Estuarine, Coastal and Shelf Science 179 (2016) 90–98

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

The role of geomorphology in the distribution of intertidal rocky macroalgae in the NE Atlantic region

Elvira Ramos [a], José Ramón Díaz de Terán [b], Araceli Puente [a], José Antonio Juanes [a, *]

[a] Environmental Hydraulics Institute (IH Cantabria), University of Cantabria, PCTCAN, C/ Isabel Torres nº 15, 39011 Santander, Spain
[b] Dpto. de Ciencias de la Tierra y Física de la Materia Condensada, Facultad de Ciencias, Universidad de Cantabria, Avda. Los Castros s/n, 39005 Santander, Spain

A R T I C L E I N F O

Article history:
Received 20 October 2014
Received in revised form
17 September 2015
Accepted 10 October 2015
Available online 21 October 2015

Keywords:
Seaweeds
Rocky shores
Coastal morphology
Coastal orientation
Active processes
Lithology

A B S T R A C T

It is known that rocky macroalgae distribution depends on several abiotic factors, but little attention has been given to geomorphological influences. This paper analysed the relation between geomorphological variables (active processes, coastal morphology, coastal orientation and lithology) and rocky intertidal macroalgae species at a local scale. Thirteen sites were sampled along the coast of Cantabria (North Spain) in order to obtain covers of macroalgae species. Multivariate analysis and logistic regression were applied, predicting the probability occurrence of macroalgae species as a response to the predictor geomorphological variables. Our results showed that coastal morphology and coastal orientation were the principal geomorphological factors explaining the structure of macroalgae communities. The most significant differences in substrate preferences were found between *Bifurcaria bifurcata*, that appears in wave-cut platforms oriented towards the east, and *Corallina officinalis*/*Ellisolandia elongata* and *Gelidium spinosum*, which are found in cliffs oriented towards the north and west. Although these variables help to characterise species distribution, their predictive value is still limited, possibly due to other factors influencing macroalgae. Thus, some of the geomorphological variables studied here are among the environmental factors that determined the distribution of intertidal macroalgae communities at a local scale, even if not always in a direct way.

1. Introduction

The successful protection and management of marine diversity, the assessment of anthropogenic impacts and the restoration of altered ecosystems rely largely on understanding the processes and factors that structure biological assemblages (Chapman, 1999). Thus, relationships between environmental factors and organisms need to be explored in order to recognise the key agents that determine the composition of communities and the distribution of species.

Several abiotic and biotic factors determine the distribution and structure of coastal benthic communities, depending on the main drivers of ecological processes and patterns at a spatial scale (Levin, 1992). At a global scale, temperature and solar radiation are mainly responsible for biogeographic differences (van den Hoek, 1982; Lüning, 1990; Ramos et al., 2014). At a regional scale, exposure to wave action, tidal range, salinity and nutrients, among other factors, may play a major role in the distribution and structure of intertidal communities (Kautsky and van der Maarel, 1990; Ramos et al., in press). However, at a local scale some of these variables do not vary significantly; therefore other factors, such as geomorphological characteristics and vertical height, seem to affect species distribution (Schoch and Dethier, 1996; Díez et al., 2003; Chappuis et al., 2014; Bermejo et al., 2015). On the other hand, changes also occur on a seasonal basis, since intra-annual fluctuations in the abiotic parameters (temperature, light and salinity) determines species reproduction and growth (Lüning, 1990; Raffaelli and Hawkins, 1996). In temperate seas, as the North coast of Spain, the period of maximum development for most seaweed populations is from late spring (June) to late summer (September), with seasonal episodic explosion of ephemeral species occurring in April–May ("naturally opportunistic species") (Juanes et al., 2008). A study carried out in the Cíes Islands (NW Iberian Peninsula) concluded that geographical features and shore slope are among the factors that explain the differences in species assemblages and

* Corresponding author.
E-mail addresses: ramose@unican.es (E. Ramos), diazjr@unican.es (J.R. Díaz de Terán), puentea@unican.es (A. Puente), juanesj@unican.es (J.A. Juanes).

http://dx.doi.org/10.1016/j.ecss.2015.10.007
0272-7714/

the tidal level at which each species is found (Troncoso and Sibaja-Cordero, 2011). A similar study in the Azores Islands showed that the agents that strongly influence community structure and determine major biotope separations are shore level and substratum type, as well as wave exposure (Wallenstein and Neto, 2006).

Focussing on geomorphological features, different variables may affect the sessile assemblages in different ways. The orientation (direction of the surface floor), slope and texture of the surface may cause differences in drainage, evaporation, sedimentation and shade, modifying the characteristic patterns of the intertidal zone (Lobban et al., 1985; Rinne et al., 2011). Roughness may also influence composition through indirect effects on herbivore activity (Jenkins et al., 2008). The type of substratum affects the retention of heat and water, which makes algae grow or survive better (McGuinness and Underwood, 1986; McGuinness, 1989), causing differences among assemblage structures and the covers of individual taxa of algae (Green et al., 2012). On the other hand, substratum nature could also affect turbidity, as it is high when the substrate is extremely soft (Dixon and Irvine, 1977). In general, the agents that cause the differences in assemblages can change in their intensity due to the geomorphology of the rocky coast (Bird, 2008).

In spite of the important role played by geomorphological characteristics in explaining patterns in the structure of rocky communities (e.g. Cerrano et al., 1998; e.g. Bavestrello et al., 2000), relatively little attention has been paid to the study of these types of interaction, except for those focused on the settlement of larval stages of fauna species depending on rock type (Fischer, 1981; Anderson and Underwood, 1994; Schiaparelli et al., 2003). Although seaweeds are among the most obvious and ecologically important components of rocky shore communities worldwide (Lubchenco et al., 1991), until now little has been known about the influence of substrate mineralogy and geomorphology on their distribution.

Given the important synergies found between geomorphology and macroalgae communities, a detailed study should be performed in order to test the specific effect of each geomorphological variable on rocky intertidal macroalgae species. In order to avoid noise caused by other abiotic factors, it will be appropriate to carry out such a study in a homogenous area based on meteo-oceanographic conditions. For this reason, the coast of Cantabria (North Spain) may be an optimal zone for this study, as it is considered a unique environmental typology at both European and regional scales (Ramos et al., 2012, 2014, in press). In addition, this coast shows geomorphology variability, allowing us to study the influences of different geomorphological factors.

This paper is aimed at testing whether geomorphological features influence the distribution and structure of rocky intertidal macroalgae communities. More specifically, the objective was to determine which geomorphological factors cause differences in macroalgae communities, at which level of community organisation these differences are caused, and the main species affected. This detailed study of seaweeds and their environment contributes to understand about the ecology and distribution patterns of these communities and, consequently, to the assessment and conservation of marine ecosystems.

2. Methodology

2.1. Study area

This study was carried out on the coast of Cantabria, approximately 200 km long, located in the north of the Iberian Peninsula (NE Atlantic). The Cantabrian Coast is divided into a series of pocket beaches and small inlets isolated between rocky headlands. Most of the coastline has quite stable cliffs, as they are formed by compact rocks, although some show clear signs of retreat (Rivas and Cendrero, 1992). The composition of the substrate is mainly massive and stratified cretaceous or carboniferous limestone, with some areas where Palaeozoic quartzite can be found. Waves on the Bay of Biscay approach mostly from the northwest with a mean significant wave height (Hs) of 1 m and a typical winter storm significant wave height of Hs $\approx$ 5 m. The tides are semi diurnal with a mean tidal range of 3 m and a spring tidal range of 5 m.

Within the intertidal area of the Cantabrian coast two clear levels can be distinguished according to macroalgae communities: the middle intertidal, dominated by *Corallina officinalis/Ellisolandia elongata* and accompanied by calcareous encrusters, *Caulacanthus ustulatus, Ceramium* spp., *Chondracanthus* spp., *Osmundea* spp., etc., and the lower intertidal, dominated by *Bifurcaria* spp. and accompanied by *Stypocaulon scoparium, Codium* spp., *Cladostephus* spp., various red small folioses, Champiaceae, etc. (Guinda et al., 2008; Ramos et al., in press).

2.2. Collection of data

In order to obtain biological data, field work was carried out during spring tides in April 2011 and May and June 2012 in 13 sites located along the coast of Cantabria (Fig. 1). We selected sites that covered as much geomorphological variability as possible in the study area. At each site, three transects perpendicular to the coast were selected, which were separated by 50–100 m and had a coverage of macroalgae greater than 50% (see detailed information about transects in Supporting Information, Table A1). A stratified sampling was carried out taking into account the characteristic zonation pattern of the study area previously described. In this way, each transect was divided into two zones: 1) Lower intertidal (belt of brown algae) and 2) Middle intertidal (belt of red algae). Three sampling stations of 50 $\times$ 50 cm were distributed at equal distances in each area. As such, 177 quadrats were sampled, 86 in the lower intertidal and 91 in the middle. Covers of macroalgae species were obtained by photo analyses as described in Ramos et al. (in press) because this is a good approach to relate physical factors to species distribution.

Geomorphological characteristics of the sampling sites were initially obtained by an analysis of the corresponding 1:50,000 Geologic Maps (Geological and Mining Institute of Spain, IGME). In some cases, additional field work was carried out to confirm uncertain data. For each sampling site, four geomorphological variables were considered: active processes, coastal morphology, coastal orientation and lithology, according to the definitions of the categories in Fig. 2.

2.3. Data analysis

The relationship between geomorphological features and intertidal macroalgae was analysed at three levels of organisation: community descriptive parameters, assemblage composition and species preferences. First, specific richness (S) and Shannon–Wiener diversity ($H' \log_2$) were calculated based on species cover in each sample. A one-way ANOVA test was carried out to prove whether differences in these indexes between geomorphological categories were statistically significant. Levene's test for equality of variances and a histogram plot to verify the normal distribution of the data had been performed. If variance was not homogenous after logarithmic transformation, a Kruskal–Wallis test was carried out.

As a second step, an ANOSIM test was applied to detect significant differences in assemblage composition among the geomorphological variables. Prior to the multivariate analysis, cover data was previously square root transformed and the similarity matrix was calculated using Bray–Curtis similarity coefficient.