# Human impacts on the endangered fan mussel, Pinna nobilis

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## Abstract

1. *Pinna nobilis* is a sensitive and vulnerable species and hence considered a good indicator of anthropogenic pressures on marine ecosystems.

2. This study provides novel data on the density and distribution of endangered *P. nobilis* for the Turkish coasts. Threats to the status of *P. nobilis*, including by-catch and illegal collection were assessed, as was the general awareness of people about the endangered status of fan mussels.

3. The data sources consisted of direct observations from diving surveys and the use of the local ecological knowledge of fishers and SCUBA-divers.

4. Results demonstrated that the density of *P. nobilis* significantly changed with environmental parameters such as depth and among different sampling areas. The number of damaged individuals was lowest in the areas that were distant from human influences such as ports and tourist beaches. The density estimations of *P. nobilis* across a wide geographic area around the Turkish coasts revealed that the density of fan mussels was highest around west coasts in comparison with to southern coasts.

5. Fishers and divers indicated that the population of this species has decreased during the last decade. The main causes of this decline were suggested to be the impacts of fishing gears, poaching, pollution and boat anchoring. The highest amount of by-catch was estimated to be taken by trawls. In general, knowledge and local awareness of the conservation importance and status of fan mussels was poor.

6. The study has identified those areas where fan mussels occur at a high density, and hence may indicate areas for possible conservation protection status. Secondly, areas exposed to the illegal harvesting of fan mussels were highlighted. Societal concern would benefit from educational activities to raise awareness of the ecological importance and conservation needs for fan mussels in Turkey.

**KEYWORDS**

bycatch, conservation, density, endangered species, fan mussel, illegal fisheries, local ecological knowledge (LEK), marine ecology, trawling, Turkey

## 1 | INTRODUCTION

The Mediterranean Sea is subject to intense human activities due to its structure of semi-enclosed basin and its densely populated coastal status (Coll et al., 2010; Hendriks et al., 2013; UNEP-MAP 2012; Vázquez-Luis, Borg, Morell, Banach-Esteve, & Deudero, 2015). Examples of the many human impacts include the consequences of bio-invasion through the Suez Canal (Katsanevakis et al., 2014), the effects of marine gas and oil platforms on the Mediterranean marine ecosystems (Mangano & Sara, 2017) and high intensities of bottom fishing disturbance (Amoroso et al., 2018). These activities threaten not only commercially important species but also endangered species and habitats (Piroddi, Coll, Liquete, Macias, & Greer, 2017). The Mediterranean basin is a hotspot of biodiversity where conservation initiatives have increased through the inception of, at a local scale, scientific projects or specific working groups (e.g. Médail & Quézel, 1999). Effective conservation efforts that focus on endangered species need to be informed by an understanding of their population status and how human activities impact upon them. Conservation efforts concomitantly may be enhanced by increasing the level of awareness and the perceptions of local people regarding the existence and function role of endangered species (Liu, Huang, & Hsu, 2015; Pienaar, Lew, & Wallmo, 2017).

In the absence of direct ecological observations, information on the geographic presence/absence and changes in population status of endangered species can be obtained from the use of local ecological knowledge (LEK) (Carter & Nielsen, 2011; Turvey et al., 2013; Turvey et al., 2014). LEK can also be used to estimate current and historical levels of human impacts on the environment and species (Shepperson et al., 2014; Turvey et al., 2014) and to determine whether management measures are needed to arrest any population decline in status. Such management is likely to be more effective if it is combined with an understanding of people's perception of the species in question, the impacts of human activities upon that species and the management measures proposed. The use of LEK is particularly important tool for the regions such as Mediterranean especially in the south and east of this region where very little information is available on biodiversity (Coll, 2010). For example, LEK has been used to better understand the status of endangered species (e.g. Mavruk, Saygu, Bengil, Alan, & Azzurro, 2018), spatial and temporal changes in the abundance of fish species (e.g. Azzurro et al., 2019), and the impact of invasive species on fisheries (e.g. Öndes, Ünal, Özbilgin, Deval, & Turan, 2018). Accordingly, LEK was considered a useful source of information to derive information on the occurrence, abundance and impacts acting upon fan mussels.

The fan mussel *Pinna nobilis* Linneaus, 1758 is an endemic bivalve of the Mediterranean Sea, and is a species considered to be highly vulnerable to a wide range of human impacts. *Pinna nobilis* is a large organism with a maximum recorded length of 120 cm

(Voultsiadou, Koutsoubas, & Achparaki, 2010), and can live for up to 50 years, although sexual maturity is reached relatively quickly, between the first and second year of growth (Coppa, 2012; Alomar, Vázquez-Luis, Magraner, Lozano, & Deudero, 2015; Richardson, Kennedy, Duarte, & Proud, 1999; Rouanet, Trigos, & Vicente, 2015). *Pinna nobilis* occurs across a depth range of between 0.5 and 60.0 m (Butler, Vicente, & De Gaulejac, 1993), and generally occurs in *Posidonia oceanica*, *Cymodocea nodosa, Zostera marina* or *Zostera noltii* meadows, but also in bare sandy (unvegetated) bottoms (Addis et al., 2009; Rabaoui, Tlig-zouari, Katsanevakis, Belgacem, & Hassine, 2011; Voultsiadou et al., 2010). The shell is partially buried at the anterior portion of the shell and is anchored in the substratum by byssus threads (Richardson, Peharda, Kennedy, Kennedy, & Onofri, 2004; Figure 1a). *Pinna nobilis* provides a number of ecosystem services; it contributes to water clarity because its filter-feeding activities retain large amounts of organic matter from suspended detritus, and its shell provides a habitat for some species by enhancing topographic complexity (Basso et al., 2015).

Fan mussels are impacted by numerous anthropogenic effects (boat anchoring, habitat degradation, trawling, dredging, illegal extraction, coastal construction, sewage discharges and other pollution factors; see Figure 1) and non-anthropogenic factors such as global warming, acidification, food web alterations and disease, causing mass mortality (Alomar, Vázquez-Luis, Magraner, Lozano, & Deudero, 2015; Basso et al., 2015; Centoducati et al., 2006; Marba & Duarte, 2010; Coppa et al., 2013; Vázquez-Luis, et al., 2017). Finally, a mass mortality event has occurred as a result of *Haplosporidium pinnae* sp. nov., a haplosporidan parasite (Catanese et al., 2018; Vázquez-Luis et al., 2017) or through mycobacterial disease (Carella et al., 2019). As a result of these impacts the occurrence and population abundance of *P. nobilis* has declined in the last few decades (Katsanevakis et al., 2011). Although *P. nobilis* has not yet been evaluated in the International Union for Conservation of Nature (IUCN) Red List, it has been listed as an endangered and protected species under the European Council Directive 92/43/EEC since 1992 (EEC, 1992). This species also has been protected in Turkey since 1998, and its exploitation has been prohibited (Acarli, Lök, & Acarli, 2011).

Fan mussels have been exploited for millennia and more recently the nacre within the shells was collected for the production of knife handles, buttons and jewellery in the 19th century (Basso et al., 2015). In the 21st century, *P. nobilis* was fished illegally in some areas, such as Lake Vouliagmeni, the islands of Symi and Kalymnos (Katsanevakis, 2007; Vafidis, Antoniadou, Voultsiadou, & Chintiroglou, 2014). *Pinna nobilis* is the subject of a species-specific Action Plan for the Mediterranean Sea in the context of the Marine Strategy Framework Directive (MSFD) of the EU (Vázquez-Luis et al., 2017). Despite the recognised threats to the status of fan mussels, little is known about the scale of illegal collection that occurs, incidences of bycatch and the historical changes in occurrence and abundance of the species (Vafidis et al., 2014). Moreover, to date, knowledge regarding the density, population structure, ecology, growth, reproduction and epibiont species composition of fan mussels is restricted to a limited number of Mediterranean countries (Basso et al., 2015). Furthermore, nothing is known about the local people's perspective (awareness) on conservation status and ecological importance of this endangered species.

Using a combination of direct observations and interpretation of LEK, the aims of the study were: (i) to provide the first comprehensive baseline data for the present and historical distribution and density of *P. nobilis* in Turkish waters (eastern Mediterranean) prior to the occurrence of the mass mortality event in 2018 (B. Akçalı pers. comm., 2018; Katsanevakis et al., 2019), (ii) to determine which environmental (depth and habitat features) and anthropogenic factors may be related to the occurrence and density of fan mussels (iii) to evaluate fisheries effects on fan mussels such as illegal collection and by-catch associated with different fishing gears; and (iv) to assess  the awareness of stakeholders (commercial fishers, spear fishers, and scuba divers) about the conservation status of this endangered species.

# 2 | METHODS

## 2.1 | Diving surveys

### 2.1.1 | Density of *P. nobilis* across a depth gradient, and in vegetated and unvegetated habitats

In order to determine the spatial differences in density of *P. nobilis* in relation to environmental gradients, observations were made at 10 locations that had low levels of human impact/activities (Şakran, Aliağa-Çaltıdere, Foça, Urla, Özbek, Eğriliman, Torasan, Akarca, Balıklıova, Gülbahçe) in the Aegean Sea (Eastern Mediterranean) between May 2017 and October 2017 (Figure 2). We also investigated whether the density of fan mussels changed across five depth zones described below. Sampling stratification by depth zone was informed by the reported distributions of fan mussels in previous studies (Basso et al., 2015; Garcia-March & Nardo, 2006). At each location and depth, divers surveyed five replicate plots, each with an area of 25 $m^2$ (5 m x 5 m). These replicate plots  were randomly (with a minimum spacing of 5 m between plots) assigned within 5 depth zones: 0-1.0 m, 1.1-2.0 m, 2.1-3.0 m, 3.1-5.0 m, 5.1-10.0 m. Previously, Garcia-March & Nardo (2006) found that plots of 25 $m^2$ gave the most precise estimate of density for fan mussels. The density of *P. nobilis* was compared in both vegetated and unvegetated habitats. The geographical coordinates for each plot were recorded.

### 2.1.2 | Comparison of the damage of *P. nobilis* with increasing levels of human disturbance

A separate study was carried out at two sampling locations (Özbek and Şakran in İzmir Province). Both locations were selected to have 1) beaches, 2) ports and 3) less affected areas (LAAs), and were similar in terms of the number of boats utilising the harbour, distances to beach area and the LAA. Both beach locations were positioned at a distance of 500 m away from their respective ports and were visited by approximately 100 swimmers per day during the tourist season, between May and October. The lengths of beaches are 400 m and 500 m for Özbek and Şakran, respectively. The Özbek fishing port covered an area of 20 000 $m^2$ and maintained 133 boats, whereas the Şakran fishing port is 5000 $m^2$ in area and had 113 boats. The sizes of the boats  ranged from 3 and 10 m. The distance from the ports of Özbek and Şakran to the LAAs were 1000 m and 2000 m, respectively. Given the interaction between humans (beaches) and boats (ports), it was hypothesised that fan mussels would have suffered higher rates of damage at these locations than fan mussels found in LAAs with lower human interference. Divers recorded fan mussels based on a visual assessment: (i) no physical damage; (ii) physical damage apparent (cracks on shell visible); and (iii) dead individuals. The same methodology described in Section 2.1.1 was deployed across five depth zones with five replicates at beaches, ports, and LAAs in both Özbek and Şakran - a total of 150 sampling quadrats were sampled - to compare the anthropogenic impact. The vegetated / unvegetated habitats were determined posteriori. The results should be considered as indicative. It was considered that damage is unlikely to be a habitat dependent variable.

### 2.2 | Local ecological knowledge (LEK)

Garcia-March & Nardo (2006) indicated that quantitative data related to the impacts of the fishing gears on fan mussels was lacking, but suggested that questionnaire studies could provide insights into the interaction between fishing gears and fan mussels. For this reason, an LEK questionnaire was used to ascertain bio-ecological characteristics, historical changes in density, impacts of fisheries, status of consumption and awareness about the conservation status of fan mussels (Appendix S1; Table 1). Questionnaire studies were carried out with commercial fishers (n = 120), spear fishers (n = 35) and scuba-divers (n = 87) in 2017 and 2018. Only stakeholders with at least 10 years of experience were selected to participate in the questionnaire study. Scuba-divers were also asked about their diving locations and their estimates of fan mussel density per 100 $m^2$. Similarly, trawl fishers were asked to identify the locations where at least one-third of their catch was composed of fan mussels.

An additional questionnaire was undertaken in 2017 and 2018 to understand whether fan mussels are used for fish bait by recreational rod-and-line fishers (n = 120). The questionnaire study aimed to gather information on the volume of fan mussels collected per fisher per year in these locations.

In addition, interviews were conducted with owners or managers of 110 seafood restaurants in Balıkesir, Çanakkale, İzmir, Aydın, Muğla, and Antalya provinces. A phone-based questionnaire gathered information on the location of the restaurant, and whether they had sold fan mussels as part of their menu. As the present study findings revealed that the species was only consumed in Özbek, another questionnaire was developed to explore the patterns of use of fan mussels in this region/location/town.

### 2.3 | Data analysis

Statistical analyses were carried out using SPSS 20. A general linear model (GLM) was used to test the relationship between density of *P. nobilis* and: (i) sampling areas; (ii) depth; (iii) habitat, with sampling area, depth and habitat type treated as fixed factors. A Kruskal-Wallis test was used to compare the damage of *P. nobilis* in areas (beaches, ports and LAAs) with different levels of human disturbance. An estimate of mean fan mussel density of *P. nobilis* based on the scuba-divers' knowledge and the locations of the highest *P. nobilis* fields based on trawlers' knowledge was mapped using Arc-GIS 10.1.

## 3 | RESULTS

### 3.1 | Density and distribution based on direct diving observations

Based on the dive surveys, a total of 705 *P. nobilis* specimens were recorded from a total surveyed area of 1,250 $m^2$. The distribution of fan mussels ranged from a depth of 0.4 m down to the deepest depth class surveyed in this study (10 m). During the dive surveys, the mean density was calculated as 11.28 individuals per 100 $m^2$ (min = 0 and max= 100 ind. per 100 $m^2$). The GLM indicated that the density of fan mussels varied significantly with depth, habitat and sampling area (Table 2). The highest density of fan mussels was recorded at the depth class of 1.1-2.0 m, but it is important to note that this is constrained by the depth limits of the dive component of this study (Figure 3a). Most of the individuals were recorded in seagrass meadows (Figure 3b). The locations with the highest densities of fan mussels found was at Torasan, whereas Akarca had the lowest density (Figure 3c). The highest density values with low numbers of damaged specimens were found in the areas least affected by human activities ($x^2 = 21.84$, df = 2, $P = 0.001$) (Figure 4).

### 3.2 | Local ecological knowledge (LEK)

Questionnaire respondents indicated that the main habitat of *P. nobilis* was seagrass meadows (81% of scuba-divers, 80% of spear fishers and 88% of commercial fishers). In addition, 76% of scuba-divers, 46% of spear fishers and 26% of commercial fishers noted the coverage of the seagrass meadows has decreased over the last decade in the sampling sites. According to the SCUBA-divers and commercial fishers, *P. nobilis* lives at a depth range of 0.5-38.0 m and 0.5-80.0 m, respectively.

Scuba-divers reported that the fan mussel density varied between 0 and 40 individuals per 100 $m^2$ , and that the mean density of fan mussels is higher around the west coasts of Turkey (Aegean Sea), in comparison with the south coasts of Turkey (Mediterranean Sea) and coasts of Marmara (Figure 5).

The majority of all groups of fishers indicated that there has been a historical decrease in the density of fan mussels (76% of SCUBA divers, 63% of spear fishers and 76% of commercial fishers). They identified that the impacts of fishing gears, poaching, pollution and boat anchoring were the main causes of this decline (Figure 6). Stakeholders considered that predator pressure, climate change and other factors (e.g. coastal settlement and beach deepening) had less of an impact on fan mussel density. Less than half (37%) of scuba-divers claimed that they had observed damaged fan mussel beds.

The estimated annual by-catch of fan mussels for each fishing gear type was: 1647 ± 2210 individuals by trawls (n= 30), 217 ± 260 individuals by purse-seines (n = 21), and 57 ± 165 individuals by set nets (n=46). No bycatch was reported for the long-line fishery (n=23). Trawlers reported that they generally fish in depths 30-300m; however, commercial fishers (30%) and scuba-divers (45%) indicated that illegal trawl operations occurred in the shallow waters, and that fishing occurred within the 1.5-nautical-mile trawl limit that coincides with the part of the marine littoral zone below 15 m depth. As a result, it may be that a large component of the fan mussel by-catch may occur as a result of illegal fishing close to the coast in shallow water.

Based on the questionnaire survey it appears that no recreational fishers (n=120) used this species as a bait. Interviews with restaurant owners indicated that fan mussels are not (and were not in the past) served at seafood restaurant in the majority of Turkey; however, fan mussels are collected illegally and consumed in May and June in the village of Özbek located in İzmir. Results show that 40 people (commercial fishers) collected this species in Özbek. These people also reported that their annual collection was estimated about 1000 individuals for food.

In general, there was low stakeholder awareness regarding the protection status of fan mussels (Table 3). Only 9% of stakeholders knew about the endangered status of this species. These individuals had acquired this information through educational activities (38%), other stakeholders (24%), newspaper/magazines and social media (38%),only 18% of commercial fishers knew that fishing for fan mussels is prohibited in Turkey.

## 4 | DISCUSSION

It has been reported previously that *P. nobilis* lives across a depth range of between 0.5 and 60.0 m (Butler et al., 1993), which is confirmed here by the different sources of evidence from the present study. Evidence of the deepest depth at which fan mussels occur was derived from LEK from trawl fishers who reported finding fan mussels in hauls made at a depth of 80 m in the eastern Mediterranean. Although in the present study direct observations were limited to shallow water, these did reveal that fan mussels were most common at a depth of 1.1.-2.0 m; however, it is difficult to know whether the peak fan mussel density in the dive survey represents the ‘optimum’ depth range for fan mussels, as the different sources of information cannot be standardized in way that makes the data comparable. Fan mussels are known to occur more commonly in vegetated sea beds in comparison with the unvegetated bottoms (Addis et al., 2009; Rabaoui, Tlig-Zouari, Katsanevakis, & Ben Hassine, 2010; Voultsiadouet al., 2010). This finding was re-emphasised by the diver survey in the present study and from the LEK (from the responses of scuba-divers and fishers). The present study also indicated that coverage of the seagrass meadows has decreased in Turkish waters over the last decade, however. Similar findings were reported by Marba, Diaz-Almela, and Duarte (2014) who emphasized a decline in the areal extent, cover and shoot density of *Posidonia oceanica* in the Mediterranean Sea during the last 50 years. Thus, this situation may threaten the status of the fan mussel population if there is an ecological dependence of fan mussels on seagrass meadows. The reported observations in the LEK study indicated that illegal bottom trawling occurred in water shallower than 15 m. This observation concurs with similar observations elsewhere (e.g. Fonseca et al., 1984; Sànchez-Jerez & Ramos-Esplàa, 1996), and may explain in part why seagrass beds have decreased in extent and may also explain why the peak fan mussel occurrence and density occurred at such shallow depths (i.e. where there was a depth refuge from fishing).

Previous studies have demonstrated that the mean density of *P. nobilis* is around 1-10 individuals per 100 $m^2$ (Garcia-March, Marquez-Aliaga, Wang, Surge, & Kersting, 2011; Moreteau & Vicente, 1982; Prado, Caiola, & Ibáñez, 2014). Little is known about the density of this species around the coastal areas of the eastern Mediterranean, particularly for Turkish waters, in comparison with the central and western Mediterranean, however (Basso et al., 2015; Vafidis et al., 2014). The mean density was estimated by Vafidis et al. (2014) as 2.7 individuals per 100 $m^2$ in Greek waters (the Aegean Sea, Eastern Mediterranean). In the present study, based on the diving surveys undertaken, the mean density of fan mussel was estimated as being relatively higher (11.28 individuals per 100 $m^2$), whereas the highest density value was estimated as 100 individuals per 100 $m^2$. Although the density estimates per unit area should be treated with caution, given the restricted number of localities surveyed, the LEK of scuba-divers provides a greater geographic coverage, and for this reason a useful data source to assess large regions in the absence of more formal survey data (Loerzel et al., 2017; Taylor et al., 2011). For example, the present study provided the density estimations of fan mussel over large areas and showed that the mean density values were higher in western parts compared with the southern parts of Turkey (Figure 5).

The evidence presented from the present study indicates that the density of fan mussel declined in Turkish waters over the last decade. Similar declines have occurred over the last 20-30 years around other Mediterranean countries, and are largely attributed to anthropogenic impacts (Centoducati et al., 2006; Deudero, Vázquez-Luis, & Álvarez, 2015) where stakeholders reported that the main causes of the decline in fan mussel populations were fishing gears, illegal collection, pollution, and boat anchoring, respectively. In addition, the recent mass mortality event of this species in the western and central Mediterranean Sea has added to the effects of these stressors (Catanese et al., 2018; Vázquez-Luis et al., 2017). The results presented here, demonstrate that the number of damaged individuals is lowest (and the density is highest) in the areas that are furthest from human activities in comparison with populations sampled at ports and beaches. Accordingly, the mean density values were lowest in the locations where anchoring occurred, as reported elsewhere (Hendriks et al., 2013; Vázquez-Luis et al., 2015). When fan mussel sustain damage, they may be more vulnerable to predators, thereby increasing mortality from predation. For instance, García-March, García-Carrascosa, Cantero, and Wang (2007) reported that when specimens became detached for a long period, predators such as octopus *Octopus vulgaris* were better able to handle and consume such individuals. Previous studies also indicated that the density and sizes of fan mussels inside the marine protected areas (MPAs) are higher than outside the protected areas (Vázquez-Luis, March, Alvarez, Alvarez-Berastegui, & Deudero, 2014; Vázquez-Luis et al., 2017).

The present study provides an initial insight into the estimated quantity of by-catch of *P. nobilis* taken by different fishing gears based on the fishers' interviews. High numbers of fan mussels were reported to have been caught by trawls, in particular when fishing was carrying out in shallow areas (at depth of less than 15 m). Although in the Mediterranean part of the European Union, the use of trawls is prohibited in water of < 50 m in depth (Garcia-March & Nardo, 2006), this does not apply in Turkish waters where there are seasonal prohibitions and a ban on trawling within 1.5 nautical miles off the coastline. Similarly, the high number of dead specimens of *P. nobilis* were found either at the trawling sites or around the mussel farms (Centoducati et al., 2006). Other fishing gears (i.e. set net, longline, and purse seine) had relatively low impact in comparison with trawls according to the questionnaire survey.

Nevertheless, Addis et al. (2009) also reported that trammel nets and gill nets used in the lagoon may influence the fan mussel populations. Many set netters and trawlers reported that fan mussel damage their fishing nets, thus they do not tend to fish areas where fan mussels are found in high densities.

Katsanevakis (2007) reported that in spite of the conservation status of *P. nobilis*, it is illegally fished in Lake Vouliagmeni by divers due to insufficient control by authorities and because locals do not have enough information about the legislation. Another example of illegal fisheries was reported by Vafidis et al. (2014); they noticed that about 45 small-scale fishing vessels were harvesting and processing this endangered species at the islands of Symi and Kalymnos, in spite of the official restrictions. The estimated annual production is estimated at 1.5 ton in this region (Vafidis et al., 2014). Fan mussels are consumed only in Özbek (İzmir) in Turkey, where the estimated annual harvest was about 1000 individuals. Fishers who fish around Özbek reported that they only collect this species in May and June when gonads have a high gonado-somatic index (GSI). Similarly, Deudero et al. (2017) reported that the reproductive peak in Spain occurs in May. The consumption of this species appears to be minimal in seafood restaurants in Turkey, however, although it is more commonly served at the seafood restaurants in Greece and the Greek Islands (Katsanevakis et al., 2011). There is no information about the scale of collection of this species in other Mediterranean countries.

Information on the ecology of *P. nobilis* in Turkish waters is scarce, so the number of doctoral programmes and scientific projects should be increased. In particular, it is vitally important to monitor the density of endangered species periodically. The present study provides the novel information about the density of *P. nobilis* for Turkey (eastern Mediterranean Sea); however, the density of *P. nobilis* should be investigated every 3 or 5 years at the sampling areas of present study because the population of *P. nobilis* has been decreasing dramatically for the last decade. Furthermore, its density and distribution should be monitored by comparative studies inside and outside the MPAs for the sustainability of marine ecosystems (Vázquez-Luis, et al., 2014).

One of the main conservation challenges was the lack of information on the endangered status of fan mussels among the locals and fishers. Moreover, the LEK results revealed that fishing operations, in particular illegal trawling in shallow waters, and also purse-seining over the benthic habitats resulted in the by-catch of fan mussels. Finally, LEK identified poaching, pollution and boat anchoring over the fan mussel beds as the other main threats. For the conservation of the species, it would be appropriate to firstly identify important areas for this species and then manage the pressures that impact negatively affect them. Shallow water sites of <15 m in depth appear to be the most important areas in present times, but this might be an artefact of human pressures curtailing the extent of the distribution of fan mussels in deeper water. A programme of observation, perhaps using citizen science, would be beneficial to improve knowledge of the distribution of this species in Turkish waters. In addition, the common fishery policy (CFP) of European Commission purposes to improve the data collection on discards and by-catch (Öndes, Kaiser, & Murray, 2017). Thus, not only target species but also by-catch species such as *P. nobilis* could be recorded by fishers using logbooks or return forms. The protection of fan mussels within MPAs would seem like a sensible approach if properly managed and enforced (Güçlüsoy, 2015, 2016). Sea grass meadows serve as important associated habitats and are effectively protected from illegal trawling elsewhere in the Mediterranean (e.g. Sànchez-Jerez & Ramos-Esplàa, 1996). Areas comprising commonly distributed locations should be closed for the purse-seiners. Small scale fishers can be encouraged to use long-lines instead of set nets; however, socio-economic pros and cons should be assessed, and a compensation scheme and/or alterative livelihood may be required. Mooring systems should be established or if they already exist, modernized in areas where fun mussels are most abundant, in order to decrease the negative impacts of anchoring (e.g. Garcia-March

& Nardo, 2006). For the locals and fishers, public awareness campaigns should be developed to increase the knowledge on the endangered status of fan mussels. The responsible governmental organisations should inform the public at public meetings. Where possible, information boards about *P. nobilis* and mitigation measures on the threats (e.g. prevent the illegal collection) on beaches, marinas and harbours should be erected. Eventually, all aforementioned mitigation measures should be incorporated into management plans if the concerned area is an MPA, and all commonly distributed locations of fan mussels should be monitored every 3 years to assess their status.

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## APPENDICES (APPENDIX A.)

Supplementary data related to this article can be found at http://

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## CONFLICT OF INTEREST

The authors are unaware of any existing conflicts of interest that would preclude or bias publication of the results contained in this article.

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## Tables

### Table 1

Content of the questionnaires related to the local ecological knowledge (LEK)

| Category of collected evidence | Specific information collected |
|---|---|
| 1. The bio-ecological characteristics of fan mussel | - Spatial distribution<br>- Depth and habitat<br>- Current status of density in different locations |
| 2. Historical changes in density | - Decrease or increase of density in the last 10 years<br>- Habitat change in term of seagrass presence/ absence |
| 3. Impacts of fisheries | - Estimated by-catch quantities of *P. nobilis* in different fishing gears (e.g. trawl, purse seine, set net, and longline)<br>- Illegal fisheries status (illegal collection and illegal trawl operations occurred in the shallow waters and fishing within the 1.5 nautical mile trawl limit)<br>- Estimated use by recreational fishers (e.g. bait) |
| 4. Status of consumption | - Whether restaurants sell *P. nobilis* or not<br>- Whether *P. nobilis* are consumed by fishers and scuba divers |
| 5. Awareness on the conservation status | - Whether local people and fishers know this species is endangered<br>- Whether fishers know this species is protected<br>- Awareness of the conservation status and source of knowledge (Social media, newspaper, legislation, education, etc.) |

**Table 2**

Summary of fitting a general linear model (GLM) using data from the diving surveys (direct observations) in the Aegean Sea, Turkey

| **Source** | **Type III Sum of Squares** | **Mean Square** | ***F*-ratio** | ***P*-value** |
|---|---|---|---|---|
| Corrected model | 2291.90[a] | 29.01 | 4.141 | <0.001 |
| Intercept | 1204.62 | 1204.62 | 171.94 | <0.001 |
| Depth | 166.40 | 41.60 | 5.94 | <0.001 |
| Habitat | 47.22 | 47.22 | 6.74 | 0.010 |
| Area | 472.99 | 52.55 | 7.50 | <0.001 |
| Depth*habitat*area | 1044.03 | 16.06 | 2.30 | <0.001 |
| Error | 1191.00 | 7.01 | | |
| Total | 5471.00 | | | |
| Corrected total | 3482.90 | | | |

Dependent variable, density; fixed factor, area; covariates, habitat and depth.

[a]$R^2$= 0.66 (adjusted $R^2$ = 0.50).

**Table 3**

The percentage of stakeholders who provided information on the endangered status of the species, their collection and consumption rates, and whether observed any collection by other people

| Groups | Awareness on endangered status (%) | Collection rate (%) | Consume rate (%) | Collection by others (%) |
|---|---|---|---|---|
| Commercial fishers (n = 120) | 3 | 27 | 25 | 38 |
| Spear fishers (n = 35) | 3 | 40 | 37 | 63 |
| SCUBA divers (n = 87) | 21 | 7 | 6 | 36 |
| **Total (n = 242)** | **9** | **22** | **20** | **41** |

**FIGURES**

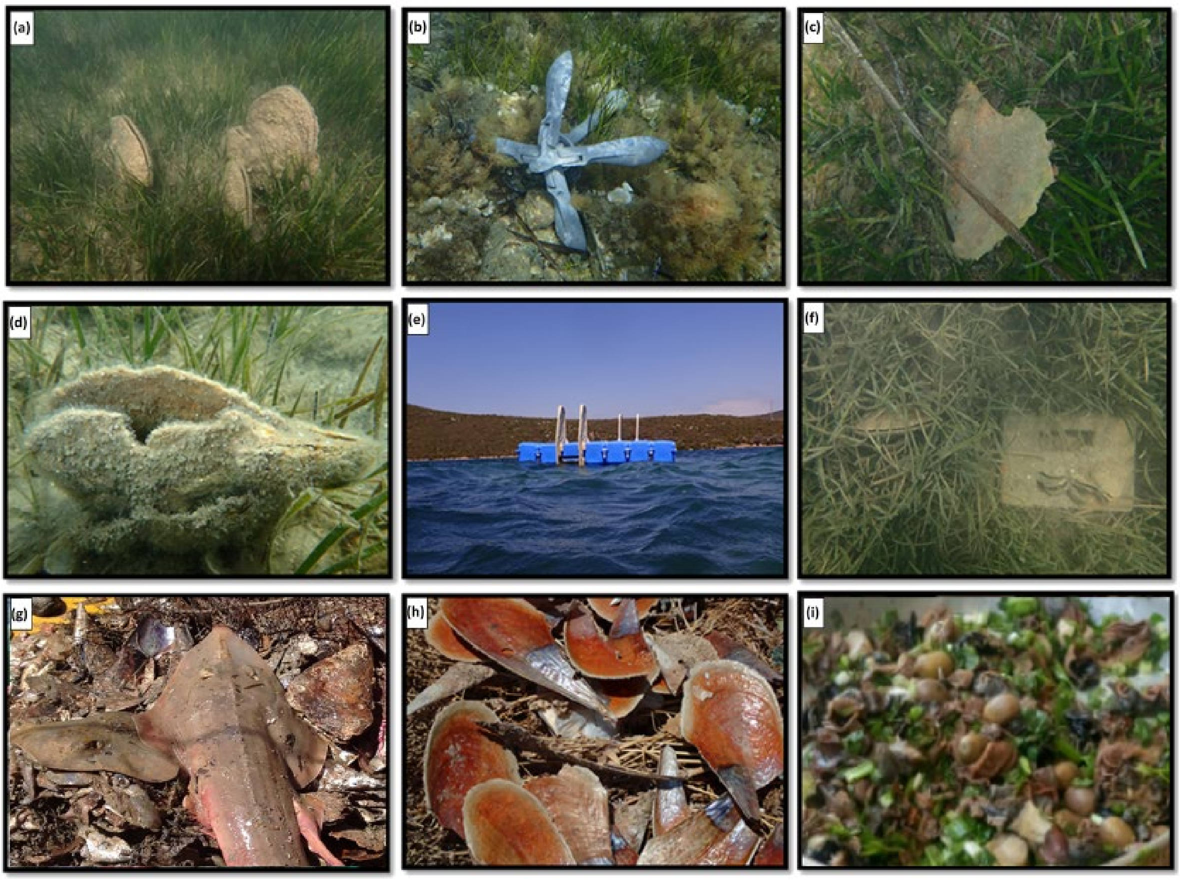


**FIGURE 1** (a) Fan mussel (Pinna nobilis) beds in the Aegean Sea. (b) Habitats threatened by boat anchorage in one of the sampling sites at a fishing port. (c) Damaged fan mussel shell in a port. (d) Damaged fan mussel specimen at a beach. (e) A buoy at one of the sampling sites. (f) View of the anchor of a buoy near a fan mussel. (g) Fan mussels as by - catch from a bottom trawl in 2017. (h) Broken fan mussel shells from local collectors. (i) A dish of fan mussels. The photo for (g) was obtained from the Dokuz Eylül University Archive, whereas all other photos were taken by the first author at the sampling sites

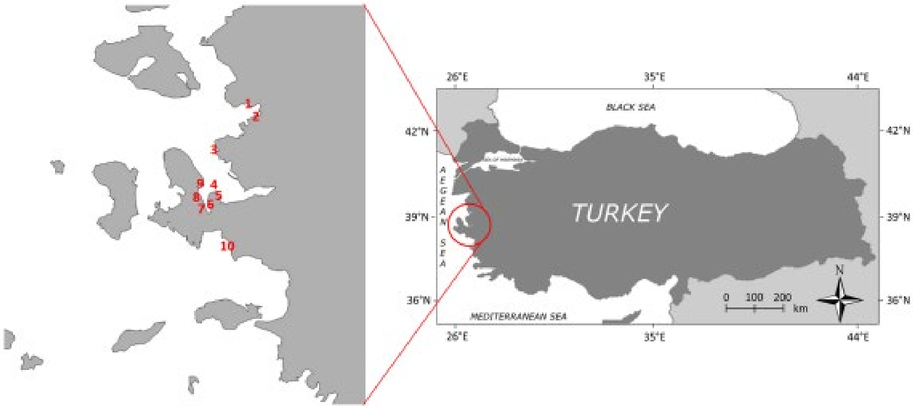


**FIGURE 2** The map of the study area includes the diving surveys in the Aegean Sea (Turkey). Sampling station codes: 1, Şakran; 2, Çaltıdere; 3, Foça; 4, Urla; 5, Özbek; 6, Eğriliman; 7, Torasan; 8, Gülbahçe; 9, Balıklıova; 10, Akarca

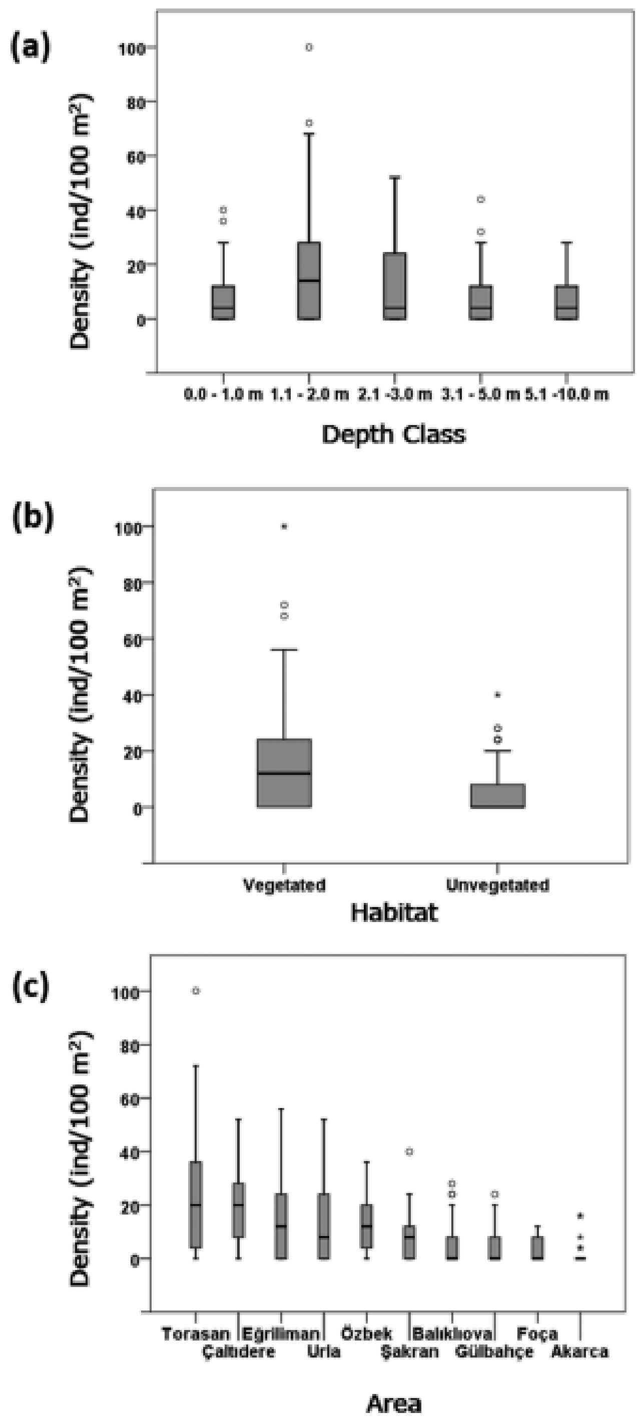


**FIGURE 3** The mean values of Pinna nobilis density (individuals per 100 $m^2$) depending on: (a) depth class (0.0 – 1.0, 1.2. – 2.0, 2.1 – 3.0,3.1 – 5.0, and 5.1 – 10.0 m); (b) habitat (vegetated and unvegetated); and(c) sampling area (Torasan, Çaltıdere, E riliman, Urla, Özbek, Şakran, Bal ı kl ı ova, Gülbahçe, Foça, and Akarca)

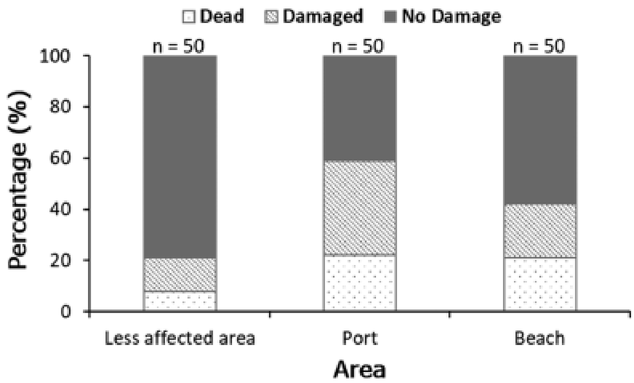


**FIGURE 4** Comparison of different areas (port, beach, and less affected area, LAA) in terms of the percentage of damage to *Pinna nobilis*. Damage scale: 1, no damage; 2, damaged individuals; 3, dead individuals (individuals were counted)

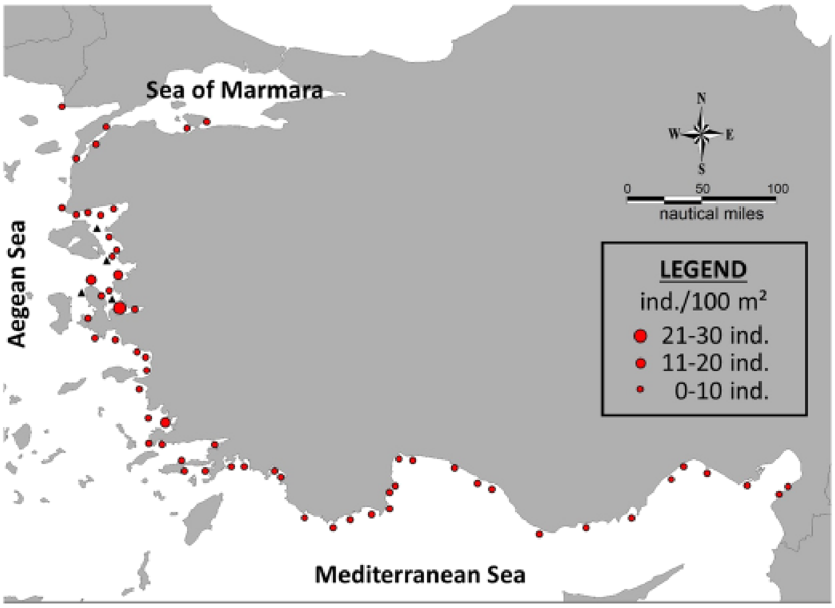


**FIGURE 5** The map of the mean density estimations of *Pinna nobilis* based on the scuba - divers ' ecological knowledge and the locations of the highest *P. nobilis* fields based on trawlers ' knowledge in Turkey. Red circles include the density classes (0 – 10, 11 – 20, and 21 – 30 individuals per 100 m$^2$) of *P. nobilis* based on divers ' information; black triangles show the locations where fan mussels are common (where at least one - third of the catch was fan mussels) according to trawlers' information.

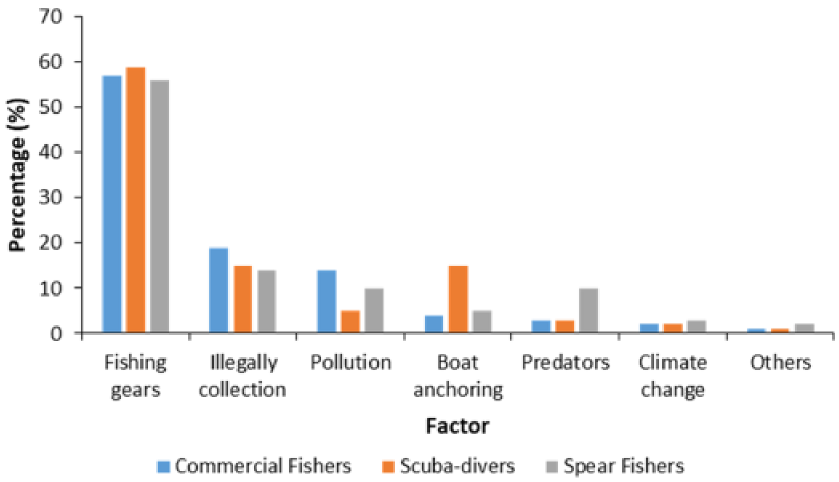


**FIGURE 6** The main perceived and reported threats that can influence a local decrease of the fan mussel population, based on the responses of the stakeholders (i.e. commercial fishers, scuba - divers, and spear fishers)