Clear regression of harvested intertidal mollusks. A 20-year (1994—2014) comparative study

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ABSTRACT

Intertidal mollusks are subjected to an intense environmental pressure, from human-induced stressors, mainly harvesting, to competition for food and space with other species. Here we used mollusk shell size as a measure of size distribution and reproductive potential of intertidal limpets. Two species of exploited limpets (*Patella candei crenata* and *Patella aspera*) were monitored throughout the littoral of Tenerife (Canary Islands, NE Atlantic Ocean), an overpopulated island with a high coastal pressure. The exploitation of these two limpet species is controlled by regional legislation, with seasonal closures and limits of harvest for professional (10 kg) and recreational harvesters (3—5 kg). A long-term comparison (1994—2014) of limpet size has been conducted as a surrogate of the state of conservation of these two limpets. Both species showed populations dominated largely by small-sized individuals (<30 mm) and a lack of large adults (>60 mm). The proximity to coastal settlements was not a factor to explain limpet assemblage structure. The temporal (1994—2014) comparative study showed a sharp decrease in the mean size of both limpet species (7 mm in *P. aspera* and 5 mm in *P. candei crenata*). These results might be indicative of overharvesting of both species in Tenerife. The conservation of the two studied species needs to be accomplished by the strict fulfillment of current protective strategies, as well as the creation of marine protected areas where intertidal harvesting is totally banned all over the year.

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1. Introduction

Mollusks have been used worldwide as food by people since prehistoric times, as evidenced by their presence in Paleolithic and Neolithic shell mounds (Keough et al., 1993; Gutiérrez-Zugasti, 2011; Turrero et al., 2012). Mollusks are an important source of protein (King et al., 1990). Additionally, mollusks have been also used as bait, collected for their shells or for recreational activities, such as aquariums or scientific manipulation (Addessi, 1994; Lasiak, 1997). This situation has triggered a higher harvesting pressure on larger individuals, with more commercial value, leading to a profound shift in size distribution, together with a drastic reduction of population abundances (López et al., 2012; Martins, 2009). Shellfish exploitation can decrease the reproductive output of mollusk populations, especially for species that show an increase in fecundity with body size, such as limpets (Tegner et al., 1996).

A consistent decrease of limpets populations has been recorded in harvested places throughout the last decades worldwide (Kido and Murray, 2003; Roy et al., 2003; Coleman et al., 2006; Martins et al., 2008). This phenomenon is accentuated because of the expansion of coastal settlements and hence, a higher coastal accessibility (Griffiths and Branch, 1997). In the Mediterranean Sea, the populations of *Patella ferruginea* are concentrated in a limited number of intertidal locations because this species has been extensively harvested and currently, is considered in danger of extinction (Espinosa, 2009). Several endemic limpet species from Hawaii (*Cellana sandwicensis*, *C. exarata* and *C. talcosa*) are becoming rare due to harvesting, with the disappearance of populations in large intertidal areas of highly-populated islands (Valledor, 2000). This situation could be alarming in isolated areas (e.g. oceanic islands) where a low connectivity between limpet populations exists (Bird et al., 2007; Goldstien et al., 2009).

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In the Macaronesian region (Azores, Madeira, Selvagens, Canaries and Cape Verde archipelago) a reduction in the abundance of several species of limpets have been observed in the last decades (Núñez et al., 2003; Martins et al., 2010). A sharp decrease has been observed in Azores, Madeira and the Canaries where consumption is considered typical (Weber and Hawkins, 2002). In the last two decades, the populations of *Patella candei* and *Patella aspera* in Azores have been subjected to intense exploitation (Hawkins et al., 2000), with a noticeable decrease in their densities (Martins, 2009). The same situation has been occurring in Madeira with these two limpet species (Hawkins et al., 2000). In the Canary archipelago, *P. candei candei* d'Orbigny, 1840, commonly known as "majoreran limpet", has been collected extensively throughout the archipelago and currently it is only represented by isolated populations on the east coast of Fuerteventura (Núñez et al., 2003). The remaining two commercial-harvested limpets (*P. candei crenata* and *P. aspera*) are still recorded in the whole archipelago and symptoms of exploitation (i.e. sharp decrease of abundances, lack of large-sized individuals, etc.) have been observed during the last decade (Navarro et al., 2005; Ramirez, 2009; López et al., 2012). However, scarce information exists about temporal trends of the overharvested limpets *P. candei crenata* (d'Orbigny, 1838) and *P. aspera* Lamark, 1819; hence, not useful information is available for developing conservation measures to supplement current laws in order to ensure the viability of these species in the Canary archipelago.

The main aim of the present study was to examine the effects of harvesting on the populations of *P. candei crenata* ("black" limpet) and *P. aspera* ("white" limpet), considering the proximity to human settlements, as a surrogate of human pressure on these species. We hypothesized that the mean limpet size decreases in "near" stations (<1 km from human settlements) compared to "far" stations (>3 km from human settlements). "Near" stations may be characterized by populations with a fragmented size structure, mainly small-sized individuals (<25 mm), with low possibilities to maintain viable populations. Moreover, a comparative study was conducted between previous data (1994) and current data collected in the present study (2014). We hypothesized that the individual size of both limpet species has decreased in the last two decades, as indicative of assemblages affected by overharvesting. These surveys are of utmost importance, since a continuing reduction in body size will be detrimental to limpet reproductive output, and a conservation plan may be needed to prevent further losses in these communities.

2. Material and methods

The study was conducted in the intertidal level in Tenerife (Canary Islands, NE Atlantic), the most human populated island in the archipelago. A total of 25 locations were sampled in summer 2014 (July—September), corresponding to settlements throughout the coast of Tenerife (Fig. 1). At each location, 4 sites were selected, 2 "near" (<1 km from settlement) and 2 "far" (>3 km from settlement). At each site, all limpets belonging to the species *P. candei crenata* ("black" limpet) and *P. aspera* ("white" limpet) were recorded within a transect of 10 × 2 m parallel to the coast. Each limpet was measured to the nearest millimeter using calipers. *P. candei crenata* is characterized by having a thin shell and dark in color, with rounded and regular margins. This species is commonly named "black" limpet because of the blackish color of the underside of its underfoot. *P. aspera* is characterized by having a shell structurally strong and light in color, with thick and irregular margins. This species is commonly named "white" limpet because of the yellowish color of the underside of its underfoot.

The rocky substratum of Tenerife is of volcanic origin and consists of a high variety of forms (platforms, cliffs, pebbles, etc.)

(Carracedo and Troll, 2013). In the present study, we selected intertidal platforms that constitute one of the best substrates for the colonization and settlement of limpets (Núñez et al., 1994). In the eulittoral zone, the most abundant conspicuous organisms include the barnacle *Chthamalus stellatus*, the gastropod *Stramonita haemastoma*, the two targeted limpets *P. candei crenata* and *P. aspera* and the littorinid *Littorina striata* (Ramirez et al., 2008). Algae were mainly represented by turf-forming species (e.g. *Gelidium*, *Dictyota* and *Laurencia*), at some places patches of the canopy algae *Cystoseira abies-marina* also occur.

A comparative study was conducted between the current data collected in 2014 and former data from a 1994 study (Núñez et al., 1995). However, only limpet size was compared since different sampling methods were used for both studies (10 × 2 m transects in current data and time sampling (30 min) in 1994). Individuals were classified in reproductive and non-reproductive, considering the size of first maturity of both species (Núñez et al., 1994). In the studied limpets, the transition from juvenile to reproductive adult occurs at the body size of 30 mm (Núñez et al., 1994). Sampling surveys conducted in 1994 were focused to obtain the CPUE (Catch per Unit Effort), as a surrogate of economic revenue for harvesters (Núñez et al., 1994). Data from 20 (Punta Antequera, San Andrés, Punta Pachona, Las Caletillas, Güímar, Abades, El Médano, Los Abrigos, Las Galletas, Puertito de Adeje, Playa San Juan, Teno, Buenavista, Garachico, Puerto de La Cruz, El Caletón, La Barranquera, Punta del Hidalgo, Taganana and Anaga) of the 25 coastal localities sampled in 2014 were used for comparative analysis (1994—2014). Data are available upon request.

In the comparative study (1994—2014), only limpets censused at the same locality were considered and factor "time" (sampling year: 1994—2014) was included. Kolmogorov—Smirnov (KS) test was used to compare limpet sizes from both surveys (1994—2014), since the test makes no assumptions about the distribution of data (Kirkman, 1996).

A univariate comparison of the sizes of the two limpet species (*P. aspera* and *P. candei crenata*) was carried out using an analysis of variance (ANOVA). One factor, proximity to human settlements, was considered with current data to explore the influence of harvesting on limpet assemblages ("proximity to human settlements"). The comparison of limpet size classes from both surveys (1994 and 2014) was analyzed by contingency tables, based on the statistic Chi(X^2)-square.

3. Results

3.1. Current situation

A total of 9240 limpets (3490 individuals of *P. candei crenata* and 5750 individuals of *P. aspera*) were measured at the 25 selected locations in the intertidal of Tenerife. In "near" sites a total of 5366 individuals were censused, being higher than in "far" sites (3874 ind). Considering both limpet species, the mean size was 24.3 ± 0.1 mm in length and 18.4 ± 0.1 mm in width, typical of a non-reproductive individual since 30 mm is the first-maturity size for the two studied species. However, if the proximity to human settlement is considered, slight differences in size were found, with smaller individuals in "near" sites (23.4 ± 0.1 mm length and 17.6 ± 0.1 mm width) compared to "far" sites (25.5 ± 0.1 mm length and 19.5 ± 0.1 mm width) (Fig. 2). These differences were explained by a high spatial variability of individuals of *P. aspera* (F = 182.8 <<0.0001). *P. candei crenata* did not show significant differences in size between limpets from "near" and "far" sites (F = 0.798, p = 0.372) (Table 1).

The size distribution of both limpets showed differences but smaller sizes were dominant in the two species, and large
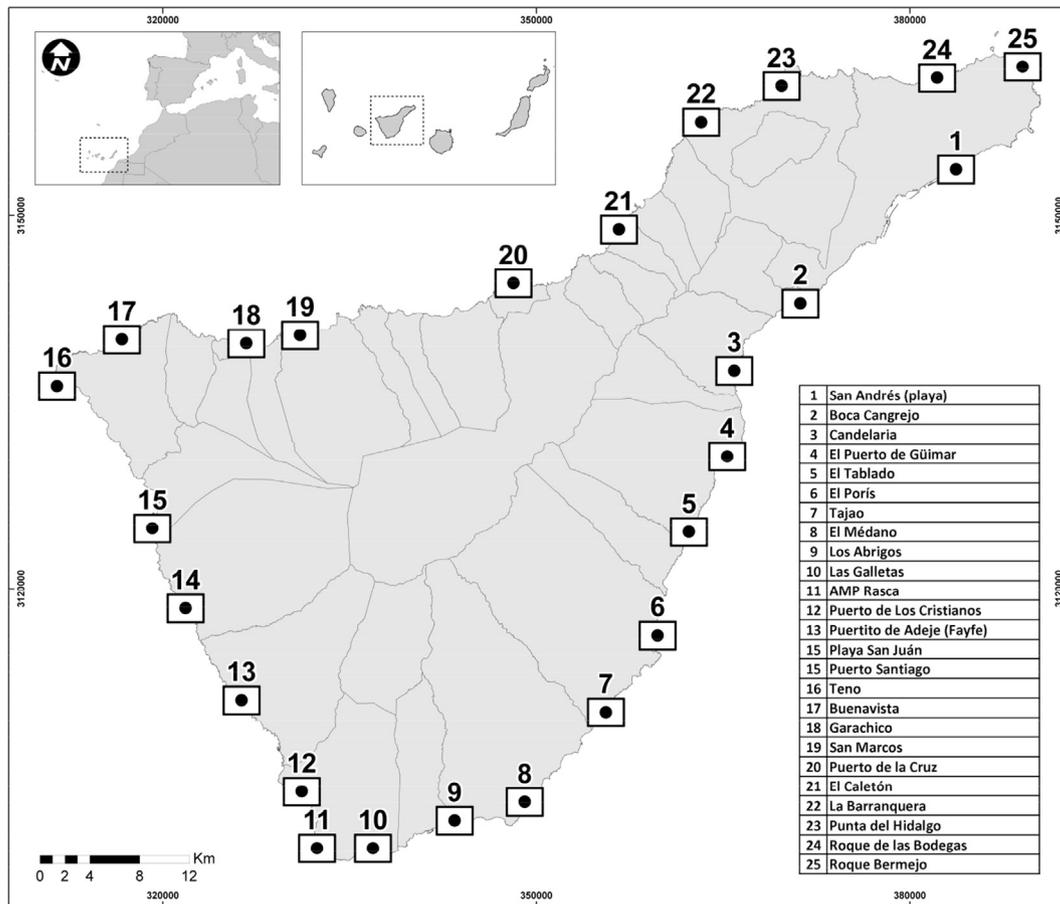
Fig. 1. Map of the study area showing sampling stations.

individuals (>40 mm) were scarce in both species. The overall mean size of *P. aspera* was 21.4 ± 0.1 mm (Fig. 3) and 29 ± 0.1 mm in *P. candei crenata*. Both size ranges of the two studied limpet species belong to non-reproductive individuals (Figs. 3 and 4).

P. aspera was dominated by individuals ranging from 16 to 20 mm length (33.04% of the overall abundance), followed by 21–25 mm individuals (24.98%). Adult-size individuals represented 4.21% of the overall abundance, with no individuals >60 mm size (Fig. 3).

P. candei crenata assemblages were dominated by individuals ranging from 25 to 30 mm (23.84% of the overall abundance), followed by 30–35 mm individuals (22.09%). Adult-size individuals were represented by 7.25% of the overall abundance, with no individuals >70 mm size (Fig. 4).

3.2. Comparative analysis (1994–2014)

In 1994, *P. aspera* ("white" limpet) was characterized by a wide range of sizes, from 5 to 60 mm, however, large-sized individuals (>55 mm) were scarce (Fig 3). A reduction of 17% of reproductive individuals (>35 mm size) has occurred in the last twenty years, from 21.2% in 1994 to 4.20% in 2014. The mean limpet size abruptly decreased from 30 ± 0.1 mm in 1994 to 23 ± 0.1 mm in 2014. Size differences of *P. aspera* between both years were highly significant ($Z = 17.440$, $p < 0.0001$).

The proportion of limpet size classes was right-skewed in 2014 compared to 1994, with the highest percentages in classes 16–20 and 20–25 mm (Fig. 3). Significant differences were found in the size classes between 1994 and 2014 ($X^2 = 23.0082$, $p = 0.0033$).
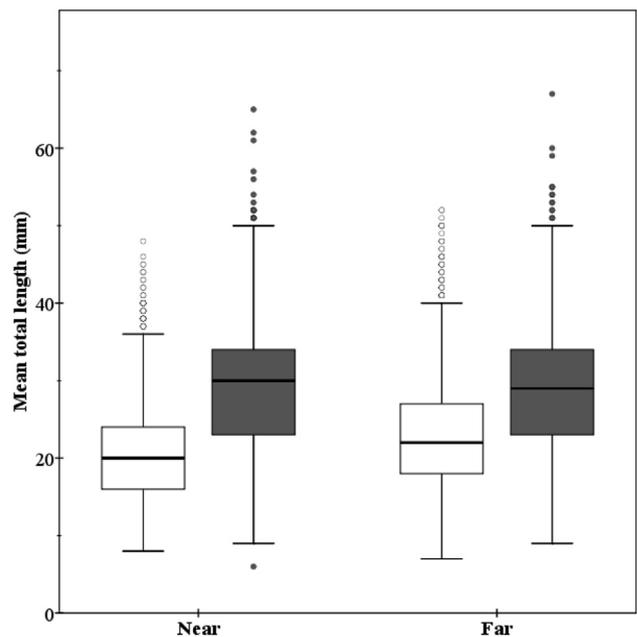

Fig. 2. Mean total length (mm) of both species of limpets considering the proximity to coastal settlements. Dark grey bars represent *Patella candei crenata* and white bars represent *Patella aspera*. Box-plot showing median (black line) and upper and lower quartiles of the data.

Table 1
One-way ANOVA of limpet size considering distance to coastal settlement as a factor. (SS: Sum of squares, DF: Degrees of freedom, MS: Mean of squares, F: F-ratio, P: Probability).

		SS	DF	MS	F	P
Patella aspera	Distance to settlement	8509	1	8509	182.857	**<<0.0001**
	Total	276,006				
Patella candei crenata	Distance to settlement	51,997	1	51,997	0.798	0.372
	Total	227,307				

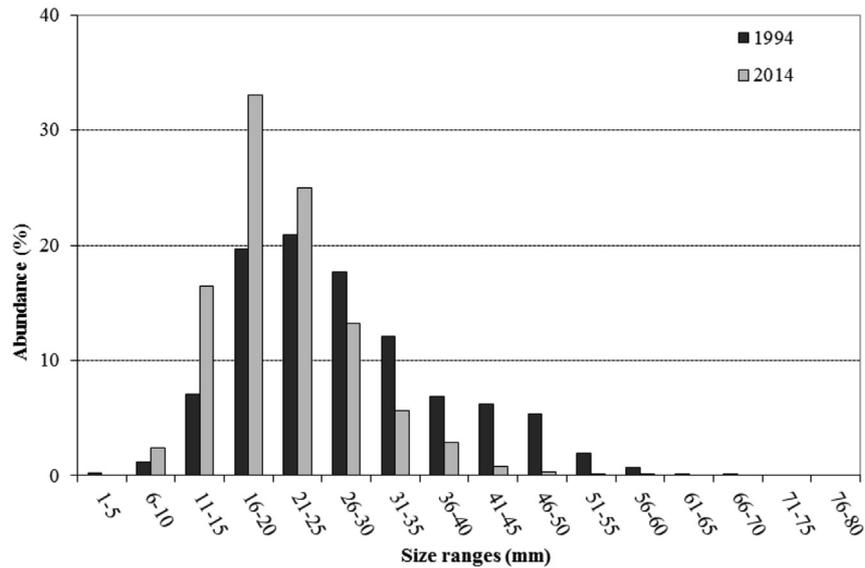Letters in bold denotes significant differences.

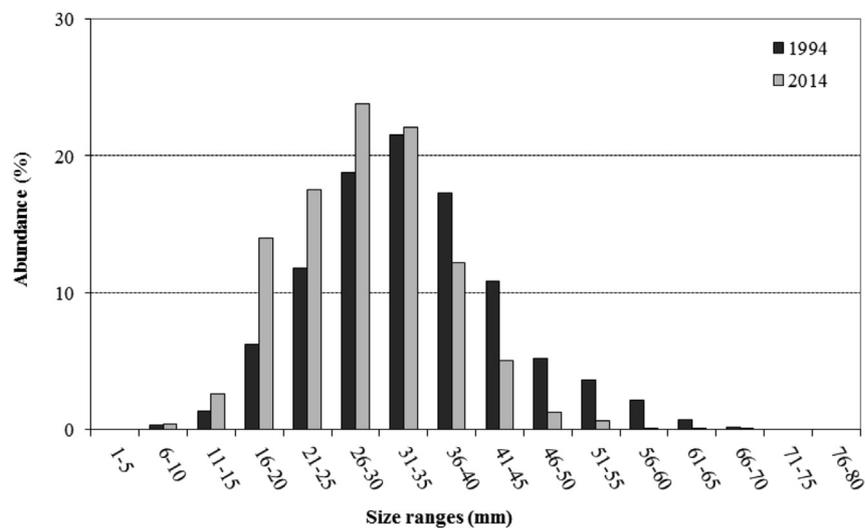**Fig. 3.** Variation of size ranges of *Patella aspera* in the last two decades.

Fig. 4. Variation of size ranges of *Patella candei crenata* in the last two decades.

The "black" limpet (*P. candei crenata*) also suffered a drastic shift on its size distribution, with a reduction of 20% of reproductive individuals (>35 mm) in the last two decades, from 40.1% in 1994 to 19.46% in 2014 (Fig. 4). The mean size of this limpet species declined from 36 ± 0.2 mm in 1994 to 31 ± 0.1 mm in 2014. The decrease of limpet size throughout the last 20 years (1994—2014) was highly significant (Z = 12.205, p < 0.0001).

The proportion of size classes was similar in the two studied years (1994 and 2014), with highest percentages of individuals in classes 26—30 mm and 31—35 mm. Differences were found in lower size-classes (21—25 mm length), which were better represented in 2014 compared to 1994. In contrast, large-sized classes (>35 mm) showed higher percentages in 1994 (Fig. 4). Differences in size classes of both surveys were not significant ($X^2 = 12.621$, p = 0.126).

4. Discussion

The overall results indicated that the two studied limpets (*P.*

candei crenata and *P. aspera*) are characterized by high-fragmented assemblages, dominated by non-adult individuals (<30 mm). Adults with high reproductive potential (>40 mm) were scarce in both species. No consistent differences were found in limpet size structure between "near" (<1 km) and "far" sites (>3 km), though slight larger individuals were recorded in "far" sites. This trend was observed only in *P. aspera*, characterized by a high number of small-sized individuals in "near" sites.

In previous studies an inverse correlation has been observed between limpet abundances and the proximity to coastal settlements (Martins, 2009). The accessibility to the coast is another noticeable factor, while harvest-ban areas (e.g. marine protected areas) have obtained good results for the conservation of limpet assemblages, with an increase of their populations (López et al., 2012). Unfortunately, no restricted-access to coastal areas exist in Tenerife and thus, no sampling was conducted in protected sites to assign temporal changes in size to harvesting. However, the present results may be indicative of an intense harvesting that could explain the small mean size in both limpets as well as the lack of spatial variability in limpets assemblages along the coast of Tenerife. Other minor factors that could affect body size distributions might be the lack of suitable substrates for colonization and settlement of these species, such as, interfaces rock-sand, and recent volcanic platforms with high anfractuosity and uneroded lava fields ("landform") (Strahler, 1970). The proliferation of fast-growing opportunistic species could be another factor to consider since they compete for space (e.g. algae *Ulva* spp and *Enteromorpha* spp) and food (e.g. the invertebrate *Siphonaria pectinata*) with the two limpet species.

The 20-year comparative study (1994—2014) showed a consistent decrease of limpet size in both species (7 ± 0.1 mm in *P. aspera* and 5 ± 0.1 mm in *P. candei crenata*), with a low representation of adult-size individuals (>35 mm). The sharp decrease of limpets' size shows the low viability of the populations of these species at medium and long-term in Tenerife. The situation is accentuated because of the lack of limpet populations with a good representation of individuals reaching the size at first maturity (30—35 mm).

The size-harvesting of limpet species is not limited to the loss of adult individuals, but it has consequences to the reproductive potential and even, ecological effects (e.g. changes in community structure and interspecific competition) (see Fernberg and Roy, 2008). The primary effects of size-selective harvesting are the overall reduction in body size and an increased mortality rate of harvested species, but other concomitant factors are associated, such as reproductive investment, changes in growth rate and relative fecundity (Fernberg and Roy, 2008, 2012). Regarding ecological implications, Boaventura et al. (2002) observed that limpets play a major role setting the upper limits of low-shore turf algae in intertidal rocky substrates and consequently, determine the algae composition and their canopy cover. The selective removal of limpet individuals vacates territory to other sessile invertebrates that are space competitors, e.g. mussels and barnacles (Fernberg and Roy, 2012). To prevent these processes is necessary to develop effective management strategies to recover limpet populations, such as regulations and the creation of harvest-ban areas.

In the Canary Islands, the exploitation of limpets is currently controlled by regulations promulgated under the Fish Law of 2003 (Law 27/2003) and the Legislative Orders of May 2nd and 10th of 2011 (BOC. n° 93, May 2011). Seasonal closures, from December to April and limits of harvest (10 kg per day for professional harvesters and 3—5 kg per day, depending on the day, for recreational harvesters) are established throughout the year in certain coastal areas to reduce the harvesting effort and to avoid disturbance during reproductive periods. However, surveillance is not as effective as it should be because of lack of means (Authors *pers. obs.*) and the coastal pressure in Tenerife is massive because most of the people live close to the coast. Thus, a series of additional conservation measures are necessary to preserve limpet assemblages in Tenerife.

Marine protected areas may be a good solution, since a recovery of exploited populations generally occurs after their establishment (Claudet et al., 2008; Edgar et al., 2014). In theory, marine protected areas could show increases in densities, mean and maximum limpet sizes, as well as reproductive output of exploited species (López et al., 2012). They could be used as complementary tools for the management and protection of resources, as well as habitats and recovery of degraded ecosystems (Micheli et al., 2012). However, the efficacy of protected areas depends on several factors, such as the substrate availability, the presence of food source (i.e. microalgal films) and the degree of overlap with other grazing species (Jenkins and Hartnoll, 2001; Thompson et al., 2002). A factor of utmost importance is enforcement to prevent illegal harvesting, common in the intertidal because of the availability of targeted species and the lack of refuge from harvesters (Martins et al. 2008).

Because of the high dispersal of limpet larvae, a network of marine protected areas specifically designed to complement the larval dispersion patterns and recruitment favor the protection of all life stages (larvae, juveniles and adults). The design of the net of protected areas should be characterized by a high connectivity among them, acting as exporting sites of biomass to surrounding areas. In Tenerife, two large marine protected areas: Anaga (NE of Tenerife) and Teno (NW of Tenerife) are in the process of establishment in the next years. They constitute suitable places to establish permanent closed seasons in order to recover limpet assemblages to non-harvested conditions, with a good representation of large-sized individuals (>40 mm). These protected areas should be accompanied by the strict fulfillment of current protective strategies that include (i) harvest limits, (ii) closed seasons in certain coastal sections of the island, and (iii) seasonal closures in extensive littoral areas, from December to April.

Acknowledgments

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