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# Status of vulnerable *Cystoseira* populations along the Italian infralittoral fringe, and relationships with environmental and anthropogenic variables

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ABSTRACT

We analyzed the occurrence and status of infralittoral fringe populations of *Cystoseira* spp. (Fucales) at thirteen rocky sites around the Italian coastline, and explored the relationships with relevant environmental and anthropogenic variables. We found *Cystoseira* populations at 11 sites: most were scattered and comprised monospecific stands of *C. compressa*, and only 6 sites also supported sparse specimens of either *C. amentacea* var. *stricta* or *C. brachycarpa*. Coastal human population density, Chlorophyll *a* seawater concentrations, sea surface temperature, annual range of sea surface temperature and wave fetch explained most of the variation of the status of *C. compressa*. We hypothesize a generally unhealthy state of the Italian *Cystoseira* infralittoral fringe populations and identify multiple co-occurring anthropogenic stressors as the likely drivers of these poor conditions. Extensive baseline monitoring is needed to describe how *Cystoseira* populations are changing, and implement a management framework for the conservation of these valuable but vulnerable habitats.

## 1. Introduction

Shallow coastal areas comprise some of the most productive, diverse and at the same time threatened marine ecosystems (Harley et al., 2006; Airoldi and Beck, 2007). Pollution, overfishing, habitat destruction, coastal development, and the introduction of alien species have all severely affected shallow marine ecosystems (Airoldi and Beck, 2007; Crain et al., 2009; Claudet and Fraschetti, 2010; Coll et al., 2010). Fragmentation and loss are further exacerbated by global climatic changes, such as acidification, increased sea-surface temperatures and increased the frequency of extreme events (Micheli et al., 2013). These escalating impacts require identification of the factors enhancing or inhibiting the future persistence of coastal ecosystems (Brown et al., 2013, 2014; Giakoumi et al., 2015), so that adequate management can be put in place. Amount of remaining biogenic habitat, physical setting, and local-scale stressors are some of the factors most frequently identified as critical in promoting or preventing the capability of marine ecosystems to respond to increasing cumulative disturbances (O'Leary et al., 2017).

Canopy-forming algae form some of the most diverse, productive and valuable ecosystems along intertidal and shallow subtidal rocky coasts (Steneck et al., 2002). In the Mediterranean Sea, canopy-forming algae are mainly comprised of species of the genus *Cystoseira* C. Agardh (Fucales, Phaeophyceae). Their distribution is controlled by several environmental variables including depth, water temperature, substratum characteristics, coastline geomorphology, wave exposure and nutrient concentrations (Giaccone and Bruni, 1973; Ballesteros, 1990; Falace et al., 2005; Ballesteros et al., 2007; Sales and Ballesteros, 2009; Nikolić et al., 2013; Lasinio et al., 2017). Further, human pressures are increasingly limiting their distribution (Chryssovergis and Panayotidis, 1995; Rodríguez-Prieto and Polo, 1996; Soltan et al., 2001; Arevalo et al., 2007; Sales et al., 2011). During the last decades *Cystoseira* populations have retracted their ranges considerably particularly close to urban areas (Benedetti-Cecchi et al., 2001; Soltan et al., 2001; Thibaut et al., 2005, 2015; Ballesteros et al., 2007; Mangialajo et al., 2007, 2008; Perkol-Finkel and Airoldi, 2010), being replaced by structurally less complex communities dominated by turf-forming, or other ephemeral seaweeds, mussels (Benedetti-Cecchi et al., 2001; Connell et al., 2014; Strain et al., 2014) or sea urchin barrens (Agnetta et al., 2015). The sensitivity of *Cystoseira* populations and other canopy algae to a variety of anthropogenic stressors is increasingly well understood (Ballesteros et al., 2007; Mangialajo et al., 2007; Asnaghi et al., 2009; Sales et al., 2011), making these systems useful indicators of water and ecosystem quality according to the Water Framework Directive (2000/

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60/EC) (Commission, E., 2000). Nevertheless, the factors ultimately explaining their distribution and capability to persist have been harder to identify (Sales and Ballesteros, 2009; Perkol-Finkel and Airoldi, 2010; Strain et al., 2015; Buonomo et al., 2017b), probably involving many interacting environmental, biological and anthropogenic variables (Strain et al., 2014). Indeed, while many regions have experienced dramatic loss of these ecosystems (Airoldi et al., 2014 and references therein; Thibaut et al., 2015), in other regions losses have been limited to the most severely impacted sites and some populations have surprisingly persisted in a relatively healthy status (Thibaut et al., 2014). Understanding what factors or combinations of factors control the ultimate distribution and conditions of these ecosystems is a key priority to establish effective conservation measures.

Several species of *Cystoseira* typically contribute to form dense, narrow (about 20–30 cm in height) fringing belts along the microtidal Mediterranean rocky coastline. Lying between the littoral and the sublittoral zones, this infralittoral fringe is a particularly vulnerable area, being subject to a range of natural as well as anthropogenic disturbances originating from both the land and the sea (Thompson et al., 2002). Despite its recognized value and vulnerability, data on the distribution and status of this habitat are surprisingly limited. Descriptions are available for some areas or regions, but broader-scale ecological analyses are rare.

We analyzed the distribution and abundance of infralittoral fringe populations of *Cystoseira* at 13 rocky coast localities along the Italian coastline, covering a range of biogeographic location, environmental characteristics and levels of anthropogenic pressures. For the most common species, *C. compressa*, we described its ecological status as a combination of percentage cover, density, morphometric characteristics, and abundance of epiphytes. Thallus height and branches length are typically affected by a variety of factors including temperature, photoperiod, and wave exposure (Gómez-Garreta et al., 2002; Falace et al., 2005), thereby providing relevant ecological indications, and low cover, density or excess coverage by epibiota can be reflective of unhealthy conditions (Reference). We further tested whether any variation in these “ecological status” descriptors was related to environmental and anthropogenic factors potentially relevant for the growth and/or distribution of macroalgae in the infralittoral fringe, including wave exposure, photosynthetic active radiation, salinity, tidal range, seawater temperature, annual range of sea surface temperature, marine Chlorophyll *a*, nitrate and phosphate concentrations, distance from nearest urban centre and coastal human population density. Light conditions can influence the growth of *C. compressa*, and wave exposure can affect its morphology (Gómez-Garreta et al., 2002; Falace et al., 2005). Seawater temperature and its variations can have profound effects on seaweeds, affecting the growth, reproduction, survival and distribution of macroalgae (Graiff et al., 2015; Martínez et al., 2015). Salinity was reported to affect the phenotypic variability of *Fucus vesiculosus* (Ruuskanen and Bäck, 1999), while the morphology of the intertidal fucoid *Hormosira banksii* changed with tidal regime (Mueller et al., 2015). Rarefaction and/or disappearance of *Cystoseira* species (Mangialajo et al., 2008; Sales and Ballesteros, 2009) have been related to high anthropogenic pressures and concentrations of nutrients (Chlorophyll *a*, nitrate and phosphate). We discuss our results in light of previous findings of *Cystoseira* along the Italian coasts to explore ongoing trends and suggest priority areas of intervention.

## 2. Materials and methods

### 2.1. Study sites, species and environmental and anthropogenic factors

The Italian peninsula and its islands extend > 950 km from north to south into the central Mediterranean basin, with a coastline of approximately 7600 km. Flat sandy shores alternate with high rocky coasts along the peninsula that is surrounded by four different seas (Fig. 1). Despite the presence of several Marine Protected Areas (MPA),

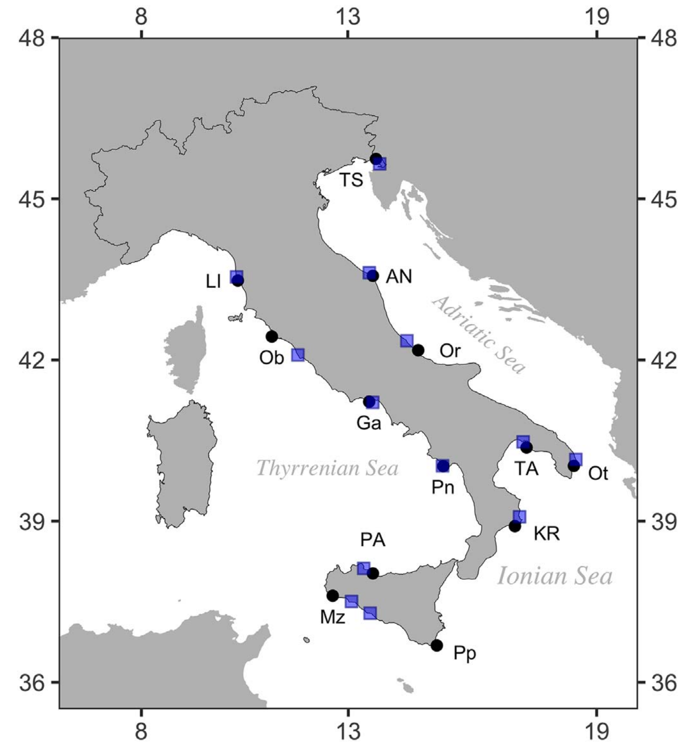


**Fig. 1.** Location of the 13 rocky study sites along the Italian coastline (black dots). TS: Trieste (Grignano), AN: Ancona (Portonovo), LI: Livorno (Calafuria), Ob: Orbetello (Santo Stefano), Or: Ortona (Punta Aderci), Ga: Gaeta (Torre San Vito), Pn: Palinuro (Faracchio), Ot: Otranto (Santa Cesarea Terme), TA: Taranto (Leporano Marina), KR: Crotone (Le Castella), PA: Palermo (Altavilla), Mz: Trapani (Mazara del Vallo), Pp: Siracusa (Portopalo di Capo Passero). The position of the ISPRA buoys is indicated by the blue squares. Geographic coordinates of the sites and ISPRA buoys are reported in Table S1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the Italian coast is generally overexploited, as the long and narrow shape and the mountainous geography tend to concentrate the large population along the coasts.

We sampled the infralittoral fringe, from mean sea level MSL to extreme low water of spring tides ELWS, $\approx -30$ cm. Few species of *Cystoseira* can potentially colonize this zone along the Italian coasts: *C. amentacea* (C. Agardh) Bory and its variety *C. amentacea* var. *stricta* Montagne, *C. mediterranea* Sauvageau, *C. tamariscifolia* (Hudson) Papenfuss, *C. compressa* (Esper) Gerloff & Nizamuddin and more rarely *C. brachycarpa* J. Agardh and *C. humilis* Schousboe ex Kützing (Giaccone and Bruni, 1973; Ballesteros and Romero, 1988; Giaccone et al., 1992, 1993, 1994; Gómez-Garreta et al., 2002; Piazzi and Cinelli, 2002; Piazzi et al., 2009; Furnari et al., 2010). *C. amentacea*, *C. compressa*, *C. brachycarpa* and *C. humilis* can potentially occur in many regions around the Italian coasts, while *C. mediterranea* and *C. tamariscifolia* are limited to few areas (Furnari et al., 2010). *C. compressa* is the most common species, being relatively tolerant to some environmental and anthropogenic stressors compared to other species of *Cystoseira* (Thibaut et al., 2005; Mangialajo et al., 2008).

Sampling was carried out at 13 locations (hereafter referred to as sites; Fig. 1; Table S1), characterized by the presence of extensive rocky shores and accessible from the coast without using a boat. The sites were selected to represent a variety of different conditions along the Italian peninsula and to cover a wide latitudinal gradient. The final choice was also dictated by the proximity to oceanographic buoys, which were needed to access important environmental parameters. All sites presented naturally exposed, gently sloping to sub-vertical rocky platforms, typically favorable for the growth of *Cystoseira* spp. (Lasinio et al., 2017). The main environmental and anthropogenic characteristics for each site are summarised in Table 1 and described as part of the results.