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The community of Cystoseira brachycarpa J. Agardh emend. Giaccone (Fucales, Phaeophyceae) in a shallow hydrothermal vent area of the Aeolian Islands (Tyrrhenian Sea, Italy)

G. Bellissimo[a], J. Rull Lluch[b], A. Tomasello[a] & S. Calvo[a]

[a] Dipartimento di Scienze della Terra e del Mare, University of Palermo, Italy

[b] Laboratori de Botànica, Facultat de Farmàcia, University of Barcelona, Spain

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The community of *Cystoseira brachycarpa* J. Agardh *emend*. Giaccone (Fucales, Phaeophyceae) in a shallow hydrothermal vent area of the Aeolian Islands (Tyrrhenian Sea, Italy)

G. BELLISSIMO[1], J. RULL LLUCH[2], A. TOMASELLO[1], & S. CALVO[1]

[1]*Dipartimento di Scienze della Terra e del Mare, University of Palermo, Italy and* [2]*Laboratori de Botànica, Facultat de Farmàcia, University of Barcelona, Spain*

Abstract
A *Cystoseira brachycarpa* community from a vent area off Panarea Island (Italy) was investigated in two sites at different pH values. At low pH, species richness and coverage were low and the community displayed a reduced reproductive capacity. Conversely, at normal pH, dense canopies of fertile *C. brachycarpa* were found.

Keywords: *Aeolian Islands,* Cystoseira brachycarpa *community, ocean acidification, shallow hydrothermal vents, Tyrrhenian Sea*
Abbreviations: c, carposporangia; e, spermatangia; o, conceptacle; p, plurilocular sporangia; t, tetrasporangia; u, unilocular sporangia

Introduction

Carbon dioxide emitted to the atmosphere by human activities is absorbed by the oceans, causing shifts in seawater carbonate chemistry and decreasing seawater pH (Intergovernmental Panel on Climate Change 2007). Surface seawater is already becoming more acidic since the beginning of the industrial era, and the average ocean pH is projected to decrease by the end of 2100 (The Royal Society 2005). In this respect, shallow water venting areas provide natural laboratories to study *in situ* water acidification effects on biota (Hall-Spencer et al. 2008; Vizzini et al. 2010; Fabricius et al. 2011). Little is known about the marine benthic algae of these areas (Acunto et al. 1996; Cocito et al. 2000; Johnson et al. 2011; Porzio et al. 2011) and the effect of the acidification induced by vents on *Cystoseira* assemblages has not been investigated yet. Communities of *Cystoseira* are characteristic of most Mediterranean infralittoral and upper-circalittoral rocky bottoms and their dominant *Cystoseira* species represent the most important habitat-forming algal species in shallow waters (Ballesteros 1992). *Cystoseira brachycarpa* J. Agardh *emend*. Giaccone [including *C. brachycarpa* var. *balearica* according to Pizzuto (1998)] is an endemic Mediterranean species widely distributed in the western Mediterranean (Ribera et al. 1992; Gómez Garreta et al. 2001). It is a photophilic species that forms dense populations on hard substrata of the upper infralittoral zone (Ballesteros 1990; Pizzuto 1999). The aim of this paper was to describe the *C. brachycarpa* community in a vent area of the Aeolian Islands (Italy), and to evaluate the effect of natural seawater acidification on its species composition and structure. Changes in the biometrics of *C. brachycarpa* and the reproductive capacity of the community species were also assessed.

Materials and methods

The study was carried out in June 2010 off the eastern coast of Panarea and two sampling sites were chosen (Figure 1(a),(b)). The first site was on the north-east side of the Bottaro islet within a hydrothermally active area, characterized by persistent CO_2-dominated gas emissions (Tassi et al. 2009).

Correspondence: G. Bellissimo, Dipartimento di Scienze della Terra e del Mare, University of Palermo, Viale delle Scienze Edificio 16, 90128 Palermo, Italy. Tel: + 39 091 23862881. Fax: + 39 091 6230219. Email: giancarlo.bellissimo@unipa.it

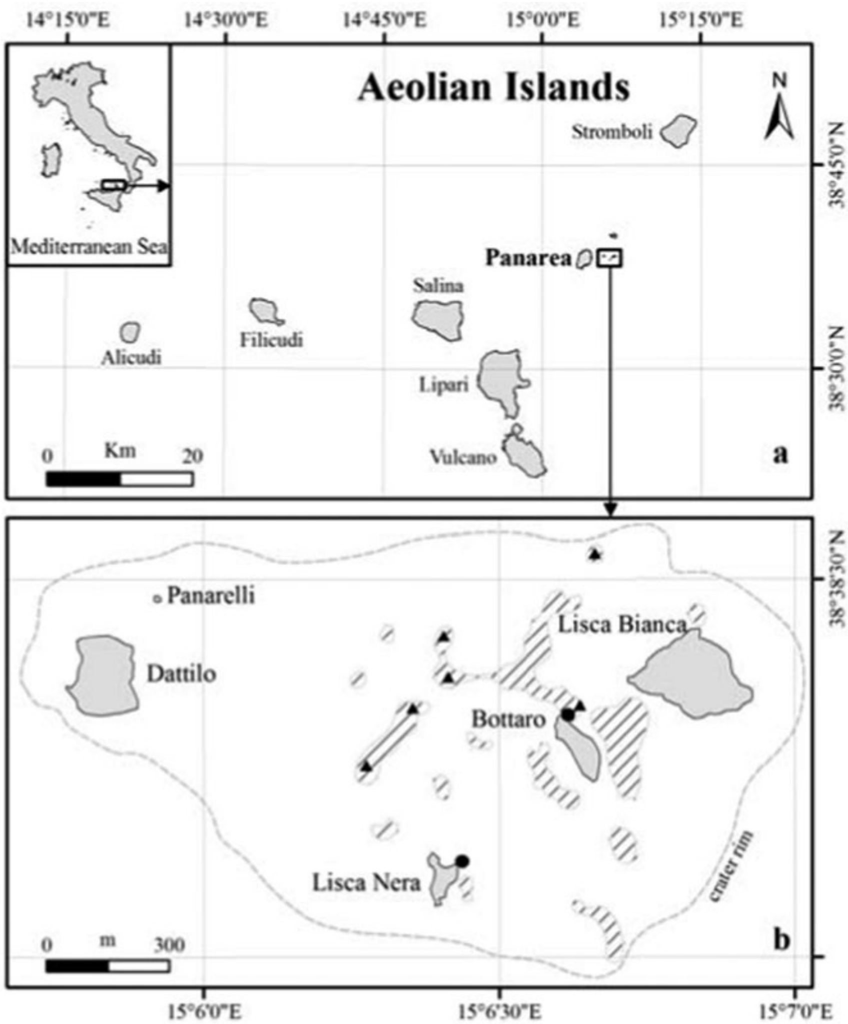

Figure 1. Location of the study area: a. Aeolian Islands, b. submarine fumarolic fields (hatching areas) with hydrothermal vents (black triangles) from Tassi et al. (2009) and location of sampling sites (black dots).

The second was at a distance of about 500 m from Bottaro, on the north-east side of the Lisca Nera islet, where no visible hydrothermal activity was observed. Samples were collected at about 7 m depth on a horizontal rocky bottom where the community appeared homogeneous. In each site, all vegetation was scraped off from two randomly placed 400 cm^2 quadrats (hereafter q1 and q2) using a hammer and a chisel. A probe was used *in situ* during 1 day (10 replicates) to pH records along the water column.

Algal species were quantified as cover in cm^2 (Ballesteros 1986). Five thalli of *C. brachycarpa* were selected randomly from each quadrat ($n = 10$ per site) and their height and the length of five randomly chosen primary branches per thallus ($n = 50$ per site) were measured (Pizzuto 1998). The reproductive phenology was also recorded.

The synecological Rhodophyceae/Phaeophyceae (*R*/*P*) Index (Cormaci et al. 1985), the Shannon–Weaver diversity (H') Index and Pielou's evenness (J) were calculated. A nested analysis of variance (ANOVA) was carried out to test for differences between sites in thallus height and branch length. "Site" was considered a fixed factor, while the factor "quadrat" was random and nested in "Site". A preliminary test for homogeneity of variance (Cochran's test) was performed, and an appropriate transformation of the dataset was carried out when necessary (Underwood 1997).

Results

A total of 82 taxa were identified in the *C. brachycarpa* community of both sampling sites (Table I), of which were 54 Rhodophyta (65.8%), 14 Phaeophyceae (17.1%) and 14 Chlorophyta (17.1%).

At Lisca Nera (mean pH 8.10 ± SD 0.06), a total of 72 taxa [51 Rhodophyta (70.8%), 13 Phaeophyceae (18.1%) and 8 Chlorophyta (11.1%)] were

Table I. Species composition of the *C. brachycarpa* community.

Site	Bottaro		Lisca Nera	
Quadrat	1	2	1	2
Sampling area (cm^2)	400	400	400	400
Exposition	NE	NE	NE	NE
Depth (m)	7.2	7.4	7	7.1
Cystoseira brachycarpa	145.37	117.58	425.25o	502.58o
Boergeseniella fruticulosa	0.42	0.21	47.57c,e	42.81t
Dictyota mediterranea	1.84t	9.81t	0.74	0.92
Padina pavonica	1.45	1.98	0.92	4.84
Herposiphonia secunda	0.23	0.11	4.61t	4.82t
Sphacelaria cirrosa	0.14	0.22	3.84	4.61
Rhodymenia ligulata		9.41	0.21	0.88
Peyssonnelia dubyi	1.21	7.21		0.78
Ceramium siliquosum	0.58		1.11	1.25e,t
Neogoniolithon brassica-florida			48.37c	47.61c
Anadyomene stellata	0.42	7.34		
Caulerpa racemosa var. *cylindracea*	0.68	4.72		
Gelidium pusillum			3.64	3.82
Heterosiphonia crispella			1.31	1.17
Cladophora echinus		1.08	0.75	
Hydrolithon farinosum			0.15c	0.11c
Pseudochlorodesmis furcellata	0.35	0.85	0.01	0.05
Halopteris filicina	0.05	0.01	0.02p	0.03
Halopteris scoparia	0.02	0.01	0.02	0.03
Lophosiphonia obscura	0.02	0.01	0.01	0.01
Phaeophila dendroides	0.01	0.01	0.01	0.01
Chondria capillaris		0.08	0.12	0.15
Laurencia microcladia	0.27		0.58c,t	0.84t
Womersleyella setacea		0.28	0.45	0.36
Polysiphonia dichotoma		0.14	0.21c	0.23t
Lomentaria clavaeformis		0.03	0.07	0.08
Gayliella mazoyerae		0.01	0.02t	0.03t
Acrochaete viridis	0.01		0.01	0.01
Blastophysa rhizopus	0.01		0.01	0.01
Stylonema alsidii		0.01	0.01	0.01
Ulvella lens	0.01		0.01	0.01
Flabellia petiolata	0.89	0.96		
Haliptilon virgatum			0.96	0.83
Dictyota fasciola			0.84	0.93
Dictyota linearis			0.74	0.62
Chondria mairei			0.63e	0.84c,t
Acrochaetium hauckii	0.32	0.58		
Peyssonnelia cf. *inamoena*			0.32	0.48
Cutleria chilosa		0.27t	0.36t	
Derbesia tenuissima	0.29	0.21		
Nitophyllum micropunctatum			0.14c,t	0.29t
Wrangelia penicillata			0.08	0.13t
Laurencia minuta ssp. *scammaccae*			0.07c,t	0.09c
Erythroglossum sandrianum			0.05	0.04
Ceramium comptum			0.04t	0.03t
Rhodophyllis divaricata			0.04	0.01
Apoglossum ruscifolium			0.02	0.03
Crouania attenuata			0.02	0.03t
Gracilaria sp.	0.02			0.03
Lejolisia mediterranea			0.02	0.03
Spermothamnion repens		0.02e	0.03	
Dasya rigidula			0.02t	0.01t
Spermothamnion flabellatum			0.02	0.01
Anotrichium barbatum			0.01c,t	0.01t
Antithamnion cruciatum			0.01t	0.01
Antithamnion heterocladum			0.01	0.01
Falkenbergia rufolanosa-stadium			0.01t	0.01t
Callithamnion corymbosum			0.01c,t	0.01e
Dasya baillouviana			0.01	0.01

Table I – *continued*

Site	Bottaro		Lisca Nera	
Quadrat	1	2	1	2
Sampling area (cm^2)	400	400	400	400
Exposition	NE	NE	NE	NE
Depth (m)	7.2	7.4	7	7.1
Dipterosiphonia rigens			0.01	0.01
Peyssonnelia bornetii				0.68
Valonia utricularis			0.25	
Acetabularia acetabulum				0.22
Cladostephus spongiosus f. *verticillatus*		0.18		
Discosporangium mesarthrocarpum				0.15p
Feldmannophycus rayssiae			0.14	
Stilophora tenella			0.1u	
Chylocladia pelagosae				0.08c
Lophosiphonia cristata			0.07	
Botryocladia botryoides				0.06
Botryocladia microphysa			0.04	
Ceramium codii		0.03		
Radicilingua reptans			0.03	
Ceramium tenerrimum				0.02t
Chaetomorpha linum	0.02			
Dasya corymbifera		0.02		
Polysiphonia scopulorum			0.02	
Ascocyclus orbicularis			0.01	
Cladophora lehmanniana		0.01		
Erythrotrichia carnea				0.01
Giraudia sphacelarioides				0.01
Ptilothamnion pluma			0.01	
Number of species	24	31	62	60
Total cover	154.63	163.40	545.15	623.78
R/P	1.3	1.9	4	4.4
H′	0.5	1.7	1.3	1.2
J	0.1	0.3	0.2	0.2

Notes: Cover values are expressed in percentage. Species with negligible abundance were assigned coverage of 0.01%. Reproductive phenology: c, carposporangia; e, spermatangia; o, conceptacle; p, plurilocular sporangia; t, tetrasporangia; u, unilocular sporangia. R/P, Rhodophyceae/Phaeophyceae Index; H′, Shannon-Weaver diversity; J, Pielou's evenness.

found. The number of species and cover were, respectively, 62% and 545.15% at q1, while 60% and 623.78%, respectively, at q2. The community was well structured and it showed a well-developed erect stratum dominated by *C. brachycarpa* (425.25% of cover at q1 and 502.58% at q2), with high mean values of both thallus height (12.64 ± SD 0.77 cm at q1 and 12.90 ± SD 0.86 cm at q2) and branch length (8.05 ± SD 0.56 cm at q1 and 8.33 ± SD 0.63 cm at q2). The turf-forming stratum was scarcely represented, mainly being composed of *Gelidium pusillum*. In contrast, numerous epiphytic species were found on *C. brachycarpa*. The Corallinales *Hydrolithon farinosum* and *Haliptilon virgatum* were also detected, although with a very low cover. The encrusting stratum consisted mainly of the Corallinales *Neogoniolithon brassica-florida*. Several fertile species, including *C. brachycarpa*, were recorded both at q1 (27.8%) and q2 (30.6%).

At Bottaro (mean pH 6.92 ± SD 0.08), a total of 38 taxa [18 Rhodophyta (47.4%), 8 Phaeophyceae (21.0%) and 12 Chlorophyta (31.6%)] were found. The number of species and cover were, respectively, 24% and 154.63% at q1, while 31% and 163.40%, respectively, at q2. The community was scarcely developed, showing a poor erect algal stratum dominated mainly by *C. brachycarpa* (145.38% of cover at q1 and 117.58% at q2); specimens of this species were also poorly developed, with low mean values of both thallus height (4.14 ± SD 0.23 cm at q1 and 4.44 ± SD 0.21 cm at q2) and branch length (2.28 ± SD 0.58 cm at q1 and 2.46 ± SD 0.37 cm at q2). In the turf-forming stratum, *Padina pavonica*, *Dictyota mediterranea* and *Caulerpa racemosa* var. *cylindracea* were the most abundant species, while few species grew as epiphytes on *C. brachycarpa*. Species of Corallinales were not detected. The encrusting stratum was lacking. The reproductive capacity of the community was low (4.2% at q1 and 9.7% at q2) and all *C. brachycarpa* specimens were sterile. *R/P*, *H′* and *J* indices values of both sampling sites are indicated in Table I. Concerning the size of

C. brachycarpa specimens, ANOVA showed statistical differences between sites for both thallus height and branch length ($P < 0.001$), whereas no differences were detected between quadrats within each site ($P > 0.05$). In particular, for both variables the mean values were higher at Lisca Nera than at Bottaro, with differences of 8.5 cm for thallus height and 5.8 cm for branch length.

Discussion

Qualitative and quantitative differences between the *C. brachycarpa* assemblages of vent and non-vent areas were detected. Changes in the structure and species composition were observed in the patchy vent community. Settlement of a large number of turf algae was probably due to the reduced canopy and abundance of *C. brachycarpa*. In addition, the shorter length of branches could explain the lower occurrence of epiphytic species, mainly Rhodophyta, which require a dense *Cystoseira* canopy to thrive, thus explaining the low *R*/*P* Index recorded. Venting assemblages seemed to be affected not only by hydrothermal activity but also by the spread of some invasive macroalgae (such as *C. racemosa* var. *cylindracea*), which commonly display high adaptability to a wide ecological range (Boudouresque & Verlaque 2002). The total lack of Corallinales in the vent community is noteworthy and in agreement with predictions based on short-term experiments where skeleton dissolution and drop in recruitment rate were reported at a pH of 7.9 (Jokiel et al. 2008; Kuffner et al. 2008). Species of Corallinales are characterized by the presence of calcite with a high content of Mg in their cell walls (Craigie 1990), and thus lowered pH levels may reduce or inhibit calcification (Martin & Gattuso 2009). The influence of hydrothermal activity was likely to affect the growth of *C. brachycarpa*. In this regard, contrasting effects of increased CO_2 have been found on algal growth. On the one hand, increased CO_2 levels may enhance growth and the effects of acidification may be heterogeneous, often species-specific (Xu et al. 2010; Zou & Gao 2010; Suárez-Álvarez et al. 2011; Johnson et al. 2012). Nevertheless, an elevated CO_2 concentration may not affect or inhibit the macroalgal growth by decreasing photosynthetic activity at high CO_2 levels or as a result of acidification of the medium (García-Sánchez et al. 1994; Israel & Hophy 2002). The low reproductive capacity detected close to vents probably produced a decrease in recruitment in the acidified area, which may be mitigated by recruiting from the surrounding non-vent communities (Porzio et al. 2011). Our investigation highlighted the high vulnerability and fragility of the *Cystoseira* species and the assemblages they form. Our results showed that shallow hydrothermalism had a negative effect on the growth and reproduction of several species, as well as on the species composition and structure of the *C. brachycarpa* community. However, further studies extending through longer time periods and including estimate production and mean annual growth, recruitment and mortality rates of *Cystoseira* are required to gain more information about the possible decline of *Cystoseira* assemblages in a future scenario of naturally acidified seawater.

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