Human harvesting of *Mytilus galloprovincialis* Lamarck, 1819, on the central coast of Portugal*

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SUMMARY: The Mediterranean mussel, *Mytilus galloprovincialis* Lamarck, 1819, has traditionally been removed from the shore by humans in coastal areas to supplement diet, for commerce or for bait. On exposed rocky shores of the central coast of Portugal, humans are an important intertidal predator, especially of mussels and of the pedunculate barnacle *Pollicipes pollicipes* (Gmelin, 1789). Four rocky shore sites near Cabo Raso with different levels of accessibility were compared in terms of harvesting pressure, substratum cover, density and size structure of *M. galloprovincialis*. Sampling surveys were conducted from March to September 2002. For substratum cover determinations a 50 cm x 50 cm square was used, while density and size structure were estimated based on scrapings performed on a 10 cm x 10 cm area. A log-linear model was used to evaluate human harvesting according to several factors. Significant differences in the harvesting intensity were related to accessibility, type of day (weekday, weekend or holiday), period of the day, weather and tidal amplitude. The differences relative to zone were not significant. The least accessible site (0.30 person day^{-1}) showed the highest values of substratum cover, and a negative correlation was found between number of harvesters and substratum cover by mussels. Size distribution also varied considerably according to site. The major difference that was noticed was that less accessible sites showed a higher number of large individuals than more accessible areas. Density in the most accessible location showed a clear decline, above all after summer holidays. Over the study period, in the more accessible sites biomass decreased while in the other locations it increased. Long-term studies are necessary to determine the real magnitude and effects of human disturbances in intertidal communities.

Key words: human pressure, harvesting, mussel, *Mytilus*, coastal areas, Portugal.

RESUMEN: EXPLOTACIÓN HUMANA SOBRE *MYTILUS GALLOPROVINCIALIS* LAMARCK, 1819, EN LA COSTA CENTRAL DE PORTUGAL. – El mejillón mediterráneo, *Mytilus galloprovincialis* Lamarck, 1819, ha sido extraído tradicionalmente por el hombre en áreas costeras para suplir su dieta, ser comercializado o utilizado como cebo. En costas rocosas expuestas del litoral central portugués, el hombre es un importante depredador de las zonas intermareales, especialmente del mejillón y del percebe *Pollicipes pollicipes* (Gmelin, 1789). Cuatro sitios rocosos cerca de Cabo Raso, con diferentes niveles de accesibilidad, fueron comparados en términos de explotación humana, cobertura del substrato, densidad y estructura de tallas de *M. galloprovincialis*. Los muestreos fueron realizados desde Marzo hasta Septiembre del 2002. Para las mediciones de cobertura del substrato fue usado un cuadrado de área 50 x 50 cm, mientras que la densidad y la estructura de tallas fueron estimadas basándose en la extracción de mejillones mediante raspado en superficies de 10 x 10 cm. Un modelo log-linear fue utilizado para evaluar la presión humana en relación con varios factores. Encontramos diferencias significativas en la intensidad de explotación en relación con la accesibilidad, el tipo de día (laboral, fin de semana o festivo), el periodo del día, el tiempo y la amplitud de marea. Las diferencias relativas a zona fueron no significativas. El sitio menos accesible (0,30 personas $día^{-1}$) mostró los valores más altos de cobertura de substrato, encontrándose una correlación negativa entre el número de mariscadores y la cobertura de mejillón. La distribución de tallas también varió considerablemente dependiendo del sitio. La mayor diferencia observada fue en los sitios menos accesibles, presentando un mayor número de individuos grandes en comparación con los sitios más accesibles. Las densidades en las localidades más accesibles presentaron una clara disminución, sobretodo después de las vacaciones de verano. Durante el periodo de estudio, en los sitios más accesibles, la biomasa disminuyó mientras que en las otras localidades incrementó. Estudios a largo plazo son necesarios para determinar la magnitud real y los efectos de las perturbaciones humanas sobre las comunidades intermareales.

Palabras clave: presión humana, explotación, mejillón, *Mytilus*, áreas costeras, Portugal.

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INTRODUCTION

The Mediterranean mussel, *Mytilus galloprovincialis* Lamarck, 1819, is a warm water mussel that is widely distributed around the world. This species can be found in the Mediterranean, along the Atlantic coast of Europe (Gardner, 1992), on the west coast of North America (McDonald and Koehn, 1988), in Australasia (McDonald *et al*., 1991) and recently as an invasive species in South Africa (Grant and Cherry, 1985).

For many centuries, this mussel has been removed from the Portuguese shore by humans to supplement diet, for commerce or for bait. At the present time, on exposed rocky shores of the central coast of Portugal, humans are an important intertidal predator, especially of mussels and the pedunculate barnacle *Pollicipes pollicipes* (Gmelin, 1789).

Several studies have documented how gradients of human disturbances could affect the intertidal community, most of them in the Southern Hemisphere (Moreno *et al*., 1984; Castilla and Durán, 1985; Hockey and Bosman, 1986; Oliva and Castilla, 1986; Castilla and Bustamante, 1989; Durán *et al*., 1987; Durán and Castilla, 1989; Kingsford *et al*., 1991; Keough *et al*., 1993; Siegfried *et al*., 1985; Underwood and Kennelly, 1990) and only a few in the Northern Hemisphere (Addessi, 1994; Pfister and Bradbury, 1996; Castro, 1998).

In most of these studies, paired comparisons between human-impacted versus non-impacted sites (Durán *et al*., 1987; Durán and Castilla; 1989; Keough *et al*., 1993; Oliva and Castilla, 1986; Siegfried *et al*., 1985) or gradients of different intensities of human exploitation (Addessi, 1994; Moreno *et al*., 1984) have been used. These studies have analysed the consequences of human harvesting behaviour, and they all conclude that this activity causes a reduction in the abundance as well as a decrease in the mean size of individuals within the population (Branch, 1975; Moreno *et al*., 1984; Castilla and Durán, 1985; Hockey and Bosman, 1986; Oliva and Castilla, 1986; Castilla and Bustamante, 1989; Durán and Castilla, 1989; Godoy and Moreno, 1989; Keough *et al*., 1993).

In Australia, Underwood and Kennelly (1990) described the predatory aspect of humans on the rocky shore of New South Wales as a function of the weather, the time of year, and the organisms collected. Kingsford *et al*. (1991) suggested that recreational fishers and beach visitors may be responsible for reductions in population densities of not only herbivorous sparid and carnivorous girelid fishes, but also intertidal ascidians, crabs and gastropods (used for bait), consequently affecting the structure and dynamics of inshore species assemblages. On the southwest coast of Portugal, Castro (1998) identified the main temporal and spatial variation patterns of human activities.

Few studies have used the accessibility of the site as a reliable indicator of human pressure. Castilla and Bustamante (1989) showed that special features of coastal geomorphology, such as small islands of difficult access, could represent important refuges or seeding grounds for adjacent shore populations of the bull-kelp *Durvillaea antartica* (Chamisso) Hariot 1892. They predict that relatively inaccessible exposed rocky shores or islands in central Chile should harbour higher biomasses of *D. antartica* than rocky shores that are readily accessible to collectors. In another study, Addessi (1994) showed that there are gradients of human disturbance, depending on the distance from the access point.

In the present study, we examined the relationship between site accessibility and the intensity of human harvesting. The substratum cover, density, population structure and biomass of *M. galloprovincialis* were analysed in order to evaluate the impact of human harvesting in intertidal areas.

MATERIAL AND METHODS

The study site was located ca. 30 km west from Lisboa, near Cabo Raso (38º42’64”N, 09º29’06”W) (Fig. 1). This area is an exposed rocky shore, with high hydrodynamism, the wave action being mainly along the N-W direction. Climate conditions are generally temperate, tides are semidiurnal (highest range ca. 4 m) and the substratum is composed of calcareous rock of Cretaceous formations (Ribeiro and Ramalho, 1997).

At this location, rocky platforms of two similar zones (Ponta da Galé and Ponta Alta), with two sites each of different accessibility (Site 1 was higher than Site 2) were sampled at low tide four times, in March, April, July and September 2002, in order to study the community of mussels. Our criteria were the distance from the nearest road and the difficulty of access to the area. Also, on 35 random days (between March and September 2002) at low tide the human harvesting pressure was monitored at these sites.

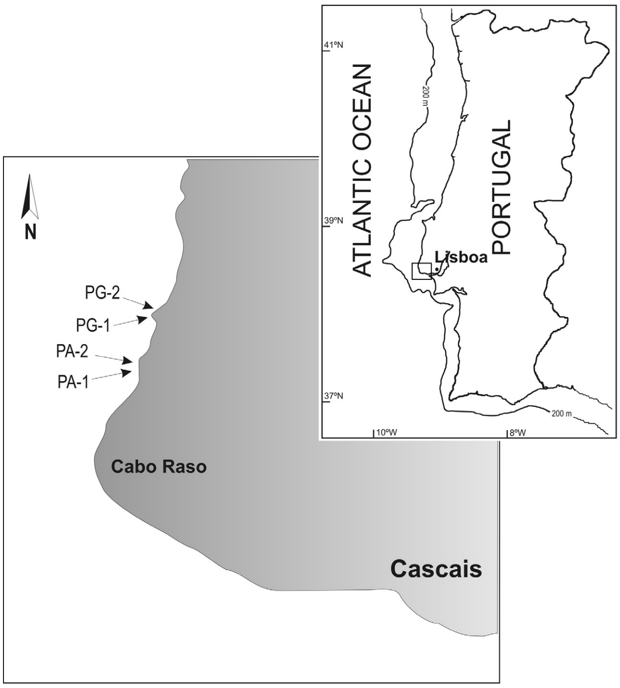

FIG. 1. – Location of sampling zones: Ponta Alta (PA) and Ponta de Galé (PG), indicating locations of survey sites (1 = more accessible; 2 = less accessible).

Two field methods were used to study the mussel community, one for the substratum cover and the other for the community structure.

The first one consisted of ten random replicated 0.25 m^2 string grid quadrats photographed for each site. The location of the quadrats was based on random numbers (0-360) that indicated the direction (we first chose a point at each site and then walked in a randomly selected direction until a mussel bed with 100% cover was found). Five substratum cover classes were considered: 0%, <25%, 25-50%, 50-75% and 75-100% (as in Addessi, 1994). The G test was used to evaluate the differences in the number of quadrats in each class between sites (Zar, 1996). The second method estimated density and size structure based on scrapings performed on a 10 cm x 10 cm area with a chisel. Ten random replicated quadrats were considered for each site and survey. Maximum shell length of mussels ≥ 10 mm was measured with a calliper (with 0.1 mm precision).

The size of the quadrats and the number of replicates for both methods were based on a preliminary study at the same location.

Biomasses were estimated using the length/weight relationship every month obtained by Saldanha (1974) from a nearby rocky shore area ca. 40 km South. The G test was also used to evaluate the differences in the number of individuals in each size class (5 mm regular interval size classes) between sites (Zar, 1996). The 0.05 significance level was considered in all these test procedures.

To evaluate the human-harvest activity, for each sampling date the people harvesting were counted at each site and the day's conditions were recorded at low tide. A log-linear model was used to evaluate the intensity of human harvesting in the different zones according to several factors: period of the day (early tide - low tide before 12:00 h; late tide - low tide after 12:00 h), tidal amplitude (low tide level <0.5 m, from 0.5 m to 0.8 m and >0.8 m), type of day (weekday, weekend or holiday), and weather (sunny, partially cloudy or windy, heavily cloudy and windy). This analysis was performed using S-Plus software and a 0.05 significance level was considered.

RESULTS

The four sites studied showed a different pattern of human exploitation. PA-1 and PG-1 showed similar values of the mean number of persons harvesting per day (2.21 person day^{-1} and 2.17 person day^{-1} respectively), while the estimates determined for PA-2 and PG-2 were considerably lower (1.03 person day^{-1} and 0.30 person day^{-1} respectively). The log-linear model results indicated that the significant differences in harvesting intensity were related

TABLE 1. – Results of the general additive model applied to human harvesting data (Df - degrees of freedom; Resid. Df - Residual degrees of freedom; Resid. Deviance - Residual deviance).

Factor	Coefficient	Df	Deviance	Resid. Df	Resid. Deviance	P-value
(intercept)	5.37	-	-	383	795.88	-
Zone	-0.17	1	2.23	381	701.28	0.13
Accessibility	-1.15	1	52.65	380	648.63	<0.05
Type of day	-0.33	1	92.37	382	703.51	<0.05
Weather	0.62	1	23.85	378	541.03	<0.05
Period of day	-2.74	1	83.74	379	564.88	<0.05
Low tide level	-1.15	1	83.78	377	457.25	<0.05

to accessibility (site), type of day, period of the day, weather conditions and tidal amplitude. The differences related to zone (PG or PA) were not significant (Table 1).

The number of persons harvesting was higher at sites with high accessibility than at the other sites. The human harvesting effort was similar on weekends and holidays, while the value obtained for weekdays was considerably lower (Fig. 2a). A higher number of harvesters was recorded during the morning than in the afternoon (Fig. 2b). The low tide level was also an important factor, and it was noted that the lowest numbers of harvesters occurred when the low tide limit was higher than 0.8 m (Fig. 2c). The weather conditions also greatly influenced the harvesting activities: during good weather the mean number of harvesters was 6.50 day^{-1}, while during bad weather it was quite low (0.25 person day^{-1}) (Fig. 2d).

The substratum cover was different at all sampling sites (G_W = 1051.2, p<0.05). The site with the lowest values of human harvesting (PG-2) showed the highest values of substratum cover, whereas in the accessible areas (PA-1 and PG-1) mean values of cover were lower, above all after summer holidays (Fig. 3). PA-2 showed an unexpected pattern, and mean values of cover there remained the lowest throughout the study period, except in September.

The temporal variation pattern of the substratum cover indicated that at the more harvested sites the *M. galloprovincialis* cover showed a marked decreasing trend, while the other sites showed similar values or a moderate decrease during the study period (Fig. 3). The effect of increased harvesting in summer holidays was observed above all at the more accessible sites.

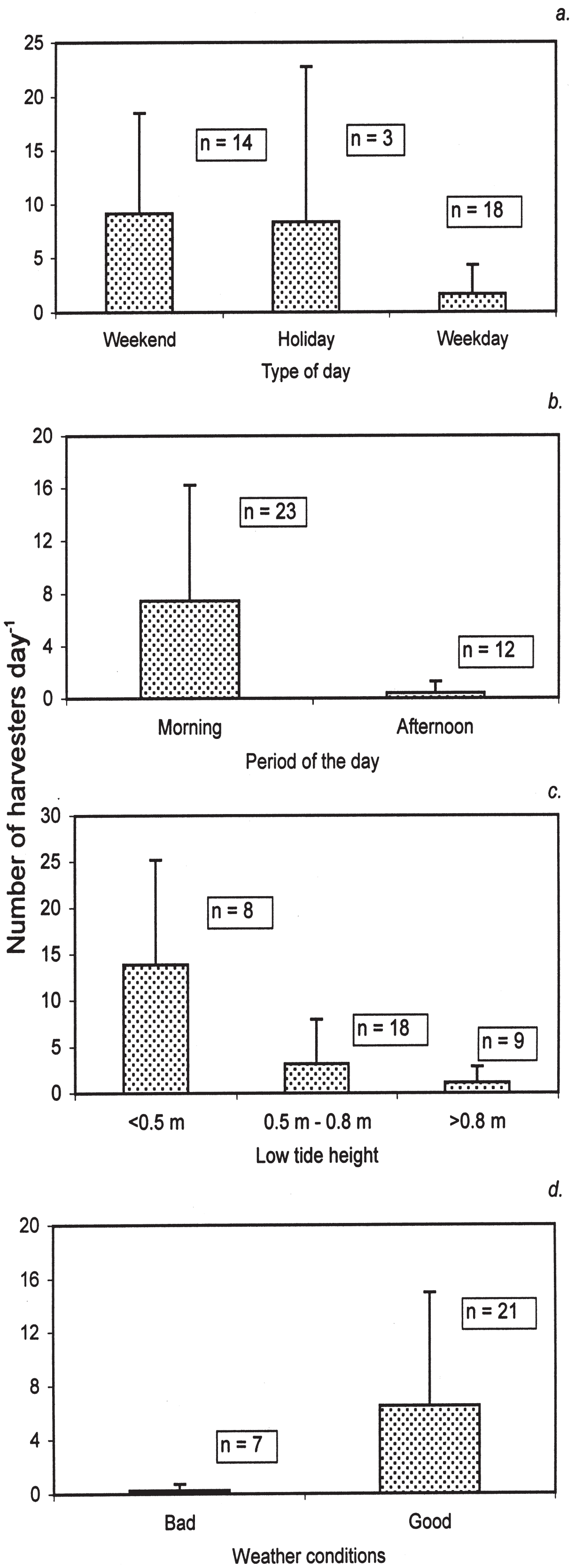

FIG. 2. – Mean number of harvesters at the study sites according to type of day (a), period of the day (b), low tide level (c) and weather conditions (d). (n = number of days of observation)

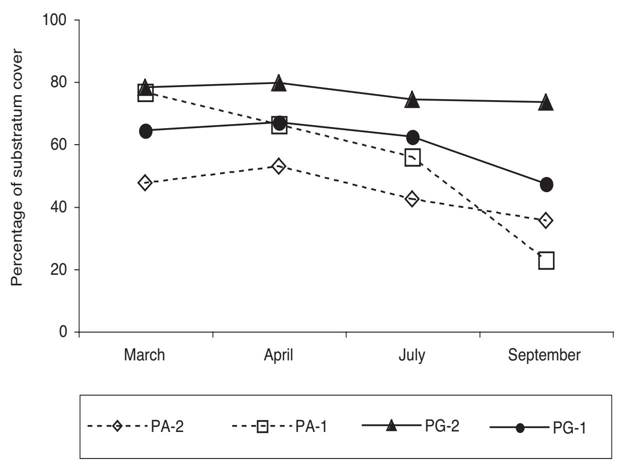

FIG. 3. – Variation of the percentage of substratum cover from March to September 2002 for each site.

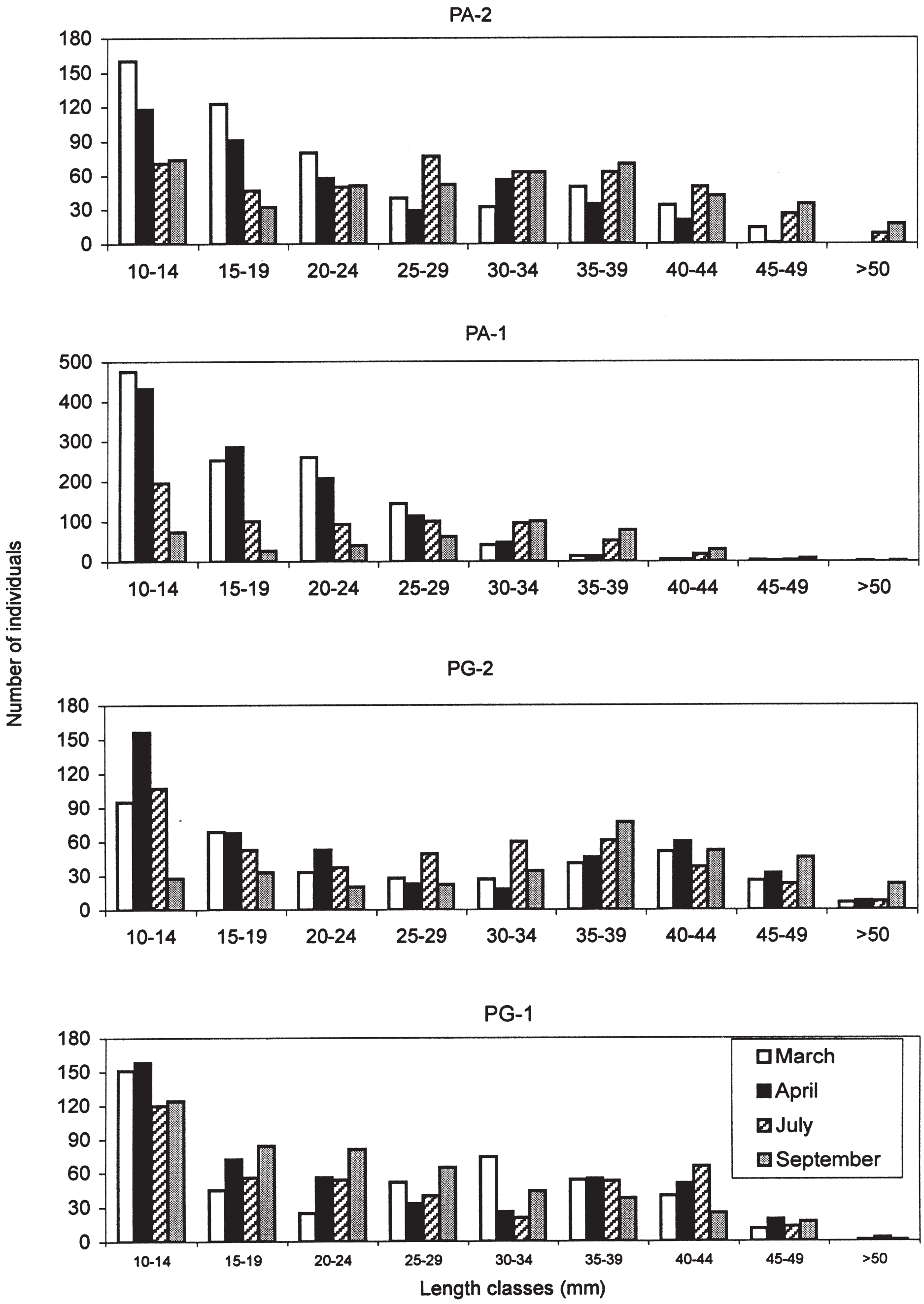

FIG. 4. – Length-frequency distribution of *M. galloprovincialis* for each site and sampling period.

Size distribution of mussels also varied considerably according to site (G_W = 858.0, $p<0.05$). This generally reflected a unimodal distribution at more accessible sites (especially PA-1) and a bimodal distribution at less accessible ones. The major difference noticed was that less accessible sites showed a higher number of large individuals than more accessible sites (Fig. 4).

The temporal variation in mussel densities was low, except at PA-1, for which density values showed a marked decreasing trend from March to September (Fig. 5).

The temporal variation of biomass estimates for each site showed that more accessible sites presented the lowest values of biomass by the end of the summer (Fig. 6).

The PG-2 biomass was always higher than the other zones, and in September showed an increase because of the increase in the number of larger mussels, which contributed most to the total biomass.

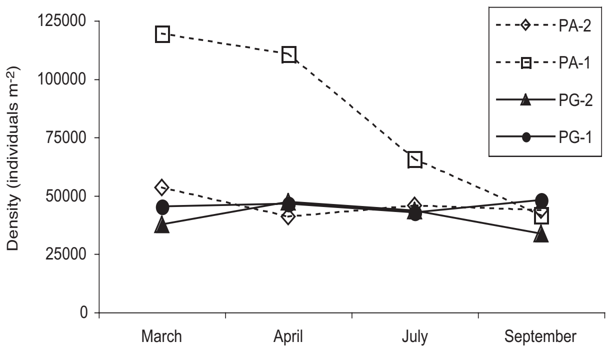

FIG. 5. – Temporal variation of *M. galloprovincialis* density according to site.

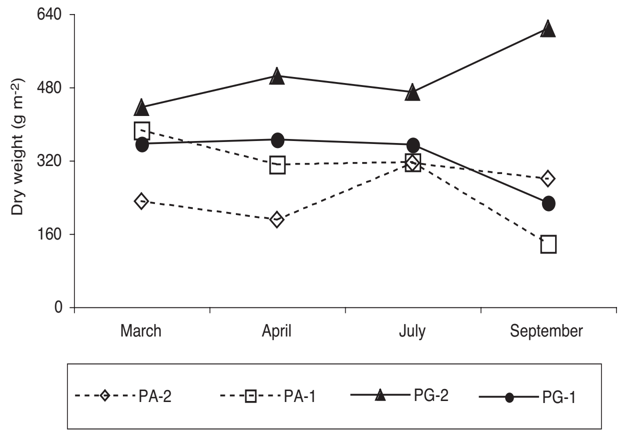

FIG. 6. – Temporal variation of *M. galloprovincialis* biomass according to site.

DISCUSSION

Several factors were related to human harvesting of mussels in the intertidal areas of the central Portuguese coast. Similar numbers of harvesters were found during weekends and holidays, while the estimates obtained for weekdays were considerably lower. Addessi (1994), in the USA, and Castro *et al.* (2000), on the southwest coast of Portugal, also reported a higher harvesting intensity during weekends and holidays than on weekdays. On the other hand, in New South Wales (Australia), people visited the shores in similar numbers on weekdays and weekends, though the number of harvesters was higher in the holidays than during the term (Underwood and Kennelly 1990). Our results suggest that this resource is not collected for subsistence and that the harvesting action is not the main professional activity of the harvesters. This situation is completely different from those reported in other geographical areas, namely South Africa, where harvesting is conducted for subsistence (Siegfried *et al.*, 1985).

The relationship between the number of persons harvesting and the tidal range and weather conditions was predictable and has also been reported by other authors (e.g. Underwood and Kennelly, 1990; Castro, 1998). The preference of the morning period for harvesting found in the present study is in agreement with other studies (Castro *et al.*, 2000; Siegfried *et al.*, 1985). On the other hand, Kingsford *et al.* (1991), in Australia, reported that the exploitation of rocky reefs was higher during the afternoon.

The significant differences obtained when comparing the number of harvesters according to site emphasised the importance of accessibility as a major determinant of human pressure. Addessi (1994), in the USA, noticed a decrease in the number of visitors with distance from public access. In our study, each site had its particular pattern of human harvesting that could be related to accessibility: PA-1 and PG-1 showed similar values of harvesting intensity and are located at accessible sites near tracks; while PA-2 and PG-2 were less visited by harvesters. It seems that traditionally people have visited PA-2 more than PG-2, even though the sites have similar levels of accessibility.

The substratum cover by mussels showed a marked decreasing trend over the study period, especially in the more accessible sites, whereas at PG-2 the temporal variation was low. This finding suggests that continuous harvesting activity could greatly affect the stability of the mussel bed. Favourable conditions to re-establish the original cover can only be found during the winter months, when human harvesting pressure is low.

Fishing of *M. galloprovincialis* (like other recreational shell fishing activities) is an uncontrolled activity that disturbs mussel communities, in which normally only large specimens are taken (Moreno *et al.*, 1984, Tsuchiya and Bellan-Santini, 1989). This has important repercussions on the future reproductive output of the population, since larger animals are more fecund than small individuals (Sharpe and Keough, 1998). Moreover, we observed that this activity was not always selective, as we reported indiscriminate exclusion of large patches of mussels. During harvesting, some people removed all the mussels regardless of shell length, since it maximised catches due to the limited time available with low water levels, after which any small mussels were discarded. The results for the level of human harvesting had a correlation with the results for size distribution. Sites with more human harvesting showed a lower size distribution while the less frequented sites had a larger size distribution. The impact of an increase in harvesting pressure during summer months was reflected by the variation pattern of substratum cover, density and biomass.

PA-1 density, as well as substratum cover, showed a very clear decreasing pattern. This could indicate that this zone is a major recruitment site, and that the last spawning period provides new recruits that we could find in the first size classes (Fig. 4). Afterwards, most of the recruits died and only some have grown successfully. In addition, human pressure during summer when large patches of mussel beds are removed could aid this decrease.

There are few cases of management in which the extraction of wild benthic resources is done through the implementation of rotational fishery schemes and/or the use of no-take areas as a source for 'overspilling' of adults or seeding grounds (Castilla, 1998). In Portugal, where there is no integrative coastal management plan, several improvements in terms of environmental policies, legislation and taxation need to be developed in the near future. Poor legislation (Anonymous, 2000) without any control of coastal activities does not guarantee the viability of all stocks of intertidal resources.

Long-term studies would be necessary to determine the real magnitude and effects of human disturbances and would be extremely useful to indicate management guidelines.

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