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Monitoring of the Endangered *Pinna nobilis* Linné, 1758 in the Mar Grande of Taranto (Ionian Sea, Italy)

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Abstract The present study aimed to improve the knowledge of the bivalve *Pinna nobilis* L. population distribution in Mar Grande of Taranto (Ionian Sea). Although historical references report the local abundant presence of this endangered species, there is a lack of updated information about its exact distribution. For this purpose, a visual census of *P. nobilis* was performed by SCUBA diving in the Mar Grande basin from September 2004 to March 2005. Pinnids were found at depths from 3 to 16 m, with a density ranging from 0.1 to 0.7 ind ha^{-1}. The survey method employed in this study was non-destructive, relatively simple to perform and easily applicable for monitoring studies. Field data were stored in a database and linked with the study area by means of the GIS technology. The results of the present study indicate a tentative of recovery of *P. nobilis* population in Mar Grande in spite of all the difficulties of a degraded and heavily polluted environment and the damages of illegal fishing methods.

Keywords GIS (Geographic Information Systems) · Mar Grande Taranto · *Pinna nobilis* · Visual census

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1 Introduction

The fan mussel (*Pinna nobilis* Linné, 1758) is the largest endemic Mediterranean bivalve, reaching a size of up to 120 cm (Zavodnik, Hrs-Brenko, & Legac, 1991), living in soft-sediment areas (Katsanevakis, 2005) and beds of seagrass *Posidonia oceanica* (Linnaeus), Delile and *Cymodocea nodosa* (Ucria) Aschers. (Richardson, H. Kennedy, Duarte, D. P. Kennedy, & Proud, 1999; Šiletić & Peharda, 2003; Zavodnik, 1967; Zavodnik et al., 1991), at depths ranging from 0.5 to 60 m (Butler, Vicente, & De Gaulejac, 1993).

Heavily exploited for commercial and food uses in the past, populations of *P. nobilis* have greatly reduced in the last 20–30 years as a result of reckless fishing, as well as incidental killing by trawling and anchoring. Destruction of eggs, larvae and adults by chemical pollutants and regression of its common habitat, the seagrass beds of *P. oceanica* due to anthropogenic activities, have also contributed to accelerate the decline of this formerly abundant species (Shahidul & Masaru, 2004). In some areas, dense populations of 15–16 ind ha^{-1} were reduced to 1 ind ha^{-1} in a single year (Vicente & Moreteau, 1991). Consequently, the fan mussel has been listed as an endangered species in the Mediterranean Sea. According to the European Council Directive 92/43/EEC on the conservation of natural habitats and wild fauna and flora, *P. nobilis* is under strict protection (Annex IV) and all forms of deliberate capture or killing of fan mussel specimens are prohibited (EEC, 1992). In order to effectively protect this endangered species there is an urgent need of updated information on the distribution of *P. nobilis* populations.

In Southern Italy, Taranto has an immemorial tradition of exploitation of the byssus produced by *P. nobilis* to hang on to substratum. The fine silk threads have been used for rich fabrics and textiles since Greek and Roman periods to the nineteenth century. At that time the fan mussel is reported to be abundant and some attempts of captive breeding have been done, then abandoned because of the breakout of the First World War. At present, there is a complete lack of data on the existing presence and abundance of *P. nobilis* in the Mar Grande of Taranto and no previous monitoring study has been carried out in this basin. This paper aims to contribute to the knowledge of the local distribution of *P. nobilis* in a site that has been subjected to intense urbanization and industrialization in the last few years (Cardellicchio et al., 1991).

2 Materials and Methods

Mar Grande (Ionian Sea) was surveyed by visual census in order to locate *P. nobilis* by SCUBA diving from September 2004 to March 2005. This area, with a surface of about 36 km^2 and a maximum depth of 42 m (Istituto Idrografico della Marina, 2002), has the characteristics of a half-closed basin, exposed to a heavy anthropic pressure (urban and industrial wastes, merchant and naval activities). The basin is delimited by the mainland, the Old Town Island, the Cheradi Islands and two artificial reefs, while the connection with the Ionian Sea is through two gaps.

Ten preliminary dives allowed to determine and classify six macroareas (A–F) on the basis of selected parameters (bathymetry, substrate, presence and type of flora, anthropic pressure, landmarks).

Ten microareas were randomly selected in each macroarea. All microareas were 100×100 m^2, except four (A8, D7, D9, E2), with a rectangular shape and a similar size (1 ha), in order to follow specific seabed characteristics (shoals). The total surveyed area was 60 ha wide as specified in Table I and Figure 1.

The geographical coordinates of the four bench marks of each microarea were identified with global positioning system (GPS) and marked with buoys. The GPS points were reported on the seabed and marked with iron stakes and orange lines (all the material was removed at the end of the study, to restore the original natural set). Each microarea was inspected both in longitudinal and latitudinal directions (Figure 2) in corridors 2–5 m far, according to the relative visibility. The inspection was conducted by a team of 4–6 divers and the support of a rubber dinghy. A diver in turn was towed with a depressor wing at the speed of 1 kn. When a pinnid was sighted, the wing was released and an operator on the dinghy surveyed the GPS coordinates to enable the exact location to be subsequently re-visited, while a second operator dived to gather information about the *P. nobilis* specimen (biometric data, position of each individual shell, depth, temperature, presence and type of flora and substrate according to visual assessment), recording them underwater on a plastic slate. The presence of dead specimens was also determined.

All field data were processed, stored in a database and linked to the study area with GIS technology (ArcView GIS 3.2). The use of the geographic information system (GIS), developed for the storage and analysis of spatially referenced information on the collected data, has been used in order to evaluate its suitability as tool for mapping researches. Spatial features were stored in a coordinate system and associated with descriptive attributes in tabular form. Spatial data and associated attributes in the same coordinate system were then layered together for mapping and analysis.

Biometric data were recorded in order to estimate the maturity of the population (Moreteau & Vicente, 1982). Using the technique described by Moreteau and Vicente (1980), and Garcia March and Ferrer Ferrer (1995), *P. nobilis* were measured in situ to avoid unnecessary removal and disturbance. The

Table I Features of macroareas and microareas

Macroarea		Microarea			
Area	Anthropic pressure		Bathymetry	Substrate	Flora
A	Military zone	1	4.3–6.5	Mud, anoxic	Absent
		2	1.8–4.5	Mud and sand	Absent
		3	20.0–22.5	Coarse drift	Absent
		4	13.5–15.5	Mud	Absent
		5	14.5–16.0	Coarse drift and mud	Absent
		6	17.5–18.5	Coarse drift	Absent
		7	11.0–13.0	Mud and fine sand	Absent
		8	4.5–5.5	Sand and rocks	Absent
		9	7.0	Coarse sand	Absent
		10	8.5–12.0	Mud	Absent
B	Mussel farm plants	1	2.0–3.5	Fine sand	*Cymodocea*
		2	1.8–3.2	Fine sand and rocks	*Cymodocea*
		3	2.8–6.0	Sand	*Cymodocea*–rare *Posidonia*
		4	4.5	Sand and mud	Absent
		5	3.5	Sand	*Cymodocea*
		6	3.5–7.7	Coarse drift and rocks	Absent
		7	8.0–9.1	Sand and mud	Absent
		8	8.9	Sand and mud	Absent
		9	6.7–10.0	Sand and mud	Absent
		10	9.0–11.0	Mud	Absent
C	Industries: oil refinery, cement factory	1	7.0	Coarse drift	Absent
		2	3.0–5.0	Fine sand	Dead matte
		3	3.0–5.0	Fine sand	Dead matte
		4	5.5–6.0	Coarse drift	Dead matte
		5	7.5	Sand	Absent
		6	7.0–10.0	Gross sand and drift	Absent
		7	5.0–7.0	Coarse drift	Absent
		8	7.0–8.0	Sand	Absent
		9	8.0–9.0	Coarse drift and sand	Absent
		10	8.0–10.0	Coarse drift and sand	Absent
D	Closeness to protected areas	1	9.0–10.0	Fine sand	Absent
		2	6.0–10.0	Fine sand	Absent
		3	6.0–10.0	Rocky	Absent
		4	6.0–9.0	Coarse drift	Absent
		5	7.5–8.5	Coarse drift	Dead matte
		6	2.5–5.5	Coarse drift	Absent
		7	3.5–5.0	Coarse drift and fine sand	Absent
		8	6.5–7.5	Coarse drift	Dead matte
		9	5.0–9.0	Coarse drift and sand	Absent
		10	2.5–4.5	Sand	Rare *Cymodocea*
E	Urban area, docks, outlets of Mar Piccolo	1	4.0–6.0	Rocky with sand	Absent
		2	13.5–29.5	Mud	Absent
		3	29.0	Mud	Absent
		4	27.0–28.0	Mud, anoxic	Absent
		5	27.0–28.0	Mud	Absent
		6	8.0–10.0	Coarse drift and sand	Absent
		7	29.0	Mud	Absent
		8	27.0	Mud	Absent
		9	15.0–20.0	Fine sand and mud	Absent
		10	17.0–30.0	Mud	Absent
F	Navigable input channel from Taranto Gulf to Mar Grande	1	25.0–29.0	Mud	Absent
		2	25.0–29.0	Mud	Absent
		3	29.0–32.0	Mud	Absent
		4	14.0–22.0	Coarse drift and rocks	Absent
		5	29.0	Mud	Absent
		6	29.0	Mud	Absent
		7	15.0–19.0	Coarse drift and fine sand	Absent
		8	29.0	Mud	Absent
		9	29.0	Mud	Absent
		10	29.0	Mud	Absent

height above the sediment (Hs) and the width at sediment level (a) were recorded. The total shell height (HT) was estimated using the following equation applied to the field data: HT=$(1.79\times a+0.5\pm0.2)+$Hs (Garcia March & Ferrer Ferrer, 1995). Although this formula was originally used for the calculation of *P. nobilis* total shell height from a different area, it was considered suitable for this study too, due to the combined use of two shell size parameters that eliminate the potential problems with the total shell

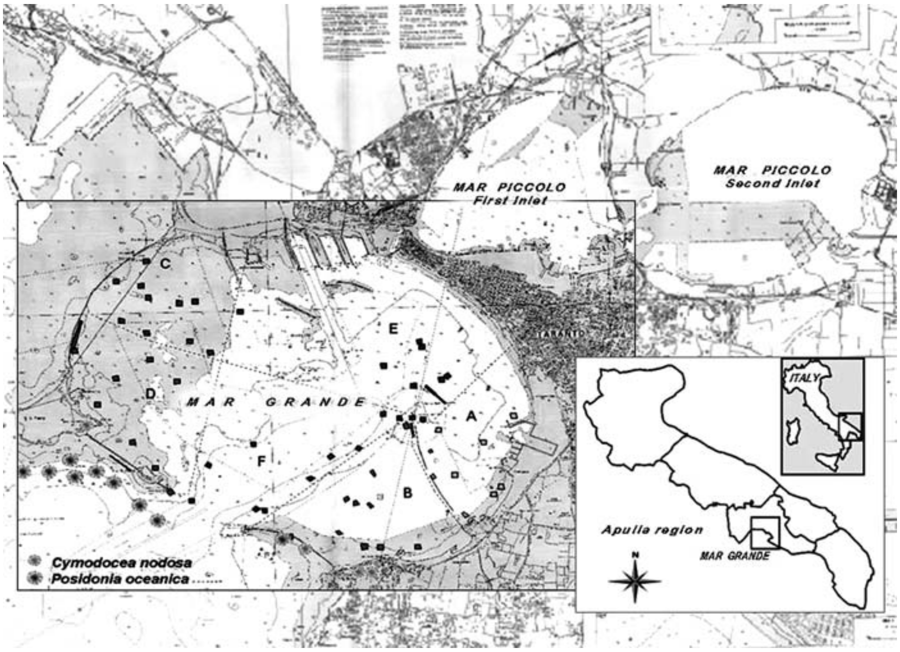

Figure 1 Macroareas and microareas in Mar Grande.

height calculation that might occur as a result of differences in shell morphology or burial depth. Specimens with a total shell height size ≤20 cm were considered juveniles according to bibliographic data (Butler et al., 1993; Combelles, Moreteau, & Vicente, 1986; Richardson et al., 1999).

3 Results

Pinnids were rare in all the checked sites, with only 14 alive and 51 dead specimens detected and measured during the study. In the checked area, *P. nobilis* specimens were found at depths from 2.5 (microarea B2) to 16 m (macroareas E and F), with a denser distribution in shallow water (Table II) and more frequently on coarse sand, fine-grained sand with rocks or sand and mud substrates, associated with *C. nodosa* meadows where they were present (microareas B2 and B3). No specimen was found on anoxic muddy substrate, were no signs of life was detected (Figure 3, Table II). In macroareas where *P. nobilis* was present, the density resulted very low (0.1 to 0.7 ind ha^{-1}). The highest density of alive specimens was recorded in macroarea B (n=7), the lowest one in macroarea A (n=1), whereas intermediate values were recorder in macroareas E and F (n=3). No pinnids were found in macroareas C and D (Figure 3, Table II). Dead specimens were mostly found in microareas with sandy substrate, were mussel farms scraps and traces of trawling were present. In fact, many dead fan shells were shattered and no biometric parameters could be reported. Pinnids distribution is reported in Figure 4.

Fan mussels with a total shell height ranging from 7.7–8.0 (estimated minimum and maximum values, calculated according to the reported formula) to 87.6–87.9 cm were observed and measured in the macroarea B, while the largest specimens (HT>50 cm) were found in the macroareas A and B. In macroareas E and F only smaller pinnids were present (HT<25 cm). Specimens measurements are given in Table III.

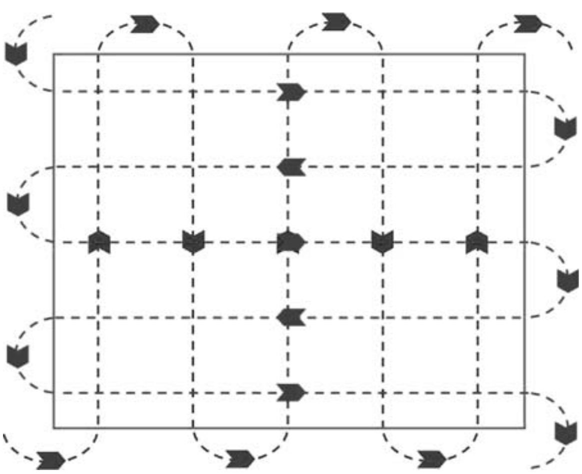

Figure 2 Features of inspection of microareas.

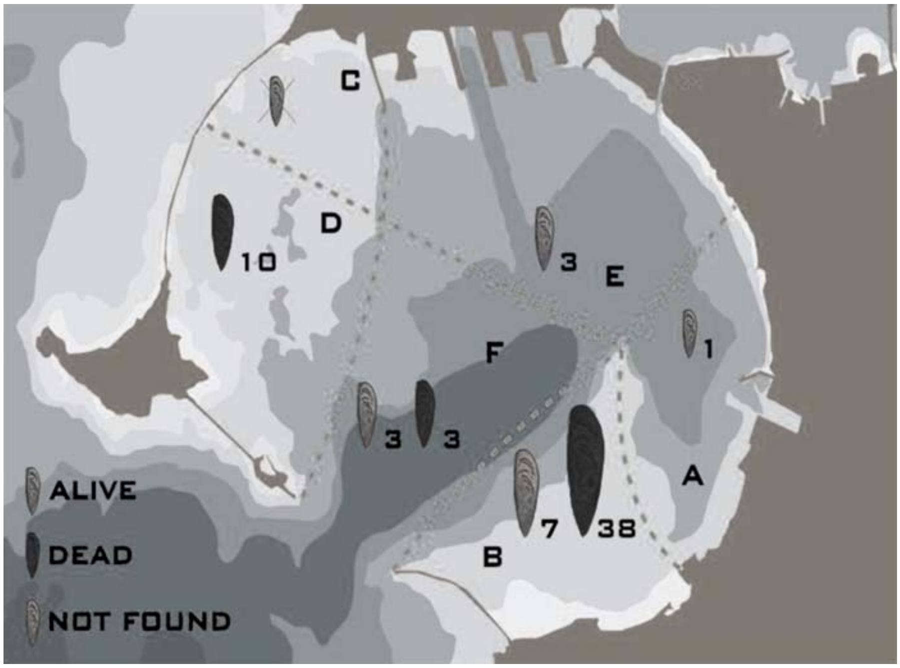

Figure 3 Surveyed areas in Mar Grande: presence of *P. nobilis* specimens.

Table II Presence of *P. nobilis* in microareas within six macroareas (A–F)

Microarea	Depth	T (°C)	Alive	Dead	Notes
A1					
A2					Traces of trawling
A3					
A4					
A5					
A6					
A7					
A8					
A9	7.0	10	1		Mussel farms scraps
A10					Mussel farms scraps
B1	2.6	13		4	Traces of trawling
B2	2.5	13	3	27	Traces of trawling
B3	4.4	12	1	1	
B4	4.5	12		1	Mussel farms scraps
B5					Traces of trawling
B6					Traces of date mussel
B7	8.6	12		4	Mussel farms scraps
B8					
B9	8.4	12	3		Mussel farms scraps
B10	10.0	12		1	Mussel farms scraps
C1					
C2					
C3					
C4					
C5					
C6					
C7					
C8					
C9					
C10					
D1					Traces of trawling
D2	8.0	10		1	Traces of trawling
D3	8.0	10		3	
D4	7.5	10		2	
D5					
D6					
D7					
D8					
D9					
D10	3.50	10		1	Traces of trawling
E1					
E2					
E3					
E4					
E5					
E6					
E7					
E8					
E9	16.0	12	3		
E10					
F1					
F2					
F3					
F4	16.0	10	1	3	

Table II (continued)

Microarea	Depth	T (°C)	Alive	Dead	Notes
F5					
F6					
F7	15.0	12	2	2	
F8					
F9					
F10					

Processing field data into a GIS map has resulted in an archive that allows the user to simultaneously visualize and analyse data. Thematic maps display the total number of alive and dead individuals of *P. nobilis*, size of alive specimens, depth and substrate type.

4 Discussion

The knowledge of the presence, health and distribution of main marine ecosystems has a primary importance in conservation and monitoring programs, and large-scale mapping programs have focused on major coastal biological indicators. Usually, best results in mapping marine communities are achieved through the combination of indirect (instrumental) and direct (visual) mapping techniques, the two approaches being not exclusive but complementary. Indirect (instrumental) methods, based mainly on side scan sonar (SSS) surveys and remote sensing (aerial and satellite imagery), are more suitable for mapping large-scale structures, such as mangroves, coral reefs, macroalgae and seagrass beds, while visual methods, including survey conducted with remotely operated vehicle (ROV), towed camera, SCUBA and snorkeling divers following fixed underwater transects, are used when small subjects have to be detected.

The non-destructive visual census proved useful as a method for monitoring the distribution of *P. nobilis* in its habitat. The use of a towed diver and a depressor wing showed to be a rapid, cheap and accurate technique to record and map in real time, both in shallow and in relatively deep water, allowing a more randomised distribution of surveyed areas than the fixed transects method in such a large basin as Mar Grande. The efficiency of the method was satisfactory, both for the accuracy of the measurements and for its easy and quick procedure which allows to obtain geo-referenced data with good precision. Processing field data in the interactive GIS map developed in this study allows to manipulate and to analyse geographically referenced data of different types. It has the capability of generating and editing different thematic maps and enables subsequent adding of new themes and/or updating current information.

Mar Grande harbour is characterized by shallow water (with the exception of the navigable channel from Taranto Gulf to Mar Grande, 30–40 m depth), fine drift or sand substrate. Human activities seem to have greatly altered the original environmental set. Emissions of cement factories and building scraps from the construction of new merchant harbour and dockyard wharfs have brought fine sand and dusts, so causing the banking of fine-grained sand and mud, which do not allow a correct oxygenation of interstitial habitat that then has become anoxic, unsuitable for the most of the marine organisms, resulting in a profound impoverishment of biocenosis (Fondazione Michelagnoli, 2003). Some areas are completely devoid of any sign of life. In macroarea C (subject to this kind of physical pollution because of the streams and the closeness to these sites) only dead *Posidonia* mattes were found, and rare *Posidonia* plants associated with *Cymodocea* were only detected in macroarea B, where the presence of mussel farm plants testify for a less degraded environment. As a matter of fact, the highest concentration of *P. nobilis* specimens was detected in the same macroarea B, with 7 alive and 38 dead specimens. Here, once again, the influence of human activities appears heavy. Dead *P. nobilis* specimens were either choked up with mussel farms scraps or killed by trawling. Although trawling is banned at depths less than 50 m, there is substantial evidence of illegal trawling in macroareas A, B and D, and many dead fan shells were shattered. The extent and the kind of industries (chemical plants, oil refineries, steel plants), together with the typology of emitted pollutants (heavy metals, phenols, cyanides, polycyclic aromatic hydrocarbons – PAHs, polychloro biphenils – PCBs, dioxin and dioxin-like compounds, hard detergents) has lead the Environmental Ministry to declare Taranto as "area at great environmental risk" (Fondazione Michelagnoli, 2003). Quantity and quality of pollutants introduced in Taranto seas (Mar Grande and Mar Piccolo), shallow basins with scarce water circulation, have

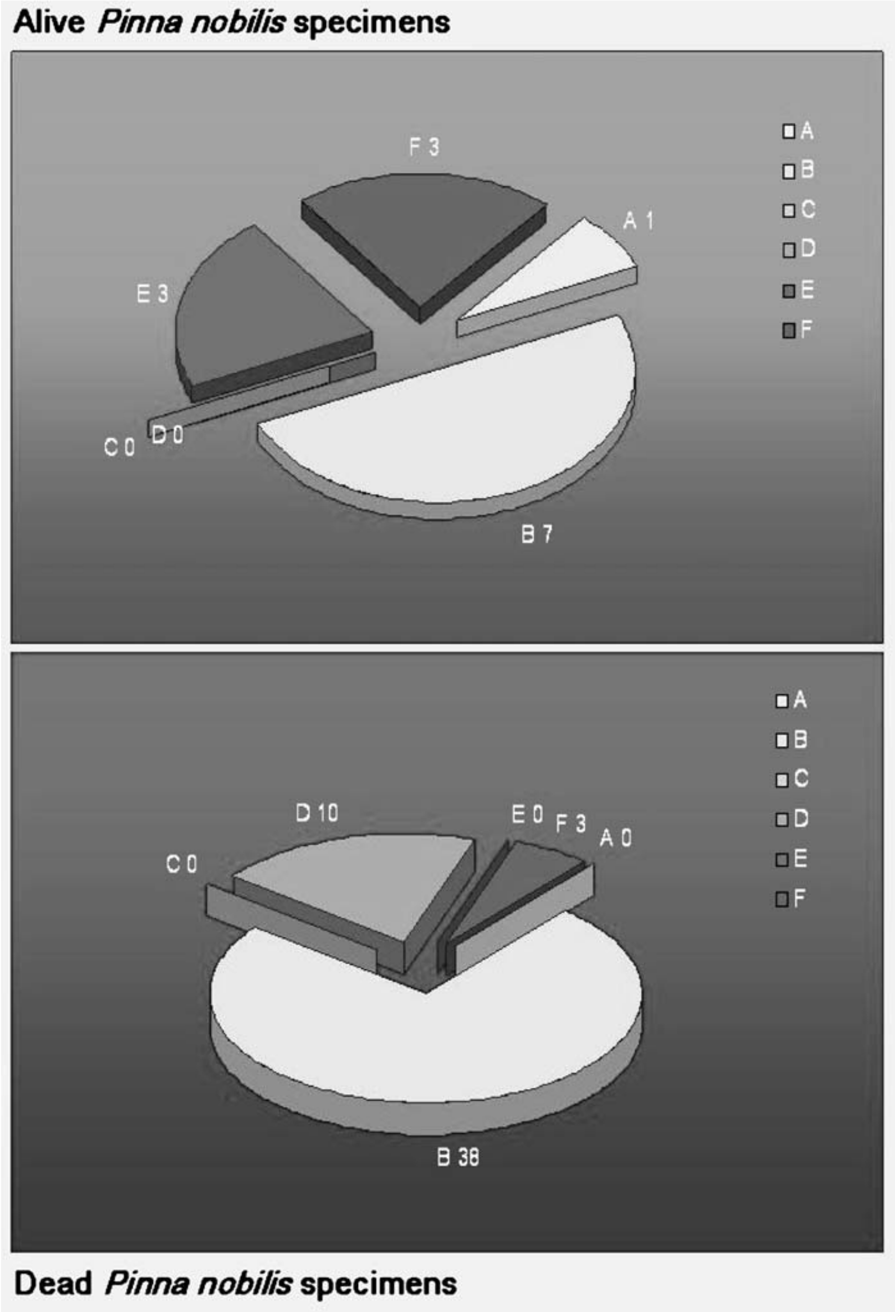

Figure 4 *P. nobilis* specimens distribution in macroareas.

lead to severe conditions of pollutants accumulation, and consequent impact on biocenotic communities. The complexity of chemical–physical–biological dynamic balances and the circulation of pollutants among the ecosystems compartments (water, air, ground, *biota*) lead to a generalized pollution, responsible of severe changes in biological communities structure (Fondazione Michelagnoli, 2003). In Taranto seas, an example is given by the beds of *P. oceanica*, among the most important benthic communities in temperate and Mediterranean coastal areas, where they have a fundamental ecological role. Seagrass support complex food webs because of their physical structure and primary production, play a primary role as breeding grounds and nurseries for fish and shellfish populations and are the usual habitat of *P. nobilis*; besides, they filter suspended sediments and nutrients from coastal waters, stabilize sediments

Table III Measurements of *P. nobilis* specimens found in Mar Grande

Microarea	Hs (cm)	a (cm)	HT (min–max, cm)
A9	21	17.5	52.6–53.0
B2	35	29.2	87.6–87.9
B2	20	16.6	50.1–50.5
B2	22	18.3	55.1–55.5
B3	5	4.1	12.7–13.0
B9	1.5	1.2	4.0–4.3
B9	3	2.4	7.7–8.0
B9	3	2.4	7.7–8.0
E9	3	2.4	7.7–8.0
E9	3	2.4	7.7–8.0
E9	4	3.3	10.2–10.5
F4	3	2.4	7.7–8.0
F7	3	2.4	7.7–8.0
F7	3	2.4	7.7–8.0

Hs Height above the sediment (field data), *a* width at sediment level (field data), *HT* total shell height (estimated, see text)

and damp waves action, protecting coasts from erosion (Moreno, Aguilera, & Castro, 2001). The regression of seagrass beds, caused by human activities (pollution, modifications of the coastal area, discharge of urban and industrial wastewater, illegal fishing techniques as trawling) is observed throughout the world, and in Taranto Gulf its presence is actually reported in Cheradi Islands southern coasts, outwardly to Mar Grande basin.

Even the low depths (3–8 m, down to a maximum of 16) in which *P. nobilis* were recorded in Mar Grande (although they have been reported to occur down to depths >30 m in different Mediterranean sites) can be ascribed to specific ecological conditions. As already reported for *P. nobilis* populations of Croatian protected areas, in anoxic conditions, due to sediment type, low oxygen saturation and the possible presence of saturated H_2S in deeper seas, no *P. nobilis* can be recorded, while they are mostly found in shallower waters (Šiletić & Peharda, 2003).

As it was to be expected, the average recorded density of *P. nobilis* in Mar Grande resulted very low (0.1–0.7 ind ha^{-1}) when compared to studies conducted in protected areas of Adriatic Sea, where typical population density is about 0.1 ind/m^2 (Butler et al., 1993; Combelles et al., 1986; De Gaulejac & Vicente, 1990), up to 0.2 ind/m^2 in *Cymodocea* beds in Croatian protected sites (Šiletić & Peharda, 2003), whilst the typical densities of *P. nobilis* populations in other Mediterranean areas is 0.01 ind/m^2. In Mar Grande too *P. nobilis* appears to have a denser distribution in association with *Cymodocea* beds rather than on bare mud sediments, as reported for Spanish pinnids populations associated with *Posidonia* (Richardson et al., 1999), probably because the branching rhizomes of seagrass are stronger foundations for the attachment of byssus threads and more stable than fine sands or mud for the stabilization of the shell.

Richardson et al. (1999) reported that *P. nobilis* growth rates vary by location: The average size of fan shells seem to vary eventually according to the availability of zooplankton. Growth analyses conducted in Spanish Mediterranean areas showed that, for example, at Carboneras the height of 30 cm corresponds to an age of two years, while at Aguamarga and Rodalquilar a two-years old *P. nobilis* has a total shell height of 20 cm. At eight years of age the pinnids of Aguamarga and Rodalquilar have a size of 42 cm and the Carboneras ones grow up to over 55 cm (Richardson et al., 1999). The largest *P. nobilis* specimen of Mar Grande had an estimated size of 87.6–87.9 cm (HT), recorded in the macroarea B, while sizes of 50.1–50.5, 55.1–55.5 and 52.6–53.0 cm were all recorded in macroareas A and B. The scarce available bibliographic data on age and growth of *P. nobilis* observed in different locations and the lack of data on trophic level of Mar Grande don't allow to deduce if those bibliographic observations and growth curves can be extrapolated to pinnids populations elsewhere in the Mediterranean; anyway the age of these specimens can be estimated as >8 years. In all the other macroareas, specimens of *P. nobilis* seem very juveniles, with an average size of 8.3 cm (min. 4.3 cm–max. 13 cm), considered as <1 year (Richardson et al., 1999).

The results of the present study indicate a tentative of recovery of *P. nobilis* population in Mar Grande in spite of all the difficulties of a degraded and heavily polluted environment and the damages of illegal fishing methods. The study was started as part of a long term investigation on the possibility of life, the presence, the density and the growth of *P. nobilis* that will allow a constant monitoring of this population in such a difficult environment as Mar Grande has become because of human activities.

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