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Assessing the suitability of the minimum capture size and protection regimes in the gooseneck barnacle shellfishery

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ABSTRACT

The suitability of a total-length-based, minimum capture-size and different protection regimes was investigated for the gooseneck barnacle *Pollicipes pollicipes* shellfishery in N Spain. For this analysis, individuals that were collected from 10 sites under different fishery protection regimes (permanently open, seasonally closed, and permanently closed) were used. First, we applied a non-parametric regression model to explore the relationship between the capitulum Rostro-Tergum (RT) size and the Total Length (TL). Important heteroskedastic disturbances were detected for this relationship, demonstrating a high variability of TL with respect to RT. This result substantiates the unsuitability of a TL-based minimum size by means of a mathematical model. Due to these disturbances, an alternative growth-based minimum capture size of 26.3 mm RT (23 mm RC) was estimated using the first derivative of a Kernel-based non-parametric regression model for the relationship between RT and dry weight. For this purpose, data from the permanently protected area were used to avoid bias due to the fishery. Second, the size-frequency distribution similarity was computed using a MDS analysis for the studied sites to evaluate the effectiveness of the protection regimes. The results of this analysis indicated a positive effect of the permanent protection, while the effect of the seasonal closure was not detected. This result needs to be interpreted with caution because the current harvesting based on a potentially unsuitable minimum capture size may dampen the efficacy of the seasonal protection regime.

1. Introduction

The primary geographical distribution area of the gooseneck barnacle *Pollicipes pollicipes* ranges from the northwestern coast of France (Brittany) to the northwestern coast of Africa (Senegal) and the Mediterranean (Algeria) (Cruz and Araujo, 1999; Barnes, 1996). This species constitutes the most economically important shellfishery resource on the intertidal rocky shores of Portugal and Spain (Cunha and Weber, 2001; Sousa et al., 2013). This species is highly prized as food (>50 Euros Kg^{-1} (Jacinto et al., 2010)) and heavily exploited by professional and recreational fishery. In recent years, this species has attracted increased harvesting pressure due to its high market value (Sousa et al., 2013; Stewart et al., 2014), the decline of other coastal fisheries has urged barnacle exploitation as a supplement to fishing activity (Bald and Borja, 2012), and the European economic crisis. In many regions of the Iberian Peninsula, this decline has resulted in the overexploitation of the stocks (Borja et al., 2011; Stewart et al., 2014). Likely, the current passive management model of the resource (i.e., non-take zones and legal minimal size of capture) of the northern regions of Spain (Cantabria, Basque Country) means a progressive decline of the resources (Jamieson et al., 1999; Bald and Borja, 2012).

However, the assessment of the performance of these management measures is not easy. The fishery capture data are often scarce and lack precise localization information, which leads to not very rigorous estimations of the fishery pressure upon this resource (Sousa et al., 2013). The highest abundances of *P. pollicipes* are located in the lower intertidal zone (Cruz et al., 2010; Pavón, 2003) of significantly energetic shores that are exposed to dominant

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swells, which are frequently related to high slopes and the presence of caves and crevices (Barnes, 1996; Cruz, 2000; Borja et al., 2006b). Consequently, the poor capture data and the physical factors determining the distribution of the genus *Pollicipes* and explaining the difficulty of sampling (Bernard, 1988; Parada et al., 2012) contribute to the lack of large-scale population assessment studies and adequate evaluations of the performance of the management measures. As an alternative, the territorial use rights for fishing (TURF), i.e., an area-based management program that assigns a specific area to an individual, group or community, has proven to be an effective approach for the small-scale management of *P. pollicipes* fisheries in NW Spain (Molares and Freire, 2003). The TURF programs grant exclusive fishing access to these communities while giving them management responsibilities, including the development of annual management plans and the maintenance of appropriate controls of fishing mortality (Young, 2013).

Regardless of the management model, the measures that are oriented toward the achievement of a sustainable exploitation of the resources in N Spain commonly include the minimum size of capture, protected areas (e.g., seasonal or permanent closures) and individual quotas (e.g., Parada et al., 2012; Sousa et al., 2013). In recent years, to react to barnacle population decline in some regions, the establishment of a minimum capture size has received special attention from managers and researchers, particularly regarding the adequacy of the part of the barnacle that is measured. The commonly used capture size in N Spain based on the total length (TL) may be inappropriate because this measure includes both the hard part (capitulum) and the soft part (the peduncle) of the barnacle. The latter has, a priori, an importantly variable typology, with both barnacles with elongated and with smooth peduncles being able to have the same capitulum size (Parada et al., 2012). This finding may lead to heteroskedastic disturbances in the relationship between TL and the capitulum length, i.e., an important variance in TL with respect to the capitulum length as individuals grow in size. This variability in TL depends on environmental factors, such as hydrodynamic patterns, degree of immersion, availability of food and intraspecific competition (Hoffman, 1988, 1989; Page, 1986; Lewis and Chia, 1981).

Several authors have regionally determined that the rostrotergum (RT) (Pavón, 2003) or rostrum-carina (RC) (Cruz, 1993) lengths are the best biometrical variables to explain the growth of this species. Consequently, these two measures and others also based on the capitulum have been considered more adequate for the establishment of the minimum size of capture in NW Spain and SW Portugal (Parada et al., 2012; Sousa et al., 2013). Sestelo and Roca-Pardiñas (2011) recently investigated the minimum capture size for this species using a non-parametric model that analyzes the length–weight relationship and its derivatives. This author suggested an RC length-based capture size that ensures the maximum yield in weight from the fishery. To our knowledge, no information has been published on the impact of the change in the minimum capture size from the TL-based measure to a capitulum-based measure. Despite considering the alternative minimum size based on the capitulum length, the assumed lower suitability of the TL measure compared to the RC or RT has not been properly investigated in terms of the variability of the TL with respect to the growth of the species, i.e., in terms of the heteroskedasticity in TL–RT or TL–RC relationships. However, along the northern coast of Spain (Gulf of Biscay), the minimum capture size is still based on the TL.

Regarding the effectiveness of closure regimes in enhancing population stocks, Cruz (2000) and Sousa et al. (2013) did not find significant effects on the density between areas with different types of exploitation regimes in SW Portugal. Temporal closures (from May to September) are not the most sustainable measures in N Spain because they may not permit the total recovery of the resource after the capture season (Bald et al., 2006). These authors observed that temporal closures could lead to a reduction of the captures by half compared to other measures. These authors developed a dynamic model that is capable of predicting the response of *P. pollicipes* populations to different management measures and suggested that the best management actions consisted of establishing permanently closed fishing areas that would act as important sources of larvae nourishing the exploited areas and biannual rotational temporal closures. Borja et al. (2006b) analyzed the effect of permanently protected zones in the density and biomass of gooseneck barnacle in Basque Country (N Spain). These authors found a significantly higher density of individuals and biomass in permanently unexploited zones (~8.0 kg m^{-2}) compared to that in unprotected areas (~1.5 kg m^{-2}). The failure of the temporal closures might be in part linked to the current minimum size in N Spain.

The extraction of *P. pollicipes* in N Spain is regulated by regional-scale management models largely based in a legal capture size of 40 mm of total length and different types of closure regimes. The purpose of this study was to investigate the effectiveness or suitability of these management measures, considering that the failure of the temporal closures may be in part associated with the potential unsuitability of the current minimum size. For this purpose, the coastline of Cantabria (Gulf of Biscay) of 215 km was selected as a case study due to (i) the fact that the management model in this region permits the analysis of three types of protection regimes (i.e., permanently open, seasonally closed, and permanently closed) and (ii) the lack of previous assessments of the efficacy of these management measures. The conditional variance of the total length with respect to the growth was analyzed (i) to properly assess the suitability of the capture size based on a measure including the soft part of the barnacle and, if unsuitable, (ii) to estimate an alternative capture size using a nonparametric regression model for the capitulum length–weight relationship. The results may confirm with a mathematical model the suitability of the capitulum length-based minimum size measures that are already implemented in other regions. The size-frequency distribution similarity between zones with different protection regimes was analyzed to evaluate their effectiveness. The results of this latter analysis were interpreted according to the differences between the original minimum capture size and the alternative size that is proposed in this study.

2. Material and methods

2.1. Study area

The total area of study covered 215 km of coast in the Cantabria region (Fig. 1). Due to the lack of proper habitat suitability data (i.e., mapping), the suitable habitat of gooseneck barnacle was identified using a compilation of information coming from cartographic data, professional shellfishers and technical personnel of the Regional Fishing Directorate. A total of 10 coastal areas of different lengths covering 60 km of coastline were considered common shellfishing zones. These areas were managed under different protection levels according to their fishery closure regime: (1) Llaranza, Ubiarco, Liencres, Arnia, Diablo and Cerdigo were opened to the fishery throughout the year; (2) Arena, Prellezo and Oreña were seasonally protected, being closed to the fishery from 1st May to 1st October; and (3) Sonabia was permanently protected and closed to the fishery throughout the year (Fig. 1). A sampling site that was representative of the abundance of each fishing zone was selected based on the compiled information from shellfishermen and technical personnel. The criteria for this selection were to have similar accessibility and wave exposure for every site.