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Deep-water stands of *Cystoseira zosteroides* C. Agardh (Fucales, Ochrophyta) in the Northwestern Mediterranean: Insights into assemblage structure and population dynamics

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ABSTRACT

Populations dominated by *Cystoseira zosteroides*, an endemic and threatened Mediterranean seaweed, colonize deep-water rocky habitats down to more than 50 m depth. Assemblages dominated by this species display high algal and invertebrate species richness. Algal biomass averages 1134 g dw m^{-2}. Erect and turf algae account for only 25% of total algal dry weight, while encrusting corallines are responsible for the remaining 75%. Sponges, bryozoans and ascidians constitute the dominant sessile macrofauna. *Cystoseira zosteroides* is the dominant erect algae, with a mean biomass of 60.6 g dw m^{-2}, and densities ranging from 4 to 7 plants m^{-2}. The alien turf alga *Womersleyella setacea* has a biomass of 104.2 g dw m^{-2} and covers most of the understory substrate. The size-frequency distribution of *C. zosteroides* populations shows differences over time. Mean annual growth of the main axis is around 0.5 cm and mean annual mortality rate is lower than 2%. Recruitment was almost nil during the studied period of time (10 years). Processes structuring these deep-water *Cystoseira* stands must be driven by episodic disturbances, after-disturbance recruitment pulses, and long periods of steady growth that last at least 10 years. However, it is also possible that recruitment is irreversibly inhibited by the alien alga *W. setacea* in which case these old-growth stands are faced with extinction. The highly diversified assemblages and the low growth and low mortality rates of *C. zosteroides* indicate high vulnerability to natural and anthropogenic disturbances, and call for effective measures to ensure their conservation.

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1. Introduction

The composition, structure and dynamics of deep-water algal assemblages are little known. Depth can be considered an environmental stress gradient, since many restricting factors for algal growth such as light availability, water movement, sedimentation rates and temperature vary predictably with depth (Zabala and Ballesteros, 1989; Garrabou et al., 2002). There are evidences that community structure (i.e. diversity and species richness) increases in complexity, and community dynamics (i.e. productivity, turnover and growth rates) slows with depth (e.g. Ballesteros, 1989, 1991a; Garrabou et al., 2002). The few data available from temperate deep-water macroalgal assemblages agree with this pattern, as they describe highly diverse algal assemblages associated with a rich macrofauna (e.g. Sears and Cooper, 1978; Spalding et al., 2003; Piazzi et al., 2004a,b; Ballesteros, 2006), and very parsimonious populations dynamics (Ballesteros et al., 1998; Garrabou and Ballesteros, 2000).

Deep-water Mediterranean coastal rocky bottoms are usually dominated by encrusting corallines (Ballesteros, 2006), although sparse stands of fleshy algae (*Cystoseira* spp.) are also known to thrive in these bottoms (Feldmann, 1937). *Cystoseira zosteroides* C. Agardh is the dominant alga in deep-water *Cystoseira* assemblages (Giaccone, 1973), and it occurs together with other species of *Cystoseira*, mainly *Cystoseira spinosa* Sauvageau v. *compressa* Cormaci et al. and *Cystoseira foeniculacea* (Linné) Greville f. *latiramosa* Gómez Garreta et al. (Giaccone and Bruni, 1973). These assemblages occur on rocky bottoms exposed to strong unidirectional currents and with light levels ranging between 1% and 0.3% of surface irradiance (Giaccone and Bruni, 1973). Although these assemblages seem to be widespread throughout the Mediterranean, quantitative available data are extremely reduced (Ballesteros, 1990; Serio, 1994) and

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almost nothing is known on the structure and dynamics of present populations (Hereu et al., 2008).

Deep-water *Cystoseira* assemblages are in decline in several Mediterranean areas (Alongi et al., 2004; Thibaut et al., 2005; Serio et al., 2006) and, although the ultimate causes of this decline are not fully understood (Boudouresque et al., 1990), changes in water turbidity and sedimentation, direct pulling up by fishing nets, eutrophication, overgrazing by sea urchins and global change are to be blamed (Boudouresque et al., 1990; Cormaci et al., 2001; Thibaut et al., 2005). Furthermore, invasion by alien species can also contribute to the observed decline of these assemblages (Ballesteros et al., 1998).

In this study we have been monitoring these *Cystoseira zosteroides* populations during ten years in order to obtain field data that allow the formulation of hypotheses regarding the possible causes of Mediterranean-wide population declines. The goals of this study were: (1) to study the composition and structure of deep-water assemblages dominated by *C. zosteroides*; (2) to describe population size structure; (3) to estimate mean annual growth, recruitment and mortality rates; and (4) to infer the structuring processes that control these deep-water algal stands based on results obtained from objectives 2 and 3.

2. Materials and methods

2.1. Study site

Two sampling stations were selected, both of them situated within the Scandola Marine Reserve (Parc Naturel Régional de Corse, Corsica, France): Garganelu and Palazzu (Fig. 1). The first station was located on the southern side of the Garganelu islet, on an isolated reef between 38 and 54 m depth. Brown algae of the genus *Cystoseira* thrive there between 42 and 49 m depth over a rocky platform slightly sloping to the north. The second station was located on the western side of the Palazzu islet, over a rocky slope facing northwest, between 38 and 43 m depth. Sampling was always performed by SCUBA diving at the beginning of October, before the fall of branchlets that occur in November (Ballesteros, 1990).

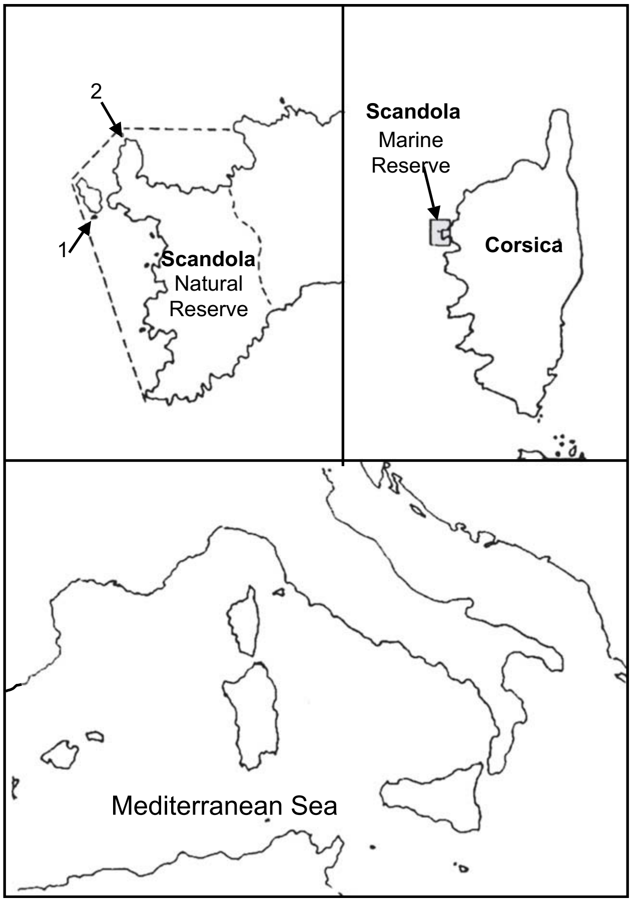

Fig. 1. Situation of the study sites in the Scandola Marine Reserve (1 – Garganelu; 2 – Palazzu).

2.2. Species composition

Floristic and faunistic composition of the assemblage was only studied in Garganelu, at depths ranging from 44 to 49 m. Abundances of relatively small, cryptic and common species were obtained by scraping off all organisms from four, haphazardly located, 50 cm × 50 cm quadrats. These samples were sealed in individual plastic bags after collection and carefully sorted in the laboratory on the day of collection. The abundances of algal species and invertebrates in the samples were quantified as grams dry weight (g dw) after drying at 105 °C for 12–24 h (Ballesteros, 1986). The biomass of the species of the genus *Cystoseira* was calculated using density data and average individual weight (see below). The abundance of large algae and invertebrates was quantified by means of 40 haphazardly located 50 cm × 50 cm quadrats divided into 9 subquadrats, allowing the estimation of the coverage of these large organisms in situ. Conversion factors to estimate biomass from coverage data recorded in the field were obtained for each species in the laboratory (Cebrian et al., 2000). Biomass data obtained by these methods were normalized to 1 m^2 surfaces.

2.3. Morphometric study

To select a single best indicator of plant size that could be easily measured in situ, thirty-five specimens of *Cystoseira zosteroides* were collected in October 1995 in Garganelu and the following parameters were measured for each one: length of the longest axis, number of axes, number of young tophules, and number of old tophules. Young tophules, which appeared during the current year, were distinguished from old tophules by having no branchlets as it also occurs in *Cystoseira spinosa* var. *compressa* (Ballesteros et al., 1998). Axes, branchlets and young and old tophules were sorted out and weighed after drying at 105 °C for 12–24 h. Correlation analyses between the different variables were carried out.

2.4. Growth, mortality and recruitment

Two approaches have been used to estimate growth rates of *Cystoseira zosteroides*. The first one takes into account that *C. zosteroides* is in a resting phase from the beginning of autumn until the end of winter, when the plants are reduced to axes covered by tophules and without branchlets (Ballesteros, 1990; Serio, 1994). Branch growth begins in late winter, with branchlets coming out from every tophule. Production of new tophules (which do not produce any branchlet until next year) begins in spring and so does the growth of the axes. The annual growth of every axis is easily identified in early autumn by its light-brown color and by its also light-brown tophules without branchlets or scars of branchlets. Annual growth for the main axis and for all the axes was measured with a caliper, with 1 mm accuracy, as the distance between the apical part of the axis and the base of the axis insertion of the last tophule without branchlets in the 35 specimens collected for the morphometric study.

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