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Abundance and fragmentation patterns of the ecosystem engineer *Lithophyllum byssoides* (Lamarck) Foslie along the Iberian Peninsula Atlantic coast. Conservation and management implications

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ABSTRACT

The crustose calcareous red macroalgae *Lithophyllum byssoides* (Lamarck) Foslie is a common ecosystem engineer along the Atlantic and Mediterranean coast of the Iberian Peninsula. This species is threatened by several anthropogenic impacts acting at different spatial scales, such as pollution or global warming. The aim of this study is to identify scales of spatial variation in the abundance and fragmentation patterns of *L. byssoides* along the Atlantic coast of the Iberian Peninsula. For this aim we used a hierarchical sampling design considering four spatial scales (from metres to 100s of kilometres). Results of the present study indicated no significant variability among regions investigated whereas significant variability was found at the scales of shore and site in spatial patterns of abundance and fragmentation of *L. byssoides*. Variance components were higher at the spatial scale of shore for abundance and fragmentation of *L. byssoides* with the only exception of percentage cover and thus, processes acting at the scale of 10s of kilometres seem to be more relevant in shaping the spatial variability both in abundance and fragmentation of *L. byssoides*. These results provided quantitative estimates of abundance and fragmentation of *L. byssoides* at the Atlantic coast of the Iberian Peninsula establishing the observational basis for future assessment, monitoring and experimental investigations to identify the processes and anthropogenic impacts affecting *L. byssoides* populations. Finally we have also identified percentage cover and patch density as the best variables for long-term monitoring programs aimed to detect future anthropogenic impacts on *L. byssoides*. Therefore, our results have important implications for conservation and management of this valuable ecosystem engineer along the Atlantic coast of the Iberian Peninsula.

1. Introduction

Marine ecosystems provide essential goods and services to mankind, but anthropogenic impacts frequently threat the function and integrity of these systems (Halpern et al., 2008). Rising anthropogenic pressure has increased the number of diffuse and chronic impacts on coastal ecosystems. These different impacts interact over a range of spatial scales, complicating the assessment and management of ecosystems. The planet mean temperature and the sea level are rising as consequence of the increase of greenhouse gases (Burrows et al., 2011; Jackson and McIlvenny, 2011). Increased emissions of carbon dioxide in the atmosphere are also producing a reduction in the seawater pH (Caldeira and Wickett, 2003). Additionally to the effects of climate change, ecological impacts related to species invasion (Grosholz, 2002) and overfishing (Myers and Worm, 2005) are acting at global scale. Furthermore, chemical pollution, recreational use of coastal areas and habitat degradation are overlapping with global impacts at regional and local spatial scales.

Ecosystem engineers are organisms that modify, create or maintain useful habitats for other organisms (Jones et al., 1994). Due to environmental amelioration and provision of large diversity of microhabitats, biogenic ecosystem engineers are very often species-rich in contrast with the surrounding areas where diversity and abundances are usually lower. Because managing ecosystem engineers can protect numerous associated species and functions, using these organisms as conservational targets has been advocated (Crain and Bertness, 2006). The ecological importance of ecosystem engineers is widely accepted nowadays but a better management of these organisms is needed. In order to develop realistic conservation and management strategies to identify and ameliorate anthropogenic impacts, managers need access to baseline ecological measurements from appropriate temporal and spatial scales. The lack of these baseline data often results in poor decision-making and environmental policy (Yaffee, 1997).

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The aim of this study is to examine the abundance and fragmentation patterns of an intertidal ecosystem engineer along a latitudinal gradient. We have selected as target species the crustose calcareous red macroalgae *Lithophyllum byssoides* (Lamarck) Foslie. This species is a common ecosystem engineer along the Atlantic and Mediterranean coast of the Iberian Peninsula forming a three-dimensional massive reefs commonly named as "encorbellement" or "trottoir" at the Mediterranean. However, the spatial distribution of this species at the Atlantic coasts of the Iberian Peninsula is quite different, i.e. small individual patches at the mid tidal level of rocky shores (Solera, 1991). Due to its ecological importance, *L. byssoides* is of international concern and appears on the lists of endangered species under protection (Cossu et al., 2006; Kashta et al., 2011). Unfortunately, it is threatened by several anthropogenic impacts acting at different spatial scales. *L. byssoides* has proved to be sensitive to pollution, coastal development, water turbidity and trampling (Boudouresque, 2004). Nowadays the global warming is another important threat for this species. On one hand, the building up of this species is linked to a stable or very slowly rising sea-level so the rising of the mean sea-level resulting from global warming could negatively affect it (Boudouresque, 2004). On the other hand, the increased amount of CO_2 produces higher acidification of the sea water with negative consequences on biogenic calcifications such as that of *L. byssoides*.

In this study, we used a hierarchical sampling design to identify scales of spatial variability in the abundance and fragmentation patterns of the ecosystem engineer *L. byssoides* along the Atlantic coast of the Iberian Peninsula. We specifically examined patterns of variability of percent of cover, volume, patch density and patch cohesion over a variety of spatial scales, ranging from meters to hundreds of kilometers. We have included fragmentation estimators because despite of its ecological relevance (Bell et al., 2001), fragmentation has often been neglected in the assessment of spatial variability of benthic assemblages. Fragmentation of habitats that results in an increase in the number of patches and also in a decrease of the mean patch size has been linked to changes in spatial distribution or patterns of spatial abundances in many systems (Bell et al., 2001).

Previous studies that have examined marine communities at different spatial scales have highlighted that variability is large at small scales in almost all the habitats examined (see revision by Fraschetti et al., 2005). Therefore, a small-scale patchy distribution of benthic organisms has repeatedly been demonstrated for nearly all populations and assemblages at the scales of centimeters or meters (Fraschetti et al., 2005). Thus, with this study we examined the hypothesis of that variability of abundance and fragmentation of *L. byssoides* will be greater at smaller spatial scales being even larger than broad-scale variability. Furthermore, this study will provide baseline values of abundance and fragmentation of *L. byssoides* that could be considered for managing and conservation purposes.

Secondly, in order to implement long-term monitoring programs, we have to detect the best variables for this purpose. Variables to detect anthropogenic impacts should be relatively stable in space and time because its stability reduces the possible confounding effect of natural variability (Glasby and Underwood, 1998; Underwood and Peterson, 1988). As a second objective of this study we therefore intend to identify more proper variables of abundance and fragmentation to detect anthropogenic impacts on *L. byssoides*.

2. Material and methods

2.1. Study area

The study area encompassed approximately 885 Km between latitudes 43° 40′ 37.55 N and 37° 31′ 22.45 N, respectively from Galician (NW Spain) to Portuguese continental coasts, with the exception of the southernmost coast of Portugal (i.e. Algarve). The coast was divided in five regions: A Mariña (AM), Costa da Morte (CM), North Portugal (NP), Central Portugal (CP) and South Portugal (SP) corresponding to the main stretches of rocky coastline (Fig. 1; Table 1). This area presents a semidiurnal tidal regime, with the largest spring tides of 3.5–4.0 m. The wave regime is dominated by swells from the NW (73%) with those from the W contributing 16%. The mean wave height varies strongly among seasons. In the spring-summer period, typical wave heights are between 1 and 3 m. Most storms occur during autumn-winter months (October-March) when wave heights often exceed 7 m (Dias et al., 2002).

There are several latitudinal environmental gradients along the Atlantic coast of the Iberian Peninsula that can drive the spatial abundance and fragmentation of *L. byssoides*. The most important of these oceanographic gradients are: (1) Sea surface temperature (SST) that shows a latitudinal gradient with an increase of the temperature from North to South (Gómez-Gesteira et al., 2008); (2) The Atlantic Iberian Peninsula coast is affected by seasonal upwelling events but these processes differ in intensity and in distance from the shore along this coast (Ospina-Álvarez et al., 2010; Prego and Bao, 1997). A more detailed description of the study area can be found in Rubal et al. (2013).

2.2. Sampling design

Sampling was done during the spring tides of July and August 2011. A fully hierarchical sampling design was used to study the spatial distribution of *L. byssoides* in terms of abundance (i.e. percentage cover and volume) and fragmentation (i.e. patch cohesion and patch density). The first spatial scale of sampling corresponds to that of the five aforementioned regions (i.e. AM, CM, NP, CP, SP) separated from each other by 100s of km. Within each region, three rocky shores, separated by 10s of km, were selected (Fig. 1; Table 1). Within each of these shores, three sites, separated by 10s of ms, were randomly selected. At each site, the percentage cover of *L. byssoides* was estimated in situ following the procedure of visual estimation proposed by Dethier et al. (1993) using five quadrats (50 × 50 cm) randomly deployed at the midshore (2–2.5 m above low tide; height varied slightly among shores) where *L. byssoides* is usually present. Patch density and patch cohesion were calculated following Schumaker (1996) and Godet et al. (2011) from pictures of five quadrats (50 × 50 cm) at each site. Patch density provides a simple measure of the fragmentation (number of patches by total area) whereas patch cohesion gives the physical relationship between each patch (Godet et al., 2011). The later variable allows quantifying the connectivity of habitat as perceived by organisms (McGarigal et al., 2002). Moreover, five patches of *L. byssoides* were scrapped at each site to measure their volume; that was determined by water displacement in the laboratory (Sheppard et al., 1980).

2.3. Data analyses

The spatial distribution patterns of the aforementioned parameters were examined by means of a 3-way nested analysis of variance (ANOVA). Data were analysed using a balanced fully-nested design with three random factors: region (5 levels), shore (3 levels, nested in region) and site (3 levels, nested in location and region) ($n = 5$). Prior to the analysis, the Cochran's C-test was employed to assess homogeneity of variances and if necessary, data were transformed. If homogeneity was not achieved after transformation, untransformed data were analysed and the more stringent criterion of $P < 0.01$ was used to reject null hypotheses (Underwood, 1997).

Variance components were obtained using mean squares by dividing the difference between the MS of the term of interest and that of the term hierarchically below by the product of the levels of all terms below that of interest. Analyses for the calculation of variance components were done on untransformed data to provide variance components comparable across all data (Fraschetti et al., 2005).

One-way analysis of variance (ANOVA) was used to test if spatial variance of abundance and fragmentation of *L. byssoides* at the spatial