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Distribution and abundance patterns of three coexisting species of *Patella* (Mollusca Gastropoda) in the intertidal areas of the NW Iberian Peninsula: Implications for management

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ABSTRACT

Using a combination of geostatistical methods and generalized additive models (GAMs), we have analyzed the combined effect of spatial, environmental and biological factors on the density of *Patella vulgata*, *Patella depressa* and *Patella ulyssiponensis*, three limpet species coexisting in rocky intertidal areas of the Galician coast (NW Iberian Peninsula). The best multivariate GAM fit to the data explained, on average, 54% of the observed variation in density of these species, revealing the influence of spatial (latitude and longitude) and environmental factors (temperature). The influence of biological factors such as reproductive status and density of the species, as well as those of coexisting species, was also detected. The results suggest the existence of spatial and temporal segregation behaviours to decrease intra- and interspecific competition. They confirm *P. vulgata* as a migratory species and reveal *P. depressa* also as a migrant limpet, while P. *ulyssiponensis* belongs to the non-migratory group. Geostatistical analysis showed that *P. depressa* is the dominant species in areas more exposed to wave action, whilst *P. vulgata* dominates sheltered area. In addition, the three limpet species are spatially structured in patches, whose density and size vary according to the type of coast (Atlantic/Cantabrian) and to the degree of wave exposure. These results reveal the importance of carrying out assessments at the local level and in those areas particularly vulnerable to exploitation, such as sheltered areas, where densities and recruitment are lower. This information can be useful for decision-making aimed at the management of this resource, as well as for the efficient distribution of effort with respect to geographical fishing areas.

1. Introduction

Limpets of the genus *Patella* are grazing gastropods inhabiting rocky intertidal areas of the East Atlantic and the Mediterranean coast in temperate latitudes. They have a key role in controlling algal coverage and, consequently, the ecological succession and biological communities established in intertidal areas (Jenkins et al., 2005; Coleman et al., 2006a,b). As for several other intertidal invertebrates, limpets have been traditionally exploited for consumption in many places around the world such as Mexico and South of the United States (Pombo and Escofet, 1996), Azores (Martins et al., 1987; Hawkins et al., 2000), and Chile (Olivares-Paz et al., 2006). Likewise, in Spain, particularly in the Canary Islands (Moro and Herrera, 2000) and Asturias, this resource is highly appreciated in gastronomy. In Galicia, the exploitation of intertidal marine invertebrates has a high cultural, social and economic importance. The income of around 4000 people, mainly women, depends on intertidal resources that are harvested by shellfishing on foot. The main species exploited by this method are clams and common cockles, reaching an economic value of 53 M euros in 2014 (http://mar.xunta.gal/). Nevertheless, this sector is currently experiencing a severe crisis because of stock collapses after long-term overexploitation (e.g., bean clams), the occurrence of deadly parasites, such as *Marteilia cochillia* causing devastation in cockles (Villalba et al., 2014), or the frequent toxic red tides that affect this coast (Sacau-Cuadrado et al., 2003) that lead to the temporary prohibition of the exploitation of filtering molluscs such as clams. In the face of this situation, shellfishers are looking for new resources to exploit. In this context, limpets have become an emerging resource; they are abundant as well as easily located and harvested. In addition, limpets are grazing molluscs, and their fishery is not closed during red tide events. Moreover, the situation of commercial extinction of the limpet *P. candei* in the Canary Islands (BOC no. 152, August 6th, 2004) opened an export

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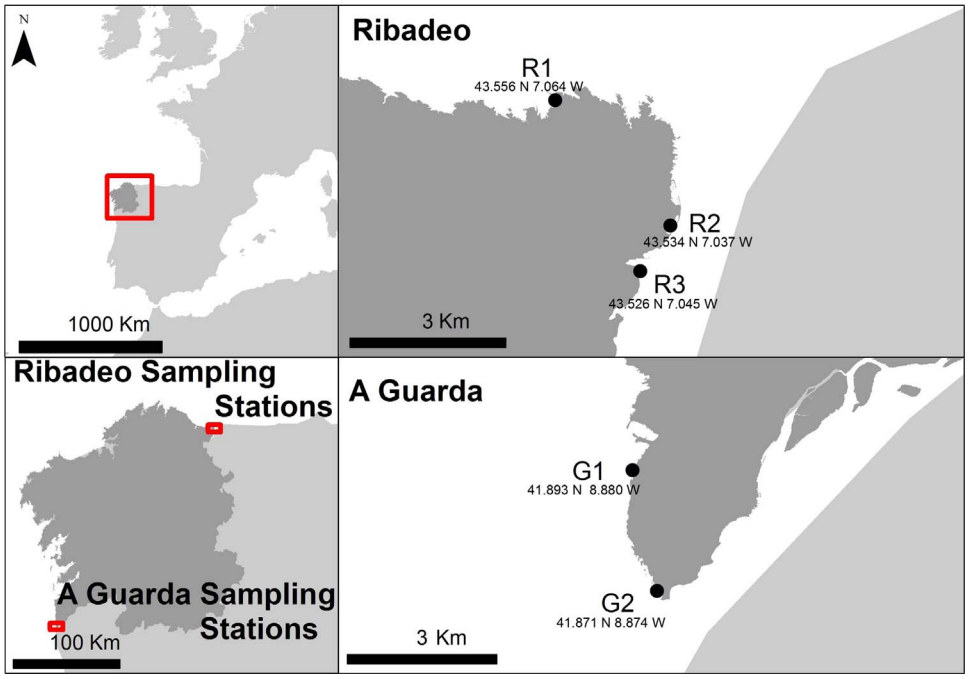

Fig. 1. Map of the sampling sites in each of the two study areas. Sampling sites Rinlo (R1), Puerto (R2), and Vilavella (R3) are shown for the Northeastern area of Ribadeo. A Grelo (G1) and Camposancos (G2) are shown for the Southwestern area of A Guarda. Coordinates (WGS 84) are shown for each site. From Fernández et al. (2015).

trade opportunity for Galician fisher's guilds. Although limpets have been scarce and sporadically exploited up to now, fishers' guilds are increasingly showing interest in this resource. Currently, 17 fishers' guilds in Galicia have an exploitation plan for limpets (Data from the Galician Ministry of the Sea [Consellería do Mar]: http://www.pescadegalicia.com/). However, as usually occurs at the start of such an activity, the limpet exploitation plans have been established based on commercial demand and without the support of scientific information. In the Galician coast (NW of the Iberian Peninsula), three species from cool/boreal and warm/Lusitanian centres of distribution converge: *P. vulgata*, Linnaeus, 1758, *P. depressa,* Pennant, 1777, and *P. ulyssiponensis*, Gmelin, 1791. Intra- and interspecific differences in their distribution and biology have been widely reported in the UK and Portuguese coasts, and have been correlated to biotic and abiotic factors that act at micro and meso-spatial scales (Boaventura, 2002; Boaventura et al., 2003; Ribeiro et al., 2009; Sundelöf et al., 2010). Nevertheless, most of the observations or empirical studies usually involved only one or two of these species. The presence of three coexisting species and their biological interactions are not yet 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.

Knowledge of spatial patterns is essential for developing efficient management strategies, as the management of a resource is influenced by the behaviour and dynamics of the stock, especially by fluctuations in distribution and abundance. Understanding the spatial distribution patterns of the resource can help managers by identifying areas of high abundance and diversity, areas of conservation interest, and areas where particular life stages occur (Katsanevakis et al., 2011). Geostatistics is a powerful tool for the detection, modelling, and estimation of these spatial patterns (Rossi et al., 1992) and has been successfully applied to map and forecast the location, abundance, and spatial characteristics of pelagic and benthic fisheries resources (Freire et al., 1991; Maxwell et al., 2009; Ortega-García et al., 2015) as well as to optimize sampling strategies (Defeo and Rueda, 2002). This approach has been proved useful to improve stock assessment and to evaluate the applicability of spatially explicit management measures, such as rotation of fishing areas or reproductive refuges (Castilla and Defeo, 2001), to reduce the risk of overexploitation (Orensanz and Jamieson, 1998).

However, geostatistical analyses can become complex for analysts from outside the field of statistics, such as biologists, coastal managers, or policy makers, and GIS systems can contribute in an enormous way to simplify the process. Good data visualization is important both for understanding data and for representing the results of statistical analysis (Krivoruchko and Gotway, 2005). Experimental surveys and geostatistics using GIS were employed in this study to map and assess the harvestable biomass of limpets, allowing us to optimize the evaluation of this resource by visualizing the spatial distribution of the three coexisting species along the intertidal areas and identifying areas of low and high abundance for each one of them.

Habitat conditions have the potential to influence local abundance and introduce variability into indices of abundance, complicating trend monitoring (Ouréns et al., 2011; Hernández-Flores et al., 2015). For this reason, understanding how a species is related to the environment is a critical factor for developing ecosystem analyses (Sagarese et al., 2014). Variations in the density of *Patella* spp. have been observed in areas with different degrees of wave exposure (Lewis and Bowman, 1975; Jenkins and Hartnoll, 2001). At a local scale, the coexistence of several species has been suggested to be made possible by habitat segregation (Costas et al., 1995) or by temporal variability on behaviour and/or distribution (Firth and Crowe, 2008). In this sense, differences in the timing of reproduction (Fernández et al., 2015, 2016) and increased aggregation of *P. vulgata* coinciding with the reproductive season have been reported (Blackmore, 1969; Coleman et al., 2006a,b).

The main objectives of the present study are (i) to model the spatial structure of abundance (density) of the three species of limpets coexisting in rocky intertidal areas of the Galician coast, (ii) to produce a map of their distribution, and (iii) to explore the relationships with extrinsic spatial (longitude, latitude) and environmental factors (temperature) and intrinsic biotic factors (reproductive stage of the population and densities of coexisting species). We have also explored the effect of limpet harvesting on the observed densities.

2. Materials and methods

2.1. Study area

Two areas located in the geographical extremes of the Galician coast were sampled to cover both the Atlantic and Cantabrian coast, as well