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*Full Length Research Paper*

# Spatial pattern of vertical zonation of rocky shore organisms and the influence of ocean exposure at the Islas Cíes (NW Spain)

**Jesús S. Troncoso[1] and Jeffrey A. Sibaja-Cordero[1,2]***

[1]Departamento de Ecología y Biología Animal, Facultad de Ciencias del Mar, Universidad de Vigo, Campus Lagoas Marcosende, 36310 Vigo, Spain.
[2]Centro de Investigación en Ciencias del Mar y Limnología (CIMAR), Universidad de Costa Rica, San Pedro, 11501-2060 San José, Costa Rica.

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**A sampling was conducted around the intertidal coast of the Islas Cíes, (NW Spain) with the goal of determining the variation of the shore landspace, based on vertical zonation profiles of sessile organisms in relationship with the Atlantic Ocean influence. The Western Coast is heavy wave beaten and the Eastern Coast is sheltered. Many species coexist in a limited intertidal space of the sheltered than in the exposed shores. The sheltered coast presents in this way, a mosaic structure of their organisms. On the other hand few species dominated the cliffs of the west coast. In this section, the upper intertidal limit of distribution was raised by the increased of humidity caused by the splash and spray. The winds also favoured the presence at the high littoral level of organisms such as brown algae, lichens and vegetation. Multivariate techniques detected differences in the communities between exposed and sheltered shores as well as between the two main islands. Distribution of species in the intertidal zone was related to the particular geomorphological feature of the coast, such as coves, points or exposed cliffs. Four different landscape intertidal patterns of vertical zonation were represented by each island face. The algae, *Asparagopsis armata* and *Bifurcaria bifurcata* characterized the sheltered North Island. *Pelvetica canaliculata* and *Fucus spiralis* had a greater presence in the sheltered side of the South Island. The fucoids were absent at the wave beaten shore. The lichens, *Verrucaria maura* and *Caloplaca marina*, and the Rhodophyta belt had a higher upper limit of distribution at the exposed sides of the North Island. Bare rock and the crust phase of *Mastocarpus stellatus* had a greater presence at the exposed side of the South Island.**

**Key words:** Intertidal ecology, Galician Coast, ocean exposure, sessile organisms, digital image analysis, multivariate analyses.

## INTRODUCTION

Patterns of vertical zonation of intertidal organisms are caused, in general, by the effects of physical stress and biotic interactions (Connell, 1972; Menge et al., 2010). Several belts or assemblages of organisms have been described and delimited in terms of the dominant species (Chapman, 1974). Thus, the high littoral is characterized by snails (Littorinidae), the middle shore is defined by sessile organisms such as barnacles and mussels, and the low littoral is dominated by algae (Ellis, 2003). The principal causes of differences in assemblages were the wave exposure, larval transport, food supply and spatial heterogeneity (Menge, 1976; Menge et al., 1997; Schiel, 2004). In addition, settlement of larval stages depends on the rock type (Fischer, 1981). These factors can change

*Corresponding author. E-mail: jeffro@costarricense.cr.

in their intensity by the coastal geomorphology of rock platforms and cliffs (Bird, 2008). The fauna in temperate rocky shore present truly marine species in the low intertidal zone and semi-terrestrial species in the supra-tidal (Ellis, 2003). De la Huz and Lastra (2008) point out that these two types of organisms respond in a different manner to physical factors in sandy beaches in the Galician shores.

Three-quarters of the world's coastline is composed of cliffs and rocky substrata in general; the majority of inter-tidal ecology studies were, however, developed in shore platforms characterized by sampling accessibility and safe conditions for the researchers (Little and Kitching, 1996; Bird, 2008). The Galician coast is mainly rocky and the cliffs dominate the shore (Pérez-Cirera, 1978; Vilas-Paz et al., 2005). By this reason, few studies were done in wave-exposed rock walls of Galicia (Niell, 1977; 1978; Olabarria et al., 2009). A basic description of the vertical distribution of organisms at the north of Galicia was provided by Pérez-Cirera (1975). Additionally, the rocky shores of the north coast of Portugal present similar assemblages of organisms (Araújo et al., 2005; Pereira et al., 2006).

The southern Galician coast is characterized by the Rías Baixas that are flooded tectonic valleys (deCastro et al., 2000). These mouth of these estuarine systems present islands with intertidal cliffs and rocky shores (Vilas-Paz et al., 2005). The benthic assemblages of these islands have scarcely been studied (Acuña-Castroviejo, 1984; Niell, 1977; Besteiro-Rodriguez et al., 2004) and the vertical zonation of intertidal organisms and their geographically variation are therefore unknown. In this way, this paper describes the vertical zonation of sessile organisms (algae, lichens, mussels and barnacles) along the rocky coast of the two main islands of the Islas Cíes (NW Spain). The aim of this work is to test if the vertical zonation profiles differ in presence, position on the rock and dominance of species according to the oceanic exposure and geographic position within the National Park of the Islas Cíes.

## METHODS

### Study site

The Ría de Vigo is located at the Atlantic coast of Spain, which is the boundary between the subpolar and temperate regimes of the coastal upwelling system of the Eastern North Atlantic. The seas-onal quasi-permanent upwelling occurs from April to October and is driven by the northerly trade winds. The Ría de Vigo is partially enclosed at the mouth by three natural islands, That is, Islas Cíes, which provide some shelter for the inner of the Ría de Vigo (Figure 1). These islands have the status of Galician Natural Parks since 1980, and that of National Park since 2002 (de Castro et al., 2000; Costas et al., 2002; Bernárdez et al., 2006; Diz et al., 2006).

The maximum deep at the south of the Islas Cíes is 53 m and at the north entrance is 30 m. In front of the West Coast of the Islas Cíes the deep is near the 100 m (García-García et al., 2005). The tidal amplitude is of 2 to 3 m during the neap and spring tides as in most of the Galician Rías (de Castro et al., 2000). The two northern islands (Figure 1) are connected at the eastern margin by a 1 km long sand barrier system (Rodas Beach), which confines a shallow lagoon (Costas et al., 2002). The walls of the Islas Cies are made up of granitic rock (García-García et al., 2005; Vilas-Paz et al., 2005). About 20% of the emerged surface corresponds to pro-nounced cliffs (Acuña-Castroviejo et al., 1984). The western side of the Islas Cíes disrupts the propagation of waves produced during storms. These waves have 7 m height and 16 s of period (Queralt et al., 2002). In Figure 1, the sites 14 to 19 and 29 to 40 have low wave energy and the sites 1 to 13 and 20 to 28 represent a high wave-beaten coast (exposed directly to oceanic influence); this classification follows that by Acuña-Castroviejo et al. (1982) in their study of the sublittoral ecotones and the wave pattern by Queralt et al. (2002).

### Methodology

The rocky shore of the south and north islands of the Islas Cíes National Park (NW Spain) were sampled at low spring tide on 28th February and 14th March 2009, respectively. The coast around the islands was divided into 40 sections (Figure 1); those sections were photographed from a boat. In each section, several pictures were taken with a digital camera (7 megapixels). A total of 482 images were taken, each one from an independent point of the rocky shore wall. The pictures encompassed the rock wall from the low sea level until the line of vascular vegetation. The height (~35 cm) of the gull, *Larus cachinans*, captured on first plane in each picture was used for calibrating the spatial scale of images and converting the x-y pixels coordinates to a metric scale. In this way, for each picture in each section the height (y coordinate of the image) above the low tide sea level of each organism was estimated in centimeters by digital image analysis with the "point" command of the UTHSCSA Image Tool, available in the web site of the University of Texas Health Science Center. The height represents the upper and/or the lower limits for marine organisms: algae, mussels, barnacles, and lichens, and the lower limit of terrestrial lichens and vascular vegetation (Sibaja-Cordero, 2008).

### Data analysis

The statistical analyses were carried out with the free software PAST (Hammer et al., 2001). For each of the 40 sections the mean height was calculated for each organism and a vertical profile with all organisms was generated. The profiles were categorized whether they are located in south or north islands, western or eastern face and exposed and sheltered to Atlantic Ocean, respectively (Figure 1).

The data matrix contained numerical information of the height above sea level, but in several sections one or more organisms were absent. The vertical profile in these cases has missing data (absence of the organism). In PAST software, the multivariate techniques can handle missing data. The absences were marked with question mark in the data frame (Hammer et al., 2001). The software calculated the Euclidean dissimilarity matrix between sections (vertical profiles) of the shore using a pairwise deletion. This means that when the distance is calculated between two sections (vertical profiles), any variable missing is ignored in the calculation (Hammer et al., 2001). However, the ordination methods as Principal Coordinate Analysis (PCoA) can detect the variable with missing value as a difference, and the profile is plotted apart in the graphic representation. To avoid strong horseshoe effects in the

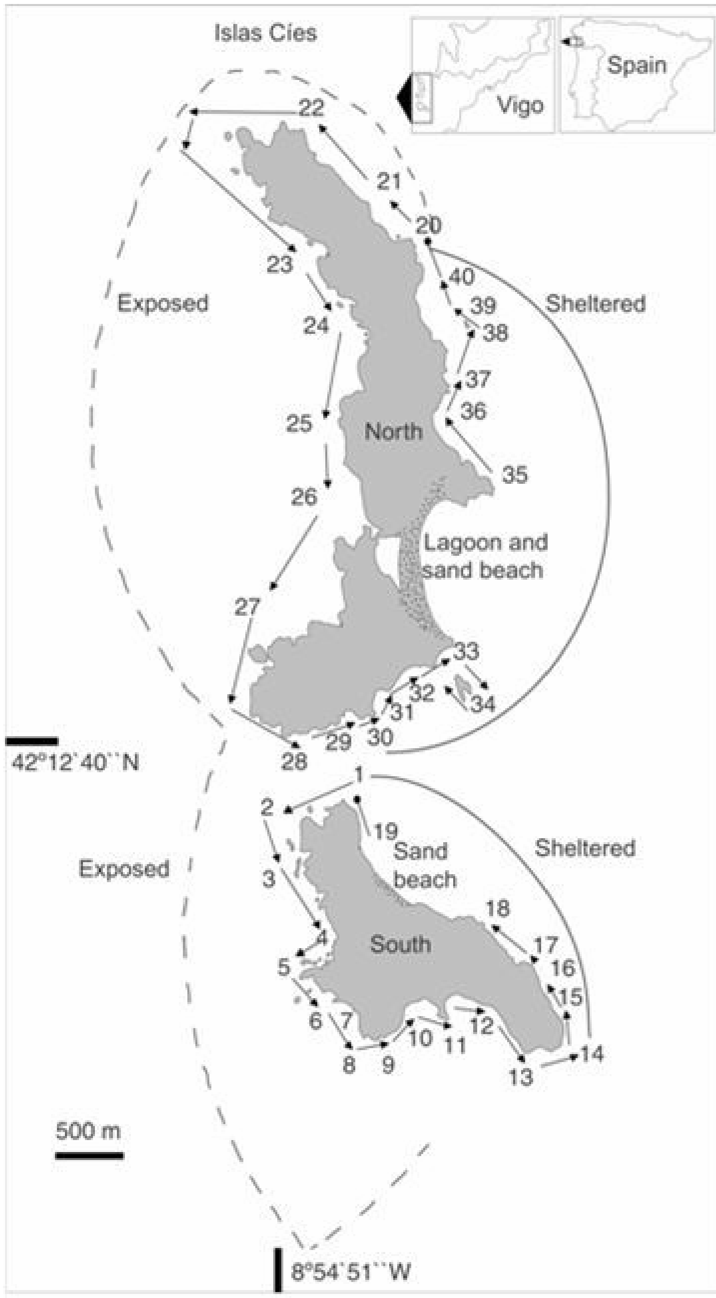


**Figure 1.** Location of vertical sections of the rocky shore in the Islas Cíes National Park, NW Spain. Classification of sections according to ocean exposure (exposed *vs.* sheltered) is based on Acuña-Castroviejo et al. (1982). Boat transects (GPS) are represented with arrows.

ordination, the mean height of the intertidal limits of each organism by section was transformed with log10, before calculating the Euclidean dissimilarity matrix (Legendre and Gallagher, 2001).

In this way, a Cluster analysis was generated by the paired group clustering method based in the Euclidean distance of the section (vertical profile), to explore the similarity of sections of the shore by their patterns of vertical zonation. Additionally, a PCoA of the same data based in the Euclidean distance was carried out to show the similarity of sections and the organism limit score which indicates where the sessile organisms occur or increase their height on the intertidal (Hammer et al., 2001; Quinn and Keough, 2003). The organism limit score of the PCoA biplot was calculated with the formula in Legendre and Gallagher (2001):

Organism limit score $_{jk} = r_{jk}\, s_j / s_k$

where $r_{jk}$ are the correlation between the data of the organism j and the sections score vector k. Also $s_j$ is the standard deviation for the data of the organism j, and $s_k$ is the standard deviation of sections score vector k (Legendre and Gallagher, 2001). In organisms that occurred in all sections, r was calculated with the Pearson coefficient and when the organisms were absent in one or more sections, the Spearman rank correlation was used with a value of 0 for the absence data.

Finally, the same Euclidean dissimilarity matrix between sections was analyzed by two-way crossed ANOSIM (R) (Clarke and Warwick, 1994). The value of R determines the level of difference; when R = the groups are completely different from each other. The factors tested were the exposure degree of the sections (exposed or sheltered) and the island identity (north or south).

## RESULTS

Figure 2 shows examples of the vertical profile found at the exposed and sheltered coast of the Islas Cíes National Park. In general, the first centimeters of the infralittoral presented several species of red algae (Rhodophyta). The dominance of species within this band varies between exposed or sheltered coast. For instance, *Asparagopsis armata* formed dense patches in the sheltered face of both islands and Chlorophyta were mostly found in patches in the sheltered infralittoral. Mussels and barnacles are present above the algae band. Above these bands and in exposed shores, there is an intermittent fringe of bare rock; in the sheltered faces, a fucoid belt occurs below the bare rock fringe. *A. armata* and *Bifurcaria bifurcata* were mainly in the sheltered shore of both islands. These species occurs higher in the intertidal of the sheltered shore of the north island. The high littoral of either exposed or sheltered shores presented the black lichen, *Verrucaria maura* and the orange lichen, *Caloplaca marina*.

The sheltered shore presented more complexity in the vertical profile, that is, there were more species and a more diversified mosaic of bands and patches of organisms. The limits of vertical distribution in the majority of organisms tended to appear higher on the shore at exposed faces for example, that of Rhodophyta, mussels, barnacles, lichens and vascular vegetation (Figure 3). Moreover, the width of the bands for species in the high littoral was compressed in the sheltered coast of both islands (Figure 3).

Cluster analysis showed two major groups of vertical profiles, mostly according to differences in ocean exposure (Figure 4a). The ordination of the PCoA showed a similar pattern with the sections of sheltered coast on one side of the graphic representation and sections of the exposed shore on the opposite side (Figure 4b). The central cluster (Figure 4a) presented profiles of both conditions of ocean exposure. The sections 14, 21, 28, 29 and 40 (Figure 1) are transitional areas between the fully exposed or sheltered condition. The exposed sections 9, 10, and 11, were clustered with the sheltered sections; PCoA ordination showed the same pattern (Figure 4b). These sections are in a small coastal cove (Enseada de Concela) of the south island (Figure 1). The upper intertidal limits of the organisms was lower in these sites (Figure 3) indicating less degree of exposure to the Atlantic Ocean. Sections 33 and 36 were best ordinate in the PCoA by their sheltered condition than in the cluster analysis (Figure 4).

The ANOSIM test showed that the ocean exposure was a significant factor in determining different vertical zonation patterns of sessile organisms ($R = 0.55$, $p< 0.0001$). The organism limit scores in the PCoA (Figure 4B) showed that the invertebrates, red algae and lichens had higher limits of vertical distribution at the exposed shore. On the other hand, *A. armata, B. bifurcata, Fucus spiralis* and *Pelvetia canaliculata* were mainly present in the sheltered coast (Figures 3 and 4). The second coordinate in the PCoA (Figure 4) showed a slightly separation of sections (vertical profiles) according to the island in which they are located. This spatial trend was confirmed by the ANOSIM test ($p = 0.037$) but the degree of difference is low ($R = 0.13$).

The profile in Figure 3 showed than *B. bifurcata* occurs in more sections in the north island. On the other hand, *P. canaliculata* and *F. spiralis* showed positive scores in the second coordinate which suggest these algae are mostly associated (higher height in the intertidal) with the sheltered face of the south island; in fact, both species were present in more sections at this island (Figure 3). The main shared feature among exposed faces was the higher upper limit of vertical distribution of the Rhodophyta band and the black lichen, *V. maura,* but higher in the north island as well as those of the lichen *C. marina* and the vascular vegetation (Figure 3) with positive scores in the second coordinate of the PCoA, near to the most exposed north sections (Figure 4). The crust phase of *Mastocarpus stellatus* and the bare rock band had a higher upper limit of vertical distribution in Sections 2, 3, 5, 8 and 12 of the exposed face of the south island (Figures 3 and 4).

## DISCUSSION

The community and their pattern of the vertical zonation in Islas Cíes at the moment of the sampling were similar in the relative position and dominance of the species in the intertidal to that of the temperate rocky shores described for Great Britain (Little and Smith, 1980; Little and Mettam, 1994; Mettam, 1994).

Moreover, the trend of increased vertical distribution of intertidal species at areas with high wave exposure was found in the rocky shore of Islas Cíes; similar patterns have been reported from other intertidal areas (Underwood, 1981). At the exposed coast of both islands, species in high littoral were distributed along the intertidal constituting wide fringes. As expected, the multivariate

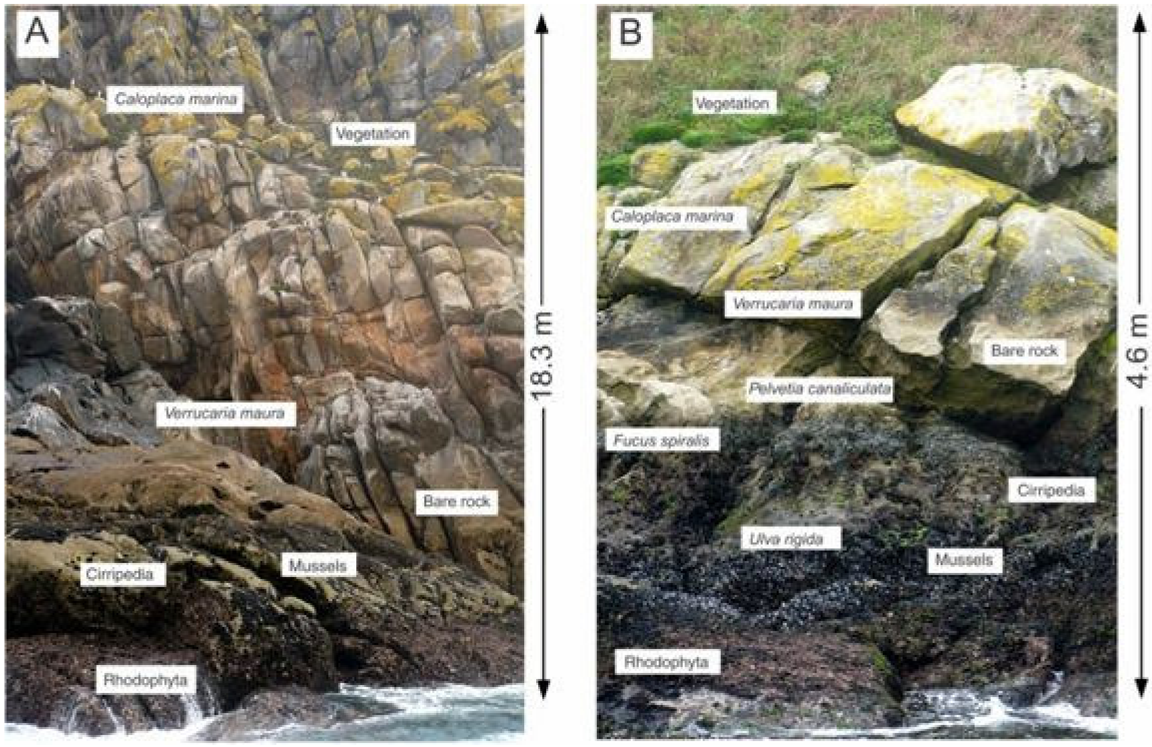


**Figure 2.** Vertical zonation of sessile organisms at the exposed (A) and sheltered (B) rocky coast of the Islas Cíes (NW Spain).

multivariate techniques indicated clear separations among the exposed and sheltered intertidal shores. The vertical profiles of exposed and sheltered shores presented differences in species assemblages, that is, the erect and foliose algae were present mainly in the sheltered shore. Other difference between exposed and sheltered shore was the higher height in the species occurs in the exposed rock wall.

The vertical distribution of littoral species on the sheltered shore of Islas Cíes was similar to those in similar areas in north Portugal (Araújo et al., 2005). The waves were unable to reach high littoral levels and the rock area for settling of marine species was reduced in north Portugal (Araújo et al., 2005). However, more marine organisms occurred in the intertidal of the sheltered coast of the Islas Cíes. The community was more complex in the sheltered face of the south island with more sessile species coexisting in the rock wall. The mid and high littoral of the sheltered face of the south island contained several patches of algae, lichens and bacterial bio-film than in the other island faces. In this way, Wallenstein et al. (2008) found in the Azores islands that the association between organisms and height at which they occur differs geographically (between islands). The changes in other intertidal species may relate to disturbances (herbivores or heavy wave), that reduced the productivity of the most dominant species (Menge and Farrel, 1989).

In the Islas Cíes, the wave patterns influence the intertidal community but in the Azores Islands, the wave exposure is a second factor in regulating the vertical zonation below the substrate ecotones (boulders, cliffs, platforms) (Wallenstein and Neto, 2006).

The two islands in the Azores Archipelago, studied by Wallenstein et al. (2008) did not present sheltered habitats. Moreover, there was some degree of variation between the islands of Santa Maria and São Miguel of the Azores Archipelago (Wallenstein et al., 2008); this pattern is similar to that showed in our study. In the Islas Cíes, the face of the islands with the same degree of exposure showed slightly structural differences in the vertical zonation profiles. The geographic accidents (bays, coves and points) were abundant and the influence of wind and sunlight varies among sites (Vilas-Paz et al., 2005). In this way, diverse microhabitats are present in the Islas Cíes that influence the composition of species and the height of this species in the intertidal. Spatial heterogeneity in Islas Cíes may be a crucial factor in determining the rocky shore communities similar with Wilding et al. (2010) in Scotland, UK and Kostylev et al. (2005) in Hong Kong.

The dominant wind in the Islas Cíes comes from north in summer and from southwest in winter (Vilas-Paz et al., 2005). The winds in other rocky shores also create large

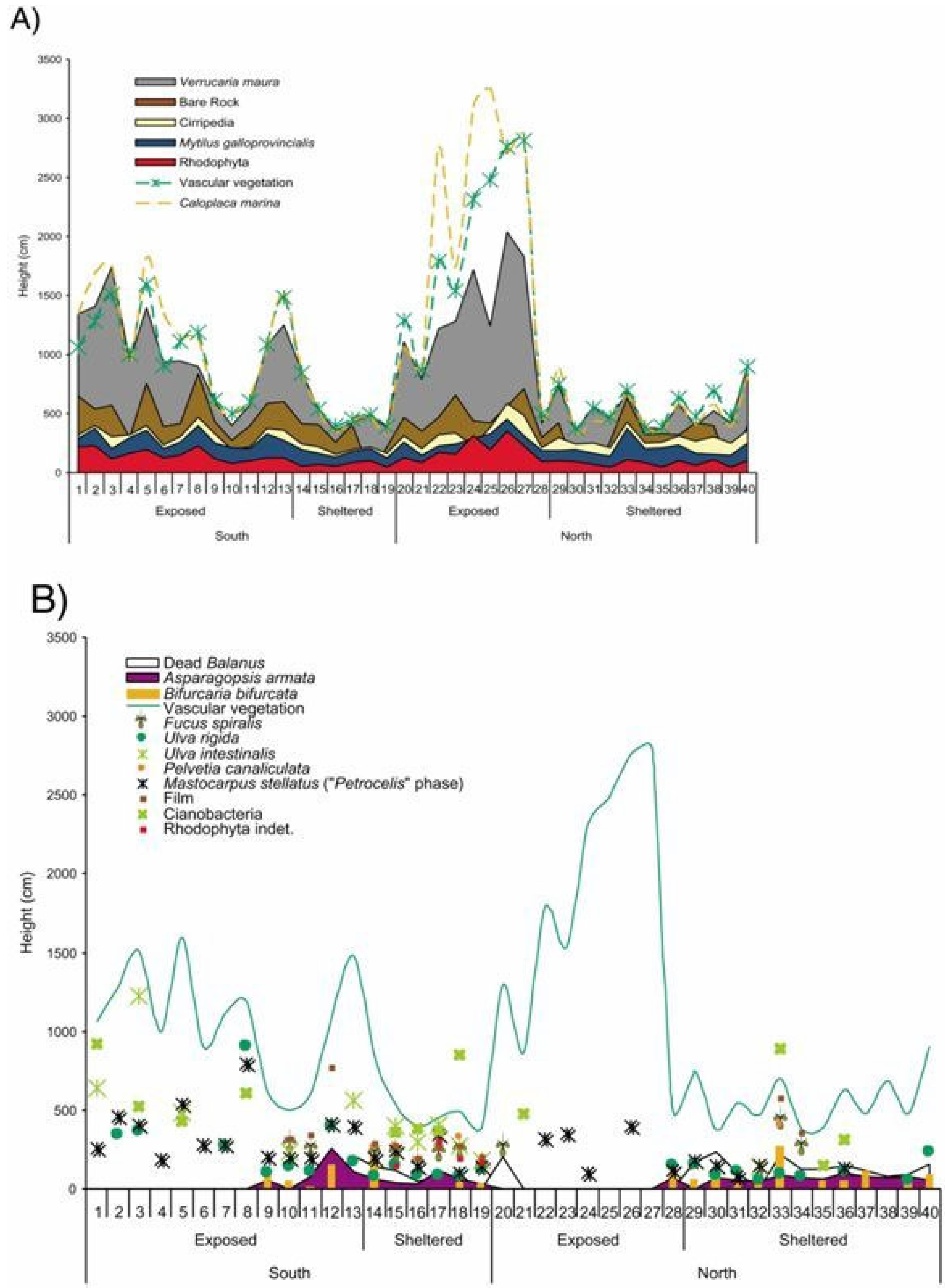


**Figure 3.** Vertical zonation of sessile organisms (mean height above the low tide of the upper and/or lower limits of distribution) by each section (1 to 40) of the rocky shores at the Islas Cíes (NW Spain, 2009). (A): organisms which form definite bands. (B): organism mainly in interrupted fringes or patches.

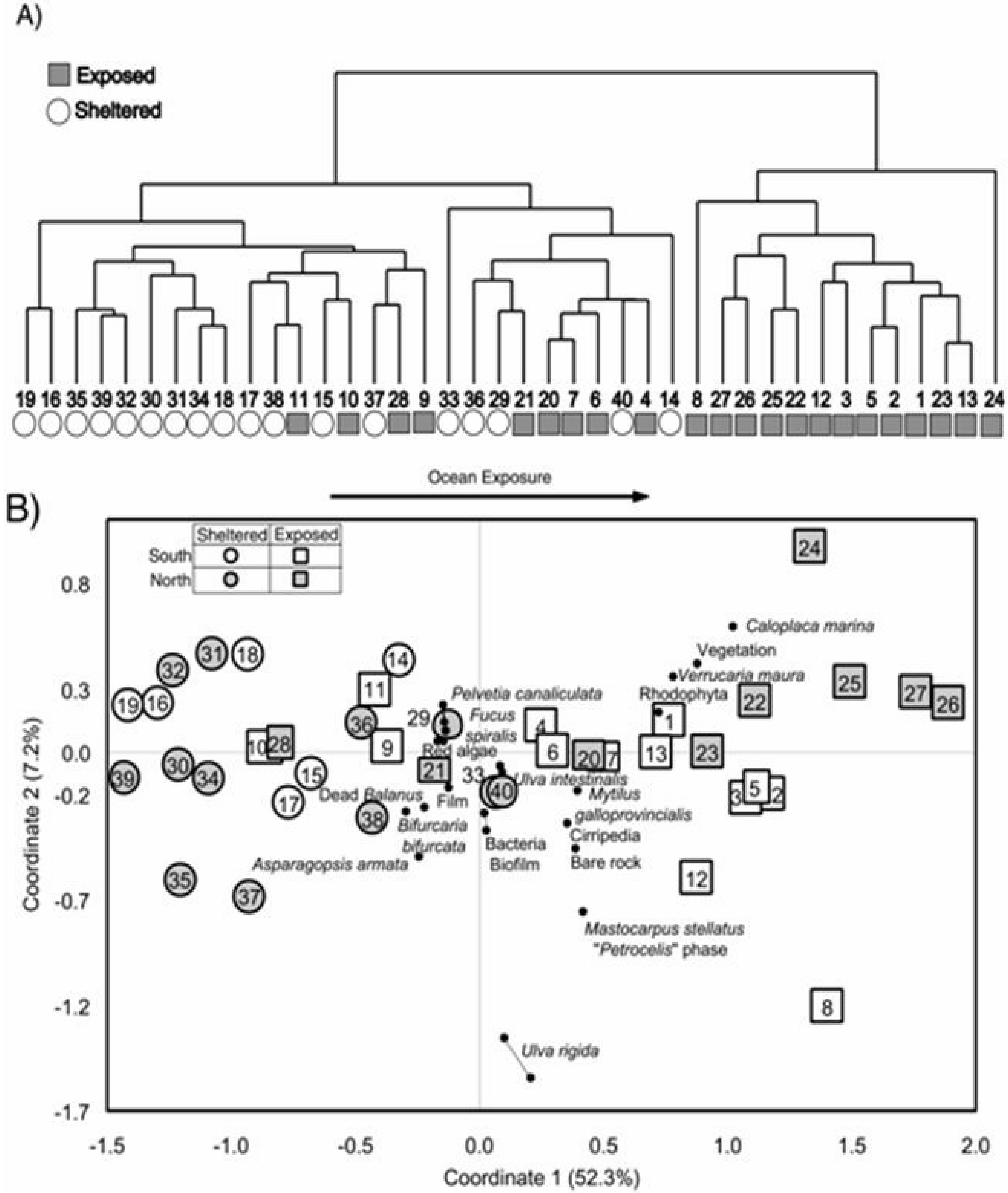


**Figure 4.** A: Cluster analysis by paired group clustering, and B: Principal Coordinate Analysis, both based in the Euclidean distance matrix of mean height above low tidal level of the rocky shore organisms by section. These analyses showed the similarity of the sections profiles of vertical zonation at the Islas Cíes (NW Spain). The black points in PCoA are the limit score for each organism. A line linked the upper and lower limit score in *P. canaliculata* and *U. rigida*.

large fetch that produce frequent and large waves (Little and Kitching, 1996). The eastern face of the Islas Cíes was sheltered from waves and strong wind astride the year. The sites 20 (Faro do Peito) to 22 (Punta do Cabalo) in north island were directly exposed to winds in summer and this might explain why fucoids were practically absent. Other factor that can explain the reduced population of fucoids in sites 21 to 22 are that in October an outflow current from the Ría of Vigo with high water turbulence reached the north mouth, near the shore of the north island in Cíes Archipelago (Souto et al., 2001).

The sheltered shore profiles were evident from site 14 (Faro do Bicos) to site 19 (Punta Pau de Bandeira) with high presence of fucoids. Niell (1977) found that *P. canaliculata* in Galicia was excluded from wind-beaten coasts. In fact, Jones and Demetropoulos (1968) indicated that *F. spiralis* does not tolerate heavy hydrodynamic conditions. Fucoids occur in the exposed face of the south island but in the Sites 10 and 11 at the Enseada de Concela, which is a cove sheltered from waves and southwest winds in winter.

The spray produced by the wave splash in the north face may help to promote the establishment of some intertidal organisms at higher heights in the rock cliffs (Little and Kitching, 1996). The lichen, *V. maura* reaches higher levels from the exposed site 24 (Punta do Chancelos) to 27 (Punta do Principe) in the north island. Moreover, the mostly terrestrial orange lichen, *C. marina* and the vascular vegetation occurred 24 m above from the low tide limit in this section of the shore. At this height, vascular plants such as *Armenia* and *Crithmum* grow as scattered pillow and can tolerate the high salinities that are present there (Vilas-Paz et al., 2005). The high humidity by the spray in the exposed faces increased the height in the shore of several opportunist species in the Islas Cíes. Patches of *Ulva intestinalis*, cianobacterial and *M. stellatus* occurs higher in this faces of the Archipelago.

At the very exposed intertidal shore in the Ría de Corme e Laxe (A Coruña, Spain; Niell, 1978), the red algae fringe and the mussel band is present from the low tide level to 3 m, which is in agreement with our results in the Islas Cíes. Above the 3 to 4.5 m mark, Niell (1979) also found barnacles and the black lichen, *V. maura*. In the exposed face of the Islas Cíes, the black lichen can, however, reach the 15 m mark above the low tidal level in most of the sites. The orange lichen, *C. marina* in the Ría de Corme e Laxe, occurs between 4.5 to 6.5 m and in the exposed face of the Islas Cíes occurs always above 10 m. The vertical profile of distribution of intertidal organisms at the Ría de Camariñas (A Coruña, Spain; Niell, 1978) is also similar to that of the exposed face of the Islas Cíes, being both characterized because *V. maura* and mussels reach higher intertidal levels than in other areas.

## Conclusion

Four different landscape patterns of vertical zonation were found at the moment of the sampling in each of the island faces. The algae, *A. armata* and *B. bifurcata* characterized the sheltered north island. On the other hand, *P. canaliculata* and *F. spiralis* had a greater presence in the sheltered side of the south island. The lichens, *V. maura* and *C. marina*, and the Rhodophyta belt had a higher upper limit of distribution at the exposed sides of the north island. Bare rock and the crust phase of *M. stellatus* had a greater presence at the exposed side of the south island. The wave force and dominant winds were possibly factors in modeling the community structure. Moreover, transition zones, geographical accidents and shore slope, also can contribute to explain the differences in assemblages of species and the height in the rocky intertidal for each species. For similarities with previous studies some degree of extrapolation of general aspects of the community (position on the rock and dominance of the common species) can be made for zones that have not been sampled previously in North Atlantic Shores.

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