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Decadal changes in the distribution of common intertidal seaweeds in Galicia (NW Iberia)

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ABSTRACT

Seaweed assemblages in Atlantic Europe are been distorted by global change, but the intricate coastal profile of the area suggests that susceptibility may differ between regions. In particular, NW Iberia is an important omission because no study has systematically assessed long-term changes in a large number of species. Using intertidal surveys for 33 common perennial seaweeds, we show that the average number of species per site declined significantly from 1998–99 to 2014 in NW Iberia. The largest drops in site occupancy were detected in kelps, fucoids, and carrageenan-producing Rhodophyta. Parallel analyses revealed significant upward trends in SST, air temperature, and strong waves; meanwhile, nutrients decreased slightly except in areas affected by local inputs. Similar changes reported for subtidal assemblages in other parts of Atlantic Europe suggest that the drivers may be ubiquitous. Nonetheless, a more proper assessment of both global and local impacts, will require further surveys, and the regular monitoring of intertidal perennial seaweeds appears as a cost-effective alternative to discriminate genuine long-term trends from transitory fluctuations.

1. Introduction

In the last 40 years, world oceans have warmed at a rate of 0.1 °C per decade while wave intensity has increased, for example, over much of the North Atlantic north of 45°N (IPCC, 2013). The increment in physical stress, together with other human impacts, is already impacting the flora and fauna of the oceans with significant changes in the distribution of populations, and a decline of sensitive species (Bijma et al., 2013; Hoegh-Guldberg and Bruno, 2010; Wernberg et al., 2011). In the particular case of macroalgae, our understanding of the links between global change and distribution has increased recently, and a number of studies have specifically documented changes in the abundance and distribution of seaweeds in the Northeast Atlantic over the last 40 years (Borja et al., 2013; Díez et al., 2012; Eriksson et al., 2002; Fernández, 2011; Gallon et al., 2014; Husa et al., 2008; Lima et al., 2007; Pehlke and Bartsch, 2008; Simkanin et al., 2005; Sjøtun et al., 2015). The strongest changes were reported for the southern edge of the Bay of Biscay where important canopy-species (*Gelidium corneum*, *Cystoseira baccata*) seemingly rearranged their distribution while several kelps (*Laminaria ochroleuca*, *Saccorhiza polyschides*) disappeared from 1991 to 2008 (Díez et al., 2012). As a result, seaweed communities in the region became more diverse but less apparent after an increase in smaller taxa with high rate renewal and warm water affinities. These changes were consistent with a rise in SST but other factors such as changes in nutrient concentrations and transparency were thought to be likewise involved (Díez et al., 2012). In Brittany, at the northern end of the Bay of Biscay, increasing SST was suggested as the cause of significant changes detected in red seaweed assemblages over a 20-year period because the strongest shifts happened in the area that warmed most (Gallon et al., 2014). Intriguingly, however, these subtidal assemblages gained cold-water species and lost warm-water ones. Similarly, a recent assessment of changes in the abundance of large brown seaweed around the British Isles over four decades has revealed contrasting regional patterns, with declines in the south for kelps and increases in northern and central areas for some kelp and wracks (Yesson et al., 2015). Further north, several studies reported striking increases in the number of algal species in the littoral zone of the Svalbard archipelago during the late 2000s and early 2010s that were attributed to higher temperatures but, also, to reduced ice scouring over the last years (Fredriksen and Kile, 2012; Fredriksen et al., 2014; Weslawski et al., 2010).

Despite the growing number of studies, our knowledge of the

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long-term changes experienced by seaweed assemblages along the European Atlantic still has gaps because some regions have been largely overlooked. These gaps can be potentially important given that the rate of environmental change, a variable that might affect species responses (Burrows et al., 2014; García Molinos et al., 2015; Sunday et al., 2015), varies between regions along the European Atlantic (Taboada and Anadón, 2012). On region overlooked in long-term studies is Galicia (NW Iberia), an area characterized by many large inlets (rías) that provide a wide range of marine environments from very sheltered conditions to highly exposed ones. As a result, the region has a high diversity of seaweeds, and nearly 85% of the species recorded for the warm-temperate NE Atlantic subregion 1 live in it (Bárbara et al., 2005; Van den Hoek and Breeman, 1990). Many of them are cold-water species, and some even have their southern distribution limit in NW Iberia. The latter include intertidal, canopy-forming carragenophytes (*Chondrus crispus*, *Mastocarpus stellatus*) and fucoids (*Ascophyllum nodosum*, *Himanthalia elongata*, *Fucus serratus*, and *Pelvetia canaliculata*). Moreover, Galicia is strongly influenced by a large upwelling system that, unlike other coastal upwelling ecosystems, has weakened its intensity in the last decades (Bode et al., 2011; Sydeman et al., 2014).

Most of the seaweed long-term studies conducted so far in the European Atlantic have focused on subtidal assemblages whereas intertidal ones have been largely neglected. One exception is the Portuguese coast where many intertidal warm water species seem to have expanded their range northwards over a 50-year period while cold-water ones showed no particular shifting trend as a group (Lima et al., 2007). More recently, the occurrence and distribution of many intertidal, and subtidal, macroalgae along a Norwegian fjord were correlated with variations in water temperature and salinity stress over a 50 year period (Sjøtun et al., 2015). Other studies of intertidal seaweeds in the European Atlantic have focused on much smaller sets of species (Duarte et al., 2013; Lamela-Silvarrey et al., 2012; Simkanin et al., 2005). The shortage of intertidal studies seems somewhat surprising if we recall that the intertidal biota is affected by a wider range of pressures such as fluctuations in both air and sea temperatures, sea level, ultra-violet radiation, storminess, and even the intensity of local human pressures such as trampling and overexploitation (Borja et al., 2013; Halpern et al., 2008; Simkanin et al., 2005). Additionally, the intertidal seems a convenient system for monitoring studies because it is accessible and well-studied, organisms are restricted to a shoreline strip with defined boundaries, and many of its species are conspicuous and/or easy to detect (Lima et al., 2007; Simkanin et al., 2005). In fact, and unlike seaweeds, intertidal invertebrates have often been used to detect temporal changes, and their long-term monitoring indicates that poleward range shifts can been faster in intertidal biota than in most terrestrial species (Hawkins et al., 2008; Helmuth et al., 2006).

In this study, we investigated the changes in the frequency and distribution of 33 common intertidal seaweeds in Galicia (NW Iberia) between 1998–99 and 2014. Data were collected on exactly the same locations by a sampling team that always included one of the researchers that conducted the 1998–99 survey (Cremades et al., 2004) to ensure that we obtained comparable datasets for both surveys and to avoid misinterpretations due to differences in sampling effort and/or changes in ambient conditions at local scale. The sampling plan included sites over a range of wave exposure levels to assess the influence of confounding factors such as wave intensity. In addition, we also analyzed trends in potentially important drivers such as water temperature (SST and *in situ* measurements), air temperature, nutrients, and wave intensity. In a scenario of warming trends, should some cold water species retreat at their southern range margin, we anticipate that their frequency in NW Iberia may decrease. Alternatively, since the flora of NW Iberia also includes some endemics to the Lusitania Province (e.g. *Bifurcaria bifurcata*, *C. baccata*, or *Pterosiphonia complanata*), these species could be more insensitive to water warming.

2. Material and methods

2.1. Study area

The study area was Galicia (NW Iberia) which covers the European coastline between 41° 52′ and 43° 48′ North and 7°00′ and 9°19′ West (Fig. 1). This coastline is extremely rugged with open coast sections interrupted by sheltered rías, and an alternation of hard substrata (rocky cliffs of variable height) and sandy beaches. Tidal regime is semidiurnal with an average range of about 3 m, a minimum range (neap tides) of 1.2 m and a maximum (spring tides) that exceeds 3.5 m (Rey Salgado, 1993). Water temperature typically ranges from 11 °C in winter to 18 °C in summer, but it occasionally reaches up to 24 °C in sheltered zones (Bárbara et al., 2005). Primary production is largely influenced by a coastal upwelling that occurs mainly during spring–summer months and brings nutrient laden Eastern North Atlantic Central Water near the coast and even inside the rias (Alvarez et al., 2011). In comparison, winters often show a landward transport that favors downwelling events when water is retained inside the rias and nutrients are depleted (Varela et al., 2004).

2.2. Environmental data

Five environmental variables were analyzed to search for trends along the period covered by the seaweed surveys (1998–2014). First, weekly sea-skin surface temperature (SST) data on a 1° grid along the NW Iberia coast between January 1990 and December 2014 were obtained from the Physical Sciences Division (NOAA/OAR/ESRL, Boulder, Colorado, USA) from their Web site (http://www.esrl.noaa.gov/psd/). Optimum Interpolation SST data (NOAA_OI_SST_V2) combines ocean temperature observations from satellite and *in situ* platforms, and includes a bias adjustment step of the satellite data to *in situ* data prior to interpolation (Reynolds et al., 2002). In the present study, we considered four data points along the west coast of NW Iberia at 9.5°W spanning from 41 to 45°N. Second, since SST data may not be accurately represent the temperature trends actually experienced by coastal organisms, we also analyzed weekly sea water temperature measurements recorded *in situ*, as well as nitrate and phosphate concentrations, from January 1998 to December 2013 (temperature) and to December 2014 (nutrients) by Instituto Tecnolóxico para o Control de Medio Mariño de Galicia (INTECMAR, Vilagarcía de Arousa, Spain). INTECMAR runs a network of sampling stations to assess water quality on a weekly basis in areas where mollusks are exploited and/or farmed. At each station, INTECMAR collects water samples at depth intervals 0–5 m and 5–10 m. In this study, we used data for seawater samples collected at three sampling stations located within and at the entrance of Ría de Muros (Suppl. Mat. Fig. S1). Third, monthly near-surface air temperatures (i.e. measured by thermometers placed approximately 2 m above the ground) on a 0.5° grid along the NW Iberia coast between January 1990 and December 2013 were obtained from University of East Anglia Climate Research Unit (CRU) (Harris et al., 2014). The CRU dataset is based on monthly observations at meteorological stations across the world's land areas, interpolated into 0.5° grid cells covering the global land surface. In this study, we considered four data points from 41 to 43.5°N at 8.75°W, just over the western shoreline of NW Iberia. Finally, the annual frequency of waves with a significant height >5 m from October to the following March was