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Current status and multidecadal biogeographical changes in rocky intertidal algal assemblages: The northern Spanish coast

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ABSTRACT

The biogeographic border between the Eastern and the Atlantic subregions of the Lusitanian Province situated on the west coast of Asturias (N. of Spain) has moved westwards in recent years. A comparative study, consisting in a resurvey of 20 shores sampled in 1977, covering 200 km showed a large-scale change affecting the mid and low eulittoral. Cold-temperate canopy species such as kelps (*Laminaria hyperborea, Laminaria. ochroleuca* and *Saccorhiza polyschides*), fucoids (*Fucus serratus*, *Fucus vesiculosus* and *Himanthalia elongata*) and *Chondrus crispus* have almost disappeared and replaced by warm-temperate species such as *Cystoseira baccata*, *Cystoseira tamariscifolia*, *Bifurcaria bifurcata* and coralline algae (*Ellisolandia elongata*, *Lithophyllum incrustans* and *Mesophyllum lichenoides*). The loss of canopy-species can have consequences for the assemblage, especially in the case of fucoid-dominated assemblages.

1. Introduction

One of the consequences of the ocean warming is the retreat of many species of temperate seaweeds in both hemispheres (Wernberg et al., 2011). In the Northeast Atlantic an increase of sea surface temperature (SST) between 0.3 and 0.8 °C per decade in the last 25 years (Gonzalez-Taboada and Anadón, 2012; Lima and Whetey, 2012) has led to the declining abundance of large brown seaweeds (Lima et al., 2007; Fernández, 2011; Lamela-Silvarrey et al., 2012; Duarte et al., 2013, 2015; Voerman et al., 2013; Yesson et al., 2015). These species (kelps and fucoids) are cold-temperate key structural species characterizing intertidal and subtidal communities and the biogeographic regions along the Atlantic coast of Europe (Dinter, 2001; OSPAR, 2010). If there is a change in the distributional limits of some of these dominating species, changes in the biographic borders may be expected.

The north coast of Spain is a rectilinear fringe approximately 1000 km long in which there is a transition between cold and warm temperate seaweed dominated assemblages (Lüning, 1990) and a differentiation between two biogeographic subregions, the Atlantic-influenced subregion and the eastern subregion (Dinter, 2001; OSPAR, 2010). The former is dominated by cold-temperate species (*Laminaria hyperborea, Himanthalia elongata, Chondrus crispus, Fucus serratus*) while the eastern is characterized by warm-temperate species such as *Cystoseira baccata, Cystoseira tamariscifolia, Gelidium corneum, Bifurcaria bifurcata and Ellisolandia elongata.* This difference is mainly caused by the summer upwelling affecting the Northwest coast of the Iberian Peninsula (Spain and Portugal) (Fraga, 1980, Fiuza, 1983; Botas et al., 1990).

The boundary between these two subregions has been moving eastwards or westwards (Sauvageau, 1897; Miranda, 1931; Fischer-Piette, 1957, 1963) and changes in the sea surface temperature (SST) were used as an explanation for these shifts in species distribution (Fischer-Piettee, op. cit.). The last record for the border was obtained in 1977 by Anadón and Niell (1981) and it was situated in the west coast of Asturias (central north west coast of Spain) until 2000–2003 (Lobón et al., 2008) but, recently, range shifts in the species distribution have been detected. These changes can be summarized as a retreat of cold-temperate species and an expansion of warm temperate species (Fernández, 2011; Fernández and Anadón, 2008; Duarte et al., 2013). The increase in SST, the increase in the height and strength of waves and a reduction in both, the strength and the duration of the summer upwelling (Anadón et al., 2009; Gonzalez-Taboada and Anadón, 2012, Borja et al., 2013; Ramos et al., 2015) may be the main drivers of the change.

Because of the east-west orientation of the coast, most of the coastal waters of the North coast of Spain are found within a narrow latitudinal band, where any northward movement of isotherms is likely to affect species across very large areas (Wernberg

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et al., 2011), so a large-scale change in the position of the boundary between the two above mentioned subregions is expected. In order to test this hypothesis, this work aimed to resurvey the same transects done in 1977 by Anadón and Niell (1981) and use them as a baseline to: 1) describe the current status of the rocky shore intertidal assemblages along 400 km of coast to find the current border, 2) determine if changes in the structure of these assemblages since 1977 have occurred and, if so, 3) identify what those changes have been.

2. Materials and methods

The study was conducted on the central north coast of Spain (Asturias, Fig. 1), where the boundary between cold and warm-temperate canopy-forming seaweeds was situated in the recent past (Anadón and Niell, 1981; Lüning, 1990; Lobón et al., 2008). Twenty shores, the same surveyed between 1977 and 78 by Anadón and Niell (1981) and Anadón (1983), covering 400 km of coastline (Fig. 1) from Buelna (43° 23′ 48″N; 4° 36′ 51″W) to Arnao (43° 33′ 28″N; 07° 01′ 20″W) were re-surveyed in 2007–8.

The sampling protocol was the same as Anadón and Niell (1981) using the same marked fixed transect as in 1977. According to the zonation pattern, samples were distributed at different levels on the shore from the supralittoral to the low eulittoral. Using the height on the Lowest Astronomic Tide (L.A.T.) as the vertical scale, seven levels were sampled, four in the low eulittoral (level 1: 0.00–0.30 m above LAT, level 2: 0.30–0.70 m above LAT, level 3: 0.70–1.00 m above LAT, level 4: 1.00–1.50 m above LAT), two in the mid eulittoral (level 5: 1.50–2.50 m above LAT and level 6: 2.50–3.00 m above LAT) and one in the high eulittoral (level 7: between 3.00 and 4.5 m above LAT). Each shore was visited during spring tides in 1977 and revisited in 2007 and 2–4 random 50 × 50 cm plots were sampled in each level. The collecting technique was the complete removal of plants and associated fauna. The only exception was level 7 that was sampled using percentage cover by two main reasons: 1) to preserve *Pelvetia canaliculata* in those shores where it was present, due to its difficulty to recover after harvesting (Lamela-Silvarrey et al., 2012), and 2) because the difficulties to remove crustose species like *Verrucaria* and barnacles. The higher levels (6 and 7) were only sampled on shores 20, 16, 11, 7 and 5, because the rest of shores are characterized by rocky cliffs and the substratum belonging to levels 6 and 7 are shingle. Apart from the fixed transects, a complete survey of each shore was done in order to provide a complete description of the zonation pattern.

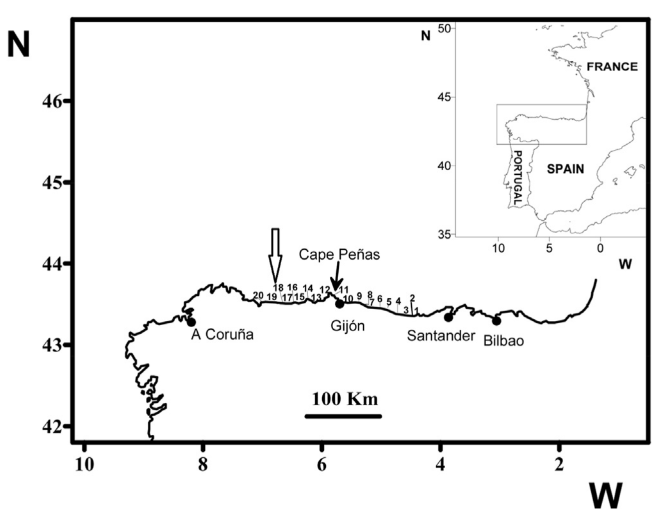

Fig. 1. The North coast of Spain and the situation of the studied shores. (1: Buelna, 2: Llanes, 3: San Antolín, 4: Ribadesella, 5: Caravia 6: La Griega, 7: Rodiles, 8: Playa España, 9: Peñarrubia, 10: Luanco, 11: Bañugues, 12: Verdicio, 13: Sta. María del Mar, 14: Concha de Artedo, 15: Cadavedo, 16: Cueva, 17: Barayo, 18: Cartavio, 19: Punta Arenales, 20: Arnao). The main arrow shows the biogeographic border in 1977 and the second indicates the situation of Cape Peñas as the limit of the influence of the summer upwelling.

Samples were analyzed the same day of collection and laboratory work consisted of separation and identification of the species. Then, they were dried (60 °C, 48 h) and weighted to the nearest 0.01 g.

Species taxonomy was updated using Guiry and Guiry (2014) (AlgaeBase, http://www.algaebase.org) and World Register of Marine Species (WoRMS, 2014, http://www.marinespecies.org), for seaweeds, lichens and fauna.

2.1. Data analysis

Vertical patterns of zonation for 5 selected shores were compared with those described in 1977, using the height on the Lowest Astronomic Tide (L.A.T.) as the vertical scale. Quantitative data on species abundance and distribution were analyzed using multivariate ordination methods on the selected subset of species and the complete set of shores. The replicate quadrats sampled in each shore level were averaged prior to multidimensional analysis. Then, the similarity of macroalgal assemblages was analyzed using non-parametric multidimensional scaling (n MDS) ordination and the Bray-Curtis coefficient as similarity index (Clarke and Green, 1988; Clarke, 1993). The multivariate analyses were performed using PRIMER for Windows v.6.0 on standardized square-root transformed data of biomass. One-way analysis of similarity (ANOSIM, Clarke, 1993) was used to test for differences between years. The contribution of each species to the observed dissimilarity between years was estimated using the similarity percentages procedure (SIMPER, Clarke, 1993). Finally, a species analysis was done for those shores in which the canopy species dominating the assemblage had reduced drastically or disappeared in 2007. After selecting the shores, all samples belonging to the same assemblage in 1977 were compared with the assemblages in 2007. Mean values of biomass (g. d. w/m^2), number of species and diversity (Shannon–Wiener index, H' lg_2) were used as structure descriptors of the assemblage.

3. Results

3.1. Patterns of zonation

Strong differences appear when comparing the zonation patterns from 1977 to 2007. For this purpose 5 shores were selected and the vertical distributions of the main assemblages according to their position on the lowest astronomic tide (LAT) are shown in Fig. 2. The main differences affect those assemblages dominated by large brown cold-temperate seaweeds: *Pelvetia canaliculata, Fucus spiralis, Fucus vesiculosus, F. serratus, Himanthalia elongata, L. hyperborea,* the cold-temperate red algae *Chondrus crispus* as well as other warm-temperate kelps (*Laminaria ochroleuca, Saccorhiza polyschides*). These species started to retreat since 2002 and by the time the shores were re-surveyed (2007) there were local extinctions in some shores while in others there was a marked decrease in biomass. In 2013 the canopy-forming cold-temperate seaweeds have been disappeared from most of the shores where they were dominant species in 1977 (author personal observation).