

SPREAD OF CAULERPA RACEMOSA VAR. CYLINDRACEA IN BACK-REEF AREAS (TUSCANY SOUTHERN COAST)

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Introduction - The invasive *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman, Boudouresque, Bryopsidales, Chlorophyta has spread swiftly along Mediterranean coasts since the early 1990s (Piazzi *et al.*, 2005). *C. racemosa*, the invasion of which is impeded by a dense cover of phytobenthos (Ceccherelli *et al.*, 2000), was defined as a stress tolerant species considering its spread in degraded areas (Buia *et al.*, 1998). It lately spread to *Posidonia oceanica* (L.) Delile back-reef areas, replacing a *Cymodocea nodosa* (Ucria) Ascherson, *Nanozostera noltii* (Hornemann) Tomlinson et Posluzny and *Caulerpa prolifera* (Forsskål) J.V. Lamouroux mixed meadow, that disappeared just before this spread (Lenzi *et al.*, 2007). This study aims at describing *C. racemosa* spread in these back-reef areas, assessing any differences in other coastal habitats and understanding its role in the colonisation of degraded areas.

Materials and Methods - In two back-reef areas (western and eastern) of *P. oceanica* barriers, in Santa Liberata bay (42°26'10.38"N 11°09'10.27"E and 42°26'10.38"N 11°09'48.22"E, Monte Argentario, Tuscany), four 5x5 m plots, two in each area (A, E and H, I, respectively) (fig. 1), at 120-150 cm depth, were randomly chosen and marked with poles and rope. In July 2005 and 2006, 15 20x20 cm were collected in each plot to determine biomass of *C. racemosa* and other macroalgal assemblages; samples were cleaned then oven-dried to constant dry weight at 90°C for 24 hours. Sub-samples of 10 g of *C. racemosa* were used to obtain morphometric measurements: branchlet and stolon thickness (BT and ST), erect axis and branchlet length (EAL and BL). Data was processed by PERMANOVA, as an univariate test and the multivariate test "canonical analysis of principle coordinates" (CAP).



FIGURE 1—Santa Liberata Bay. A, E, H, I, sampling plots.

TABLE 1—Means and standard deviations of *C. racemosa* morphometric parameters (in mm) and biomass (*C.r.*: g d.w. m⁻²) and other algae biomass (OA: g d.w. m⁻²) by plots of western site (A, E) and eastern site (H, I), in 2005 and 2006. EAL, erect axis length; ST, stolon thickness; BL, branchlet length; BT, branchlet thickness; *C.r.*: OA = ratio between the biomasses.

		EAL	ST	BL	BT	<i>C. r.</i>	OA	<i>C.r.</i> :OA
A	2005	4.85 ± 1.67	1.35 ± 0.17	2.00 ± 0.27	2.17 ± 0.29	1.08 ± 1.88	99.1 ± 70.1	0.01
	2006	4.91 ± 1.91	1.34 ± 0.21	1.98 ± 0.23	2.25 ± 0.21	74.3 ± 53.2	76.8 ± 46.3	0.97
E	2005	5.21 ± 1.52	1.34 ± 0.10	2.31 ± 0.51	2.43 ± 0.46	1.00 ± 1.00	150.6 ± 77.2	0.01
	2006	5.27 ± 1.79	1.29 ± 0.11	2.21 ± 0.61	2.37 ± 0.43	54.9 ± 36.5	344.9 ± 337.3	0.16
H	2005	4.74 ± 1.66	0.83 ± 0.19	1.17 ± 0.24	1.39 ± 0.29	0.67 ± 1.15	240.6 ± 47.3	0.00
	2006	12.15 ± 2.73	1.25 ± 0.13	3.55 ± 0.55	2.52 ± 0.39	60.4 ± 28.7	236.0 ± 104.4	0.26
I	2005	4.86 ± 1.80	0.83 ± 0.18	1.56 ± 0.30	1.41 ± 0.20	1.00 ± 0.66	81.5 ± 55.7	0.01
	2006	8.15 ± 1.91	1.11 ± 0.08	3.21 ± 0.55	2.13 ± 0.03	58.6 ± 13.6	110.9 ± 25.1	0.53

Results and Discussion - Biomass and morphometric data are reported in Table 1. PERMANOVA showed a significant interaction of factors Year and Site for all parameters. Individual pairwise comparisons performed on interaction factor (Year*Site) showed that ST and BT were significantly different in the two back-reefs (higher in the west) in 2005 ($P < 0.001$ and $P < 0.05$, respectively), but unchanged in 2006, while BL and EAL were significantly different in the two back-reefs (higher in the east) in 2006 (both $P < 0.05$), but unchanged in 2005.

CAP analysis (fig. 2) of the morphometric multivariate data set showed an absence of variation in the west back-reef between 2005 and 2006, and significant differences in the east back-reef between 2005 and 2006. This was due to an increase during 2006 of BT, BL, ST and EAL (negative correlation -0.899, -0.897, -0.820 and -0.463, respectively, with CAP1). The same correlation model discriminated the 2005-2006-west group observations from those of the 2005-east group. The 2006-east group was significantly discriminated from the 2005-2006-west group, mainly due to EAL and ST, the former being higher (positive correlation 0.583 with CAP2) and the latter lower (negative correlation -0.446 with CAP2) in the first group with respect to the second. Our samples were characterized by thalli of *C. racemosa* having a short erect axis with respect to those reported in other parts of the Mediterranean. Ranges were 1.2–8.6 mm in the west and east sites in 2005, 6.2–6.5 mm in the east site and 2.2–8.6 mm in the west site in 2006. A thin stolon with low EAL may be better adapted for penetrating very dense algal turf. Indeed, the lower values of ST and BT in the east than in the west back-reef in 2005 could be related to the manner of initial colonisation of the invasive algae in the east back-reef. In this site, the larger EAL and BL in 2006 could be due to population stability and loss of pioneer likeness. *C. racemosa* biomass (g d.w. m⁻²) increased by a factor of 55 to 90 in the four plots, and the "*C. racemosa* to other macroalgal biomass" ratio (*C.r.*:O.A.) increased by a factor of 16 to >100, between July 2005 and July 2006. PERMANOVA confirmed the *C. racemosa* biomass increase, showing a significant difference in relation to the factor Year and no difference in relation to the factor Site. Altogether, *C. racemosa* biomass showed a range of 0.00–3.25 g d.w. m⁻² in 2005 and of 12.90–106.52 in 2006. Our data confirms the considerable substrate-covering capacity and rapid development of biomass that *C. racemosa* has shown in the Mediterranean so far (Piazzi *et al.*, 2005), and also the species' aggressiveness on shallow sheltered bottoms with dead mat, as in back-reefs.

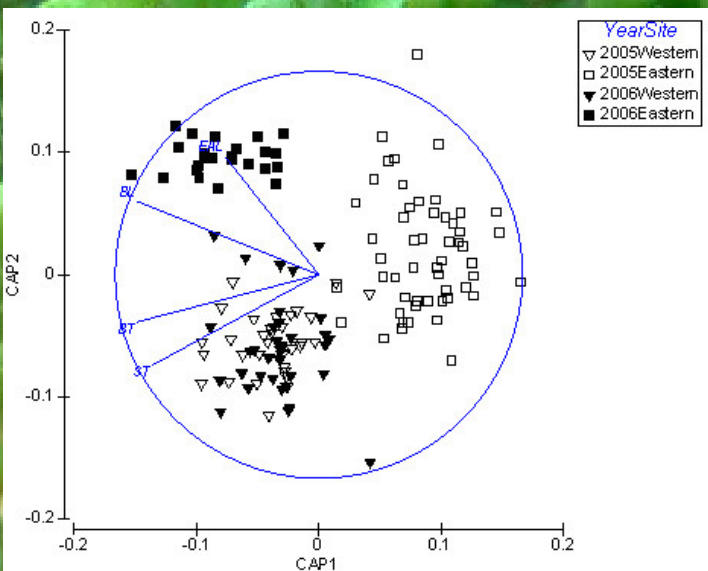


FIGURE 2—Diagram of canonical analysis of principle coordinates (CAP) performed on *C. racemosa* morphometric data set. Vectors length and direction indicate the contribution of each response variable (EAL, erect axis length; ST, stolon thickness; BL, branchlet length; BT, branchlet thickness) to the discrimination pattern of observation groups and their correlation with the CAP1 and CAP2 axis.

Conclusions - The invasion of *C. racemosa* was very rapid and, according to Lenzi *et al.* (2007), possibly very recent, as indicated by its low biomass in 2005 and relatively high value in 2006. The species invaded the back-reefs, preferring a substrate of *P. oceanica* dead mat with thin algal turf. Piazzi *et al.* (2001) claim that the presence of algal species forming turfs is a major regulator of *C. racemosa* performance in the Mediterranean. Its spread may have occurred because of the decline of the mixed meadows (*C. nodosa*-*N. noltii*-*C. prolifera*) in the back-reef areas, that was attributed to a reduction in the sediment organic matter due to high tourist pressure (Lenzi *et al.*, 2007). Its distribution in shallow waters, the relatively high biomass and the considerable substrate-covering capacity suggest a good adaptation to high light conditions and the presence of a suitable substrate without competitors.

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