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Distribution and habitat of the fan mussel *Pinna nobilis* Linnaeus, 1758 (Mollusca: Bivalvia) along the northern and eastern Tunisian coasts

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Abstract: Although the bivalve *Pinna nobilis* Linnaeus, 1758 has been recorded in previous studies in the Tunisian inshore areas, the status of this endangered species is still poorly known and there is a knowledge-gap about its distribution and ecology. The present work is a contribution to the knowledge of the fan shell distribution and the density of individuals along the northern and eastern Tunisian coasts, at depths situated between 0 and 6 metres. An important part of Tunisian coast was surveyed, stressing some observations concerning the species ecology and its preferred biotopes. The size structure of the five densest populations was also described. The fan shell density varied among these localities from 0.02 individuals 100 m^{-2} in Tabarka Elcorniche beach (northern coast) to 20 individuals 100 m^{-2} in the locality of Stah Jaber (eastern coast). It seems that *P. nobilis* prefers to be located within sheltered habitats with optimal hydrodynamic conditions, in particular low current velocities and turbulences, low wave action and in sandy-muddy or muddy substratum. Regarding the size structure analysis, it appeared that the majority of the five examined populations, except for Teboulba, was dominated by small individuals that do not exceed a maximum shell length of 40 cm. It also seems that the sheltered and shallow sites constitute appropriate recruitment areas for juveniles of *P. nobilis*.

Résumé : *Distribution et habitat de la grande nacre* Pinna nobilis *L. 1758 (Mollusca : Bivalvia) le long des côtes nord et est de la Tunisie.* Bien qu'elle ait été signalée plusieurs fois sur les côtes tunisiennes, la distribution de l'espèce menacée *Pinna nobilis* est encore peu connue et peu d'informations sont disponibles sur l'écologie et la structure des populations tunisiennes de cette espèce. Le présent travail est une contribution à la connaissance de la distribution du jambonneau de mer sur le littoral nord et est du pays, de sa densité dans les secteurs prospectés et de ses biotopes préférés, à des profondeurs allant de 0 à 6 m. La structure de taille des cinq populations les plus denses a été également décrite. Dans ces sites, la densité du mollusque varie de 0,02 individus 100 m^{-2} sur la plage d'El Corniche de Tabarka (littoral nord) à 20 individus 100 m^{-2} au niveau de la localité de Stah Jaber (littoral est). La grande nacre semble préférer les zones abritées dont les conditions hydrodynamiques sont favorables, en particulier les faibles courants et turbulences, la faible action des vagues, et où le substrat est sablo-vaseux ou vaseux. Les populations les plus denses du jambonneau de mer sont en majorité jeunes. Enfin, les sites abrités et peu profonds semblent constituer des lieux de recrutement des juvéniles de *P. nobilis*.

Keywords: Pinna nobilis ● Bivalve ● Populations ● Distribution ● Tunisian coast ● Biotope

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Introduction

The fan mussel *Pinna nobilis* Linnaeus, 1758 is a Mediterranean endemic species. It is the largest Mediterranean bivalve and one of the largest in the world, since it can reach more than one metre of total antero-posterior length (Zavodnik et al., 1991). It lives up to 20 years according to Butler et al. (1993), while in Thermaikos Gulf (Greece) an age of 27 years has been reported (Galinou-Mitsoudi et al., 2006). During the last few decades, the populations of *P. nobilis* have strongly decreased because of abusive extraction by amateur divers, loss of their natural biotope (seagrass meadows) and negative effects of pollution on larvae (Vicente, 1990; Vicente & Moreteau, 1991; Richardson et al., 2004). As a consequence, the mollusc has been included in the list of Mediterranean endangered species (Annex IV of the Habitat Directive and Annex II of the Barcelona Convention).

P. nobilis occurs in coastal soft-bottom areas at depths between 0.5 and 60 m, mostly among meadows of the seagrasses *Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina* or *Zostera noltii* (Zavodnik, 1967; Zavodnik et al., 1991) but also in bare sandy bottoms (Katsanevakis, 2006). It lives partially buried by the anterior part of the shell (Zavodnik et al., 1991; Richardson et al., 1999; Templado, 2004) anchored with its developed byssus filaments that selectively attach to particles and solid structures existing in the substratum (García-March, 2005). Authors having recorded the benthic biocenosis where the species is common (Murillo, 1995; Ramos, 1998; García-March, 2003 & 2005; Templado, 2001; García-March & Kersting, 2006; García-March et al., 2006a & b) have reported a preferential appearance of *P. nobilis* in *P. oceanica* meadows and a close association between the two species. *P. oceanica* offers to *P. nobilis* the most suitable structures for the implantation of *Pinna* byssus filaments (García-March, 2003 & 2005), attenuates the water speed and reduces the drag forces that act on the pinnids increasing their optimal survival size (García-March & Kersting, 2006; García-March et al., 2006a & b).

In Tunisia, apart from the study carried out by Tlig-Zouari (1993) about this species in the archipelago of Kerkennah and its records in ancient malacofauna describing lists (Dautzenberg, 1883; Seurat, 1934; Gaillande, 1970; Ktari-Chakroun & Azzouz, 1971; Azzouz, 1973; Rosso, 1977; Zaouali, 1978; Zaouali & Beaten, 1985; Boudouresque et al., 1986; Romdhane & Chakroun, 1986; Soufi-Kechaou & Aloui Bejaoui, 2004), there is no precise data about its distribution, current status or even its ecology. For that reason, we chose to study this species in Tunisian coastal waters, taking into account not only its distribution on the northern and eastern coasts of the country, but also its habitat characteristics and the size structure of its populations in shallow waters (≤ 6 m depth).

Materials and Methods

Nineteen sites from six different sectors of the Tunisian coasts (Fig.1 & Table 1) were prospected. These sites are, from the north to the east, Tabarka El Corniche beach, Negro Cape, Sidi Mechreg (Coast of Tabarka), Echaâra, Njila, Menzel Jemil, Oued Tinja (Bizerta lagoon), Ghar El Melh lagoon, Tunis northern lagoon, Marsa beach, Sidi Rais Beach, Port Prince beach (Gulf of Tunis), Kelibia beach, Hammamet beach (Gulf of Hammamet), Sousse's beach, Hergla lagoon (Coast of Sousse), Stah Jaber beach, Khniss and Teboulba (Bay of Monastir). A total of 27 surveys were carried out, with one or two campaigns per site, at a depth ≤ 6 metres. At the majority of the stations, two 100 m lines were placed either parallel or perpendicular to the shoreline (Gambi & Doppiano, 1994). Two divers swam along the lines, counting all alive individuals encountered within 2 m width corridors on both sides of the line, recording the site characteristics (type of sediment, vegetation, etc.) and collecting empty shells. Therefore, *Pinna nobilis* density was determined in a 400 m^2 transect. In each site, the Pinnid density estimation was realized by two transects, leading to a total explored surface of 800 m^2. For the stations of Tabarka El Corniche beach and Hammamet beach, the paucity of pinnids made it necessary to explore a square surface of 100 x 100 m (10.000 m^2). The average density of each site was expressed in individuals 100 m^{-2}.

According to the density values obtained by precedent works (Vicente et al., 1980; Moreteau & Vicente, 1982; Giacobbe & Leonardi, 1987; De Gaulejac & Vicente, 1990; Zavodnik et al., 1991; Templado, 2001; García-March, 2003 & 2005; Siletik & Peharda, 2003; Richardson et al., 2004; Centoducati et al., 2006; García-March & Kresting, 2006; García-March et al., 2006a & b; Katsanevakis, 2006 & 2007a), we made a relative estimation scale of *P. nobilis* density: low when it was lower than 5 individuals 100 m^{-2} average when it varied between 5 and 10 individuals 100 m^{-2}, high when it varied between 10 and 15 individuals 100 m^{-2} and very high when it exceeded 15 individuals 100 m^{-2}.

In order to minimize the impact of sampling on the populations, collection of *P. nobilis* individuals was carried out only on the densest populations, wherever the Pinnids were distributed on a wide area. Thus, according to the estimated density of the populations, five sites were selected to take samples (30 *P. nobilis* specimens from each site). These localities are Echaâra (Bizerta lagoon), Njila (Bizerta lagoon), Sidi Rais (gulf of Tunis), Stah Jaber (bay of Monastir) and Teboulba (bay of Monastir). At the labo-

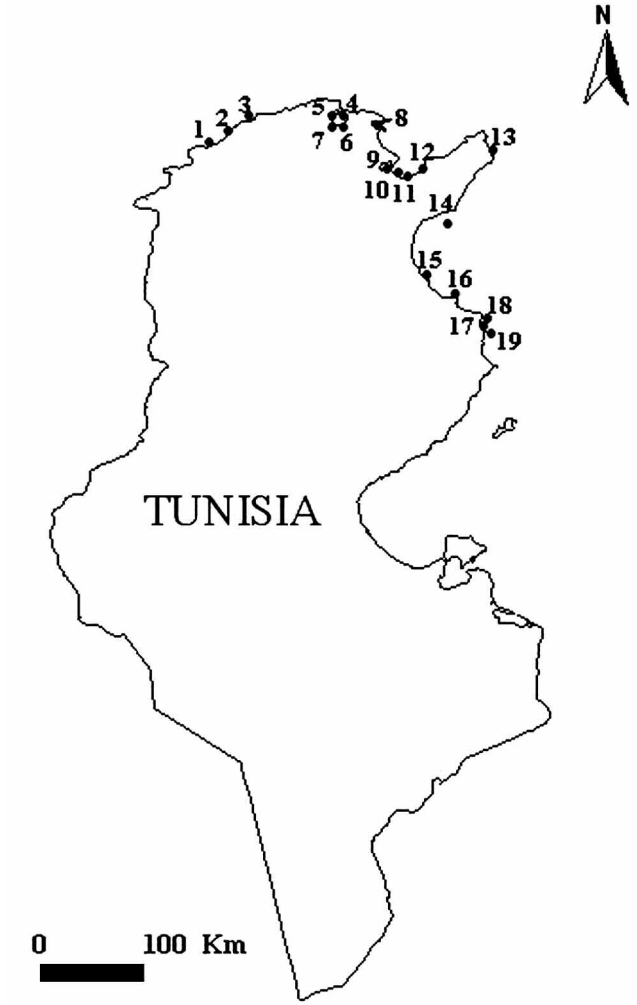

Figure 1. *Pinna nobilis.* Study area sampling stations (1. Tabarka El Corniche beach, 2. Negro Cape, 3. Sidi Mechreg, 4. Echaâra, 5. Njila, 6. Menzel Jemil, 7. Oued Tinja, 8. Ghar Elmelh lagoon, 9. Tunis North lagoon, 10. Marsa beach, 11. Sidi Rais, 12. Port Prince, 13. Kelibia beach, 14. Hammamet beach, 15. Sousse's beach, 16. Hergla lagoon, 17. Stah Jaber, 18. Khniss, 19. Teboulba).

Figure 1. *Pinna nobilis.* Région d'étude et stations d'observation (1. Plage d'Elcorniche de Tabarka, 2. Cap Negro, 3. Sidi Mechreg, 4. Echaâra, 5. Njila, 6. Menzel Jemil, 7. Oued Tinja, 8. Lagune de Ghar Elmelh, 9. Lagune nord de Tunis, 10. Plage de la Marsa, 11. Sidi Rais, 12. Port Prince, 13. Plage de Kelibia, 14. Plage de Hammamet, 15. Plage de Sousse, 16. Lagune de Hergla, 17. Stah Jaber, 18. Khniss, 19. Teboulba).

ratory, the shell length (SL) of all sampled pinnids was noted. The samples were preserved thereafter to be used for a future study about the growth and the biology of the species. For practical purposes, we considered small specimens those with SL ≤ 40 cm and large specimens those with SL ≥ 40 cm. The comparison between the average values of SL, made within the five studied populations was carried out using a one way analysis of variance (ANOVA). The difference between the 5 studied populations was also analysed using a post-hoc comparison (Tukey HSD).

Results

Among the 19 prospected sites, *P. nobilis* was observed in 12 localities: Tabarka El Corniche beach, Negro Cape, Sidi Mechreg, Echâara, Njila, Menzel Jemil, Sidi Rais, Port Prince, Hammamet beach, Stah Jaber, Khniss and Teboulba. On the northern and eastern Tunisian coasts, *P. nobilis* lives half-buried in a substrate of varied nature and texture (Table 1). It is sandy-muddy in Tabarka El Corniche beach, Echaâra, Sidi Rais, Stah Jaber and Teboulba, sandy in the localities of Negro Cape, Sidi Mechreg, Port Prince and also in Hammamet's beach and muddy in the cases of Njila, Menzel Jemil and Khniss. Moreover, it is worth mentioning that within certain sites such as Echaâra, Njila, Khniss and Teboulba, the substrate is mixed with small stones or biodetritic material. Concerning the substratum covering, *P. nobilis* was observed in its preferred biotope, *P. oceanica*, only in the locality of Port Prince. In the majority of prospected sites, it is settled either within the mixed meadows of the marine seagrasses *P. oceanica* and *C. nodosa* (Tabarka El Corniche beach, Sidi Rais beach, the beach of Hammamet and that of Teboulba), or only within *C. nodosa* meadows (Echaâra, Njila and Stah Jaber). *P. nobilis* was also observed within an algae-covered muddy substrate, in the case of Menzel Jemil (Table 1).

On a total surface of 33600 m^2, explored during this study, we counted 845 *P. nobilis* specimens. The mean density of individuals for each locality varied considerably from one sector to another (Figs 2 & 3) and was between 0.02 and 20 individuals 100 m^{-2} (Table 1). The highest densities of individuals were recorded in the following sites: Stah Jaber (20 individuals 100 m^{-2}), Njila (17 individuals 100 m^{-2}), Teboulba (15 individuals 100 m^{-2}), Echaâra (14 individuals 100 m^{-2}), Sidi Rais (13 individuals 100 m^{-2}) and Khniss (13 individuals 100 m^{-2}). The lowest are those of Tabarka El Corniche beach (0.02 individuals 100 m^{-2}), Negro Cape (2 individuals 100 m^{-2}), Sidi Mechreg (1 individual 100 m^{-2}), Menzel Jemil (3 individuals 100 m^{-2}) and Hammamet beach (3 individuals 100 m^{-2}). Mean density of individuals is average in Port Prince (7 individuals 100 m^{-2}) (Table 1).

Mean SL of the five densest populations varied between 23.8 ± 8.05 cm (Sidi Rais) and 41.0 ± 9.13 cm (Teboulba). The majority of *P. nobilis* populations (Echaâra, Njila, Sidi Rais and Stah Jaber) were primarily made up of small

Table 1. *Pinna nobilis.* Description of the different populations found in the present survey. Average densities: density < 5 ind. 100 m^{-2}: Low; 5 < density < 10 ind. 100 m^{-2}: average; 10 < density < 15 ind. 100 m^{-2}: high; density > 15 ind. 100 m^{-2}: very high. Grey bands correspond to sampling populations.

Tableau 1. *Pinna nobilis.*Description des différentes populations rencontrées au cours du présent travail. Densités moyennes : densité < 5 ind. 100 m^{-2} : faible ; 5 < densité < 10 ind. 100 m^{-2} : moyenne ; 10 < densité < 15 ind. 100 m^{-2} : forte ; densité > 15 ind. 100 m^{-2} : très forte.

Sectors	Sites	Average density (ind.100 m^{-2})	Status	Substratum	Covering
Tabarka	El Corniche beach	0.02	Low	Sandy - muddy	*Cymodocea nodosa – Posidonia oceanica*
	Negro Cape	2	Low	Rocky - sandy	Rhodophycea + *P. oceanica*
	Sidi Mechreg	1	Low	Rocky - sandy	Rhodophycea + *P. oceanica*
Bizerta lagoon	Echaâra	14	High	Sandy – muddy + biodetritic material	*Cymodocea nodosa*
	Njila	17	Very high	Muddy	*Cymodocea nodosa*
	Menzel Jemil	3	Low	Muddy	Ulvacea
	Oued Tinja	0	-	Muddy	*Cymodocea nodosa*
Gulf of Tunis	Ghar El Melh lagoon	0	-	Muddy	*Z. marina* + *C. nodosa*
	Tunis north lagoon	0	-	Sandy - muddy + Muddy	*Ruppia cirrhosa* + *Chaetomorpha linum*
	Marsa beach	0	-	Rocky (+ sandy surfaces)	Rhodophycea + *C. nodosa* + *P. oceanica*
	Sidi Rais	13	High	Sandy - muddy	*C. nodosa - P. oceanica*
	Port Prince	7	Average	Sandy	*P. oceanica*
Gulf of Hammamet	Kelibia beach	0	-	Sandy	*P. oceanica*
	Hammamet beach	0.03	Low	Sandy	*C. nodosa - P. oceanica*
Coast of Sousse	Sousse's beach	0	-	Sandy	*C. nodosa - P. oceanica*
	Hergla lagoon	0	-	Muddy	Ulvacea
Bay of Monastir	Stah Jaber	20	Very high	Sandy - muddy	*C. nodosa*
	Khniss	13	High	Muddy + biodetritic material	*C. nodosa* + ulvacea
	Teboulba	15	High	Sandy – muddy + biodetritic material	*C. nodosa - P. oceanica*

Table 2. *Pinna nobilis.* Variability of minimal (Min), maximal (Max), Average, Mode and Standard Deviataion (SD) values of the shell length (SL) within the five examined populations (N: number of measured specimens).

Tableau 2. *Pinna nobilis.* Variations des valeurs minimales (Min), maximales (Max), moyennes, du mode et de l'écart-type (SD) de la longueur de la coquille (SL) entre les cinq populations examinées (N : nombre des spécimens examinés).

Populations	**N**	**Min SL** (cm)	**Max SL** (cm)	**Average SL** (cm)	**SD**	**Mode**
Echaâra	30	23.4	53.5	34.32	9.39	31.0
Njila	30	10.2	46.5	32.01	7.47	31.1
Stah Jaber	30	19.3	34.8	28.03	3.53	29.8
Teboulba	30	13.2	55.3	41.57	9.13	46.2
Sidi Rais	30	10.2	42.3	23.81	8.05	29.1

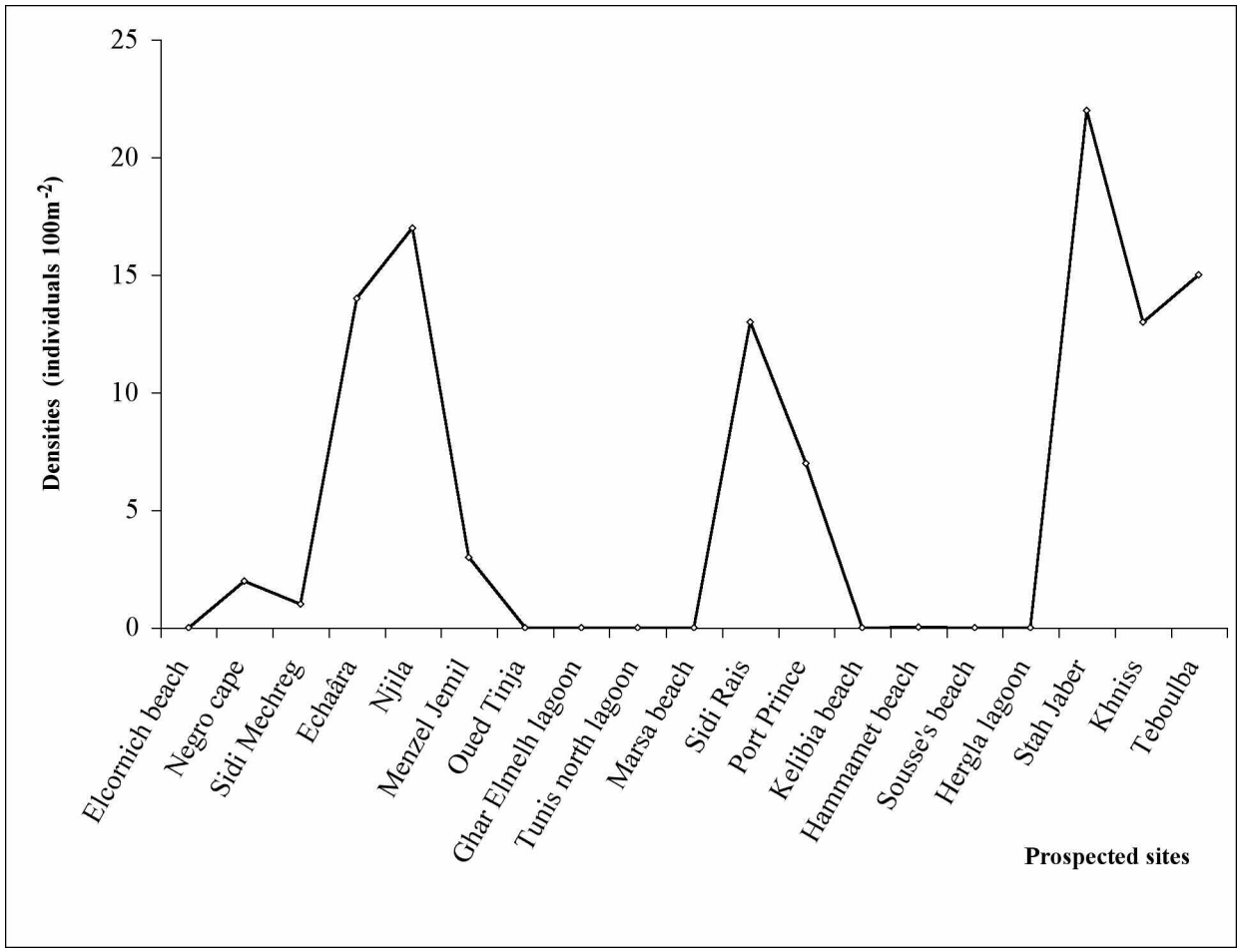

Figure 2. *Pinna nobilis.* Spatial variations of densities along the northern and eastern Tunisian coasts.
Figure 2. *Pinna nobilis.* Variations spatiales des densités le long des côtes nord et est de la Tunisie.

specimens, whose size did not exceed 40 cm (Fig. 4). On the contrary, Teboulba population showed the highest mean SL (41 cm) and was distinguished by the dominance of large individuals > 40 cm (Table 2). There were significant differences in mean size among populations (ANOVA: $F = 38.75$; $p < 0.001$). The results of post-hoc comparison revealed a significant difference between most populations. The most significant differences were recorded between Teboulba and all the other populations (Table 3). There was no significant difference between the populations of Echaâra and Njila, and the population of Echaâra was significantly different to the other three populations (Stah Jaber, Teboulba and Sidi Rais). Njila showed significant differences with the populations of Teboulba and Sidi Rais. Finally, mean SL of the populations of Stah Jaber and Teboulba were significantly different, despite these populations belong to the same sector (Bay of Monastir).

A total of 22 empty shells were found during our surveys (Table 4). 7 shells have been found in the locality of Echaâra, 5 shells in Njila, 5 shells in the lagoon of Ghar El Melh, one shell in Port Prince and 4 shells within the locality of Khniss. The length of found empty shells ranged between 13 and 42 cm (Table 4). We counted 14 intact shells (63.63%) and 8 broken shells (36.36%). Breaks occur always in the posterior (exposed) part of the shell.

Discussion

With the exception of the five sites of Echaâra, Njila, Sidi Rais, Stah Jaber and Teboulba, *P. nobilis* was found with varying densities on the northern and eastern coast of Tunisia. No Pinnids were found in Marsa beach, Kelibia beach, Sousse beach and the lagoon of Hergla. The species disappeared from certain localities such as the northern lagoon of Tunis where it was previously mentioned by Shili (1995) and from Oued Tinja (Bizerta lagoon) where it had been observed by Zaouali (pers. comm., 2004). This could

Table 3. *Pinna nobilis.* Post-hoc comparison (Tukey HSD) (* The difference is significant at the 0.05 level).
Tableau 3. *Pinna nobilis.* La comparaison Post-hoc (Tukey HSD) (* La différence est significative au niveau 0,05).

I	J	Mean Difference (I-J)	Standard Error	Sig	95% Confidence Interval Lower Bound	Upper Bound
Echaâra	Njila	2.3083	2.0149	0.782	-3.1878	7.8045
	Stah Jaber	6.2900*	2.0149	0.015	0.7938	11.7862
	Teboulba	-7.2550*	2.0149	0.003	-12.7512	-1.7588
	Sidi Rais	10.5100*	2.0149	0.000	5.0138	16.0062
Njila	Echaâra	-2.3083	2.0149	0.782	-7.8045	3.1878
	Stah Jaber	3.9817	2.0149	0.278	-1.5145	9.4778
	Teboulba	-9.5633*	2.0149	0.000	-15.0595	-4.0672
	Sidi Rais	8.2017*	2.0149	0.000	2.7055	13.6978
Stah Jaber	Echaâra	-6.2900*	2.0149	0.015	-11.7862	-0.7938
	Njila	-3.9817	2.0149	0.278	-9.4778	1.5145
	Teboulba	-13.5450*	2.0149	0.000	-19.0412	-8.0488
	Sidi Rais	4.2200	2.0149	0.222	-1.2762	9.7162
Teboulba	Echaâra	7.2550*	2.0149	0.003	1.7588	12.7512
	Njila	9.5633*	2.0149	0.000	4.0672	15.0595
	Stah Jaber	13.5450*	2.0149	0.000	8.0488	19.0412
	Sidi Rais	17.7650*	2.0149	0.000	12.2688	23.2612
Sidi Rais	Echaâra	-10.5100*	2.0149	0.000	-16.0062	-5.0138
	Njila	-8.2017*	2.0149	0.000	-13.6978	-2.7055
	Stah Jaber	-4.2200	2.0149	0.222	-9.7162	1.2762
	Teboulba	-17.7650*	2.0149	0.000	-23.2612	-12.2688

Table 4. *Pinna nobilis.* Number of collected empty shells and their status.
Tableau 4. *Pinna nobilis.* Nombre et état des coquilles vides récoltées.

Sites	Number of empty shells and their limit sizes	Status of empty shells
Echaâra	7 (14 - 42 cm)	4 : presence of breaks 3 : no break
Njila	5 (18 - 24 cm)	4 : presence of breaks 1 : no break
Ghar El Melh lagoon	5 (13 - 22 cm)	No break
Port Prince	1 (23 cm)	No break
Khniss	4 (18 - 32 cm)	No break

be due to the restoration works carried out in these lagoons. *P. nobilis* also disappeared from the lagoon of Ghar El Melh where it was cited by Romdhane & Chakroun (1986). This loss could be related to the recent modifications of environmental conditions (confinement, pollution, etc.) in this lagoon (Moussa et al., 2005).

The low densities recorded in the coast of Tabarka (El Cornihe beach, Negro Cape and Sidi Mechreg) could be explained by the strong hydrodynamics (high currents velocity and high wave action) that characterize this area and, perhaps, by the rocky nature of the substrate, preventing the settlement of young pinnids. As for the low densities estimated on the beach of Hammamet, they could be related to the important tourist activity that exists in the area of "Yasmine Hammamet". Most of *P. nobilis* populations encountered in the northern and eastern coast of Tunisia during the present study were not located within meadows of *P. oceanica*, but within *C. nodosa* meadows and sometimes even in biotopes with algal cover only. One remarkable feature of *P. nobilis* populations studied herein, is that the highest densities were recorded in sheltered biotopes, characterized by weak hydrodynamics (low wave action and low current velocity) and sandy-muddy substrates mixed with boulders, gravel and biodetritic material. It seems that this ecosystem type is favourable for the maintenance and survival of the Pinnids. This observation led us to believe that in sheltered biotopes, the substrate type is less important than in exposed coasts, probably because hydrodynamics is reduced. Strikingly, the highest density has been recorded in Stah Jaber (Figs 2 & 3), in spite of the pollution caused by the Monastir fishing port situated in the proximity, and the higher probability of *P. nobilis* shell breakage by the anchors of boats.

Focusing on the relationship between substratum availability/habitat type and the occurrence of *Pinna*, we remarked that highest densities, except for Njila where the substratum is only muddy (with *C. nodosa*), were recorded

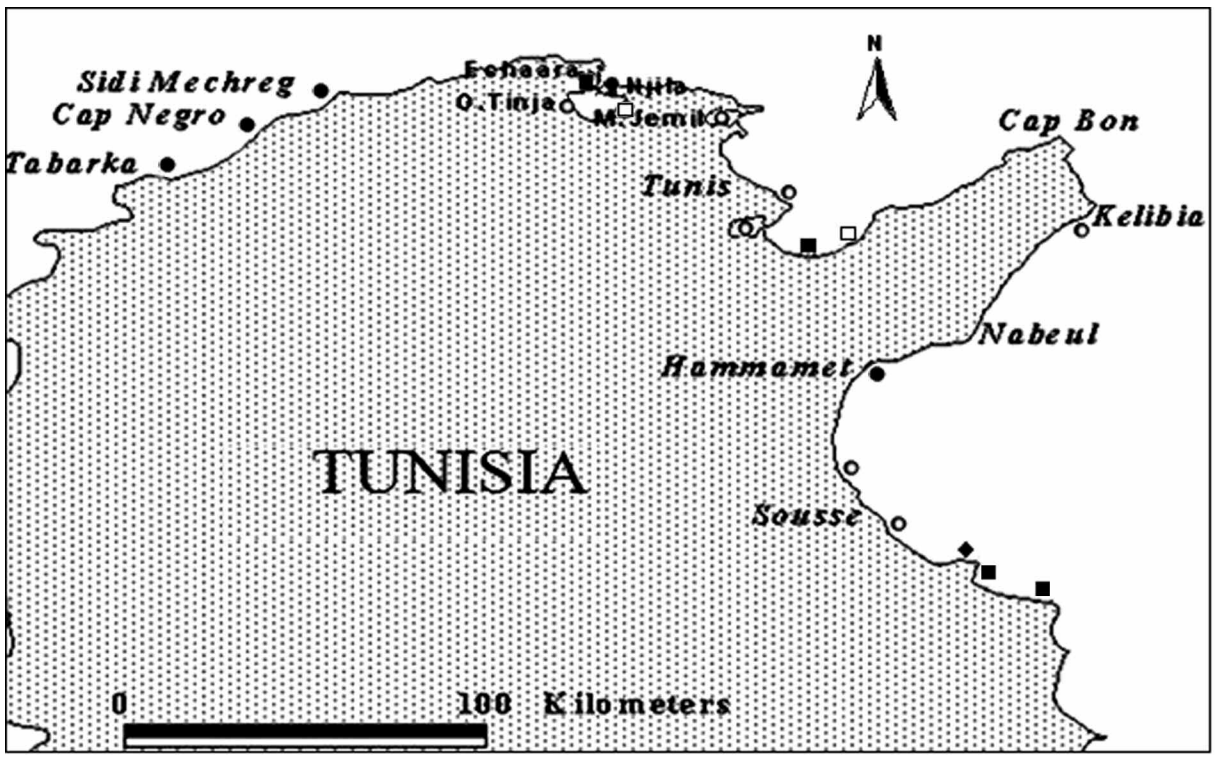

Figure 3. *Pinna nobilis.* Distribution of densities in the study area (**o** no occurrence; ● Low density; □ Average density; ■ High density; ♦ Very high density).

Figure 3. *Pinna nobilis.* Distribution des densités dans le secteur d'étude (**o** Densité nulle ; ● Densité faible ; □ Densité moyenne ; ■ Densité élevée ; ♦ Densité très élevée).

on a sandy-muddy substratum mixed with biodetritic material among *C. nodosa* or *P. oceanica* + *C. nodosa* beds. The dominance of sandy-muddy substratum was previously mentioned by Gamulin-Brida (1974) and Zavodnik et al. (1991) who similarly reported that Fan mussels prefer fine, well-sorted sandy sediments partly mixed with mud overgrown by meadows of marine phanerogams *P. oceanica* and *C. nodosa*. The only *P. nobilis* population found associated with *P. oceanica* is that of Port Prince where the substratum is only sandy unmixed with biodetritic material. The absence of the latter material lead to deduct that in absence of *P. oceanica*, *Pinna* prefers to be settled in a substratum mixed with stones, shell remains and gravels to which the byssus filaments can attach since the latter seagrass offers to fan shells the adequate structure that allows their adequate implantation (García-March, 2003 & 2005).

The highest densities of individuals observed in the present work are lower than those observed by Tlig Zouari (1993) and Soufi Kechaou & Aloui Bejaoui (2004) in Kerkennah islands (Table 5). The mean density, estimated by these authors in this area, was about 5 individuals m^{-2}. On the other hand, they are relatively higher than those mentioned in other areas of the Mediterranean. Indeed, the estimated density of this Mollusc in the National park of Port-Cros (France) varied from 1.93 individuals 100 m^{-2} (Vicente et al., 1980) to 1 individual 100 m^{-2} (Combelles et al., 1986). In Italy, Giacobbe & Leonardi (1987) estimated the density of the population of the strait of Messina to be 6.89 individuals 100 m^{-2}. However, in the Mar Grande of Taranto (Ionian Sea), *P. nobilis* density ranged from 0.1 to 0.7 individuals 100 m^{-2} (Centoducati et al., 2006). In the Spanish coasts, some authors have reported densities of individuals fluctuating between 4 and 10 individuals 100 m^{-2} in some areas of Murcia, Almería, the Balearic and Chafarinas islands (Richardson et al., 1999; Templado, 2001; García-March, 2003). In Moraira bay (eastern Spanish coast), the *P. nobilis* population density ranged between 6 and 10.3 individuals 100 m^{-2} (García-March et al., 2006a & b). Moreover, the mean density of *P. nobilis* in the Columbretes Islands Marine reserve (Western Mediterranean, Spain) has been estimated to be 1.5 individuals 100 m^{-2}, with a maximum density of about 16 *P. nobilis* 100 m^{-2} observed in *C. nodosa* meadow of El Carallot islet (García-March & Kersting, 2006). In Greece, the fan shell population of Lake Vouliagmeni showed a

Table 5. *Pinna nobilis.* Comparison of the estimated densities of individuals found in different Mediterranean areas with the values obtained in the present study.

Tableau 5. *Pinna nobilis.* Comparaison entre les densités estimées dans différentes régions de la Méditerranée et les valeurs obtenues dans cette étude.

References	Country	Estimated denity of *Pinna nobilis*
Tlig-Zouari (1993)	Tunisia (Kerkennah islands)	5 individuals m^{-2}
Soufi Kechou & Aloui Bejaoui (2004)	Tunisia (Kerkennah islands)	5 individuals m^{-2}
Present study	Tunisia (North and East of Tunisian coast)	between 0.02 and 20 individuals 100 m^{-2}
Vicente et al. (1980)	France (Port-Cros)	1.93 individuals 100 m^{-2}
Combelles et al. (1986)	France (Port-Cros)	1 individuals 100 m^{-2}
Giacobbe & Leonardi (1987)	Italy (Strait of Messina)	6.89 individuals 100 m^{-2}
Centoducati et al. (2006)	Italy (Mar Grande of Taranto)	between 0.1 and 0.7 individuals 100 m^{-2}
Richardson et al. (1999)	Spain (south-east Spanish coast)	between 4 and 30 individuals 100 m^{-2}
Templado (2001)	Spain (Balearic Islands)	up to 10 individuals 100 m^{-2}
Templado (2001)	Spain (Murcia and north of Almeria)	up to 10 individuals 100 m^{-2}
García-March (2000)	Spain (Moraira bay)	between 1 and 12 individuals 100 m^{-2}
García-March (2003)	Spain (Chafarinas Islands)	3.3 individuals 100 m^{-2}
García-March & Kresting (2006); García-March et al. (2006a)	Spain (Moraira bay)	between 6 and 10.3 individuals 100 m^{-2}
Katsanevakis (2006)	Greece (Lake Vouliagmeni)	between 0 and 17 individuals 100 m^{-2}
Katsanevakis (2007a)	Greece (Lake Vouliagmeni)	Mean density of 0.45 individuals 100 m^{-2}
Zavodnik (1967)	Croatia (Eastern Adriatic Sea)	9 individuals 100 m^{-2}
Siletik & Peharda (2003)	Croatia (Mljet National Park)	between 2 and 20 individuals 100 m^{-2}

density that varied between 0 and 17 individuals 100 m^{-2} (Katsanevakis, 2006). The latter author has also reported, using the density surface modelling approach in the same lake, a mean density of 0.45 individuals 100 m^{-2}, with maximum densities (at depths between 12 and 13 m, Katsanevakis, 2007a). In the Adriatic Sea, Zavodnik (1967) estimated a mean of 9 individuals 100 m^{-2}. Thereafter, Siletik & Peharda (2003) reported that the fan shell population density in the Mljet National Park fluctuated between 2 and 20 individuals 100 m^{-2}.

The size structure of the five examined *P. nobilis* populations showed that the majority of these populations, except for Teboulba, are characterized by the predominance of small sized individuals. The shell length, estimated for the five populations, ranged between 23.8 ± 8.05 cm (Sidi Rais) and 41 ± 9.13 cm (Teboulba). As depicted by the size distribution of the five examined *P. nobilis* populations (Fig. 4), the majority of these populations are dominated by one or two size groups (i.e. Echaâra, Njila, Stah Jaber and Teboulba). This population structure could be caused by the alternation of periods of successful and poor recruitment in different years. The histograms of Echaâra and Njila populations (Bizerta lagoon) show the existence of two modes, which could be due to the occurrence of two different years of successful recruitment. The only histogram that shows a size distribution more typical of constant recruitment and mortality (positively skewed) is that of Sidi Rais population (Fig.4). According to Cerrato (1980), the results obtained herein confirm that fan shell undergoes, in the north and the east of Tunisian coast, years with very good recruitment and others when the recruitment is scarce.

During our prospecting, large individuals were usually observed fixed within *P. oceanica* meadows and deeper than small specimens (e.g. Sidi Rais, Port Prince and Teboulba sites). A similar size segregation has also been observed by precedent authors (Zavodnik, 1967; Vicente et al., 1980; Moreteau & Vicente, 1982; Combelles et al., 1986; Vicente, 1990; Vicente & Moreteau, 1991; Tlig-Zouari, 1993; De Gaulejac, 1993; Templado, 2001; Siletik & Peharda, 2003; García-March, 2003 & 2005; García-March et al., 2006a & b; Katsanevakis, 2006) and seems to be related to the effects of hydrodynamic forces (García-March et al., 2006b). The latter authors showed that the maximum length reached by specimens of shallow waters from Moraira population (Spain western Mediterranean) is significantly smaller than that of individuals living at deep waters, and suggested that the size of individuals is determined by the hydrodynamic forces interacting with *P. nobilis* and by the depth of settlement. The same could be true for the populations studied herein. Furthermore, large *P. nobilis* specimens are more affected by water flow energy than small individuals (Foulquié & Dupuy, 2003; García-March, 2003; García-March et al., 2006b) since the

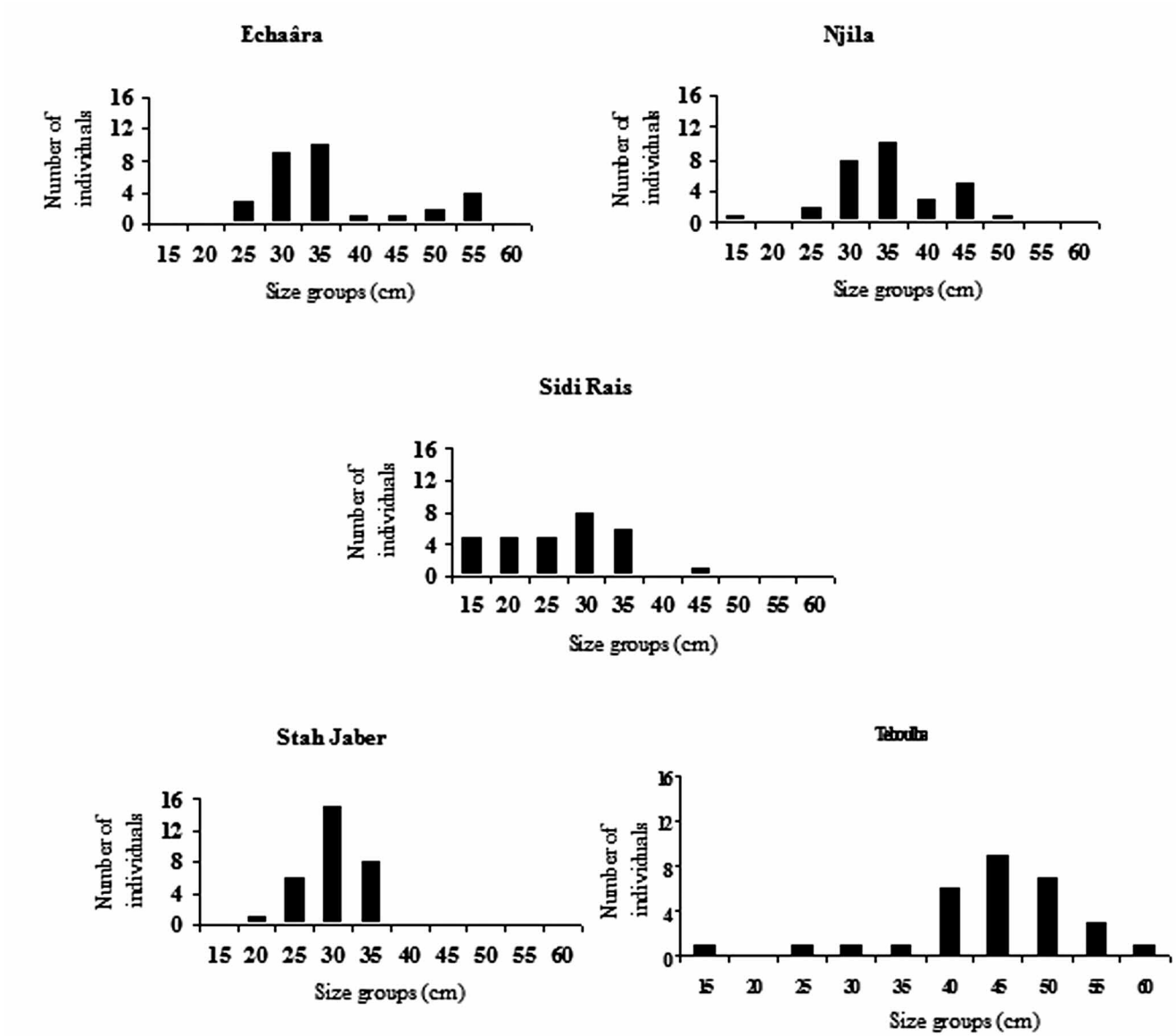

Figure 4. *Pinna nobilis.* Distribution of individuals according to the total height.
Figure 4. *Pinna nobilis.* Distribution des individus selon la hauteur totale.

drag forces are higher on large Pinnids and can cause their dislocation and also because continued hydrodynamic stress could increase mortality by fatigue before reaching the critical dislodgement size (García-March et al., 2006a). The mortality rate of large individuals in shallow populations is greater than that in deep populations (García-March et al., 2006a & b). The predominance of adults in Teboulba population could be also related to the presence of *P. oceanica* meadows. Such ecosystem is favourable for the survival of Pinnids, because roots and rizhomes constitute an exceptional substrate for the anchoring of byssus threads, and seagrasses reduce considerably the water speed and hydrodynamic forces on the sea-bottom level (Gacia et al., 1999; Van Keulen & Borowitzka, 2000; Granata et al., 2001). Eventually, the trade-off between water depth, drag forces, shell size and orientation stated by García-March et al. (2006b) is the adequate hypothesis that can explain not only the high densities of populations observed herein, but also the increase of size with water depth.

The SL values observed in the present study are higher than those mentioned by Tlig Zouari (1993) in the populations of Kerkennah islands. The latter author estimated an average size of 20.1 cm, spread out between 9

and 35 cm, in a total of 139 specimens and at a depth that does not exceed 1.5 meter. Otherwise, the examination of empty shells showed that *P. nobilis* mortality mostly affects small sized specimens. Indeed, young individuals, especially during their first year of life, are much more vulnerable to predation (Vicente, 1990; Vicente & Moreteau, 1991; Fiorito & Gherardi, 1999, Katsanevakis, 2007b).

Summarising, the present study has given relevant information and details about the distribution, densities and size structure of the shallow *P. nobilis* populations in the north and the east of Tunisian coast. More studies are necessary to characterize the species populations in the south Tunisian coastal waters, as well as in deeper waters and meadows of *P. oceanica*. According to an enquiry that we made with Tunisian fishermen, some populations of *P. nobilis* exist in the Eastern Tunisian coast, in the regions of Sekrine, Elkalâat and Elmajazet (500-1000 m off the shoreline). The species also exists in the beaches of Echaba (region of Mahdia), El Awabed, El Louza, Kerkennah islands, Esskhira and around the little islands of Bssila, Lakhwa and El Bay (Kneiss Islands). It also lives around the island of Djerba, with high densities in the beach of Melita.

According to our observations, the main threats to the species in Tunisia are the water pollution, destruction of seagrass meadows, boat anchoring, aquaculture farms (e.g. Bizerta lagoon where there is a farm for the culture of *Mytilus galloprovincialis* and *Crassostrea gigas*) and especially the species removal not only by amateur divers and fishermen but also by tourists (e.g. Hammamet). The latter threat is very dangerous, as it usually damages the adult specimens which are fundamental for the populations' survival (Butler et al., 1993). In Greece (Lake Vouliagmeni), illegal fishing of *P. nobilis* by free divers, was the main cause of mortality in shallow areas and mostly for large individuals (Katsanevakis, 2007b). During our survey in Bizerta lagoon, we observed that *P. nobilis* was removed by amateur divers, especially in shallow areas where it is possible to find pinnids at a depth that does not exceed one meter. Likewise, the species is also removed by tourists in the Island of Djerba and by fishermen in the lagoon of El Bibane, who usually use the animal as bait (pers. observation). The uncontrolled removal of pinnids observed during our prospecting, is certainly due to the insufficient control and the non application of the environmental Tunisian laws, established after the Barcelona convention in 1995, that prohibit the removal of *P. nobilis* individuals. In front of this situation, it is urgent to establish strict protection measures and show strictness in the application of Tunisian environmental laws, protecting the endangered species *P. nobilis*.

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