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Spatial variability and response to anthropogenic pressures of assemblages dominated by a habitat forming seaweed sensitive to pollution (northern coast of Alboran Sea)

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ABSTRACT

The *Cystoseira ericaefolia* group is conformed by three species: *C. tamariscifolia*, *C. mediterranea* and *C. amentacea*. These species are among the most important habitat forming species of the upper sublittoral rocky shores of the Mediterranean Sea and adjacent Atlantic coast. This species group is sensitive to human pressures and therefore is currently suffering important losses. This study aimed to assess the influence of anthropogenic pressures, oceanographic conditions and local spatial variability in assemblages dominated by *C. ericaefolia* in the Alboran Sea. The results showed the absence of significant effects of anthropogenic pressures or its interactions with environmental conditions in the *Cystoseira* assemblages. This fact was attributed to the high spatial variability, which is most probably masking the impact of anthropogenic pressures. The results also showed that most of the variability occurred on at local levels. A relevant spatial variability was observed at regional level, suggesting a key role of oceanographic features in these assemblages.

1. Introduction

Rocky shores around the world are increasingly being subjected to a variety of anthropogenic stresses, acting at different spatial and temporal scales (Airoldi and Beck, 2007; Coll et al., 2010), and producing noteworthy shifts between alternative stable states in marine ecosystems (Knowlton, 2004; Viaroli et al., 2008; Orfanidis et al., 2011). Recent research has been focused on identifying and assessing the effects of local anthropogenic pressures on the littoral community (e.g. Diez et al., 1999; Arévalo et al., 2007; Seridi et al., 2007) and its interaction with global stressors as ocean warming and acidification (e.g. Brown et al., 2013; Strain et al., 2015). This information is especially important for management, since local anthropogenic stressors are more easily amendable by management and conservation actions (Russell and Connell, 2012; Brown et al., 2013). However, these anthropogenic stressors are superimposed on the stress caused by natural environmental factors and it is difficult to distinguish their contribution (Crowe et al., 2000; Bermejo et al., 2013). Furthermore, these pressures act together, causing non-additive (i.e. synergistic, antagonistic) or additive effects on littoral communities (Knowlton and Jackson, 2008; Brown et al., 2013; Strain et al., 2015). These facts make the discrimination between the two, and the achievement of effective management actions, more difficult. In this sense, proper experimental designs at different spatial scales are useful to estimate the effects produced by anthropogenic stressors on the community, and to identify putative non-additive interactions with environmental conditions.

Canopy forming brown seaweeds which belong to the orders Laminariales, Tilopteridales and Fucales, are among the main habitat forming species on most temperate rocky shores (Lüning, 1990). Currently, many of these species are suffering strong declines in their populations worldwide, which have been attributed to local and global stressors in the context of global change (Steneck et al., 2002; Fernández, 2011; Mineur et al., 2015). In this sense, coastal development has been pointed out as one of the most important factors explaining the loss of habitat forming macrophytes, mainly as a consequence of the increase in water turbidity and eutrophication as well as other habitat related changes (Airoldi and Beck, 2007; Mangialajo et al., 2008). These losses are causing relevant deleterious consequences for local economies and biodiversity (Serio et al., 2006; Voerman et al., 2013). In fact, habitat destruction or degradation is considered the most important threat to the diversity, structure, and functioning of marine coastal ecosystems and to the goods and services they provide (Lotze et al., 2006; Airoldi and Beck, 2007; Coll et al., 2010).

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Significant losses of *Cystoseira* forests (Fucales) have been reported (Thibaut et al., 2005; Serio et al., 2006) and several species of this genus have been identified sensitive to human disturbances in the Mediterranean Sea (Arévalo et al., 2007; Seridi et al., 2007; Mangialajo et al., 2008) and proximate Atlantic coasts (Diez et al., 1999) along different pollution gradients. On these coasts, *Cystoseira ericaefolia* group is among the most important marine habitat forming species on littoral and upper sublittoral rocky shores. This group is conformed by three closely related species: *C. amentacea*, *C. mediterranea* and *C. tamariscifolia* (Giaccone and Bruni, 1971; Amico et al., 1985; Gómez-Garreta et al., 1994); which are not possible to be assigned unambiguously on the basis of their morphology (Ballesteros and Catalán, 1981; Gómez-Garreta et al., 1994). These species can constitute extensive and dense forests in wave exposed or moderately exposed places, in the littoral and upper sublittoral zone (Barceló-Martí et al., 2000; Rodríguez-Prieto et al., 2013), where they are a key element of the landscape (Ballesteros et al., 2007; Bermejo et al., 2013; Thibaut et al., 2014). The *Cystoseira* forests form a complex 3-dimensional physical structure, providing a complex habitat for other algae, invertebrates and fishes (Bellan and Bellan-Santini, 1972; Bulleri et al., 2002; Cheminée et al., 2013) and thus playing an essential role in the conservation of the biodiversity and ecosystem functioning (Ballesteros, 1989; Giaccone et al., 1994).

Due to the ecological importance of assemblages dominated by *Cystoseira* spp. and the decline of their populations within the past decades, these species have recently been protected in the Mediterranean Sea (Annex II of the Barcelona Convention, COM/2009/0585 FIN), their assemblages being considered as habitats of community interest by the UE (Directive 92/43/EEC; Annex I, "Rocky reefs"). Furthermore, as a consequence of the sensitivity of these species to a variety of anthropogenic pressures, they are considered as a relevant biological element by different Atlantic (Díez et al., 2012) and Mediterranean (Orfanidis et al., 2003; Ballesteros et al., 2007) indices to assess the ecological status in the context of the Water Framework Directive (WFD; Directive 2000/60/EC). Previous data of assemblages dominated by *C. ericaefolia* species are available in different localities along the eastern (e.g. Ballesteros et al., 1984; Ballesteros, 1988; Boisset and Gómez-Garreta, 1989) and western Mediterranean Sea (Soltan et al., 2001; Benedetti-Cecchi et al., 2001; Bulleri et al., 2002). However, in the Alboran Sea, the most western ecoregion of the Mediterranean Sea, these studies are scarce, being too local (Ballesteros and Catalán, 1981) or general (Ballesteros and Pinedo, 2004).

The position of the Alboran Sea, in the transition towards the Atlantic Ocean, and its special orographic features, produces complex oceanographic and meteorological conditions (García-Lafuente et al., 1998; García-Lafuente and Ruiz, 2007), which determine the distribution and the structure of the littoral and sublittoral communities (Conde, 1989; Bermejo et al., 2013). This area can be considered as a soft transition between the Atlantic Ocean and the Mediterranean Sea (Báez et al., 2004; Ballesteros and Pinedo, 2004), and three biological subregions matching with regional oceanographic patterns can be identified. This feature suggests a key role of regional oceanography in the structure and composition of littoral communities along the northern coast of this sea (Bermejo et al., 2015).

In this context, the main objectives of the study were: i) to assess the influence of anthropogenic pressures, oceanographic conditions and local spatial variability in determining the taxonomic and functional composition of littoral assemblages dominated by *C. ericaefolia* species along the rocky shores of the northern coast of the Alboran Sea; and ii) to establish a suitable baseline describing the structure and composition of assemblages dominated by *C. ericaefolia* species along the studied coasts. To accomplish these goals an observational experiment was developed, taking advantage of the complex oceanographic conditions and the wide range of anthropogenic disturbances that can be found along this coast. Due to the lack of previous data for the studied localities, all comparisons were developed between localities under different levels of anthropogenic pressures in each of the biological subregions previously identified along these coasts.

2. Materials and methods

2.1. Study area

The northern coast of the Alboran Sea is mainly oriented in a longitudinal direction (from aprox. 5° 30′ W to 0° 30′ W, and from 36° N to 37° 30′ N; Fig. 1), which reduces the influence of other confounding climatic factors that covariate with latitude (e.g. day length, solar irradiation, temperature), being environmental conditions mainly driven by local oceanographic conditions (Conde, 1989; Bermejo et al., 2015). Three coastal subregions with different oceanographic dynamics have been identified on its northern coast (Bermejo et al., 2015; Fig. 1): i) western Alboran (from site "Mi" to "TQ"), where littoral environmental conditions are determined by the existence of a semi-permanent upwelling, which determines a lower mean seawater temperature (c.a. 17 °C) and richer nutrient waters; ii) eastern Alboran (from site "GV" to "ST"), where the prevailing coastal conditions are determined by the dynamics of Mediterranean Surface Waters (MSW), it shows the broadest thermal amplitude (from 25 °C in summer to 14 °C in winter) and the most oligotrophic character (Parada and Canton, 1998; Baldacci et al., 2001); and iii) central Alboran (from site "Ar" to "CR"), characterized by alternative episodes of upwelling and the presence of MSW, specially during summer. These alternative episodes are driven by winds, and produce short-time oscillations in temperature and nutrient availability, which should cause an acute stress for benthic organisms (Bermejo et al., 2015).

Diverse anthropogenic pressures related to high-density population (e.g. in sites "CH" or "TQ"), intensive agriculture (sites "CR", and "GV"), industrial activities or marine traffic impact these coasts, affecting the development of biological communities (Díaz-de Alba et al., 2011; Alonso Castillo et al., 2013; Bermejo et al., 2013, 2014). However, the studied area also comprises different protected areas under low anthropogenic pressures such as the Natural Parks of "El Estrecho" (western Alboran; site "Mi") and "Cabo de Gata" (eastern Alboran, sites "Co" and "Ne"), or the Site of Community Importance "Calahonda-Castell de Ferro" (central Alboran, site "Ri"), which show a high percentage of cover by natural lands and are far from important pollution sources (Fig. 1).

2.2. Anthropogenic pressures assessment

Anthropogenic pressures were assessed based on the land use (e.g. Lopez-Royo et al., 2009; Nikolić et al., 2013) along a two kilometre long and half a kilometre wide stretch following the surrounding coast to the sampling site (ca. 1 km^2). Three types of land uses were considered: natural, agricultural and urban. For each type of land use, the percentage of cover was calculated from the total area of the stretch considered using the Quantum Geographical Information System (QGIS). The geographical data needed were obtained from the CORINE land cover maps of Spain (National Geographical Institute, http://www.ign.es/ign/layoutIn/corineLandCover.do). For statistical analysis, sampling sites were classified as follows: under "None/Low" anthropogenic pressures, when the percentage of natural land was higher than 60% and urbanized lands lower than 30%; or under "Moderate/High" anthropogenic pressures, when the percentages of natural land were lower than 60% or urbanized land higher than 30%.

2.3. Sampling of "C. ericaefolia" assemblages

The samples of assemblages dominated by *C. ericaefolia* were taken between 2011 and 2012, at 18 sites along the northern coast of the Alboran Sea (Fig. 1). To diminish the effects of seasonal variability, field samplings were carried out during late spring and midsummer (June–August).

Three or four replicates of quadrats of 17 × 17 cm^2 separated between five and ten metres were taken in assemblages dominated by