Rapid Communication

Invasions of the non-indigenous red alga *Lophocladia lallemandii* (Montagne) F. Schmitz off the Island of Ischia (Tyrrhenian Sea, Italy)

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Abstract

This paper describes the distribution and spread of the non-indigenous red alga *Lophocladia lallemandii* (Montagne) F. Schmitz along the coast of the Island of Ischia (Tyrrhenian Sea, Italy). *Lophocladia lallemandii* was monitored through surveys from July 2019 to January 2020 at the Capo Sant'Angelo (Ischia), where *L. lallemandii* was observed, but not reported, in the years preceding the invasion of the upper rocky infralittoral shore reported here. It is noteworthy that a large portion of the study area is included within one of the two "B no-take" zones of the Marine Protected Area of the "Regno di Nettuno" ("Neptune's Realm"). During the surveys, the alga was first observed in the middle of July 2019 and totally disappeared by the middle of January 2020. Algal cover showed two peaks in August (55%) and November (58.5%). Fertile thalli (tetrasporophytes) of *L. lallemandii* were observed in all of the analysed samples. Thalli were not always strongly attached to the substrate or other algae and could often be easily detached by strong hydrodynamic conditions. These detached thalli were found laying on the bottom in dense turfs or floating or stranding on the beach. Noteworthy were the macroflora and fauna, the latter essentially composed by mollusks and amphipods, living among the branches of the alga, and various fishes hiding within the thick algal turf. These observations indicate that this alga may be a source of food and refuge for the native animal community of the upper rocky infralittoral zone.

Key words: biological invasions, alien species, macroalgae, monitoring, phenology, associated fauna, Mediterranean Sea

Introduction

Biological invasions, an ongoing phenomenon accelerated in recent decades by globalization, are a major driver of global change that threaten biodiversity and natural ecosystem functioning. Invasive NIS (non-indigenous species) may have significant environmental (substitution of native species; biodiversity loss; habitat modifications and alterations in community structure; ecosystem service changes), socio-economic or human health impacts (Wallentinus and Nyberg 2007). The dramatic accelerating rate of invasive NIS and the sheer magnitude of shipping traffic traversing the Mediterranean Sea, make this Basin a true hotspot of marine biological invasions (Occhipinti-Ambrogi et al. 2011a, b; Katsanevakis et al. 2013; Verlaque et al. 2015; Alós et al. 2016; Galil et al. 2017).

Biological invasions may severely affect islands, important hotspots of biodiversity, as well as Marine Protected Areas (MPAs) whose major aim is biodiversity conservation (Mannino and Balistreri 2017, 2018; Mannino et al. 2014, 2017, 2018; Domina et al. 2018). However, it is unclear if MPAs hinder invasive NIS expansion due to "invasion resistance" through high native species richness, or favor NIS introduction and spread through tourism activities which increase disturbance and vectors (boat anchors, diving, etc.) (Ardura et al. 2016; Giakoumi and Pey 2017; Blanco et al. 2020). MPAs can play an important role as "sentinel sites" where the effects of NIS invasion can be studied and management strategies can be developed to counter such negative effects. In order to develop effective management plans to impede invasive NIS expansion, data on the distribution and spread dynamics of current invasive NIS are essential (e.g. Gestoso et al. 2017; Piazzi et al. 2018; Katsanevakis et al. 2020).

Among invasive NIS, *Lophocladia lallemandii* (Montagne) F. Schmitz was probably introduced into the Mediterranean Sea via the Suez Canal (Verlaque 1994; Streftaris and Zenetos 2006) and is currently widespread throughout most of the Mediterranean Sea (Adriatic Sea, Algeria, Corsica, Egypt, Greece, Libya, Malta, Sardinia, South Italy, Spain, Tunisia and Turkey) (Edwards et al. 1975; Furnari and Scammacca 1971; Giaccone 1978; Giaccone et al. 1986; Cossu et al. 1993; Gomez-Garreta et al. 2001; Bedini et al. 2011; Gambi et al. 2019). The invasive potential of *L. lallemandii*, ability to cover both rocky bottoms and seagrass meadows, and negative effects on the seagrass *Posidonia oceanica* (L.) Delile (Ballesteros et al. 2007; Sureda et al. 2008) and the associated fauna (Cabanellas-Reboredo et al. 2010; Deudero et al. 2010) have been reported from the Balearic Islands (Patzner 1998; Cebrian and Ballesteros 2010), along the Tuscan Archipelago (Bedini et al. 2011) and more recently off Capo Sant'Angelo (Island of Ischia, the largest of the Phlegrean islands in the Gulf of Naples; Gambi et al. 2019).

Due to the presence of a high number of NIS, the Phlegrean islands represent an interesting area to study the distribution and expansion of both indigenous and non-indigenous thermophilous species (Occhipinti-Ambrogi et al. 2011a, b; Gambi 2014; Gambi et al. 2016, 2018, 2019). *Lophocladia lallemandii*, in particular, is included in the black list of invasive marine species by the IUCN (2012), and it is important to monitor its introduction and spread in the area off Capo Sant'Angelo, where massive occurrences of the alga were already observed (Gambi et al. 2019). Indeed, even though high biomasses of *L. lallemandii* in the Island of Ischia have been observed sporadically since 1998/1999, the first documented large bloom event was reported in 2009 by two of the authors (LT, GI) at the western side of Capo Sant'Angelo (the area called "Le Parate"), in the

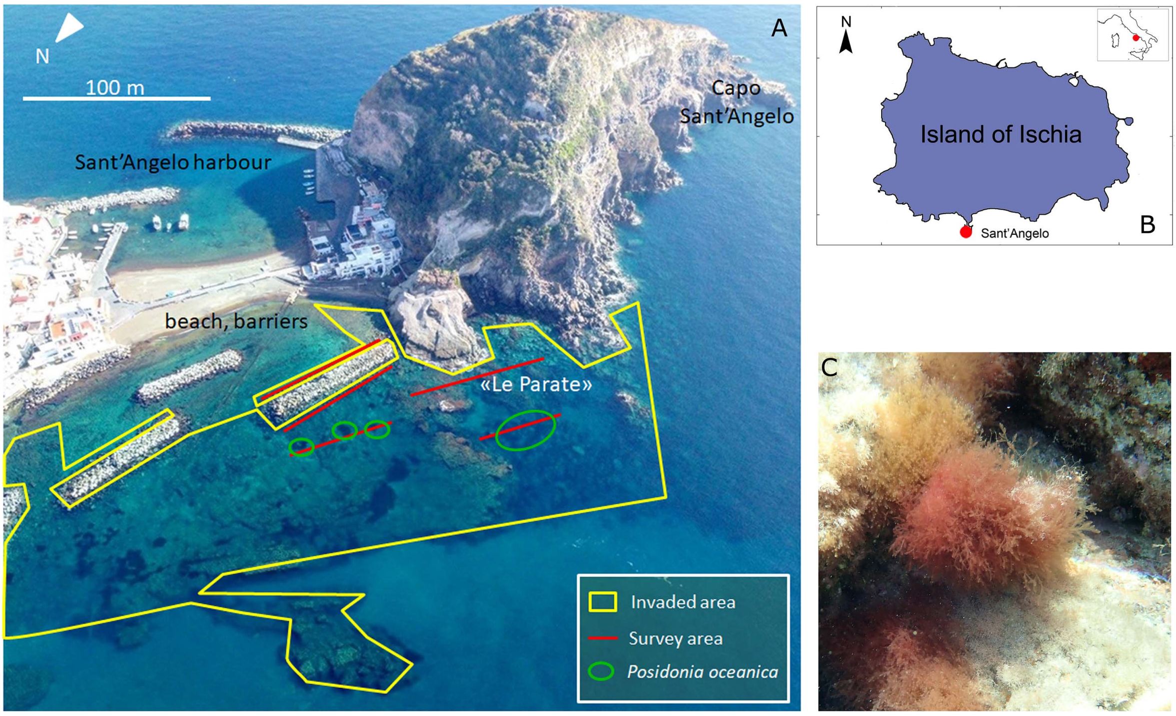

Figure 1. A drone picture of the study area (the Sant'Angelo promontory) along the coast of the Island of Ischia (A); a map of the Island of Ischia indicating the study area (B), and a tuft of *Lophocladia lallemandii* (C). In (A), the area defined by a yellow line represents the area invaded by the alien alga *Lophocladia lallemandii*, while the lines in red represent the surveyed area, and the green circles the presence of *Posidonia oceanica* patches on the rocky bottom (drone Photo courtesy of Luca Poerio Iacono).

southern zone of the island, from 0.5 to about 15 m depth (Gambi et al. 2019). From 2009 onwards, *L. lallemandii* occurred almost every year in the area, with different degrees of development and abundance/cover, growing on the rocky reefs up to 15 m depth, sometimes forming dense turf, especially during the summer months. In 2018 a new episode of massive invasion in this area was reported by Gambi et al. (2019). Therefore, we decided to survey this area with the aim to assess the extent of *L. lallemandii*, its presence over time, variability in cover, and reproductive output in order to document the cycle of colonization, as well as to estimate the associated flora and fauna.

Materials and methods

Study area

The study was conducted on the Island of Ischia that is located, together with the nearby islands of Procida and Vivara (collectively called the Phlegrean islands), on the northern side of the Gulf of Naples and is included within the MPA of the "Regno di Nettuno" ("Neptune's Realm"), instituted in November 2007 (Gambi et al. 2003). The surveys were carried out on the southern side of the Island of Ischia, in the area called "Le Parate", located in the western part of Capo Sant'Angelo (Figure 1, 40°41′42.49″N; 13°53′27.64″E). Capo Sant'Angelo and its promontory represent one of the two "B no-take" zones within the MPA zonation pattern (www.nettunoamp.org), where entrance is allowed only for bathing, guided snorkel tours and SCUBA diving, while anchorage and fishing are prohibited. A few surveys revealed that *L. lallemandii* was scarcely present in the area around this site (e.g., San Pancrazio cliff, approx. 4 km north-east of our study area (40°42′4.52″N; 13°57′18.73″E) and "La Nave" (40°42′25.19″N; 13°51′11.43″E), a big exposed rock approx. 3.5 km on the north-west of Capo Sant'Angelo.

The area around Capo Sant'Angelo is very vulnerable to wave action (having a large fetch and southerly winds) and current and is characterized by deep vertical cliffs and canyons heads. The cliffs host a rich rocky reef flora and fauna and, in the deeper areas, spectacular Coralligenous formations, including populations of the red coral *Corallium rubrum* (Linnaeus, 1758) (Gambi et al. 2003; Bavestrello et al. 2014). The western side of Capo Sant'Angelo, between the promontory and the main island, is characterized by a pocket beach protected by various rocky artificial barriers located approx. 50–70 m from the shore (40°41′47.35″N; 13°53′29.95″E), while on the eastern side there is a small harbour for local fishermen and pleasure boats (Figure 1).

Sampling and processing

The study was conducted in 2019–2020, when the alga was visually detectable, i.e., from July 2019 (when a few thalli of the alga started to become visible) to January 2020, when they completely disappeared. The species could have also been present before July with small-sized thalli, but they were not detectable by visual inspection. *Lophocladia lallemandii* was surveyed along "Le Parate" rocky reef and the inner and outer zones of the artificial barriers in front of the beach (40°41′47.35″N; 13°53′29.95″E) (Figure 1). The presence of the alga and its level of invasion were assessed in two main substrate typologies, i.e. along 300 m of natural rocky shore off "Le Parate" (from 1 to approx. 10 m depth) and along 200 m of artificial barriers (inner and outer portions; 1–5 m depth). During the surveys, visual inspection as well as photos and videos were taken to document *L. lallemandi* distribution/cover. *In situ* observations highlighted that the thalli were not always strongly attached to other algae, or to the substrate, so strong hydrodynamic conditions could easily detach some of them.

Collection of *L. lallemandi* thalli, together with visual measures of abundances as percentage cover, were conducted within the first 3 m depth, on 10 randomly placed, replicate samples (25 cm × 25 cm quadrats) in August, October and November. At least 20 thalli of *L. lallemandi* were collected during each survey to check the phenology and the associated organisms. After collection, thalli were preserved in 60% ethanol. The frequency of fertile specimens and sterile specimens for each sampling period was estimated under a binocular microscope and expressed as a population percentage. Sorting and identification of species associated with

Figure 2. Colonization of *Lophocladia lallemandii* in the study area: A–B) early colonization (July 2019) of the alga on the rocky shore (3 m depth); C) colonization of the alga at the base of a *Posidonia oceanica* patch (5 m depth); D–E) late colonization (November 2019) of the alga on the rocky bottom (5 m depth) (Photos by Luca Tiberti and Gianluca Iacono).

L. lallemandii thalli (macroalgae and macro-invertebrates) were performed under a stereo microscope. Additionally, large invertebrates and fishes not collected from the quadrats were identified during the field work, as well as from photos and videos.

Results

Lophocladia lallemandii was common along the surveyed area, approx. 200 m along artificial barriers and 300 m along the natural coast of "Le Parate". However, we estimated that the invaded area was much wider, approx. 8–9 hectares of sea bottom (Figure 1).

In the area, the alga was first observed in the middle of July, with a very patchy presence of small thalli (6–8 cm length, the cover was not estimated) (Figure 2A, B). In August the dimensions and cover of thalli on the rocky barriers had increased (up to 15–20 cm length, 55% cover) (Figure 2), and some thalli were also observed close to patches of *P. oceanica* (Figure 2C). At the end of August, numerous detached thalli were observed laying on the bottom and floating. In October smaller thalli, with an overall cover of 35.5%,

Table 1. List of the taxa collected in association with *Lophocladia lallemandi* at the Capo Sant'Angelo (Island of Ischia, Italy).

Taxa
Macrophytes
Amphiroa rigida J.V. Lamouroux
Anadyomene stellata (Wulfen) C. Agardh
Ceramium comptum Børgesen
Chondria capillaris (Hudson) M.J. Wynne
Cladophora prolifera (Roth) Kützing
Corallina officinalis Linnaeus
Dictyota dichotoma (Hudson) J.V. Lamouroux
Digenea simplex (Wulfen) C. Agardh
Halopithys incurva (Hudson) Batters
Herposiphonia secunda (C. Agardh) Ambronn
Hypoglossum hypoglossoides (Stackhouse) Collins & Hervey
Hypnea musciformis (Wulfen) J.V. Lamouroux
Jania rubens (Linnaeus) J.V. Lamouroux
Laurencia obtusa (Hudson) J.V. Lamouroux
Padina pavonica (L.) Thivy in W.R. Taylor
Peyssonnelia squamaria (S.G. Gmelin) Decaisne ex J.Agardh
Pterothamnion crispum (Ducluzeau) Nägeli
Stypocaulon scoparium (Linnaeus) Kützing
Invertebrates
Bittium latreilli (Payraudeau, 1826)
Cerithium lividulum Risso, 1826
Gibbula ardens (von Salis Marschlins, 1793)
Rissoa ventricosa Desmarest, 1814
Amphipoda Maeridae sp.
Amphipoda Caprellidae sp.
Amphipoda Hyalidae sp.
Amphipoda Dexaminidae sp.

were observed only in the outer part of the rocky barriers. In November, however, numerous big thalli (58.5% cover) were observed on the inner part of the rocky shore whilst they were considerably smaller on the outer part of the barriers and covered a smaller percentage of area (35% cover). At the end of November, a series of strong storms and adverse climatic conditions prevented us from performing any surveys in December, but the occurrence of the species was monitored along the beach whilst checking for the stranded thalli.

Fertile thalli (only tetrasporophytes) were found in all the analysed samples. The percentage of tetrasporophytes ranged from 5% in October to 70% in November.

The rocky bottom, where *L. lallemandii* settled, was colonized by other macroalgae, with *Digenea simplex* (Wulfen) C. Agardh, *Halopithys incurva* (Hudson) Batters, *Padina pavonica* (Linnaeus) Thivy and *Stypocaulon scoparium* (Linnaeus) Kützing displaying the highest coverage values (Table 1). The associated fauna in the collected samples showed mainly mollusks and amphipods with mesograzer species, such as *Gibbula ardens* (von Salis Marschlins, 1793), *Rissoa ventricosa* (Desmarest, 1814), and herbivorous-detritivores ones (most of the amphipods) (Table 1). It is worth mentioning that other macrophytes, including the alien macroalga *Caulerpa cylindracea* Sonder, various mega-invertebrates, including the range expanding Atlantic decapod *Percnon gibbesi* (H. Milne Edwards, 1853) (Mannino et al. 2017), and several fishes hiding within the thick algal turf, were observed during the visual census (in all 44 taxa, see Supplementary material Table S1 and Figure S1).

Discussion

The invasion events of *L. lallemandii* have occurred over the past 20 years (since 1998/1999 according to local knowledge), but have been neglected and poorly documented (Gambi et al. 2019) until now. In this paper we document for the first time the seasonal cycle of the invasion event of *L. lallemandii* in this area. We confirm the seasonal trend of the phenomenon (from mid-July 2019 till mid-January 2020), with two peaks of abundance observed in August and in November. A similar trend was observed by Cebrian and Ballesteros (2010), with an increase during Summer and Autumn when the number of reproductive structures (tetrasporocysts) was also high. This pattern could be related to the tropical origin of *L. lallemandii* (Boudouresque and Verlaque 2002). Moreover, the presence of tetrasporophytes only led us to hypothesize that *L. lallemandii* would have a high potential reproductive output by means of spores, in addition to the high recruitment abilities and vegetative fragmentation (thalli can be easily broken or detached and float or lay in the bottom), which would explain the capacity for fast spread by this alga (Ballesteros et al. 2007; Cebrian and Ballesteros 2007, 2010).

Samperio-Ramos et al. (2015) observed an increase of *L. lallemandii* growth and photosynthetic yield with water warming up to 29 °C, congruent with the tropical origin of the species. Therefore, the sea temperature warming projected for the Mediterranean for this century (Bianchi 2007) might facilitate its spread in the basin. The sea surface temperature in the Western Mediterranean Sea has increased by 0.36 ± 0.06 °C s.e./decade in the past three decades (Nguyen et al. 2020). In the waters of the Island of Ischia, and in the whole Tyrrhenian Sea, an increasing warming trend has been observed in recent decades, and the winter (February) minimum "14 °C divide" isotherm has shifted northwards as compared to 30 years ago, confirming the trend observed in other areas along the Italian coast (Bianchi et al. 2019). Although sea surface warming is a phenomenon occurring around the whole Island of Ischia, it is not entirely clear why the invasive events of *L. lallemandii* are restricted to Capo Sant'Angelo, but it is likely due to the ecological characteristics of this site. Capo Sant'Angelo is south-facing and particularly exposed to wave and current actions and possible up-welling from the nearby canyons surrounding the Cape and promontory. The type of substrate or complex interactions with the local reef community could also favor the invasion of *L. lallemandii*. Not predictable events, for instance the availability of propagules and a low competition with native species, could even have allowed this species to first settle perhaps decades ago, and ideal environmental conditions have allowed the species to proliferate and re-colonize from propagules or hidden gametophyte persistent in the area.

Noteworthy is the presence of other macroalgal species co-occurring with *L. lallemandii*, macro and mega-invertebrates living among the branches of the alga, and several fish species hiding or swimming within the dense algal turf. Although these data on co-occurring species are limited and requires more appropriate sampling and a comparison with zones not invaded by this alien alga, it suggests that *L. lallemandii* may represent a source of food and refuge for the community of the upper infralittoral zone. Although it has not yet been proven, it is very likely that the associated organisms feed on the alga, as was recently demonstrated for the sea urchin *Paracentrus lividus* (Lamarck, 1816) both in natural and laboratory conditions (Cebrian et al. 2011). Cabanellas-Reboredo et al. (2010) also found that *L. lallemandii* slightly decreased the trophic level of the consumer *Pinna nobilis* (Linnaeus, 1758) possibly due to the physiological effects of the lophocladines produced by the alga (Gross et al. 2006; Cabanellas-Reboredo et al. 2010). *Lophocladia lallemandii* has also been shown to negatively impact colonies of the erect bryozoan *Reteporella grimaldii* (Jullien, 1903) at shallow *P. oceanica* meadows (Deudero et al. 2010). Bryozoan densities at non-invaded seagrass plots are higher than those at invaded plots with a fourfold decrease in number of colonies (Deudero et al. 2010). Bedini et al. (2014) compared the structure of mobile epifaunal assemblages associated with Mediterranean *Cystoseira* beds between areas invaded and non-invaded by *L. lallemandii*. Significant differences in the epifaunal assemblages between invaded and non-invaded beds were found only in the periods when the invasive species reached maximum values of cover and biomass (Bedini et al. 2014). Although the richness and total abundance of organisms were not significantly different between invaded and non-invaded beds, amphipods, isopods and polychaetes were more abundant in the invaded areas, while mollusks and decapods dominated in non-invaded areas (Bedini et al. 2014). High abundances of amphipods associated with *L. lallemandi* have been also documented by Rodriguez et al. (2009) in the Balearic Islands. Therefore, the role of this highly invasive species in structuring the composition of associated fauna is still not clear and requires further studies.

Even though the invasive potential of *L. lallemandii* has been ascertained in the Balearic Islands (Cebrian and Ballesteros 2010), the Tuscan Archipelago (Bedini et al. 2011), and Sant'Angelo (Ischia) (Gambi et al. 2019; present study), the turf this alga forms on marine vegetation (other algae and phanerogams) may certainly represent a serious threat to native vegetation (Ballesteros et al. 2007; Marbà et al. 2014). At present, we have not observed any negative interactions between *L. lallemandi* and the *P. oceanica* meadow occurring at the Capo Sant'Angelo because *L. lallemandi* was mainly observed in small open patches, at the base of the *P. oceanica* rhizomes, or at the meadow edges. However, since the Island of Ischia, especially its northern side, is surrounded by extensive *P. oceanica* meadows (Buia et al. 2003), as well as extended rocky shores (Gambi et al. 2003), regular monitoring of *L. lallemandi* is essential. Indeed, the invasion events reported along the coast of the Island of Ischia, which could increase over time to also involve areas nearby, represents further evidence of the invasive potential of *L. lallemandii*. In this regard, the Sant'Angelo site, included almost entirely within the B no-take zone of the Marine Protected Area, should be considered a valuable natural laboratory to continue regular monitoring of this phenomenon.

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Supplementary material

The following supplementary material is available for this article:

Table S1. List of macrophytes, mega-invertebrates and fishes visually observed during the surveys on *Lophocladia lallemandi* at the Capo Sant'Angelo (Island of Ischia, Italy).

Figure S1. Mega-invertebrates and fishes observed in association with *Lophocladia lallemandii* at the Capo Sant'Angelo: A) Juveniles of *Chromis chromis*; B) the sea anemone *Anemonia viridis*; C) a school of the herbivorous fish *Sarpa salpa*; D) the mollusk nudibranch *Felimare picta*; the fishes: E) *Muraena helena*; F) *Scorpaena porcus*; G) *Sygnathus typhle*; H) *Mullus surmuletus.* Photos by Luca Tiberti and Gianluca Iacono.

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