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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)

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SUMMARY: We investigated the spatial distribution, size structure, shell orientation and valve colonization by epibionts of the endangered Mediterranean bivalve *Pinna nobilis* in three continuous but different habitats in the Gulf of Oristano (Sardinia, western Mediterranean). The sampling stations chosen were: an estuarine area (E) of coastal salt-marshes characterized by unvegetated sea-bottoms; and two areas in a seagrass meadow characterized by an extensive *Posidonia oceanica* meadow (M_w) and patched mixed meadows of *P. oceanica* and *Cymodocea nodosa* (M_e). We found significant differences in mean densities among stations and the highest value was found in the estuarine area. Shell orientation showed that there was uniform circular distribution of specimens in the M_w station and a unimodal distribution in the M_e and E stations, where specimens were set at 0°N and 10°NNE, which is a pattern related to sea drift. Shell epibiosis displayed differences between habitats. The highest valve colonization was in the estuary, with filamentous dark algae and *Ostrea edulis* reaching almost 90 percent of shell coverage. This study provides new information on habitat preferences and data for assessing local populations of *P. nobilis* that is useful for its conservation and improving the knowledge of its ecology.

Keywords: *Pinna nobilis,* Bivalvia, endangered species, population density, size distribution, epibiosis, Sardinia, western Mediterranean.

RESUMEN: Densidad, estructura de tallas, orientación de las conchas y colonización de epibiontes de la nacra *Pinna nobilis* L. 1758 (Mollusca: Bivalvia) en una zona estuarina de Cerdeña (Mediterráneo Occidental). – Se investigó la distribución espacial, la estructura de tallas, la orientación de las conchas y la colonización de las valvas por parte de epibiontes, de la especie protegida *Pinna nobilis* en el Golfo de Oristano (Cerdeña, Mediterráneo Occidental). Las estaciones de muestreo se encontraban en tres hábitats continuos pero diferentes: una zona estuarina (E) de humedales costeros caracterizada por un fondo sin vegetación; una zona caracterizada por una amplia pradera de *Posidonia oceanica* (M_w) y una tercera compuesta de una pradera mixta parcheada de *P. oceanica* y *Cymodocea nodosa* (M_e). La máxima densidad media se encontró en el estuario. La orientación de las conchas indicó una distribución circular y uniforme de los ejemplares en la estación M_w, y una distribución unimodal en las estaciones M_e y E, donde los ejemplares estaban orientados a 0°N y 10°N-NE, patrón relacionado con las corrientes dominantes. La epibiosis de las conchas mostró diferencias entre los hábitats. La máxima colonización de las valvas fue en el estuario, con algas brunas filamentosas y *Ostrea edulis*, llegando a casi el 90% de cobertura de la concha. Este estudio ha permitido obtener nuevos datos sobre el hábitat preferencial de *P. nobilis*, y evaluar las poblaciones locales proporcionando informaciones útiles para el conocimiento de la ecología y mejorar la conservación de esta especie.

Palabras clave: *Pinna nobilis*, bivalvos, especies en peligro de extinción, densidad poblacional, estructura de tallas, epibiosis, Cerdeña, Mediterráneo Occidental.

INTRODUCTION

The fan mussel, *Pinna nobilis* L., is an endemic Mediterranean species considered to be endangered, whose preservation is promoted mainly through the Barcelona Convention (protocol ASPIM Annex 2) and the Habitats Directive (Annex IV). Although protection measures were introduced in the early 1990s, there is a knowledge-gap in the conservation status of the populations. A review of the available scientific and non-scientific literature within the Aquatic Science and Fisheries Abstracts database (ASFA) and the Zoological Records revealed 30 studies from 1978 to 1992 (before the protective measures) and 42 from 1992 to 2007 (after the introduction of the Habitats Directive) (Table 1). Most investigations of the ecology of the fan mussel are descriptive, with few mensurative experimental studies and even fewer 'manipulative' experimental studies that test specific hypotheses. Furthermore, these investigations focus exclusively on the coastal areas of the European Mediterranean regions (France 30, Spain 16, Italy 5, Greece 4, Croatia 3, Tunisia 1, Unknown 13), leaving a large gap of knowledge in the insular areas as well as the north African countries. For these reasons, various authors have called for more wide-ranging studies on the ecology of this species as well as population assessments (Vicente, 1990; Butler *et al.*, 1993; Ramos, 1998; Templado, 2001; Richardson, 2004; García-March, 2006).

P. nobilis is a long-lived species (up to 20 yr) (Moreteau and Vicente, 1982; Butler *et al.*, 1993) that lives in a depth range of between 0.5 and 60 meters (Butler *et al.*, 1993) usually in meadows of *Posidonia oceanica* and mixed meadows of *P. oceanica* and *Cymodocea nodosa* (Zavodnik, 1967; Zavodnik *et al.*, 1991). Well structured populations are also found in sandy and muddy bottoms of coastal and estuarine zones (Katsanevakis, 2006). Spatial distribution seems to be strictly correlated with a depth/size segregation i.e. there are very few large specimens in shallow and exposed-shore areas (Zavodnik, 1967; Vicente *et al.*, 1980; Moreteau and Vicente, 1982; Vicente, 1990; Vicente and Moreteau, 1991; Templado, 2001). *P. nobilis* follows an aggregative distribution, with a density variability that usually ranges between 0 and 10 individuals/100 m^2 (Vicente, 1990; Zavodnik *et al.*, 1991; García-March *et al.*, 2006). Higher density values are registered only in particular habitats of coastal salt-marshes and protected inlets (De Gaulejac and Vicente, 1990; Catsiki and Catsikieri, 1992).

Table 1. – Number of studies on *P. nobilis* in particular research areas (source: ASFA; Zoological Records; 1978-2007).

Research areas	No.
Ecology	18
Physiology	4
Biochemistry	16
Population studies	10
Growth	5
Bioaccumulation	4
Reproduction	2
Interspecific relationships	6
Biometric measurements	2
Protection	2
Implantation	2
Palaeontology	1

These ecological features make populations particularly vulnerable to anthropogenic impacts such as structural changes in seagrass meadows in response to environmental stress; mechanical impacts due to dredging, anchoring, trawling and entanglement nets; eutrophication in estuarine and coastal systems causing physical modifications of habitats; illicit harvesting for human consumption and for shell collection (Vicente, 1990; Zavodnik *et al.*, 1991; Vincente and De Gaulejac, 1993; Katsanevakis, 2007). Dislodgement by waves is an important natural cause of mortality as evidenced by the studies of García-March *et al.* (2007a, b) and predation is also an important cause of mortality. Gilthead bream, *Sparus aurata* (Sparidae) and the common octopus, *Octopus vulgaris* (Octopodidae) can represent natural hazards for fan mussel populations (Fiorito and Gherardi, 1999; García-March *et al.*, 2007a, b), but other Sparidae and fish from other families, crabs and carnivore molluscs might also predate on juveniles of *P. nobilis* (Katsanevakis, 2007).

The information we have on *P. nobilis* along the coastal areas of Italy is from studies by Corriero and Pronzato (1987) on the epibiosis of shells, and Centoducati *et al.* (2006) who assessed the population in the "Mar Grande di Taranto" (Ionian Sea). In Sardinia the only information comes from studies by Porcheddu *et al.* (1998) and recently by Caronni *et al.* (2007) who studied the transplantation of a few specimens to the Marine Protected Area of Tavolara, off the east coast. However, an extensive assessment of *P. nobilis* populations has never been carried out before, mainly due to the obvious difficulties of direct observation in these kinds of investigation. In Sardinia, the fan mussel has historically been much exploited in four main areas: the Gulf of Alghero (NW coast), the Gulf of Palmas (SW coast), the Gulf of Olbia (NE coast) and the Gulf of Oristano (W coast). There was heavy exploitation from the 18th century until the first decades of the 20th century for the production of "sea silk" from byssus, used to make fine cloth (gloves, ties, small carpets) and pearl accessories. Since the northern part of the Gulf of Oristano contains a fairly widespread population of *Pinna nobilis*, we focused our investigation in this location (Fig. 1). It is an area of great environmental contrast and importance that includes: two large and productive coastal lagoons (Cabras and Mistras), which have a fish yield of about 210 kg/ha/yr, and which are included in the list of Wetlands in the Ramsar Convention; a small-scale fishery employing at least 300 fisherman; and a Marine Protected Area (MPA Penisola del Sinis Isola di Mal di Ventre) that falls partially within the studied location. According to the Europe-wide network "Natura 2000", part of the area has been classified as a "Site of Community Importance" (SCI) and "Special Protected Area" (SPA) for the preservation of natural heritage (Fig. 1). Despite the conservation and classification measures listed above, there is currently a large gap in the scientific knowledge of the marine environment, the transition areas and their ecological status in general. Only recently, an environmental monitoring program has indicated that human-modified inlet activities have lead to modifications of the estuarine habitat which disrupt physiochemical and ecological processes (Como *et al*., 2007).

Since the area has a valuable but contrasting natural environment, the goal of this paper is to investigate the conservation status of fan mussel populations in neighbouring but different habitats. In particular, this study had the following specific objectives: to assess density, size structure, valve orientation and epibiosis colonization of *P. nobilis*.

MATERIALS AND METHODS

Study site

The Gulf of Oristano has a surface of approx. 150 km^2, is bounded to the west by rocky capes, and has a mostly sandy shoreline along an alluvial plain with several salt-marshes and lagoons. The research was carried out on the northern side of the Gulf, in an area known as the "Dead Sea" because

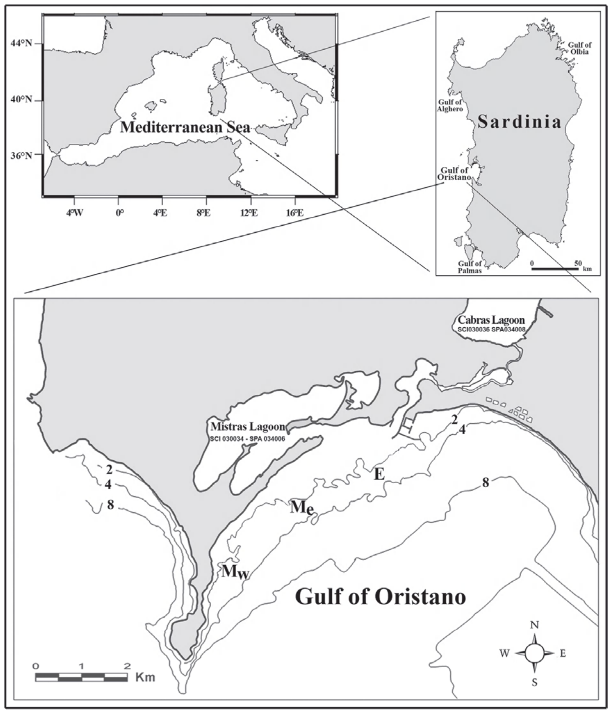

FIG. 1. – The Gulf of Oristano location with the sampling stations where *Pinna nobilis* populations were studied.

it is characterized by shallow, calm waters, as it is sheltered from the predominant winds of the fourth quadrant, mainly the mistral (NW). An extensive meadow of *P. oceanica* (approx. 15 km^2) characterizes the western part of the study area while the eastern part is occupied by patchy mixed meadows of *Cymodocea nodosa* and *P. oceanica,* except in the estuarine areas off the Cabras and Mistras lagoons, a major source of mud sediment and biogenic sand (De Falco *et al*., 2000).

The sampling stations were chosen at depth intervals of 2 to 6 meters: two were selected in the seagrass meadow area, referred to as M_w (Meadow west = *P. oceanica* meadow) and M_e (Meadow east = mixed meadows of *P. oceanica* and *C. nodosa*); the third station E (Estuary = unvegetated bottoms) was chosen off the estuarine area (Fig. 1). Stations were first visualized on a digitalized map using the software OziExplorer (v.3.90.3a). Fifteen randomly replicated quadrats (10x10 m) were selected for each station and coordinates of edges (Lat/Long) were extracted from the digitalized map (WGS84 geodetic referenced system) to provide the GPS position, which is useful during field surveys. The study was conducted between September 2006 and October 2007 with the majority of samples taken in spring and autumn.

Sampling

Underwater counts of live and dead specimens within each quadrat were carried out with direct visual observations by SCUBA divers. Density was expressed as the number of specimens/100 m^2. The size of each individual (cm) within each quadrat was measured using the multi-calliper system proposed by García-March *et al.* (2002). Measurements were taken of the antero-posterior length outside the substratum (Hs), and of the maximum and minimum dorso-ventral lengths, usually called width (a). Total shell height (Ht) was estimated using the following equation: Ht = (1.79 a + 0.5 ± 0.2) + Hs (García-March and Ferrer, 1995). Considering that the equation by García-March and Ferrer was calculated for a different area, we assumed that there is a potential bias in height estimation.

The compass orientation (0-360°) of the valves compared to the hinge line of each live specimen was measured with an underwater compass.

Epibiosis on the valves of *P. nobilis* was studied with a non-destructive sampling method. At each station, ten fan mussels with a Ht of 50 to 60 cm were selected, and the right-left valves photographed with a digital camera (Nikon D100) protected in an underwater casing and with a chassis (15x20 cm) mounted on the macro objective. The pictures (resolution of 4000 dot/inch) were analyzed on a PC using the software TpsDig2 for geometric, morphometric analyses, which is effective for calculating shell epibiontic coverage (cm^2). Adopting this non-destructive sampling method allowed a taxonomic resolution that ranged from species to genera, family and order. Other taxa were grouped according to their morphology using the acronyms proposed for morphological groups by Fraschetti *et al.* (2005): filamentous dark algae (DFA) (mostly red algae belonging to the order Ceramiales), filamentous green algae (GFA) (the order Cladophorales), and encrusting coralline red algae (ECR) (including *Lithophyllum* sp. and *Peyssonnelia* spp.).

Data analysis

The spatial patterns of *P. nobilis* abundances were analyzed with a one-way ANOVA (fixed factor Station, with quadrats providing replicates). Prior to performing the ANOVA, we tested for heterogeneity of variance with Cochran's C-test, while a Scheffé post-Hoc test enabled us to analyze the effects of interaction between stations.

The size/frequency distribution was compared among stations using the Kolmogorov-Smirnov (K-S) test.

Valve orientation was analyzed in three ways: a) the number of observations were visualized with rose diagrams for each station, considering lag classes of 10°; b) the resultant vector r was calculated in each station to represent a measure of data concentration (Mardia, 1972); c) the Rayleigh test (Fisher, 1993) was applied to determine any significant variation from the uniformity of distributions (random distribution) of valve orientation. The Rayleigh's z was used for testing the null hypothesis H_0: the sampled population is uniformly distributed around a circle (i.e., H_0: ρ=0) vs. H_1: the population is not a uniform circular distribution (H_1: $\rho \neq 0$). In this case the mean angle (θ) was calculated to indicate the central tendency of the distribution.

Epibiontic data were analyzed using one-way Analysis of Similarities (ANOSIM) (Clarke, 1993) based on differences in the spatial scales (Meadow vs. Estuary). The R-statistic value was used to determine the dissimilarity between stations. Values close to one indicate that the composition of the groups is very different, whereas values near zero indicate that there is little difference (Clarke, 1993). Differences between stations were represented by non-metric Multidimensional Scaling ordinations (nMDS). Similarity Percentage Analysis (SIMPER) (Clarke, 1993) enabled us to identify the "important taxa" that contributed to similarity among stations.

Univariate data were processed with Brodgar 2.5.1 (Highland Statistics Ltd.), while multivariate analyses were performed with PRIMER v6 (Plymouth Marine Lab. UK).

RESULTS

Population density

A total of 530 specimens of *P. nobilis* were counted and measured over a surface of 4500 m^2. Densities of live, dead and overall specimens are reported in Table 2.

Box-plots highlighted a sharp difference between the Meadow and the Estuary densities. This pattern seems to be constant for the different data combinations i.e. for overall specimens (T), and the separate data for live (L) and dead individuals (D) (Fig. 2).

TABLE 2. – Densities (ind. /m[2]) of live, dead and overall specimens of *P. nobilis* in each station.

Station	live	dead	live + dead
M_w	3.3±2.4 SD (n=69)	1.08±1.3 SD (n=42)	4.4±3.1 SD (n=111)
M_e	3.9±3.6 SD (n=76)	0.8±0.8 SD (n=39)	4.7±4.0 SD (n=115)
E	11.6±4.6 SD (n=169)	8.8±4.4 SD (n=135)	20.3±6.7 SD (n=304)
Total	6.3±5.2 SD (n=314)	3.6±4.6 SD (n=216)	9.8±8.9 SD (n=530)

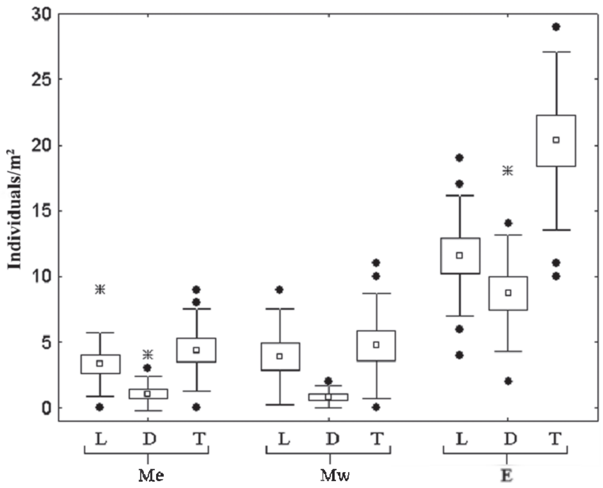

FIG. 2. – Boxplot of densities (L, live; D, dead; T, total specimens).

There were some outliers (large observations), which were mainly in the Estuary station. These are indicators of a high aggregative pattern of specimens within quadrats.

The ANOVA test confirmed previous descriptive analysis of data. Analysis of total density (live + dead specimens) produced statistically significant difference within stations (P<0.01; Cochran's test=ns). Furthermore, the post-Hoc Scheffé's test highlighted that differences are not significant in the pairwise comparison between Meadow stations (M_e vs. M_w; P=ns) and significant in the comparison between Meadows and Estuary (M_e vs. E: P<0.05; M_w vs. E; P<0.05). The same results were obtained when only data for live specimens were considered (P<0.01; Cochran's test = ns).

Size structure

Frequency of Ht classes showed that a bimodal distribution was clearer for the Estuary (primary mode 20 cm Ht, secondary 60 cm Ht) than for Meadow stations grouped together (20 and 55 cm Ht respectively) (Fig. 3a). The size range is larger for the Estuary station, where adult specimens of 95 cm Ht were found. Dead individuals registered a unimodal size distribution with a wide range of classes, from 20 to 100 cm Ht, and were mainly found in the Estuary (Fig. 3b). The Kolmogorov-Smirnov test used to contrast frequency distributions of live specimens (due to the small amount of data for dead individuals) within Meadow stations (M_w vs. M_e) showed no significant differences (K-S test= 0.67; P= 0.75; D= 0.3). When the frequency distribution in the Meadow stations was contrasted with that of the Estuary station (M vs. E), a statistically significant difference was obtained (K-S test= 1.34; P<0.05; D= 0.6).

Valve orientation

Analysis of valve orientation by rose diagrams revealed a marked pattern of distribution within the first and fourth quadrants for the M_e (Fig. 4b) and E stations (Fig. 4c). This pattern was less pronounced for the M_w station where few specimens were ori-

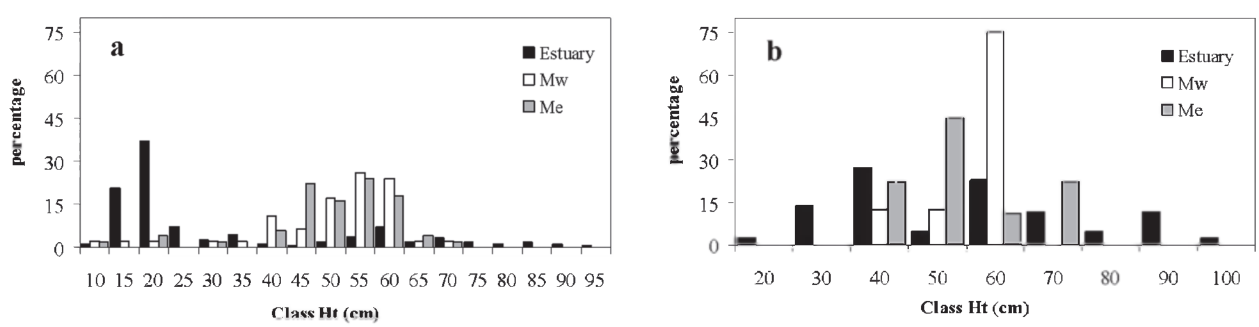

FIG. 3. – Size distribution of live (a) and dead (b) specimens of *P. nobilis* for each sampling station.

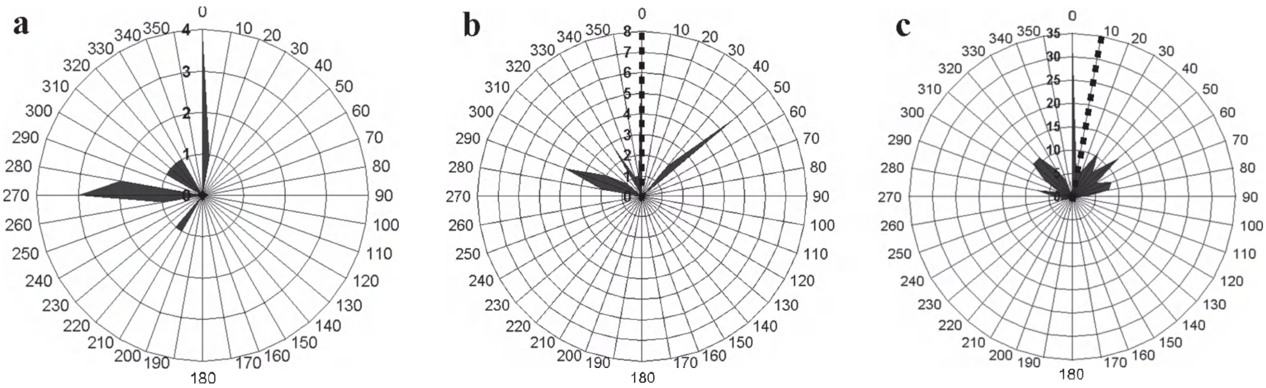

FIG. 4. – Rose diagrams reporting shell orientation in the M_w (a), M_e (b) and E (c) stations (dotted line indicates the mean angle).

ented, and also in the third quadrant (Fig. 4a). The amount of angular dispersion (r) followed a progressive pattern from the M_w station (r= 0.24), with the lowest value (high dispersion), to the Estuary (r= 0.62), which had the highest value (low dispersion). The middle station, M_e (r= 0.53), displayed an intermediate value. Application of the Rayleigh test revealed a significantly uniform data distribution (z= 1.6; P<0.05) in M_w (accept H_0) and non-significant uniformity in the M_e (z=11.5; P= ns) and E stations (z= 62.7; P= ns) (reject H_0). Finally, the calculation of the mean angle was θ= 0°NNE for specimens sited in the M_e station and θ= 10°N for the Estuary.

Epibiosis

An overall shell surface of 11500 cm² which corresponded to 30 individuals was photographed and analyzed. We identified 16 taxa and 3 morphological categories (Table 3).

Results indicated that the shells of *P. nobilis* were completely colonized by epibionts in the Estuary, and were mainly covered by filamentous dark algae, DFA, (72.1%) and the European flat oyster, *Ostrea edulis* (15.9%) (Table 3), which occurred on respectively 100% and 50% of the entire sample of individuals collected. Lower values of DFA were found in the M_w and M_e stations (57.3 and 16.4 respectively) but occurrence was registered in almost all specimens. Encrusting coralline red algae (ECR) was only found in the Meadow stations, where it covered more than 27.6% of the overall specimen surface in the M_e station and 4.9% in M_w. An ANOSIM between the Meadow and Estuary stations showed a global R= 0.34 (P<0.05), which indicates that there were different assemblage patterns in the epibiontic

TABLE 3. – List of epibionts on shells of *P. nobilis* (Cov%, percentage coverage; f%, percentage frequency of recovery).

	M_w		M_e		E	
	Cov %	f %	Cov %	f %	Cov %	f %
Aplidium sp.					0.3	40
Dictyota dichotoma			2.5	10		
Dictyota linearis	12.9	30	10.0	30	5.7	20
Eudendrium racemosum					0.1	40
Flabellia petiolata	0.3	10	0.1	10		10
Hildenbrandia rubra	3.5	40	1.0	10		
Lithophyllum sp.					1.7	20
Murex sp.			0.4	10		
Ostrea edulis	18.3	50	11.6	60	15.9	50
Padina pavonica			0.1	10		
Paracentrotus lividus	0.5	20	0.6	10		
Peyssonnellia sp.					0.2	10
Schizobrachiella sanguinea			0.6	10	1.3	10
Anthozoa			0.1	10		
Cyanobacteria					0.3	10
Serpulidae	0.2	30	0.4	60	0.1	50
DFA	57.3	100	16.4	90	72.1	100
ECR	4.9	50	27.6	60		
GFA	0.4	10			2.4	10
Valves not colonized	1.8		28.7			

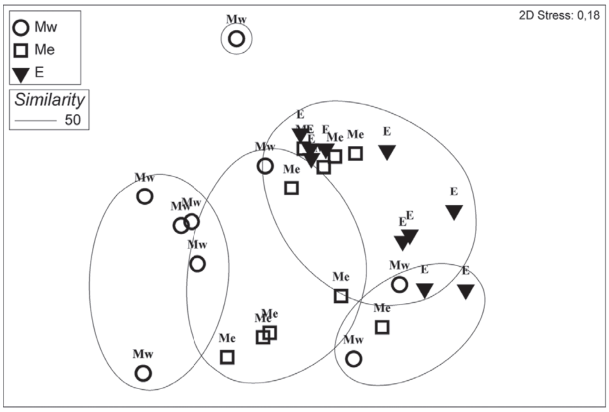

Fig. 5. – MDS plot representing differences in epibiosis assemblages on *P. nobilis* valves between stations.

Table 4. – Important taxa identified with SIMPER analysis (Av.Ab, Average Abundance; Av.Diss, Average Dissimilarity).

	M	E	M vs. E	
Species	Av. Ab		Av. Diss	SD
DFA	40.30	72.11	19.33	1.47
ECR	24.40		12.20	0.82
O. edulis	16.67	14.23	9.60	1.19
D. linearis	8.50	6.10	6.23	0.63
H. rubra	4.89		2.45	0.55
GFA	0.17	3.34	1.74	0.35

community. This was also confirmed by the nMDS plot (stress= 0.18), which showed a separation of centroids between the Meadow and Estuary stations (Fig. 5). According to values of Average Dissimilarity from the SIMPER analysis, DFA, ECR, *Ostrea edulis*, *Dictyota linearis* and *Hildebrandia rubra*, were the main causes of the differentiation between stations (Table 4).

DISCUSSION

In this study we examined density, size structure, shell orientation and epibiontic colonization of *Pinna nobilis* populations on small and large spatial scales in an area of both natural and socio-economic importance in western Sardinia. Population distribution patterns in the studied area may be summarized as follows:

Specimen densities showed significant differences between the habitats analyzed. In the estuary site, off the coastal lagoons, we identified a particularly high mean value (12 specimens/100 m^2 and ~20 considering live + death specimens). In absolute terms, these values are much higher than those estimated in the oldest European national park i.e. Port Cros National Park (France) (1 specimen/100 m^2) (Vicente *et al.*, 1980; Moreteau and Vicente, 1982) and those found in the Adriatic Sea on sea bottoms colonized by *Cymodocea* spp. (9 specimens/100 m^2) (Zavodnik *et al.*, 1991). Only Templado (2001) found values similar to ours on the south coast of Spain (10 specimens/100 m^2). A summary of density data from the scientific literature by geographical area and substrata is reported in Table 5. The seagrass meadow stations were characterized by lower densities (4 specimens /100 m^2), which were in line with mean values reported in other investigations.

The size structure of the populations highlighted a different pattern within the stations and characteristic habitats analyzed. In the estuarine area we found a high percentage of small individuals. These specimens, according to growth parameters determined by García-March *et al.* (2007a), belonged to the first and second year classes. Adults were also well represented; in fact large live and dead individuals (>80 cm Ht) were found, although with lower frequency values than small individuals. These large specimens are more than 20 years old (García-March *et al.*,2007a; Siletic and Peharda, 2003), and are of particular importance in the spawning and recruitment processes because they represent the source of new individuals.

In the seagrass meadow the population was mainly characterized by large specimens (40 to 60 cm Ht).

The analysis of valve orientation highlighted the tendency of specimens found in the east meadow station and estuarine area to be positioned between 0°N and 10°NNE. The latter value is also consistent with a hydrodynamic model of the water circulation between the Cabras lagoon and the inlet area (Ferrarin and Umgiesser, 2005). The environmental system is greatly affected by the wind from the NW (mistral) which represents over 45% of the wind events per year in the area (Ferrarin and Umgiesser, 2005). The mistral is indeed the driving force for the hydrodynamic activity of the lagoon, while the secondary effect of the tide modulates the discharges through the inlet.

Therefore, shell orientation seems to be strictly related to prevailing drift, which is a fundamental condition for capturing nutrients, a pattern already found by García-March *et al.* (2007b).

We also observed that the amount of circular dispersion of the angles follows a progressive gradient from the eastern to the western stations. We hypoth-

TABLE 5. – Densities of *P. nobilis* reported from literature considering geographical area and substrata.

Geographic area	ind/100 m^2	Substrata	Source
Moraira Bay (Spain)	6-10	*P. oceanica*	García-March *et al.*, 2007a
Ionian Sea (Italy)	0.001-0.007	*P. oceanica/C. nodosa*	Centoducati *et al.*, 2006
Lake Vouliagmeni (Greece)	1.1	mud	Katsanevakis, 2006
Columbretes Island (Spain)	1.5	*Cymodocea* spp.	García-March *et al.*, 2006
Moraira Bay (Spain)	1-12	*P. oceanica*	García-March *et al.*, 2005
south Adriatic Sea (Croatia)	2-20	*Cymodocea* spp.	Siletic and Peharda, 2003
southern Spain	10	—	Templado, 2001
Chafarinas Islands (Morocco)	3.2	—	Guallart, 2000
south-east Spain	4-30	*P. oceanica*	Richardson *et al.*, 1999
Kerkena island (Tunisa)	0.03-0.07	*P. oceanica*	Tlig-Zouari, 1993
Greece	6	—	Catsiki and Catsikiery, 1992
Adriatic Sea (Croatia)	9	*Cymodocea* spp.	Zavodnik *et al.*, 1991
Corse (France)	6	*P. oceanica*	De Gaulejac and Vicente, 1990
Port Cros Park (France)	1	*P. oceanica*	Moreteau and Vicente, 1982

esize that this pattern is related to the irregular topography in the western station, where *P. oceanica* meadows with many intermatte channels, pools and front steps, can alter water direction and speed; however, it may also be related to the sheltered position of the station. The estuarine area is characterized by a regular bottom in which water direction is regular as is the orientation of valves (De Falco *et al.*, 2000; Granata *et al.*, 2001).

An analysis of shell epibiosis provides further information on the relationships between specimens and the habitat features. In absolute terms, the highest valve colonization was in the estuarine area, filamentous dark algae and the European flat oyster *O. edulis* (typically associated with highly productive estuarine and shallow coastal water habitats) represented more than ninety percent of epibiontic coverage. Nine other species characterized the estuary, although they had low coverage values. Some of them were found exclusively in this environment, i.e. *Aplidium* sp., *E. racemosum*, *Lithophyllum* sp., *Peyssonnellia* sp., and Cyanobacteria. The Meadow stations also had exclusive species, among which the encrusting coralline red algae stands out. Although epibiotic analyses were carried out with a small sample size, we believe they represent a starting base that is useful for a spatial and temporal evaluation of the system's environmental state of health, which is important but undoubtedly secondary to data on population assessment. However, we believe that an integrated analysis and temporal comparison of *P. nobilis* populations could emphasize the role of *P. nobilis* as a "sentinel species" in sensitive coastal zones.

We have thus concluded that the spatial distribution of *Pinna nobilis* specimens can vary and does depend on local ecological features and processes. The estuarine areas of the Cabras and Mistaras lagoons are important sources of sediments and suspension, which are particularly helpful in the settlement processes of fan mussel larvae in the passage from the planktonic to the benthic phase. In fact, sediment characterization and the hydro-dynamism of the water-sediment interfaces are considered key factors in the process of active habitat selection by settling larvae of soft-sediment invertebrates (Thorson, 1950; Butman, 1987). The species–habitat relationship observed in the field provides some evidence of habitat selection; however, causality cannot be established since other unknown processes may occur. For example, Hannan (1984) provided some evidence of the initial settlement of planktonic larvae; he demonstrated that, in the field, larvae initially fall with the same velocity as a particle of sediment with a similar weight.

The spatial variability of *P. nobilis* can also be related to the displacement capacity of individuals during ontogenesis (Zavodnik, 1967; Vicente *et al.*, 1980), which is a mechanism that is well-known for other bivalve species, even those unable to swim (Sigurdsson *et al.* 1976). Bivalves can actively enter the water column by moving to the surface of the sediment and secreting a thread from the byssus gland. This byssus thread increases the viscous drag exerted on the bivalve, enabling it to be transported on relatively small currents, and is termed 'byssus drifting' (Sigurdsson *et al.*, 1976). We assume that the spatial distribution of larvae and post-larvae of *P. nobilis* reflects this mechanism of transport as passive particles. In this case, settlement and distribution would be determined by the same physical processes that determine the distribution of sediments with similar fall velocities. However, the effects of byssus drifting could reduce the constriction of the hydrodynamic regime and facilitate active sediment choice, mainly in the estuarine area. Moreover, due to the large number of dead specimens in the estuary, we also hypothesize that some perturbations have occurred. The mechanical modifications of the Cabras lagoon inlet (Como *et al.*, 2007) and the presence of a small-scale fishery that operates with trammel and gill nets in the lagoon inlets could be the main causes of these perturbations. To exhaustively identify the sources of mortality and estimate their rates could be the aims for future investigations. The fan mussel could be a useful target species for field monitoring and an indicator of environmental conditions in the estuarine area, as suggested by Vicente and de Gaulejac (1993).

These coastal habitats have recently received much attention from policymakers, but coastal marine system theory still needs to be integrated across scales to account for local processes and anthropogenic disturbances which can result in biological changes on different spatial scales. It is imperative to protect threatened species with environmental policies based on applying rigorous science, but it is also necessary to verify their response to the enforcement of conservation measures. Appropriate and properly targeted financial support is also needed for non-commercial species such as the fan mussel. Only through an integrated framework approach and a dynamic perspective on ecology will managers achieve the underlying goals of marine and coastal area conservation.

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