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Spatial variability of the reproductive cycle and physiological condition of *Patella* spp. (Mollusca Gastropoda) in the NW of the Iberian Peninsula: Implications for exploitation

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ABSTRACT

The reproductive cycle and the physiological status, measured through a standardized condition index, of limpets *Patella depressa* and *Patella ulyssiponensis* were studied along the Galician coast (NW of the Iberian Peninsula) from July 2010 to June 2011. The observed data were adjusted using linear and nonlinear general models. This allowed analyzing and quantifying the influence of independent factors, such as individual size and degree of wave exposure, on the cycles. Populations of *P. depressa* showed mature individuals nine months a year with a resting period from June to September. The amplitude of the fertile period increased with limpet size and with wave protection. On the other hand, the condition index decreased with increasing limpet sizes and, for a given size, it was higher in sheltered areas than in exposed ones. *P. ulyssiponensis* showed mature individuals eleven months a year with a small resting period in May or June. The amplitude of the reproductive cycle increased with limpet size but this variable did not show any significant influence on the condition index. No size/sex relation was observed either for *P. depressa* or *P. ulyssiponensis*. The results have contributed some valuable information to help design exploitation plans: Given that the limpet exploitation in these coasts is multispecific and includes a third species *Patella vulgata*, in case the resource is intended to be managed by temporal closures during the fertile period, it should be established following the fertile period of *P. vulgata*, which is restricted to 3–4 cold months, while the studied species show mature individuals throughout much of the year. It is recommendable to not harvest the largest individuals, since energetic condition decreases with size; in addition, larger individuals show longer maturity periods and might therefore contribute to recruitment to a greater extent. Size distribution observed in sheltered areas showed a lack of juveniles. This can be pointing to lower recruitment, suggesting caution in order to avoid overexploitation in these areas.

1. Introduction

Limpets of the genus *Patella* are generally present in rocky intertidal zones in temperate areas of the Eastern Atlantic and the Mediterranean, constituting a key organism in controlling algal coverage and, consequently, succession processes in rocky intertidal zones. Limpets have been widely exploited for human consumption since the Palaeolithic period (Turrero et al., 2014). As a consequence of intense exploitation, some species are endangered, such as *Patella ferruginea*, which is currently considered the most threatened marine invertebrate in the Mediterranean (according to the European Council Directive 92/43/EEC). In areas of the Atlantic coast, such as the Canary Islands and Azores, *Patella candei* is in a similar situation of commercial extinction (BOC, 2004; OSPAR, 2010). This opened a commercial opportunity for the Galician fisher's guilds, which started to exploit limpets mainly to be exported to the Canary Islands. From 1998 on, this fishery has being growing, since limpets have become an interesting secondary resource that complements the income of shellfish gatherers during closure periods or when captures of other species are low: Limpets are abundant and easily located and harvested. In addition, limpets are grazing molluscs and their fishery is not affected by red tides associated to Diarrheic Shellfish Poisoning (DSP) and Amnesic Shellfish Poisoning (ASP), which so frequently occur in these coasts, forcing the closure of the harvesting of filtering molluscs. Nowadays 13 fisher's guilds in Galicia are involved in this activity (Data from the Galician Ministry of the Sea [Consellería do Mar] http://www.pescadegalicia.com/). The fishery concerns three Atlantic *Patella* species that co-exist in rocky intertidal areas of the Galician coast (Costas et al., 1995): *Patella vulgata*, Linnaeus, 1758, *Patella depressa*, Pennant, 1777 and *Patella ulyssiponensis*, Gmelin, 1791. Differences in their biology and population dynamics have

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been widely documented, showing a great intra- and inter-specific variability related to biotic and abiotic parameters (Baxter, 1983; McCarthy et al., 2008; Morais et al., 2003; Moore et al., 2007; Ribeiro et al., 2009). In spite of their variability, both at a micro and mesoscale, no studies have been carried out in Galicia, where the coast shows important differences regarding substrate type and oceanographic conditions, depending on its location in the Atlantic or the Cantabrian coast. Moreover, the presence of the characteristic "Rías" along both coastal areas provides a coastal landscape with a wide range of degrees of wave exposure, which is a determining factor for the population structure as well as for the amplitude of the breeding period (Fernández et al., 2015). Therefore, there is a lack of the suitable scientific knowledge required to develop exploitation plans adapted to the particularities of each area. The reality is that exploitation plans are being established based on commercial demand and without the support of scientific information; in addition, the presence of several species and their differences in population dynamics or reproductive cycle are not being taken into account in the exploitation plans that are established for "limpets" in general. This could lead to the development of an unsustainable fishery and, consequently, to the overexploitation of limpet populations in certain areas. This situation is particularly undesirable because of the key role of limpets in the rocky intertidal community structure. For this reason, we carried out a study between 2009 and 2011 supported by the fisher's guilds of A Guarda and Ribadeo, in which, during a yearly period, we collected diverse information about the 3 species that are currently being exploited in Galicia.

The main objective of the present study is to analyze the spatial variation of the reproductive cycle and physiological condition of the exploited species *P. depressa* and *P. ulyssiponensis* in the Galician coast, and to determine and quantify the influence of independent factors, such as Atlantic or Cantabrian location, the degree of wave exposure and the individual size of organisms, on the spatial variability of these cycles. Finally, this study is aimed to bring valuable information to contribute to the design of locally adapted exploitation plans that help to the sustainability of the fishery and avoid potential undesirable results for the rocky intertidal community in these areas.

2. Material and methods

The general methodology is described in depth in Fernández et al. (2015). Next, a brief description is provided together with specific models obtained for the annual breeding and physiological condition cycles of *P. depressa* and *P. ulyssiponensis*.

2.1. Sampling and processing

Two areas located in the geographical extremes of the Galician coast were sampled: the area of Ribadeo (R), that is located in the Cantabrian coast and composed mainly by schist, and the area of A Guarda (G), located in the Atlantic and mostly granitic in composition. Within each of these two areas, several sites were selected including, when possible, sheltered and wave-exposed zones (Fig. 1): In Ribadeo, three sites were sampled according to differences in their degree of wave exposure (following Cremades et al., 2004): the high exposed Rinlo (R1); the sheltered with estuary-like characteristics Vilavella (R2), and the sheltered Puerto (R3) located in a harbor site. In A Guarda no sheltered areas exist: here we selected A Grelo (G1) and Camposancos (G2), both very exposed to wave action.

In each sampling site, 30 adult individuals (>15 mm) of *P. depressa* and, when present, also 30 individuals of *P. ulyssiponensis*, were collected each month, from July 2010 to June 2011.

The collection of organisms was done by clearance in haphazardly selected areas at low spring tide, along the intertidal zone. They were transported in seawater to the laboratory and then frozen at −80 °C until analysis. For each individual, gonad maturity stage, sex, total length and biomass were determined.

Gonad maturity stage and sex was determined macroscopically in frozen conditions, following description by Ribeiro (2002) based on Orton et al. (1956): Stage 0 (gonad empty or poorly developed), stage I (gonad almost empty), stages II and III (intermediate stages), stages IV (gonad almost full) and stage V (gonad full). The color of gonad was red or green for females, and cream or orange for males.

Maximum shell length of limpets (SL), was measured with a caliper with a 0.01 mm precision.

Biomass was estimated as dry weight (DW) by drying in a drying oven at 60 °C until constant weight.

2.2. Data analyses

2.2.1. Population structure and sex ratio

Differences in size structure among the limpet populations were analyzed through the Kolmogorov–Smirnov test (KS test).

Differences in the average size of limpets among areas were determined though the *U* the Mann–Whitney.

Sex ratio was analyzed with respect to size and coastal area (Atlantic/Cantabrian), and for *P. depressa*, also to the degree of wave exposure (exposed/sheltered), through a generalized linear model (GLM), assuming a quasibinomial error distribution (logit link function) and establishing the presence of females/males (1/0) at each sampling site as a binary response variable. As none of these parameters were significant, no final models were obtained for any of the two species.

2.2.2. Reproductive cycle

An analysis of the reproductive cycle was carried out in two phases: initial phase (using the data observed from July to December 2010), and final phase of the reproductive cycle (using the data observed from December 2010 to June 2011). *P. depressa* and *P. ulyssiponensis* showed mature gonads from September and then the cut-off point used to separate both phases could be selected before December. Nevertheless, in order to facilitate the comparison of the cycle among the three species co-existing in Galicia, the same cut-off point used to analyze the reproductive cycle of *P. vulgata* (Fernández et al., 2015) was selected. In order to analyze both phases, a GLM with a binomial error distribution (logit link function) was used. To determine the start and end of the phases, the proportion of individuals with gonads in stages 3–5 relative to individuals with gonads at rest or poorly developed (stages 0 and 1) was established along the year, using day of year (Day) as predictor variable. The model was adjusted jointly for males and females, due to the impossibility to determine sex of individuals with resting gonads. This model allowed assessing the effect of independent variables such as coastal area (Cantabrian/Atlantic), individual size and wave exposure (sheltered/exposed), in the initial and final phases of the reproductive cycle. Significance of the variables in the binomial GLM was assessed through the Wald test (χ^2). Final models were selected through the Akaike Information Criterion (AIC), performing a stepwise selection process (Zuur et al., 2009).

P. depressa: The final model obtained for initial and final phases for this species did not include the coastal area because this variable was not significant (Wald test; $\chi^2 = 1.7$, df = 1, $P(>\chi^2) = 0.19$).

$$M_i = \frac{e^{\pi_i}}{1+e^{\pi_i}},\ \text{logit}(M_i) = \pi_i = e^{b_0 + b_1 \cdot \text{Day} + b_2 \cdot \text{SL} + b_3 \cdot \text{Exp}}$$

where M_i is the probability of an individual being mature; b_0, b_1, b_2 and b_3 are the model parameters (see values in Table A1