esteve, G., Vázquez Luis, M., Company, S.D., 2015. Temporal trends in sessile epibionts of the endemic bivalve Pinna nobilis variability in Lophocladia lallemandi colonization. Thalassas: An International Journal of Marine Sciences, 31, 19-29.

Becker, C., Türkay, M., 2017. Host specificity and feeding in European pea crabs (Brachyura, Pinnotheridae). Crustacea, 90, 819-844.

Bray, J.R., Curtis, J.T., 1957. An ordination of upland forest communities of southern Wisconsin. Ecological Monographs, 27, 395-349.

Butler, A., Vicente, N., De Gaulejac, B., 1993. Ecology of de pteriod bivalves Pinna bicolor Gmelin and Pinna nobilis L. Life, 3, 37-45.

Cabanellas-Reboredo, M., Blanco, A., Deudero, S., Tejada, S., 2010. Effects of the invasive macroalga Lophocladia lallemandi on the diet and trophism of Pinna nobilis (Mollusca: Bivalvia) and its guests Pontonia pontiniphylax and Nepinnotheres pinnotheeres (Crustacea: Decapoda). Scientia Marina, 74, 101-110.

Cabanellas-Reboredo, M., Vázquez-Luis, M., Mourre, B., Álvarez, E., Deudero, S. et al., 2019. Tracking a mass mortality outbreak of pen shell Pinna nobilis populations: A collaborative effort of scientists and citizens. Scientific Reports, 9, 13355.

Carella, F., Antufermo, E., Farina, S., Salati, F., Mandas, D. et al., 2020. In the wake of the ongoing mass mortality events: co-occurrence of Mycobacterium, Haplosporidium and other pathogens in Pinna nobilis collected in Italy and Spain (Mediterranean Sea). Frontiers in Marine Science, 7, 48.

Catane, G., Grau, A., Valencia, J. M., García-March, J. R., Vázquez-Luis, M. et al., 2018. Haplosporidium pinnae sp. nov., a haplosporidan parasite associated with mass mortalities of the fan mussel, Pinna nobilis, in the Western Mediterranean Sea. Journal of Invertebrate Pathology, 157, 9-24.

Çınar, M.E., 2003. Ecological features of Syllidae (Polychaeta: Polychaeta) from shallow-water benthic environments of the Aegean Sea, eastern Mediterranean. Journal of the Marine Biological Associations of the United Kingdom, 83, 737-745.

Çınar, M.E., 2006. Serpulid species (Polychaeta: Serpulidae) from the Levantine coast of Turkey (eastern Mediterranean), with special emphasis on alien species. Aquatic Invasions, 1, 223-240.

Çınar, M.E., Ergen, Z., 2001. On the ecology of the Nereididae (Polychaeta: Annelida) in the Bay of İzmir, Aegean Sea. Zoology in the Middle East, 22, 113-122.

Çınar, M.E., Dağlı, E., Çağlar, S., Albayrak, S., 2015. Polychaetes from the northern part of the Sea of Marmara with the description of a new species of Polydora (Annelida: Polychaeta: Spionidae). Mediterranean Marine Science, 16 (3), 524-532.

Çınar, M.E., Bakır, K., Öztürk, B., Doğan, A., Açıkgöz, Ş. et al., 2020. Spatial distribution pattern of macroinvertebrates associated with the black mussel Mytilus galloprovincialis (Mollusca: Bivalvia) in the Sea of Marmara. Journal of Marine Systems, 211, 103402.

Cižmek, H., Čolic, B., Gračan, R., Grau, A., Catane, G., 2020. An emergency situation for pen shells in the Mediterranean: The Adriatic Sea, one of the last Pinna nobilis shelters, is now affected by a mass mortality event. Journal of Invertebrate Pathology, 173, 107388.

Coppa, S., Guala, I., de Lucia, G.A., Massaro, G., Bressan, M., 2010. Density and distribution patterns of the endangered species Pinna nobilis within a Posidonia oceanica meadow in the Gulf of Oristano (Italy). Journal of the Marine Biological Associations of the United Kingdom, 90, 885–894.

Cosentino, A., Giacobbe, S., 2007. Aspects of epizoobiontic communities of southern Wisconsin. Cahiers de Biologie Marine, 48, 187-197.

Demirci, A., Acarli, S., 2019. Estimation growth parameters of endangered the fan mussel species (Pinna nobilis L.) by using different growth models from Izmir Bay, Aegean Sea, Turkey. Fresenius Environmental Bulletin, 28, 7368-7374.

Forsskål, P., 1775. Descriptiones animalium avium, amphibiorum, piscium, insectorum, vermium; quae in itinere orientali observavit Petrus Forskal. Post mortem autors edidit Carsten Niebuhr Adjuncta est materia medica Kahirina atus tabula maris rubri geographica. Copenhagen, 164 p.

Geldiay, R., Kocataş, A., 1972. İzmir Körfezi’nin bentos, isit Carsten Niebuhr Adjuncta est materia medica Kahirina atus tabula maris rubri geographica. Copenhagen, 164 p.

Gönlü, O., Güreşen, Z., 2001. On the ecology of the Nereididae (Polychaeta: Annelida) in the Bay of İzmir, Aegean Sea. Thalassas: An International Journal of Marine Sciences, 12, 1-34.

Gönila, O., Güreşen, Z., 2001. On the ecology of the Nereididae (Polychaeta: Annelida) in the Bay of İzmir, Aegean Sea. Thalassas: An International Journal of Marine Sciences, 12, 1-34.
opoda, Rhynchonellata) for the Turkish seas. *Journal of Black Sea/Mediterranean Environment*, 20, 228-252.

Hendriks, I.E., Tenan, S., Tavecchia, G., Marbà, N., Jordà, G. *et al.*, 2013. Boat anchoring impacts coastal populations of the pen shell, the largest bivalve in the Mediterranean. *Biological Conservation*, 160, 105-113.

Katsanevakis, S., 2006. Population ecology of the endangered fan mussel *Pinna nobilis* in a marine lake. *Endangered Species Research*, 1, 1-9.

Katsanevakis, S., Thessalou-Legaki, M., 2009. Spatial distribution, abundance and habitat use of the protected fan mussel *Pinna nobilis* in Souda Bay, Crete. *Aquatic Biology*, 8, 45-54.

Katsanevakis, S., Tsirintanis, K., Tsaparlis, D., Doukas, D., Sini, M. *et al.*, 2019. The cryptogenic parasite *Haplosporidium pinnae* invades the Aegean Sea and causes the collapse of *Pinna nobilis* populations. *Aquatic Invasions*, 14, 150-164.

Kersting, D.K., Garcia-March, J.R., 2017. Long-term assessment of recruitment, early stages and population dynamics of the endangered Mediterranean fan mussel *Pinna nobilis* in the Columbretes Islands (NW Mediterranean). *Marine Environmental Research*, 130, 282-292.

Kersting, D., Benabdi, M., Čižmek, H., Grau, A., Jimenez, C. *et al.*, 2019. *Pinna nobilis*. The IUCN Red List of Threatened Species 2019: e.T160075998A160081499.

Kersting, D.K., Vázquez-Luis, M., Mourre, B., Belkhamssa, F.Z., Álvarez, E. *et al.*, 2020. Recruitment disruption and the role of unaffected populations for potential recovery after the *Pinna nobilis* mass mortality event. *Frontiers in Marine Science*, 7, 594378.

Lattos, A., Giantis, I.A., Karagiannis, D., Michaelidis, B., 2020. First detection of the invasive haplosporidian and mycobacteria parasites hosting the endangered bivalve *Pinna nobilis* in Thermaikos Gulf, North Greece. *Marine Environmental Research*, 155, 104889.

Marion, A.F., 1898. Notes sur la faune des Dardanelles et du Bosphore. *Annales du Musée d’Histoire Naturelle de Marseille. Série II. Bulletin notes zoologiques, géologiques, paléontologiques*, 1, 163-182.

Öküz, E., Yüksel, A., Noyan Yılmaz, I., Aslan Yılmaz, A., Karlan, S.U. *et al.*, 2007. Marine Biodiversity of Dağça-Bozbazar Specially Protected Area (Southeastern Aegean Sea, Turkey). *Journal of Black Sea/Mediterranean Environment*, 13, 7-17.

Öndes, F., Kaiser, M.J., Gütülsöy, H., 2020a. Human impacts on the endangered fan mussel, *Pinna nobilis*. *Aquatic Conservation: Marine Freshwater Ecosystems*, 30, 31-41.

Öndes, F., Alan, V., Akçalı, B., Gütülsöy, H., 2020b. Mass mortality of the fan mussel *Pinna nobilis* in Turkey (eastern Mediterranean). *Marine Ecology*, e12607.

Özalp, H.B., Kersting, D.K., 2020. A pan-Mediterranean extinction? *Pinna nobilis* mass mortality has reached the Turkish Straits System. *Marine Biodiversity*, 50, 81.

Özsoy, E., Altıok, H., 2016. A review of hydrography of the Turkish Straits System. In: Özyüz, E., Çağatay, M.N., Balkis, N., Balkis, N., Öztürk, B. (Eds.), The Sea of Marmara: Marine Biodiversity, Fisheries, Conservation and Governance. Turkish Marine Research Foundation (TUDAV), Publication No: 42, Istanbul, pp. 13-42.

Panarese, R., Tedesco, P., Chimienti, G., Latrofa, M.S., Quaglio, F. *et al.*, 2019. *Haplosporidium pinnae* associated with mass mortality in endangered *Pinna nobilis* (Linnaeus 1758) fan mussels. *Journal of Invertebrate Pathology*, 164, 32-37.

Pergent, G., Pergent, C., 1985. Cartographie de l’herbier a *Pseudoria oceanica* de la Baie d’Urla-Iskele (Turquie). *Rapports et Procès-Verbaux des Internationale pour l’Exploration Scientifique de la Mer Méditerranée*, 29, 6.

Plečaš, D., 2017. Epibionti na pleanetoj periski (*Pinna nobilis* Linnaeus, 1758; Mollusca: Bivalvia). MSc Thesis, University of Zagreb, Faculty of Science, 37 pp.

Rabaoui, L., Tihz-Zouari, Ben Hassine, O.K., 2008. Two species of Crustacea (Decapoda) associated with the fan mussel, *Pinna nobilis* Linnaeus, 1758 (Mollusca, Bivalvia). *Crustacea*, 81, 433-446.

Rabaoui, L., Tihz-Zouari, S., Cosentino, A., Ben Hassine, O.K., 2009. Associated fauna of the fan shell *Pinna nobilis* (Mollusca: Bivalvia) in the northern and eastern Tunisian coasts. *Scientia Marina*, 73, 129-141.

Riley, K., Ballerstedt, S., 2005. *Spirobranchus triqueter* A tubeworm. In: Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Associations of the United Kingdom. 1794.2.

Rouanet, E., Trigos, S., Vicenti, N., 2015. From youth to death of old age: the 50-year story of a *Pinna nobilis* fan mussel population at Port-Cros Island (Port-Cros National Park, Provence, Mediterranean Sea). *Scientific reports of the Port-Cros national park*, 29, 209-222.

Šarić, T., Župan, I., Aceto, S., Villari, G., Palić, D. *et al.*, 2020. Epidemiology of Noble Pen Shell (*Pinna nobilis* L. 1758) mass mortality events in Adriatic Sea is characterised with rapid spreading and acute disease progression. *Pathogens*, 9, 776.

Searpa, F., Sanna, D., Azzena, I., Mugetti, D., Cerruti, F. *et al.*, 2020. Multiple non-species-specific pathogens possibly triggered the mass mortality in *Pinna nobilis*. *Life*, 10, 238.

Šiletić, T., Petarha, M., 2003. Population study of the fan shell *Pinna nobilis* L. in Malo and Veliko Jezero of the Mijet National Park (Adriatic Sea). *Scientia Marina*, 67, 91-98.

Torgerson, W.S., 1958. Theory and methods of scaling. New York: Wiley.

Trigos, S., García-March, J., Vicente, N., Tena, J., Torres, J., 2014. Utilization of muddy detritus as organic matter source by the fan mussel *Pinna nobilis*. *Mediterranean Marine Science*, 15 (3), 667-674.

Trygonis, V., Sini, M., 2012. *photoQuad*: A dedicated seabed image processing software, and a comparative error analysis of four photoquadrat methods. *Journal of Experimental Marine Biology and Ecology*, 425, 99-108.

Tsatsoglu, E., Zoulikas, C., Panagopoulo, C., Johnsson, S., Manoutsoglou, E. *et al.*, 2018. Spatial distribution, abundance and habitat use of the endemic Mediterranean fan mussel *Pinna nobilis* in the Gera Gulf, Lesvos (Greece): comparison of design-based and model-based approaches. *Mediterranean Marine Science*, 19 (3), 642-655.

Vafidis, D., Antoniadou, C., Voultsiadou, E., Chintiroglou, C., 2014. Population structure of the protected fan mussel *Pinna nobilis* in the south Aegean Sea (eastern Mediterranean). *Journal of the Marine Biological Associations of the United Kingdom*, 94, 787-796.

Vázquez-Luis, M., Álvarez, E., Barrajón, A., García-March, J.R., Grau, A. *et al.*, 2017. S.O.S *Pinna nobilis*: A mass mortality event in Western Mediterranean Sea. *Frontiers in Marine Science*, 4, 220.