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Spread of the introduced red alga *Lophocladia lallemandii* in the Tuscan Archipelago (NW Mediterranean Sea)

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Abstract – This paper describes the distribution and patterns of spread of the red alga *Lophocladia lallemandii* in the Tuscan Archipelago (NW Mediterranean Sea). *Lophocladia lallemandii* is recorded from three islands of the archipelago. Invasive traits were only detected at Pianosa Island where the affected stretch of coast has increased from 1.2 km in 2008 to 10.7 km in 2010. The abundance of the alga was found to increase with depth and strong differences among habitats were found in shallow stands. The presence of populations of *Cystoseira* spp. seemed to facilitate the spread of the alga. In *Cystoseira* assemblages, the biomass of *L. lallemandii* could represent up to 44 % of the biomass of *Cystoseira* spp. and epiphytes. The ability of *L. lallemandii* to colonize canopy species exposes habitats ecologically important to be invaded, and contradicts the classic concept of ecosystem resistance to biological invasions.

Biological invasions / *Cystoseira* / *Lophocladia lallemandii* / Mediterranean Sea

Résumé – **Distribution de *Lophocladia lallemandii*, algue introduite, dans l'archipel Toscan (Méditerranée SW).** L'article décrit la distribution de *Lophocladia lallemandii* dans l'archipel Toscan et son développement. *Lophocladia lallemandii* était présent dans trois îles de l'archipel, mais un comportement envahissant a été observé seulement à l'île de Pianosa où le linéaire de côte envahie est passé de 1,2 km, en 2008, à 10,7 km en 2010. L'abondance de l'algue augmentait avec la profondeur et des différences ont été observées entre habitats dans la zone la plus superficielle. La présence de peuplements à *Cystoseira* spp. semble favoriser l'installation de *L. lallemandii*. Dans les peuplements à *Cystoseira* spp., la biomasse de *L. lallemandii* pouvait représenter jusqu'à 44 % de la biomasse de *Cystoseira* spp. et des épiphytes. La capacité de *L. lallemandii* à coloniser les espèces dressées expose des habitats écologiquement très importants à l'envahissement, et contredit le concept classique de résistance des écosystèmes aux invasions biologiques.

Invasions biologiques / *Cystoseira* / *Lophocladia lallemandii* / Mer méditerranée

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INTRODUCTION

Introduced seaweeds are responsible for severe biological invasions worldwide (Ribera & Boudouresque, 1995; Schaffelke *et al*., 2006; Schaffelke & Hewitt, 2007) and particularly in the Mediterranean Sea (Boudouresque & Verlaque, 2002). The red alga *Lophocladia lallemandii* (Montagne) F. Schmitz is widespread in tropical and subtropical waters and it has been probably introduced in the Mediterranean Sea through the Suez Canal (Boudouresque & Verlaque, 2002). Since then, the alga has been recorded in many areas of the Mediterranean Basin, such as Adriatic Sea, Algeria, Corsica, Egypt, Greece, Libya, Malta, Sardinia, South Italy, Spain, Tunisia and Turkey (Gomez-Garreta *et al*., 2001), even though the invasive traits of *L. lallemandii* have been described only in Balearic Islands (Patzner, 1998; Cebrian & Ballesteros, 2010). In the invaded areas, the alga is able to spread on rocky bottoms and seagrass meadows developing high values of percentage cover and biomass (Cebrian & Ballesteros, 2010). Negative effects of *L. lallemandii* invasion have been described for the seagrass *Posidonia oceanica* (L.) Delile (Ballesteros *et al*., 2007; Sureda *et al*., 2008) and for the associated fauna (Cabanellas-Reboredo *et al*., 2010; Deudero *et al*., 2010).

In Italy, *L. lallemandii* has been reported in the southern continental and insular coasts (Edwards *et al*., 1975; Giaccone, 1978; Giaccone *et al*., 1986; Cossu *et al*., 1993), where no invasive events related to this species have been observed up to now. Recently, *L. lallemandii* was found in NW Italy, at Tuscan Archipelago National Park (Bedini, 2009; Piazzi *et al*., 2010).

The present study describes the distribution and spread patterns of *Lophocladia lallemandii* in the Tuscan Archipelago. In particular, we evaluated the trend of expansion of *L. lallemandii* during a three-year period, its abundance both at different depths and habitats and its relative biomass in native macroalgal assemblages.

MATERIAL AND METHODS

The Tuscan Archipelago is located in the northwestern Mediterranean Sea and it is composed by 7 islands (Fig. 1). The distribution of *Lophocladia lallemandii* in the Tuscan Archipelago was obtained on the basis of surveys and query to diving operators.

The spread of the alga was followed at Pianosa Island, where the most important colonization has been found. The distribution of *L. lallemandii* around the island was evaluated from 2008 to 2010. Each year, in October, the period of maximum vegetative spread of the alga (Cebrian & Ballesteros, 2010), diving operators followed transects parallel to the coast to detect the presence of the alga and the level of invasion. The invasion was quantified as km of linear extent of coastline adjacent to the affected areas (Vaugelas *et al*., 1999).

The abundance of the alga was evaluated at Pianosa Island in October 2010. In invaded areas, *L. lallemandii* colonized the rocky bottom from about three meters to about 10 meters of depth. Below 10 m depth, a *Posidonia oceanica* (L.) Delile meadow covers the bottom all around the island. The rocky bottom between 10 m and 4 m of depth was colonized by *Cystoseira* spp. assemblages

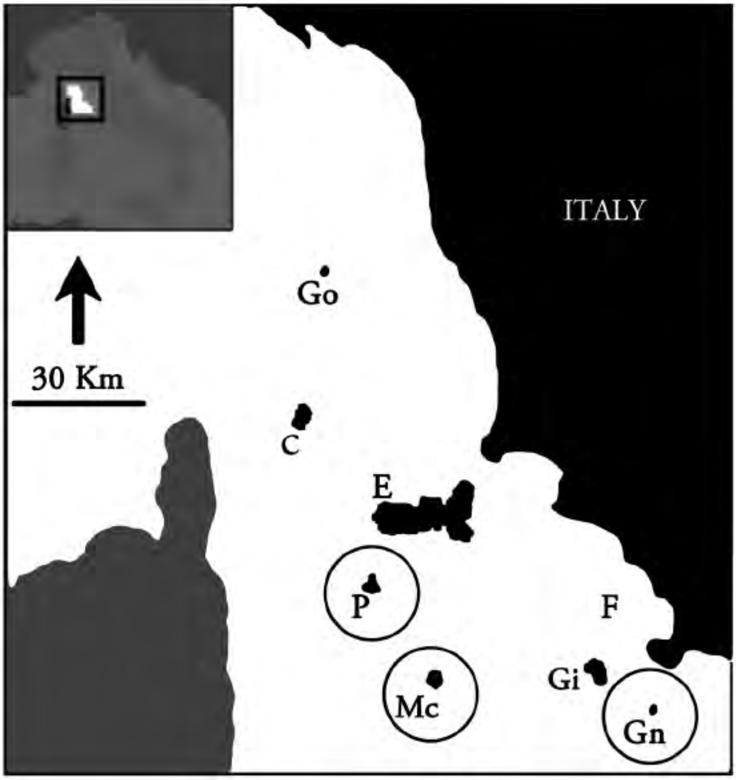

Fig. 1. Distribution of *Lophocladia lallemandii* (circles) in the Tuscany Archipelago. Go: Gorgona Island, C: Capraia Island, E: Elba Island, P: Pianosa Island, Mc: Montecristo Island, F: Formiche di Grosseto, Gi: Giglio Island, Gn: Giannutri Island.

(mostly *C. crinita* Duby, *C. brachycarpa* var. *balearica* (Savageau) Giaccone and *C. spinosa* Sauvageau); at 3 m depth, a patchy distribution of *Cystoseira* spp. and algal turf assemblages was present. The following habitats were considered at 3 m depth: *Cystoseira* spp. assemblages, turf assemblages on horizontal rocky bottom, turf assemblages on vertical rocky bottom. *Cystoseira* spp. assemblages and *P. oceanica* meadow edge were studied at 9 m depth. For *Cystoseira* spp. assemblages three depths were considered: – 9 m, – 6 m, – 3 m. The abundance of the alga was measured as percentage cover obtained by photographic samples. For each habitat or depth, two sites were randomly chosen within the area invaded by the alga and five replicate samples were collected in each site. Each sample consisted of 40 cm × 40 cm quadrats. Cover was estimated through random-point-quadrat (100 points per quadrat) method (Dethier *et al.*, 1993). The statistical significance of differences in *L. lallemandii* abundance between habitats or depths was tested by 2-way Univariate Analyses of Variance (ANOVA, Underwood, 1997), with Habitat as fixed factor and Site as random factor nested in Habitat. Homogeneity of variance was tested by Cochran's C test. Student-Newman-Klaus SNK test was used to discriminate among levels of significant factors.

To evaluate the biomass of *L. lallemandii* in relation to other algae in *Cystoseira* assemblages, three samples of *Cystoseira* spp. were collected in each of two sites invaded by *L. lallemandii* at 3, 6 and 9 m of depth; each sample consisted of all *Cystoseira* thalli present in 200 cm^2 surface. Both *L. lallemandii* and other epiphytes were separated from *Cystoseira*. Biomass was expressed as kg dry weight (kg dw) obtained after drying the material for 48 h at 60°C.

RESULTS

Lophocladia lallemandii was recorded in three islands of the Tuscany Archipelago: Montecristo, Pianosa and Giannutri (Fig. 1). The species generally occurred in shallow subtidal rocky bottoms directly anchored to substrate or epiphytic of other macroalgae; at Montecristo Island it also colonized coralligenous assemblages at a depth of about 30 meters. Areas completely invaded by the alga were only detected at Pianosa Island (Fig. 2). The affected coast of the island,

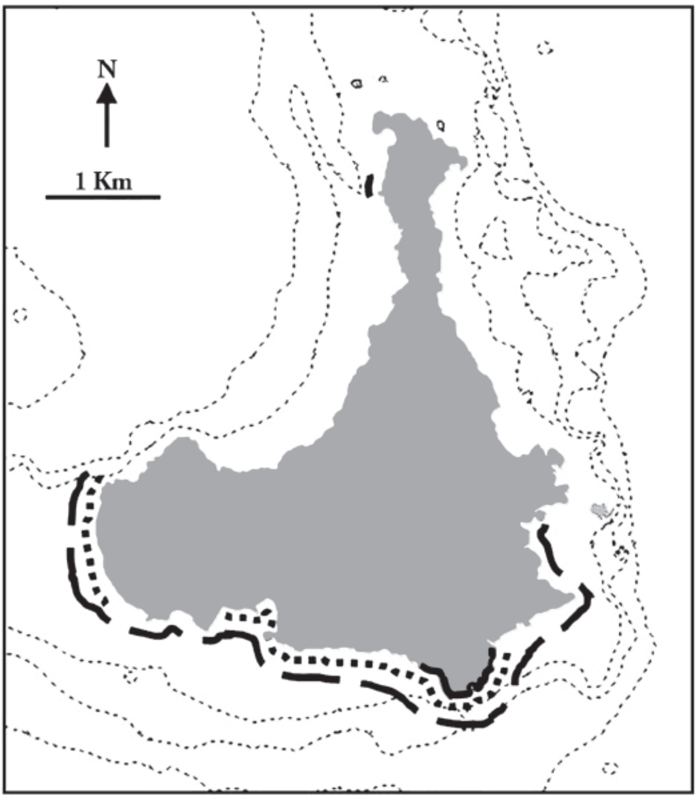

Fig. 2. Spread of *Lophocladia lallemandii* around Pianosa Island. 2008: solid line; 2009: dotted line; 2010: interrupted line.

increased from 1.2 km in 2008 to 10.7 km in 2010. In the invaded areas, the alga started to develop in July and reached its maximum spread in October/November. The alga colonized the rocky bottom between 3 and 10 m deep. Below 10 m, a continuous *Posidonia oceanica* meadow seemed to stop the spread of *L. lallemandii*. The alga was present in areas free from the seagrass within the meadow up to 18 m of depth.

The percentage cover of *Lophocladia lallemandii* in *Cystoseira* assemblages increased with depth, ranging between 19.6 ± 5.7 (mean ± SE, n = 10) at – 3 m and 64.8± 7.8 at – 9 m (Fig. 3A). ANOVA analysis detected significant differences among depths for *L. lallemandii* cover in *Cystoseira* assemblages ($F = 129.7$, $P = 0.046$); SNK test showed that values of cover at – 3 m were significantly lower than the others.

At – 3 m, the highest abundance was measured in turf assemblages on vertical substrates and the lowest in turf assemblages on horizontal substrates; *Cystoseira* assemblages showed intermediate values (Fig. 3B). At – 9 m, *L. lallemandii* was more abundant in *Cystoseira* assemblages than in *Posidonia oceanica* meadow edge (Fig. 3C). ANOVA detected significant differences between habitats at – 3 m ($F = 17.8$, $P = 0.043$); SNK test

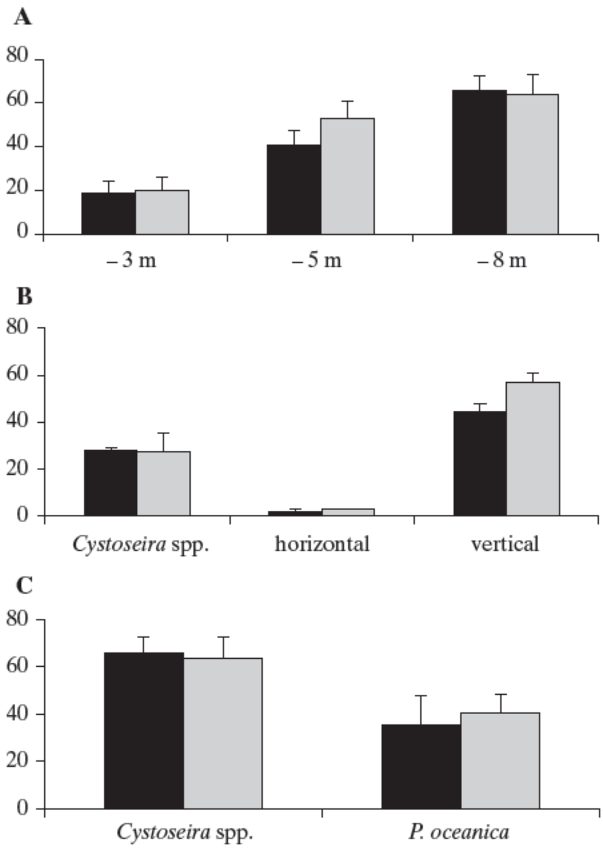

Fig. 3. Percentage cover of *Lophocladia lallemandii* in relation to depth and habitat. Site 1 in grey and site 2 in black. **A.** *Cystoseira* assemblages. **B.** Macrophyte assemblages at 3 m depth: *Cystoseira* spp. assemblages and turf assemblages on horizontal and vertical bottoms. **C.** Comparison in *Cystoseira* spp. assemblages and *Posidonia oceanica* meadow edge.

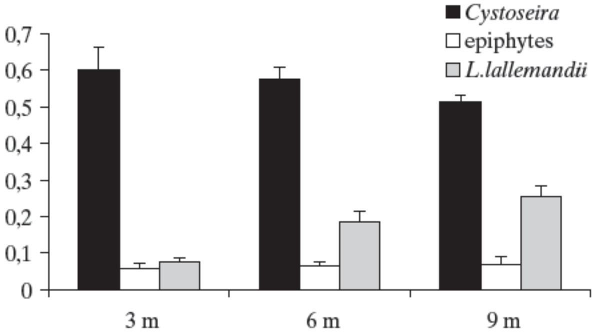

Fig. 4. Biomass of *Lophocladia lallemandii*, *Cystoseira* spp. and associated epiphytes in relation to depth.

showed that percentage cover of *L. lallemandii* was significantly higher on turf assemblages on vertical bottom than in *Cystoseira* assemblages and in this latter than in turf assemblages on horizontal bottom. Differences between *Cystoseira* spp. assemblages and *P. oceanica* meadow edge at – 9 m were not significant ($F = 13.8$, $P = 0.344$).

The biomass of *C. crinita* and its epiphytes reached 0.0120 ± 0.0006 kg dw 200 cm^{-2} (mean ± SE, n = 6) and 0.0014 ± 0.0002 kg dw 200 cm^{-2} respectively at 3 m of depth (Fig. 4). The biomass of *L. lallemandii* ranged from 0.0015 ± 0.0005 kg dw 200 cm^{-2} at 3 m of depth to 0.0051 ± 0.0006 kg dw 200 cm^{-2} at 9 m of depth (Fig. 5), where represented the 43.1% of that of the *Cystoseira* + epiphyte biomass (encrusting Corallinales excluded).

DISCUSSION

Results of the survey highlighted the invasive traits of *Lophocladia lallemandii* in the Tuscan Archipelago, where it rapidly colonized increasing number of seabed areas, constituting dense populations on native benthic vegetation.

The lack of information about the presence of *L. lallemandii* in many other coastal areas of Italy does not allow defining the dynamics of spread along the western coasts of the Italian peninsula. Probably, the colonization of the Tuscan Archipelago represents a normal increase of geographic distribution from the nearest populations in Sardinia or Southern Italy, but it could be also related to human-mediated vectors.

Patterns of spread of *L. lallemandii* were similar to those shown by other invasive seaweeds in terms of increasing length of affected coastline among different years (Piazzi *et al.*, 2001; Meinesz *et al.*, 2001). The seasonal dynamics of *L. lallemandii* in the Tuscan Archipelago agrees with that described for Balearic Islands, which were related to water temperature (Cebrian & Ballesteros, 2010). As other seasonal invasive seaweeds (Piazzi *et al.*, 2005), *L. lallemandii* completely disappeared during the vegetative rest period, but the invaded areas exponentially increased the following years. Values of biomass measured in the present survey were lower than those reported for Balearic Islands (Cebrian & Ballesteros, 2010). Observed differences are probably related more to different invasion stages than to differences in the environmental conditions. In fact, colonization of Pianosa Island is recent, while Balearic Islands have been invaded more than 10 years ago (Patzner, 1998). However, biomass of *L. lallemandii* was higher than all other *Cystoseira* epiphytes and it exceeded the 40% of *Cystoseira* + epiphytes biomass in the deeper stands.

Throughout the investigated bathymetrical range, percentage cover of *L. lallemandii* increased with depth and strong differences among habitats were found in the shallow stands. The presence of *Cystoseira* spp. seemed to facilitate *L. lallemandii* development, suggesting that this pattern could be related to hydrodynamism; in fact, water movements can easily detach the alga from substrate (Cebrian & Ballesteros, 2010) and both *Cystoseira* thalli and vertical substrata may probably represent more suitable habitats in the highly exposed coasts.

Cystoseira assemblages as well as *Posidonia oceanica* meadows can generally offer a valid mechanical resistance to the seaweeds invasion thanks to their thick canopy and density (Piazzi & Cinelli, 1999; Ceccherelli *et al*., 2000; Bulleri *et al*., 2010). Nevertheless, *L. lallemandii* seems to be facilitated by the presence of both *Cystoseira* and *P. oceanica*. Dense *P. oceanica* meadows were not invaded in the Tuscan Archipelago, but the alga began to colonize the meadow edge or the low density areas inside the meadows, suggesting that a longer period of colonization could lead to important invasion of meadows, as it was described for Balearic Islands (Ballesteros *et al*., 2007; Deudero *et al*., 2010). Due to its high reproductive output by spores (Cebrian & Ballesteros, 2010) and the ability to utilize canopy-forming seaweeds or seagrasses as substrate, *L. lallemandii* shows different competitive mechanisms compared to other important Mediterranean invaders, such as *Caulerpa* spp., *Sargassum muticum* (Yendo) Fensholt, *Asparagopsis* spp. or *Codium fragile* (Suringar) Hariot. The ability of *L. lallemandii* in colonizing canopy species exposes ecologically important habitats to be invaded, changing the concept of invasion resistance (Bulleri *et al*., 2010). Both seagrass meadows and *Cystoseira* stands have an important ecological role in coastal ecosystems, in terms of productivity and biodiversity. In fact, the typical tridimensional structure of these habitats allows to host very diversified biological communities and the resulting high values of biodiversity are enhanced by wealth of microhabitats and food and by the role played as refuge from predators (Ballesteros *et al*., 1998, 2009). Thus, the effects of colonization of *L. lallemandii* on both *Cystoseira* stands and *P. oceanica* meadows needs to be investigated in order to understand the extent of threat of this biological invasion for Mediterranean coastal systems.

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