

Populational status of the endangered mollusc *Patella ferruginea* Gmelin, 1791 (Gastropoda, Patellidae) on Algerian islands (SW Mediterranean)

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Abstract

Populational status of the endangered mollusc Patella ferruginea Gmelin, 1791 (Gastropoda, Patellidae) on Algerian islands (SW Mediterranean).— Patella ferruginea is the most endangered endemic marine invertebrate on the Western Mediterranean coasts according to the European Council Directive 92/43/EEC. A total of 1,017 individuals were recorded in the present study along western Algerian islands, with mean densities ranging from 0.8 to 35.3 ind/m per linear transect and averages of 4.8 ind/m per linear transect for Western Habibas Island and 22 ind/m for Plane Island, making these islands a hot spot for the species in the Mediterranean. The expected total number of specimens in Habibas would therefore be 50,400. The mean size of P. ferruginea on the Habibas Islands (4.45 cm) was significantly ($p < 0.001$) greater than on Plane Island (2.78 cm). Recruitment was high in Plane Island and the northern sector of the western Habibas Islands. Large adults had very conical shells. The fact that Habibas Islands is now a marine reserve could explain these differences in populations. Conservation of these populations should be a priority in order to avoid extinction of the species.

Key words: *Patella ferruginea*, Algeria, Conservation, Limpet.

Resumen

Estado de las poblaciones del molusco protegido Patella ferruginea Gmelin, 1791 (Gastropoda, Patellidae) en las islas argelinas (SO Mediterráneo).— Patella ferruginea es el invertebrado marino endémico más amenazado de las costas del Mediterráneo occidental según la Directiva 92/43 de la Unión Europea. En este estudio se registraron un total de 1.017 ejemplares en las islas occidentales argelinas, con densidades medias de 0,8 a 35,3 ind/m de transecto lineal y valores medios de 4,8 ind/m en la isla Habibas occidental y de 22 ind/m en la isla Plana. Estas poblaciones representan un "punto caliente" de la especie a nivel de todo el Mediterráneo. La estima de población para las islas Habibas es de 50.400 individuos, uno de los más elevados para la especie. La talla media de P. ferruginea fue significativamente ($p < 0,001$) mayor en la isla Habibas occidental (4,45 cm) que en la isla Plana (2,78 cm). El reclutamiento fue muy elevado en la isla Plana y en el sector norte de la isla Habibas occidental. Los ejemplares de mayor talla muestran conchas muy cónicas. El establecimiento de una reserva marina en las islas Habibas podría explicar las diferencias halladas entre las poblaciones. La conservación de estas poblaciones debe ser una prioridad para evitar la definitiva extinción de la especie.

Palabras clave: *Patella ferruginea*, Argelia, Conservación, Lapa.

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Introduction

Patella ferruginea Gmelin, 1791, endemic to the Mediterranean, is the most endangered marine invertebrate on Western Mediterranean rocky shores according to European Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora, 1992 (Ramos, 1998), and it is presently under serious threat of extinction (Laborel-Deguen & Laborel, 1991; Templado & Moreno, 1997). This is a long-lived protandrous hermaphrodite (Espinosa et al., 2008) that achieves sexual maturation as a male from 20–30 mm and then changes to female around 42–60 mm, although males can be observed up to 80 mm (Espinosa et al., 2006; Guallart et al., 2006a). It requires clean waters and medium–strong wave action (Espinosa, 2006). Study of the population status of the species and relevant pressure factors indicate better management and conservation measures are essential.

Population size structures, in the sense of distribution of body size within particular populations, are affected by environmental changes, ecological interactions and, in many cases, human exploitation. These structures are an important indicator of the population status and can be used comparatively across sites and through time to identify the forces controlling population dynamics. Size structures also have been used to track losses of large individuals from populations which are often the target of exploitation by humans (Rochet & Trenkel, 2003), as occurs with limpets, which are collected as food or as fishing bait because of their large muscular foot (Pombo & Escofet, 1996). Human exploitation can also decrease the reproductive output of intertidal invertebrate populations in which there is an increase in individual fecundity with body size (Levitan, 1991; Tegner et al., 1996), and such is the case with *P. ferruginea* Gmelin, 1791 (see Espinosa et al., 2006). All of these considerations are especially true for broadcast spawners such as limpets that depend on high gamete concentrations to increase the probability of successful fertilisation (Hockey & Branch, 1994) and avoid the 'Allee' effect (Courchamp et al., 2008).

The Western Algerian Islands (Rachgoun, Habibas and Plane) are sites of high ecological value given the number of endemic and endangered Mediterranean marine species living there (Bachet et al., 2007). Important populations of the endangered mollusc *P. ferruginea* Gmelin, 1791 have been recorded on Rachgoun (Frenkiel, 1975) and Habibas Islands (Boumaza & Semroud, 2001). The latter islands were declared a Marine Natural Reserve in 2003 by the Algerian Government (decree n° 03.147, 29 March) (Ben Haj & Bernard, 2005).

The aim of this study was to determine the population parameters (size frequencies and density) of the *P. ferruginea* population at the Western Habibas and Plane Islands. Such information would be useful in order to detect future changes produced by pressure factors such as human collecting or predation.

Material and methods

Study area

The study was conducted during April 2008 on the Western Habibas and Plane Islands. Located off the West coast of Algeria (fig. 1), these islands are under the influence of the Atlantic waters from the Alborán Sea (Robinson et al., 2001) and they are located at the southern end of the Almería–Orán oceanographic front (see Templado et al., 2006). The approximate perimeter of the Habibas Islands is 10,500 m and the substrate is composed of rocky shores of volcanic origin (Ben Haj & Bernard, 2005), without presence of sandy or boulder beaches. The shoreline is twisting with several separate small islets. The distance from Habibas Islands to the nearest mainland is 9.5 km, whereas for Plane Island the distance to the nearest mainland is about 5 km. The distance between the two islands is 20 km.

Sampling methods

Four sectors were considered in Western Habibas Island (East, South, West and North) and three delimited transects were established inside each sector (fig. 1, table 1). In Plane Island two transects were located, approximately in the West and North areas, because the reduced size and regular shape of the island made it difficult to establish different sectors. The transects were 10 metres in length (Laborel-Deguen & Laborel, 1991; Guerra-García et al., 2004), of similar slope (30°–60°) and were measured with a tape measure to follow the coast profile. Collected *P. ferruginea* specimens were measured with a calliper to the nearest mm on their longitudinal axis (Guerra-García et al., 2004). All individuals found above or under the transect tape were recorded and measured. As small individuals are difficult to detect (Guallart et al., 2006b), care was taken to observe this fragment of population.

Data analysis

As with many ecological impact data (Clarke & Warwick, 2001), the assumptions for parametric statistics are not met by some of our data, which have severe departures from normality and equal variances. The ANOVA test is, however, robust for deviation from normality and if the number of cases is high and balanced between groups it is possible to undertake the analysis even if the condition of equal variances is not met (Underwood, 1997). Only one ANOVA test without equal variances was performed with the large dataset pooled in the Habibas and Plane sites for mean sizes. The rest of the analyses performed were checked for homogeneity of variances by means of the Levene test and the use of logarithmic transformation when required to satisfy homocedasticity. Differences between means were examined *a posteriori* with the Student–Newman–Keuls test. Reduction of data only to summary statistics such as mean sizes greatly reduces the information available for comparisons

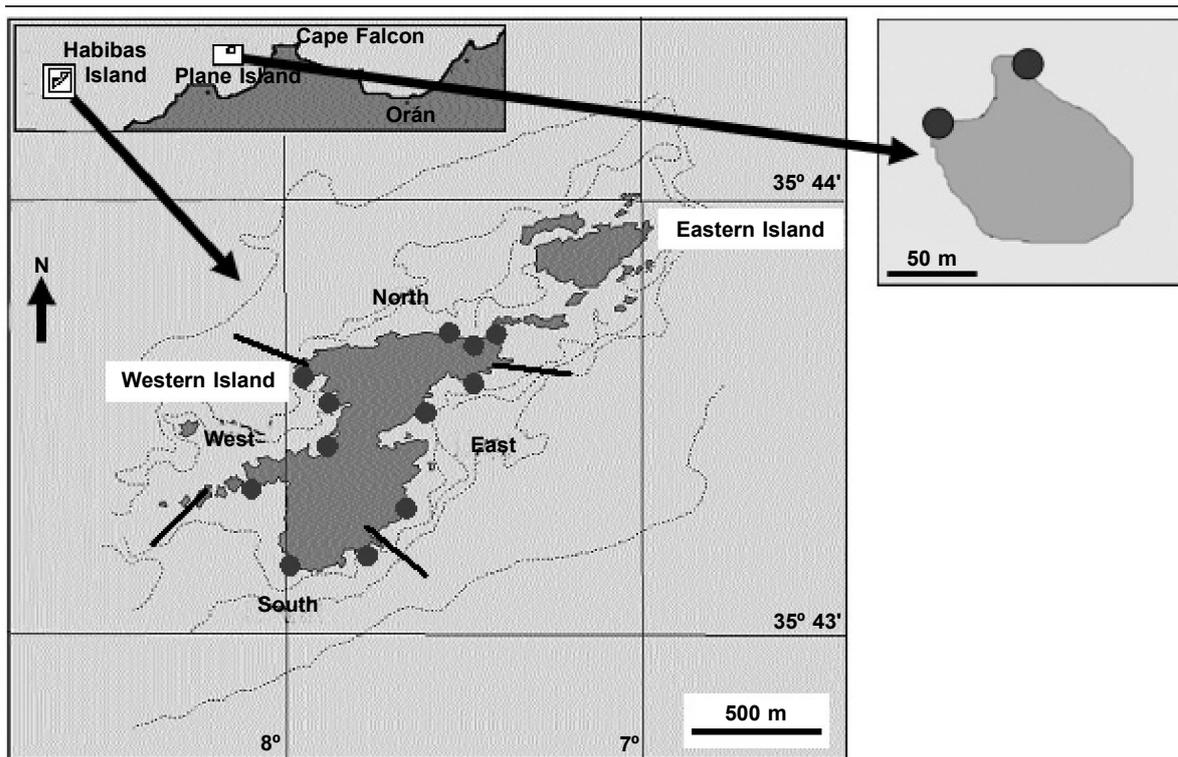


Fig. 1. Map of the study site showing the location of Habibas and Plane Islands. In Western Habibas Island the perimeter was divided into four sectors: East, South, West and North (spots indicate the sampling sites for *Patella ferruginea*).

Fig. 1. Mapa del área de estudio, mostrando la situación de las islas Habibas y de la isla Plana. El perímetro de la isla Habibas occidental se dividió en cuatro sectores: este, sur, oeste y norte (los círculos negros indican los lugares de muestreo para *Patella ferruginea*).

(Sagarin et al., 2007). Therefore, multivariate MDS (non-metric multidimensional scaling) statistics were additionally used, based on the UPGMA method (Unweigh Pair-Group Method using arithmetic averages) and the Bray-Curtis similarity index to test for differences in size structures between sites. Kruskal's stress coefficient was used to test ordination (Kruskal & Wish, 1978). Multivariate analysis was carried out with the PRIMER® 6.0 package.

Results

A total of 1,017 individuals of *P. ferruginea* were recorded and measured on the different transects. From these, 577 were found in Western Habibas Island (120 m of shoreline surveyed) and 440 in Plane Island (20 m of shoreline surveyed). Mean densities varied greatly depending on the transect (table 2) from 0.8 ind/m to 35.3 ind/m per linear transect, with averages of 4.8 ind/m per linear transect for Western Habibas and 22 ind/m for Plane Island. There were no differences between sectors on Western Habibas Island in terms of densities ($F_{3,8} = 1.97$; $p = 0.197$) owing

to the extreme variability within sectors, although the North sector showed the greatest densities of *P. ferruginea*. The whole population at Habibas Islands was estimated at some 50,400 individuals (recruits included).

Mean sizes were 4.45 cm (± 2.59) in Western Habibas Island and 2.78 cm (± 1.63) in Plane Island, with a range from 2.4 cm (Plane 2) to 7.5 cm (E1) (see table 2). Size structures for each island (Habibas and Plane) showed a different shape; Habibas showed many larger sized individuals, while these were very scarce or absent at Plane Island (figs. 2A, 2B) despite the notable recruitment on both islands. The adults found on Western Habibas Island had a mean size of 6.11 cm, compared to 4.19 cm for adults on Plane Island. Differences in size between the two populations were statistically significant ($F_{1,015} = 140$; $p < 0.001$). Additionally, two different and significant skews were detected (table 3): a negative skew for the Habibas population (many large specimens) and a positive skew for Plane Island (many small specimens). Nevertheless, a bimodal distribution was observed for both populations owing to the intense recruitment. The size frequency distribution,

Table 1. Location of sampling sites: T. Transect.

Tabla 1. Localización de los lugares de muestreo: T. Transecto.

Sector	T	Coordinates
Habibas Island		
East	1	35° 43.562' N / 1° 07.640' W
East	2	35° 43.497' N / 1° 07.759' W
East	3	35° 43.237' N / 1° 07.844' W
South	1	35° 43.154' N / 1° 07.970' W
South	2	35° 43.155' N / 1° 08.112' W
South	3	35° 43.322' N / 1° 08.215' W
West	1	35° 43.439' N / 1° 07.988' W
West	2	35° 43.518' N / 1° 07.981' W
West	3	35° 43.572' N / 1° 08.056' W
North	1	35° 43.653' N / 1° 07.635' W
North	2	35° 43.649' N / 1° 07.588' W
North	3	35° 43.665' N / 1° 07.597' W
Plane Island		
	1	35° 46.291' N / 0° 54.174' W
	2	35° 46.290' N / 0° 54.066' W

however, was platykurtic (wide and flattened) in both populations. Size frequencies at each site were highly variable (fig. 3). Nevertheless, there were a lot of large individuals throughout and many recruits were found in the sites N1 and N3, as well as in Plane 2. Conversely, large specimens were scarce at sites Plane 1 and particularly in Plane 2. Furthermore, differences in mean size through sites in Habibas were detected ($F_{11,565} = 32.8$; $p < 0.001$) and the SNK test showed different subsets of sites:

E1 S3 W1 S2 N2 E3 W2 S1 W3 E2 N1 N3

(underlined sites belong to the same subset and are ordered by decreasing size from E1 to N3).

Recruits (< 3 cm, see Frenkiel, 1975; Espinosa et al., 2006) were more abundant in Plane Island (47.72%) than in Western Habibas (32.75%) (table 3), whereas inside Western Habibas the North sector showed a higher number of recruits (fig. 3). Multivariate analysis clearly separated the populations of Plane Island and those settled on the North sector of Western Habibas due to the presence of high recruitment at these sites and, subsequently, the different shape on size–frequency distributions (fig. 4).

Empty shells from 6 to 7.5 cm were observed in terrestrial areas of the Western Habibas Island near seagull nests (mainly *Larus cachinnans*). The shell–shape (both in live and dead specimens) was very conical, specially for larger individuals.

Table 2. Population datasets from each site. Transects are 10 m in length: * Numbers in brackets indicate number of specimens, densities, mean sizes and SD taking into account only the adults (> 3 cm).

*Tabla 2. Conjunto de datos poblacionales para cada localización. Los transectos son de 10 m de longitud: * Los números entre paréntesis indican los especímenes, las densidades, los tamaños medios y las DE que tienen en cuenta sólo a los adultos (> 3 cm).*

Site	Number of specimens*	Density* (ind/m)	Mean size* (cm)	SD*
E1	9 (9)	0.9 (0.9)	7.5 (7.5)	1.57 (1.57)
E2	8 (7)	0.8 (0.7)	5.1 (5.7)	1.91 (0.64)
E3	44 (43)	4.4 (4.3)	6.2 (6.4)	1.35 (1.07)
S1	32 (28)	3.2 (2.8)	5.6 (6.2)	1.95 (1.14)
S2	58 (55)	5.8 (5.5)	6.5 (6.8)	1.68 (1.15)
S3	9 (9)	0.9 (0.9)	7.1 (7.1)	1.07 (1.07)
W1	10 (10)	1 (1)	6.8 (6.8)	1.54 (1.54)
W2	13 (13)	1.3 (1.3)	5.6 (5.6)	1.48 (1.48)
W3	45 (38)	4.5 (3.8)	5.5 (6.5)	2.41 (1.27)
N1	65 (47)	6.5 (4.7)	3.8 (5)	1.99 (0.91)
N2	31 (31)	3.1 (3.1)	6.4 (6.4)	0.83 (0.83)
N3	253 (98)	25.3 (9.8)	2.8 (5.7)	2.33 (0.94)
Plane 1	87 (72)	8.7 (7.2)	4.2 (4.8)	1.67 (0.98)
Plane 2	353 (158)	35.3 (15.8)	2.4 (3.9)	1.42 (0.59)

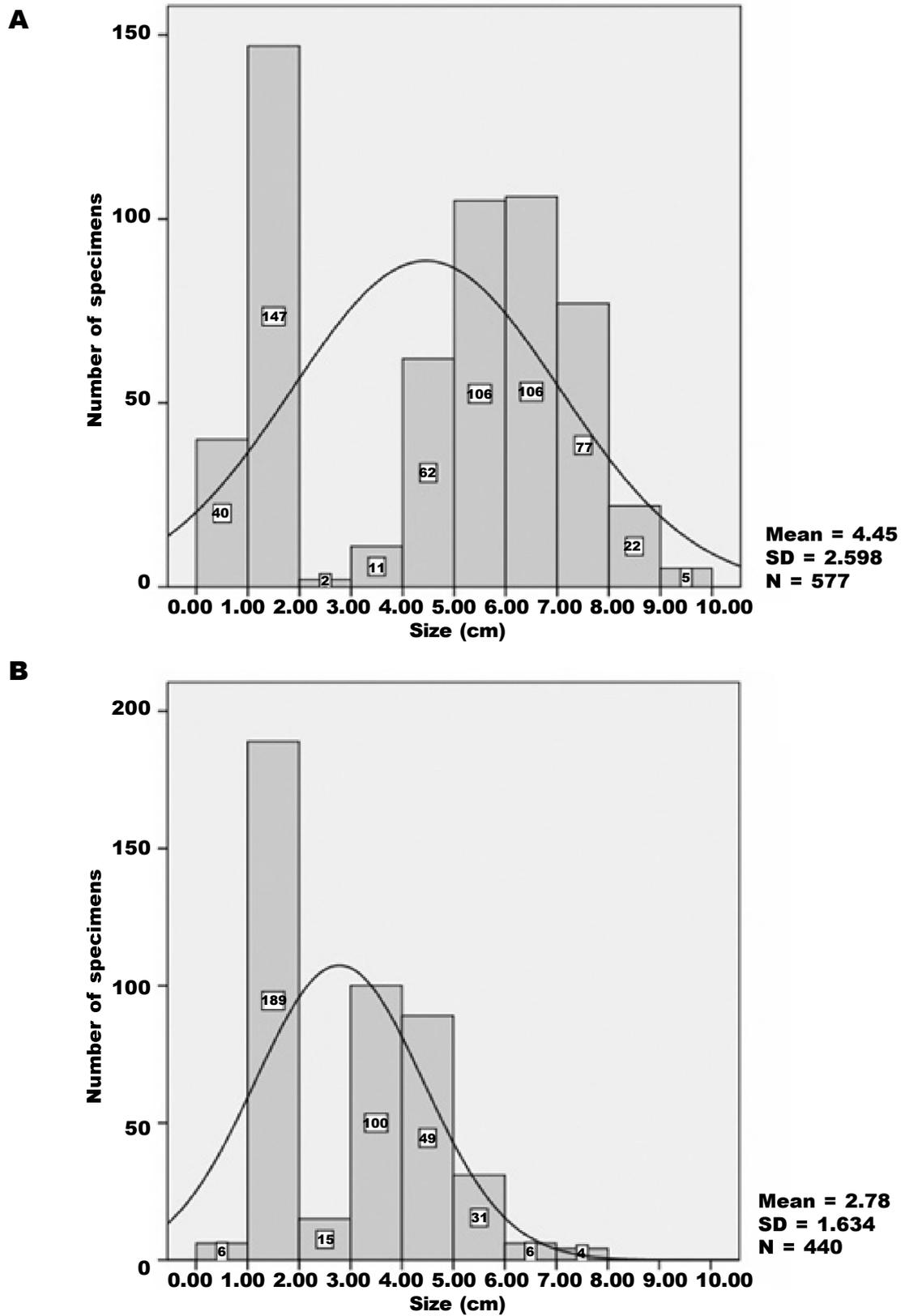


Fig. 2. Size frequencies: A. Western Habibas Island; B. Plane Island. The data were pooled.

Fig. 2. Frecuencias de tamaños: A. Isla Habibas occidental; B. Isla Plana. Los datos se han agrupado.

Table 3. Summary statistics for *Patella ferruginea* sizes (cm) by sites for all samples: N. Number of specimens (percentage of recruits, < 3 cm); M. Mean; SD. Standard deviation; S. Skewness (* skewness is considered significant when its absolute value is greater than 2*SE of skewness); SES. SE skew; K. Kurtosis (** kurtosis is considered significant when its absolute value is greater than 2*SE of kurtosis); SEK. SE kurtosis; Kt. Kurtosis type. (Values in brackets only for adults, > 3 cm.)

Tabla 3. Resumen de las estadísticas de los tamaños de *Patella ferruginea* (en cm) según localización: N. Número de especímenes (porcentaje de reclutas, < 3 cm); M. Media; SD. Desviación estándar; S. Asimetría estadística (* la asimetría estadística se considera significativa cuando su valor absoluto es mayor que 2*EE de la asimetría estadística); SES. EE de la asimetría estadística; K. Curtosis (** la curtosis se considera significativa cuando su valor absoluto es mayor que 2*EE de la curtosis); SEK. EE de la curtosis; Kt. Tipo de curtosis. (Los valores entre paréntesis corresponden a adultos, > 3 cm.)

Site	N	(%)	Max	Mean	SD	S	SES	K	SEK	Kt
Habibas	577	32.75	9.7	4.45 (6.11)	2.59 (1.24)	-0.284*	0.102	-1.408**	0.203	Platykurtic
Plane	440	47.72	7.2	2.78 (4.19)	1.63 (0.84)	0.312*	0.116	-1.105**	0.232	Platykurtic

Discussion

The densities of *P. ferruginea* Gmelin, 1791 found in Western Habibas and Plane Islands, 4.8 individuals per linear metre (ind/m) and 22 ind/m respectively, are among the highest in the Mediterranean. Data available in the literature indicate 0.79 (ind/m) of linear transect in Corsica (Laborel–Deguen & Laborel, 1991), 0.7 ind/m in Zembra Island, Tunisia (Boudouresque & Laborel–Deguen, 1986), 0.06 ind/m in Alborán Island (Paracuellos et al., 2003), 0.23 ind/m in Cala Iris Islet, National Park of Al Hoceima, Morocco (Bazairi et al., 2004), 0.08–0.14 ind/m in Algeciras Bay, Spain (Espinosa et al., 2005), 3.95 ind/m (only adults > 30 mm) in Chafarinas Islands (Guallart et al., 2006b), 5.39 ind/m in Melilla (González–García et al., in Guallart et al., 2006b), 0.67 ind/m as an average in Ceuta (Guerra–García et al., 2004), 1.86–6.86 ind/m in some areas of Ceuta (Espinosa et al., in press). These data show the Western islands of Algeria (together with the nearby sites of Chafarinas Islands and Melilla, and the further away site of Ceuta) are a hot spot of the species in the Mediterranean, taking into account the dense populations settled also in Rachgoun Island (Frenkiel, 1975; Fabrice Bernard, pers. comm.). The densities of *P. ferruginea*, however, decrease to the east because only one specimen was observed all around the Sridjina Island on Eastern Algeria (Fabrice Bernard, pers. comm.), and the densities in Tunisia are also very low (unpub. data). In order to preserve the species at a global scale, the conservation of all these hot spot populations is a priority.

Direct removal of organisms will have major effects at both local and regional scales and is likely to increase over the next 25 years, especially in developing countries where rapidly expanding human populations will put further pressure on resources

(Thompson et al., 2002). The future of *P. ferruginea* Gmelin, 1791 populations on Algerian coasts is therefore compromised unless conservation measures and good management programs are established. Moreover, the presence of small oil spills (pers. obs.) along the shoreline indicates populations such as *P. ferruginea* Gmelin, 1791 in intertidal zones are at risk of catastrophic events.

The population at Habibas Islands has stabilised in recent years. The study undertaken by Boumaza & Semroud (2001) in summer 1997 showed a mean density of 4.5 ind/m per linear transect (over 100 m of shoreline) and abundance of large specimens. Eleven years later the mean density was 4.8 ind/m per linear transect (over 120 m of shoreline) and marked presence of large specimens was noted. Habibas Islands was declared a marine reserve area in 2003 (decree n° 03.147, 29 March) (Ben Haj & Bernard, 2005) and this might have played a main role in the stabilisation of the species, taking into account the regression found in other populations throughout Mediterranean (Laborel–Deguen & Laborel, 1991). Furthermore, Keough et al. (1993) found that three species of intertidal molluscs were significantly larger at the protected sites and one of these species was markedly less abundant at heavily visited sites. The percentage of larger specimens (> 6 cm) with regard to the range (2–9 cm) differs considerably between populations: 15% in Ceuta and Melilla (under high urban and anthropogenic pressure), 30% in Chafarinas and 53.5% in Habibas (both marine protected areas). In a study on limpets, Branch & Odendaal (2003) described the benefits of marine protected areas to preserve large and more fecund species that act as a focus for larval export via the rebalance of sex–ratio. The presence of large specimens in Habibas island guarantees the success of reproduction, taking into consideration that the expected sex–ratio would be

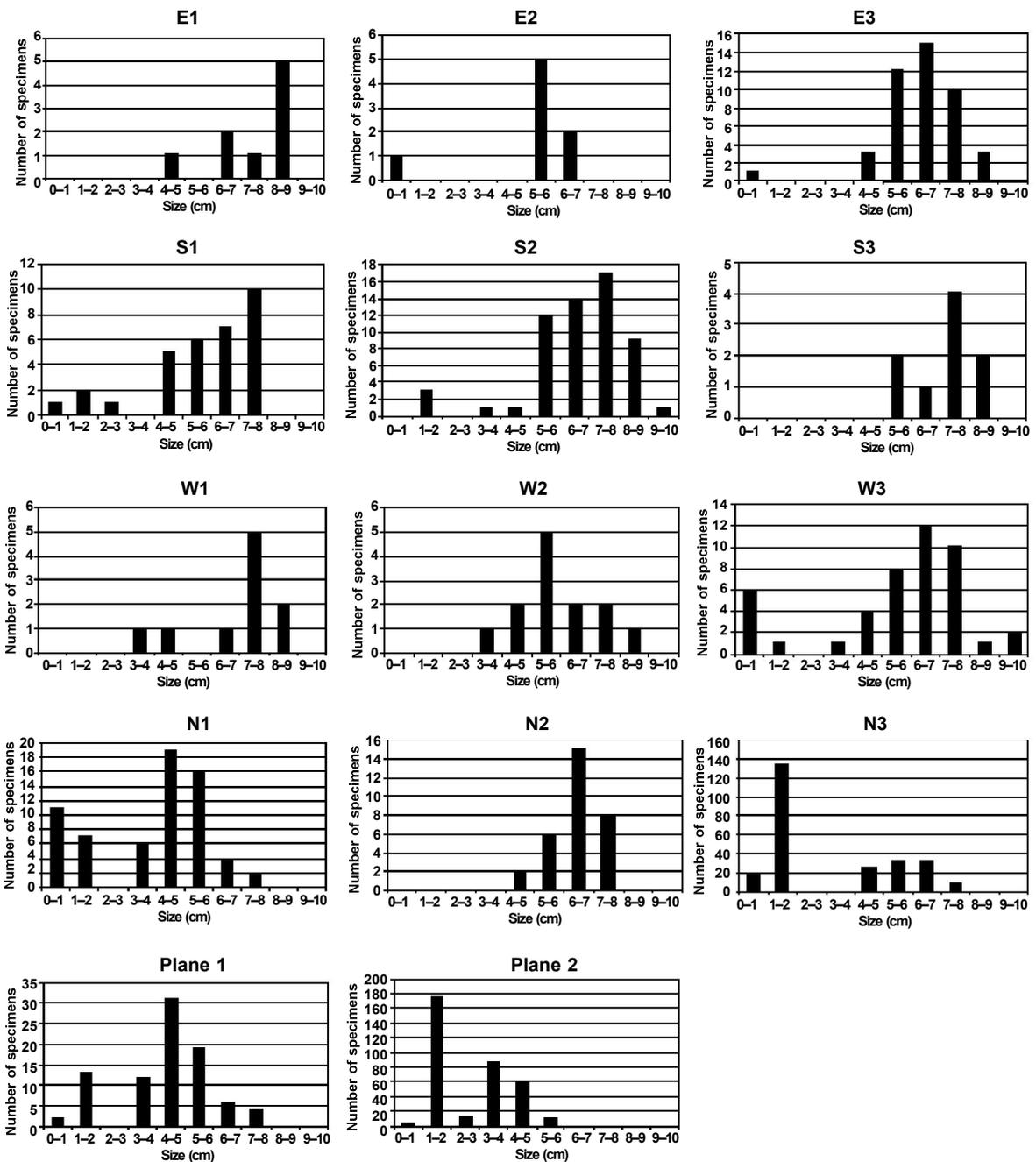


Fig. 3. Size frequencies for each sampling site.

Fig. 3. Frecuencias de los tamaños para cada lugar de muestreo.

in the range 2–2.7:1 (males:females) in Habibas but 7.3–20:1 in Plane Island, according to the distribution of sexes through sizes reported for the species (Guallart et al., 2006a, 2006b; Espinosa et al., 2008) in two different populations from the Mediterranean.

Human foraging of intertidal invertebrate resources has occurred since prehistoric times (Mannino

& Thomas, 2002). Although technological advances have enabled access to sites further away, the impact on intertidal populations continues due to increases in human population densities (Pombo & Escofet, 1996; Castilla, 1999), and such impacts are expected to increase in the future (Thompson et al., 2002). Furthermore, the sex distribution through sizes in *P. ferruginea* Gmelin, 1791 makes

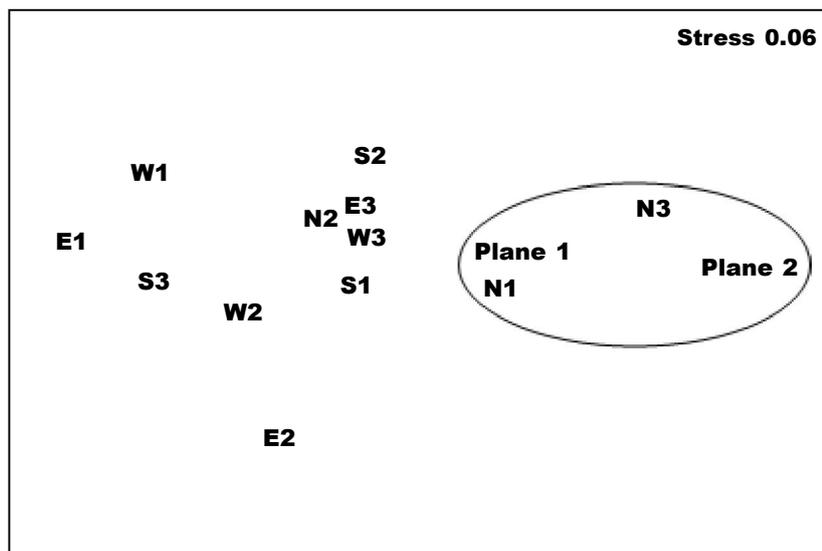


Fig. 4. MDS (Multidimensional Scaling) analysis based on size frequencies for the sampling sites under study.

Fig. 4. Análisis MDS basado en las frecuencias de los tamaños en los lugares de estudio.

this species extremely vulnerable to poaching (see Espinosa et al., 2006), since the depletion of large, more fertile individuals, and a higher proportion of females, could bias the reproductive output towards a complete collapse. Moreover, recent studies from fisheries have shown that exploitation of larger and older females can have disproportionate effects on populations (Berkeley et al., 2004; Palumbi, 2004). In fact, catching of large limpets will be more important if these animals contribute disproportionately to reproductive effort in a local population (Keough et al., 1993) as happens with *P. ferruginea* Gmelin, 1791 (see Espinosa et al., 2006). In both fishes and invertebrates, the reserve effect has been shown to favour an increase in the mean size of specimens (Edgar & Barrett, 1999). The population of Western Habibas Island appears to be highly reproductive (large breeders and high recruitment), showing a good size–frequency distribution (balance between small and large individuals). However, the population at Plane Island, although extremely dense, shows a relative absence of large specimens and this could compromise the viability of the population in the next future. The presence of many recruits on Plane Island in spite of the shortage of larger sized specimens could be explained by the fact that the Algerian Current flows intensely from west to east between 1° W and 4° E at a mean speed of 40 cm/s (peaks of 80 cm/s), whereas the superficial current flow continues eastward to Straits of Sicily with some instability and anti–cyclonic eddies (Arnone et al., 1990; Perkins & Pistek, 1990; Robinson et al., 2001). The larvae could therefore be transported from Habibas to Plane Island

and further east. Indeed, to the east of Plane Island on the Stidia shores (mainland Argelia) there is a high density (9.75 ind/m) of relatively small specimens (with a well–defined mode of 33.5 mm and a maximum length of 51 mm), according to Mezali (2005). This possibility should be verified by genetic studies. As compared to Habibas Islands, Plane Island is in close proximity to the mainland, it has no legal protection as a marine reserve, and there are large towns on the coast in front of this island. With these differences in mind it could be expected that the size distribution would be the result of human pressure by collecting.

Other forces controlling population dynamic of *P. ferruginea* Gmelin, 1791 on the Algerian islands could be predation by marine birds such as seagulls. There are large populations of *Larus cachinnans* and *Larus audouinii*: 1,340 and 690 individuals, respectively, in Habibas Islands (Ben Haj & Bernard, 2005). Although predation by seabirds over *P. ferruginea* Gmelin, 1791 has not been corroborated, Laborel–Deguen & Laborel (1991) indicated that seagulls could be significant predators of the species. Guallart et al. (2006b) found shells of *P. ferruginea* Gmelin, 1791 several metres from the intertidal zone in the Chafarinas Islands and put forward the hypothesis of predation by seagulls.

Further studies on genetic and ecological topics of Algerian populations are required to elucidate whether the patterns observed in other populations are consistent throughout the distributional area of the species. Additionally, conservational measures should be implemented to prevent this endangered mollusc becoming extinct.

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