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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.

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