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Statistical analysis of the distribution of infralittoral *Cystoseira* populations on pristine coasts of four Tyrrhenian islands: Proposed adjustment to the CARLIT index

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ABSTRACT

The influence of geomorphological features on the distribution of *Cystoseira* populations along the coasts of four pristine islands in the Tyrrhenian Sea (Italy, central Mediterranean) was studied by means of a model-based statistical analysis. The most relevant trait that determined the presence of these populations was found to be the coastline slope at the level of the infralittoral fringe. Our findings indicate that slopes above 60° reduce the likelihood of *Cystoseira* communities. The effects of the coastline slope on the CARLIT index are considered and discussed in view of these findings. Pending further studies on the implementation of the CARLIT index in the Mediterranean basin, we suggest that any changes to the procedure or the hasty multiplication of reference sites be avoided, and instead propose a simple empirical adjustment of the EQ values to be able to more accurately monitor coasts with steep slopes using this index.

1. Introduction

Cystoseira amentacea (C. Agardh) Bory (Phaeophyceae) is a brown alga that forms dense and continuous populations on upper infralittoral pristine rocky shores of the Mediterranean Sea (Ballesteros et al., 2007). The CARLIT (Cartography of littoral rocky shore communities) index, a EU Water Framework Directive (2000/60/CE) monitoring method developed and first applied to the Mediterranean coasts of Spain, assigned to *Cystoseira amentacea*, as well as to almost all other surface *Cystoseira* species, a high bio-indication sensitivity level (Ballesteros et al., 2007; Table 1). As *C. compressa* (Ballesteros et al., 2007; see also Thibaut et al., 2005) and, more recently, *C. barbata* (Nikolić et al., 2013) have also been observed in slightly more polluted waters, the protocol assigned a lower bio-indication sensitivity level to these species when present without other *Cystoseira* species. Therefore, according to the CARLIT index, the Mediterranean algal communities of the upper infralittoral zone dominated by *Cystoseira* species, as well as the build-ups (*trottoirs*) of *Lithophyllum byssoides* (Lamarck) Foslie, indicate undisturbed environments, those dominated by Dictyotales and geniculate or crustose Corallinales indicate slightly polluted environments, and those dominated by *Ulva*, *Cladophora* and Cyanobacteria indicate extremely polluted environments (Ballesteros et al., 2007; see also Arevalo et al., 2007; Pinedo et al., 2007; Mangialajo et al., 2008a). To date, the CARLIT index has been applied in Spain (Ballesteros et al., 2007; Bermejo et al., 2013, 2014; Cavallo et al., 2016; Torras et al., 2016), Italy (Mangialajo et al., 2007; Asnaghi et al., 2009; Guala et al., 2010; Sfriso and Facca, 2011; the present paper), France, Malta (Blanfuné et al., 2011, 2017, already available on http:/dx.doi.org/10.1016/j.ecolind.2016.07.049), Croatia (Nikolić et al., 2013) and Albania (Blanfuné et al., 2016).

Since the distribution of the upper infralittoral macroalgal communities is affected not only by water quality but also by the coastline geomorphology, multivariate analyses have previously been applied (Ballesteros et al., 2007; Nikolić et al., 2013) to six categories of coastline (morphology, substrate constitution, slope, orientation, type, i.e. natural or artificial, and wave exposure) to identify the geomorphological factors that most influence the dis-

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Table 1
Variable legend.

Name of variable	Description	Type	Categories/units
Aspect	Orientation of the coast	qualitative	East (E), North (N), North-East (NE), North-West (NW), South (S), South-East (SE), South-West (SW), West (W)
Elevation	Elevation of the coast	quantitative	Continuous (meters)
Landform	Morphology of the coast	qualitative	Metric Block (MB), Low Cliff (LC), High Cliff (HC), Beach (B), Other
Coast Slope	Slope of the coast	quantitative	Degrees (circular)
Coastline slope	Slope of the coastline at the infralittoral fringe	qualitative	Low Slope [0°–30°](LS), Medium Slope [30°–60°] (MS), High Slope [60°–90°] (HS)
Sum of Neighbors (SN)	Number of occurrences in neighboring sites as a proxy of spatial association information	quantitative	Counts
Cystoseira	Presence and absence of *Cystoseira* belts	binary	0/1

tribution of these communities. The analyses revealed that the coastal morphology (i.e. the type of coast: high, low or composed of metric or decametric blocks), the natural or artificial type of substrate (Ballesteros et al., 2007), as well as the coastal morphology and the coastline slope (Nikolić et al., 2013) were the most relevant variables involved in determining algal distribution.

The importance of the role played by the coastline slope in the establishment of *Cystoseira* populations on pristine coasts first emerged in 2010, when the CARLIT index was applied by our group to the whole coastline of the Pontine islands (Ponza, Palmarola, Zannone, Ventotene, S. Stefano), which comprise the most pristine areas in the Lazio region (central Italy) and include two islands designated Marine Protected Areas (Ventotene and Zannone). The ecological status assigned by the CARLIT index to the coasts of these islands was moderate to good, which is in contrast to the high status assigned by the regional monitoring agency (ARPA Lazio) on the basis of physical-chemical data. The lower status assigned by the CARLIT index was particularly evident on Palmarola, an uninhabited island a long way from any anthropic impacts, where the ecological status was defined as "moderate", even though a *trottoir* of *Lithophyllum byssoides* was found on one rock, known as the Faraglioni di Mezzogiorno, that lies off the island. In order to understand why the CARLIT index did not yield the results that were expected for the Pontine islands, we analyzed the relationship between the presence of upper infralittoral *Cystoseira* spp. and the geomorphological features along the coasts of the Zannone by means of statistical models. The study, presented at a conference (Jona Lasinio et al., 2011), revealed that the steepness of the coastline appears to play a fundamental role in correctly predicting the presence of *Cystoseira* on the coastline. When the CARLIT index was subsequently applied to the coasts of the Island of Giglio (another pristine island in the central Mediterranean Sea in the Tuscany region), it worked perfectly, revealing a high ecological status of the coastal waters. The statistical analyses that had previously been applied to the Zannone were applied to Giglio and to the two Pontine islands of Ponza and Ventotene in order to further confirm the relationship between the presence of *Cystoseira* species and the geomorphological characteristics of these islands. The results of these studies are presented and discussed in the present paper.

A substantial innovation in this study is the use of a statistically rigorous approach that assesses (and hence accounts for) the uncertainty surrounding the quantification of biological indicators. The relationship between bio-indicators and environmental features (e.g. algal population and geomorphological factors) is commonly assessed by means of multivariate analyses, such as principal component analysis, multidimensional scaling or other descriptive tools that do not shed light on the statistical significance of findings, i.e. no uncertainty evaluation is undertaken when these relationships are described in this type of analysis. A protocol that includes simple statistical models that take into account every feature was used in this study to identify which attributes of the landscape significantly affect the presence/absence of *Cystoseira* belts along the coastline. This model-based approach can be used to define and rigorously infer relationships between features, thereby accounting for the uncertainty naturally associated with bio-indicator evaluations.

2. Material and methods

2.1. Study area and field data

The study was carried out along the upper infralittoral rocky shore in two sites in the central Mediterranean Sea (Tyrrhenian Sea): the Pontine Island**s** (40.907 N, 12.953 E), an archipelago encompassing five islands (Ponza, Zannone, Palmarola, Ventotene, Santo Stefano) and the Island of Giglio (42.352 N, 10.901 E). The study area is shown in Fig. 1, which highlights the islands' positions in relation to the Italian coast. The coasts of Ventotene, Ponza and Zannone were monitored in spring in 2009 and 2010 while those of Giglio were monitored in summer in 2012 and in autumn in 2014 by means of the CARLIT index (Ballesteros et al., 2007; Mangialajo et al., 2008b). The survey included the entire perimeter of the coastline of each island, with the exclusion of beaches and harbors as well as the sector of the coast of Giglio where the cruise ship Costa Concordia ran aground in January 2012 (the coastal sectors excluded are indicated as Other in Fig. 3). The islands' coastlines were surveyed using an inflatable boat, which was guided as closely as possible to the shore to record the length of each homogeneous sector of the coast as regards both the upper-infralittoral algal communities and the geomorphological factors, and thus build a field database. The field database was then used to build an integrated database by combining and calibrating the geomorphological features on the basis of a digital elevation model (DEM) which was, in turn, used for modeling purposes (see below). The following variables were considered in this study: (1) population type, (2) coastal morphology (landform) [high cliffs (HC), low cliffs (LC), metric blocks (MB), others/beaches (B)], (3) length (in meters) of the homogenous coastal sectors, (4) elevation, (5) coastline slope at the infralittoral fringe [three categories: low (horizontal slope, 0°–30°), medium (sub-vertical slope, 30°–60°) and high (vertical slope, 60°–90°)] and (6) aspect (orientation) of the coastline. Differences in the geology of the substrate between Giglio (prevalently granitic) and the Pontine islands (prevalently volcanic) were not taken into account in this study as the substrate constitution was not found to be a highly relevant geomorphological feature in determining alga distribution by either Ballesteros et al. (2007) or Nikolić et al. (2013). The values observed were then transferred into georeferenced maps of the islands and the ecological value (EQV) of each island was calculated according to the reference values pro-