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The spread of *Caulerpa cylindracea* in Calabria (Italy) and the effects of shipping activities

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ABSTRACT

A survey to state the spread of *Caulerpa cylindracea* in the Calabrian Tyrrhenian coasts has been undertaken. The research aims to value the role of shipping activities in the ten-year's study from 1999 to 2009, as a vector in the spreading of the species. The outcome of this study has shown that, during the last ten years, the species has colonized most of the regional coastline, on all kinds of substrata, in areas closed to harbours and subjected to high rate of sedimentation. The main effects of *Caulerpa cylindracea* colonization have resulted in a gradual decrease of crustose species while the turf ones have increased their abundance, altering the native structure of the macroalgal assemblages. These results confirm the extremely invasive behaviour of this strain in the Calabrian Tyrrhenian coasts and, more generally, in the Mediterranean Sea.

1. Introduction

The genus Caulerpa Lamoroux is a complex and heterogeneous group of green algae characterized by a high degree of morphological variability strongly affected by environmental factors (Nizamuddin, 1964; Rehm and Almodovar, 1971), as highlighted by some researchers who find out a marked seasonal variation in the morphology of Caulerpa genus (Meinesz et al., 1995; Collado-Vides and Robledo, 1999).

From over a century, the Mediterranean basin is subject to a dispersal phenomenon of this algal genus and particularly of some non-indigenous species such are: *Caulerpa chemnitzia* (Esper) J.V. Lamouroux, *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini, *Caulerpa racemosa* var. *lamourouxii* f. *requienii* (Montagne) Weber–van Bosse. Amongst them, *Caulerpa taxifolia* var. *distichophylla* is the newest alien Caulerpa species in the Mediterranean Sea (Jongma et al., 2013). The italian coasts are, also, highly affected by algal marine species invasion and 33 alien macrophyta were recorded along the 7375 km of the national boundary (Occhipinti-Ambrogi et al., 2011).

Caulerpa racemosa, indopacific and termophilic species of wide distribution, has spread first in all the Eastern Mediterranean basin, beginning from the Tunisian coasts (Hamel, 1926) and actually is spreading, also, in the Western Mediterranean basin (Piazzi et al., 1994). The first record of *Caulerpa racemosa* on the Italian coasts dates from 1993 in S. Panagia Bay (Syracuse, Sicily) and in Lampedusa Island (Pelagian Islands, Sicily) (Alongi et al., 1993). Afterward, the species has shown a rapid range of expansion into the Western Mediterranean coasts of Italy: Liguria (Bussotti et al., 1996), Tuscany (Piazzi et al., 1994, 1997), Sardinia (Cossu and Gazale, 1996), Campania (Gambi and Terlizzi, 1998), Calabria (Cantasano, 2001) and Sicily (Giaccone and Di Martino, 1995). In the last decade, the trend of *Caulerpa racemosa* spreading has undergone an impressive increase, probably due to the special morphological and functional adaptability of this species to different kind of coastal environments (Klein and Verlaque, 2008). In all the Mediterranean Sea, three different taxa of the *C. racemosa* complex coexist: *C. racemosa* var. *turbinata-uvifera* (J. Agardh) Eubank, now stated as *C. chemnitzia* (Esper) J.V. Lamouroux, *C. racemosa* var. *lamourouxii* (Turner) Weber-Van Bosse and a third “invasive variety” (Verlaque et al., 2000) close to *C. racemosa* var. *occidentalis* (J. Agardh) Boergensen. Afterward, this invasive species was recognized, through a morphological and genetic study (Verlaque et al., 2003), as *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque et

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Boudouresque. At last, recent molecular studies (Belton et al., 2014) have shown the genetic independence of *Caulerpa racemosa* var. *cylindracea* as a species-level entity and it has been proposed the reinstatement of the original strain *Caulerpa cylindracea* Sonder (hereafter *C. cylindracea*). This taxon, belonging to the family Caulerpaceae and endemic from south-western Australia, recently introduced into the Mediterranean Sea (Klein and Verlaque, 2008), has settled all along the Mediterranean coast of Italy for about 500 km in length (Piazzi et al., 2005b). Therefore, *C. cylindracea* has become one of the most dangerous invaders for its heavy impact on marine benthic ecosystems (Klein and Verlaque, 2008; Katsanevakis et al., 2010) and it has been included in the 100 worst invaders for the Mediterranean Sea (Streftaris and Zenetos, 2006). In fact, the studies indicate a decrease in the diversity of macrophyta species in presence of *C. cylindracea*, mainly caused by a process of accumulation and burial for sediments induced by the mat (Piazzi et al., 2005b). Since its first Mediterranean report (Nizamuddin, 1991), the species is spreading rapidly throughout most of the Western Mediterranean coasts of Italy (Piazzi et al., 1997; Buia et al., 1998; Piazzi and Cinelli, 1999; Ceccherelli and Piazzi, 2001), colonizing wide areas of the basin from the surface to more than 40 m depth and, also, in intertidal areas, on all kinds of marine bottoms (Verlaque et al., 2003; Piazzi et al., 2005b), where their dense meadows can feature up to 27.000 erected blades per square meter (Zenetos et al., 2010). Really, most of the Mediterranean non-indigenous species come from Suez Canal, which remains the main pathway of introduction of alien species in the basin (Katsanevakis et al., 2013; Galil et al., 2014, 2015). Likewise, also shipping activity is another important vector of allochthonous species in Mediterranean coastal waters (Ruiz et al., 1997; Katsanevakis et al., 2013; Galil et al., 2014) where the transport occurs through ships' fouling, ballast waters and/or by anchorages (Ribera-Siguan, 2003). By this way, transportation by anchors and/or by fishing nets could have supported the fast and impressive spread of *C. cylindracea* in all the Western Mediterranean Sea (Papini et al., 2013). Also in Italy, shipping activities are an important waterway in the transport and spreading of alien species for its central position in the Mediterranean Sea and for the presence of many island connections. Just for example, from statistical data released by the National Institute of Statistics (ISTAT, www.istat.it/archivio/140422/2005-2013), 457,078 million tons of goods were moved in 2013 year while, at the same time, a number of 73,238 passengers travelled in Mediterranean basin. This trend is, actually, ongoing and Italy has become one of the leading regions in the commercial and tourist traffic amongst European countries. In particular, as regards the invasive species *C. cylindracea*, many coastal areas were interested by its occurrence. Really, the sites firstly colonized by this invasive species were, for the most part, the shallow waters of tourist and fishing harbours (Piazzi and Cinelli, 2003). Afterward, in the time lag of some months, the species expanded quickly in neighbouring waters highly eutrophic, as in sediments enriched by organic materials and/or in changing conditions of pristine benthonic populations (Piazzi et al., 2001; Balata et al., 2004). Finally, at the end of this invasive process, *C. cylindracea* spreads in the remaining biotopes, even in good ecological conditions, so that it can appears, also, in Marine Protected Areas (MPA) designed and managed to preserve their ecological status (Piazzi et al., 2005a; Katsanevakis et al., 2010).

The entire study was conducted, along the Calabrian Tyrrhenian coast in the period 1999–2009 within a general trend showing the rapid expansion of the species in the whole Italian coasts, where *C. cylindracea* could be considered as a strong habitat modifier (Wallentinus and Nyberg, 2007). The research aims to provide a first regional survey in the process of colonization and spreading of *C. cylindracea*, testing the hypothesis that this invasive species could expand its range especially in coastal areas close to regional harbours, as a consequence of shipping activities.

2. Materials and methods

The study was carried out, from 1999 to 2009, in the south - western Mediterranean Sea, along the Calabrian Tyrrhenian coasts from Praia a Mare (Cosenza) to Scilla (Reggio Calabria) for a coastline of 242 km in length. The study has been realized through single time monitoring collections in the same stations of a regional program of macroalgal census. Twenty-two sampling sites were chosen in the infralittoral zone on rocky and soft bottoms from 1 to 10 m depth (Fig. 1). Samples of *C. cylindracea* were collected by SCUBA diving on different locations and depths. The survey points were selected within a systematic review of the regional coastline, realized during a ten years program, directed towards a floristic assessment of macrophytobenthos along the Calabrian Tyrrhenian coasts on locations that had not been monitored in previous years. As previously mentioned, all the stations were located in shallow waters and, especially, at the depths of 4–6 m (Fig. 2). The selection of the 22 sites, realized, also, to report the presence of this invasive species, was based on the following requirements: (1) good spatial coverage of the survey area; (2) representative samples on all major habitat types of the study area; (3) narrow range of surveyed depths.

Amongst the 22 sampling sites, the study was carried out at two stations (Torre Ruffa and Diamante) of the Calabrian Tyrrhenian coast on shallow habitats partially covered by sediments. The study, conducted from 1999 to 2009, was carried out to analyse and value on time the process of colonization of *C. cylindracea*. In particular, the stations of Torre Ruffa and Diamante were chosen for an intense study oriented to value the effects of *C. cylindracea* spreading on the pattern of macroalgal assemblages in different stages of this biological invasion. The two selected stations, chosen for their different stage of colonization, were located at 4–5 m depth on a pioneer stage of invasion (Diamante, 39°40′11.71″N – 15°49′45.36″E) and at 1–2 m depth on an older one (Torre Ruffa, 38°38′31.65″N - 15°50′04.93″E). The general features of the two sampling areas have been described (Table 1).

The two sites were selected after dividing the entire areas into five different habitat types: Borders of *Posidonia oceanica* meadows (BPO), Dead Matte (DM), Coarse Sand (CS), Fine Sand (FS) and Rocky Substrata (RS) from 1 m to 5 m depth. In each site, two areas of about 400 m × 400 m in size were chosen. In every area, four monitoring strips 50 m long were, randomly, positioned in rocky substrata, to verify the presence of *C. cylindracea* at each site. The line transects were made up with nylon lines marked, every 5 m, with underwater signals arranged using a diving reel. After deploying each line transect, the number of *C. cylindracea* fronds were counted at each signal within a 20 cm × 20 cm square along each line as ten plots of 400 cm^2 along each transect. For each plot, the structure of assemblages and the habitat types were, also, recorded. Besides, in each plot was estimated the structure of the assemblages. In particular, the proportion of turf (T), encrusting (C) and erect layers (E) were calculated as the sum of the percentage cover of all the algae belonging to each layer, according to Piazzi et al., 2001. At the end, for each plot, ten samples were collected by scuba – diving, preserved in 5% solution of formaldehyde in seawater and, later, observed under microscopes to determine the algal species present in the sites colonized by *C. cylindracea*. The morphometric data of the samples were measured (Table 3) and analysed in the Phycological Laboratory of the University of Rome (La Sapienza), Plant Biology Department, utilizing Zeiss Axiolab optic microscope and Wild Herbrugg stereomicroscope.

In the same way, the assessment of human pressure by shipping

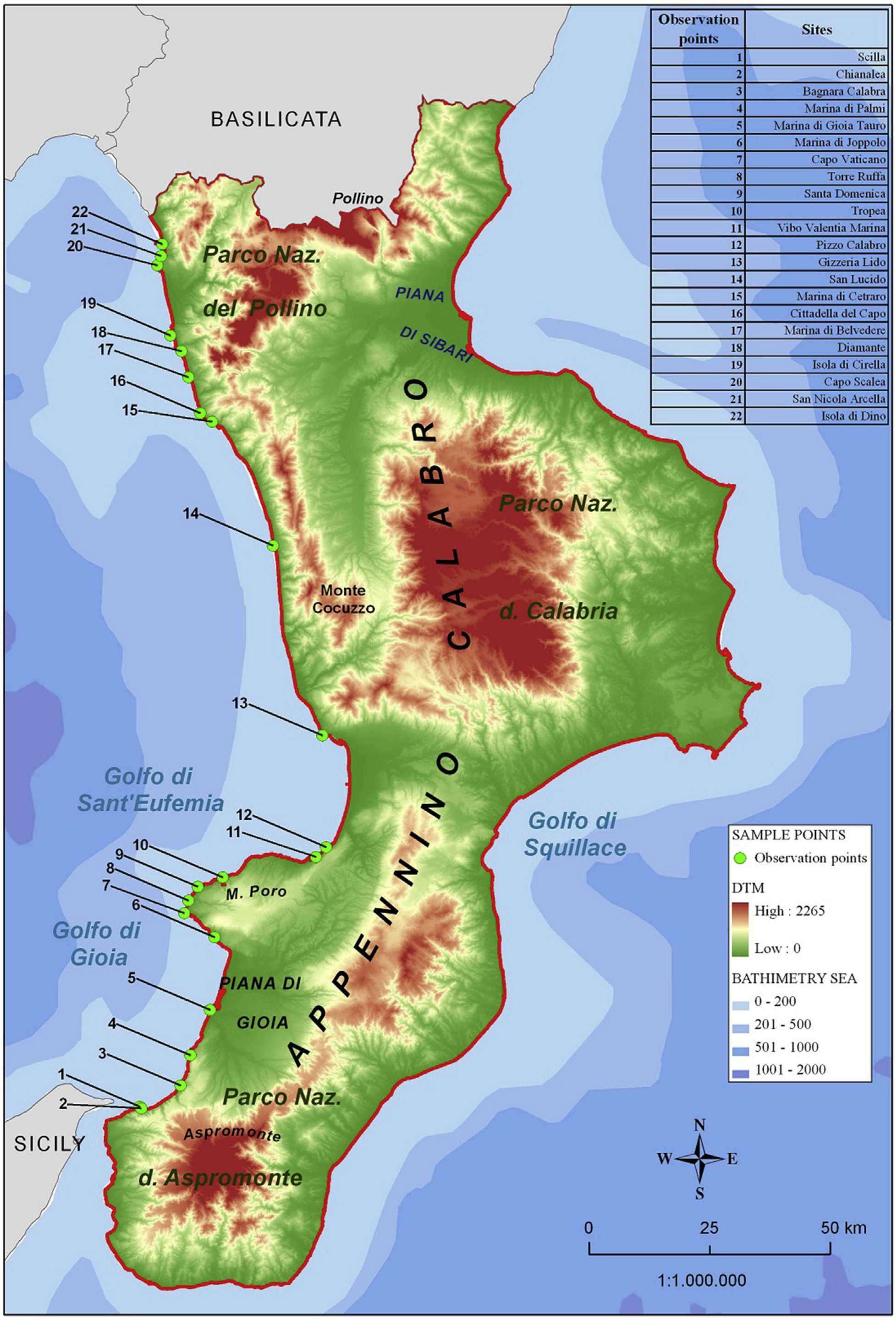

Fig. 1. Distribution of *C. cylindracea* in the Calabrian Tyrrhenian coasts.

activities was established by consulting statistical data released by the harbour authority of Vibo Valentia Port (38°43′26″ N, 16°07′40″ E). This Italian harbour looks out in the Southern Tyrrhenian Sea and covers an area of about 250,000 m^2 with a linear extension of 1,652 m, a water mirror of 314,653 m^2 and a depth between 8,6 m and 12,4 m. It is a commercial and industrial harbour with a handling of goods, as the 90% of its whole traffic. The oil products are the main merchandise handled in the port and directed towards two important plants owing to the oil companies AGIP SPA and MERIDIONALE PETROLI SRL. The harbour is developed on three docks able to lodge 450 boats up to 50 thousand tonnage of tons. The harbour authority of Vibo Valentia has provided numerical data on maritime traffic for 2015 year where these statistics are comparable and can be extended, also, to the yearly means for the time series 1999–2009.

3. Results

The number of colonized areas in the Calabrian Tyrrhenian coasts has, vastly, increased since the first report dated 1999

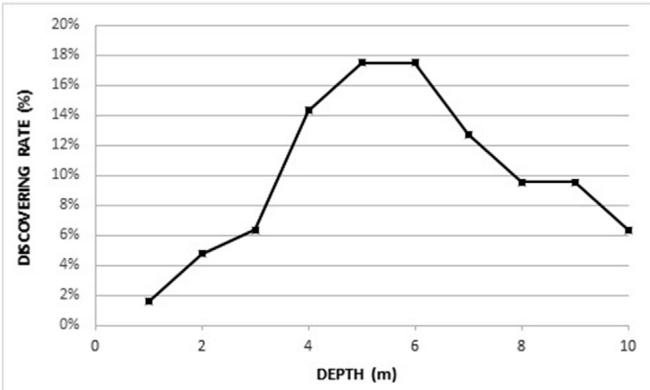

Fig. 2. *C. cylindracea* discovering rates at the different depths of collecting sites.

Table 1
General features of the two selected sampling areas at Torre Ruffa and Diamante stations.

General features	Torre Ruffa	Diamante
Sizes of sampling areas (m^2)	16 ha	16 ha
Dates of collections	30/09/1999	30/10/2009
Depth ranges (m)	1-2 m	4-5 m
Types of substrata	Mixed substratum	Mixed substratum
Light conditions	Intense illumination	Intense illumination
Water motion	Moderate	Scarce
Fauna	Present	Present

(Cantasano, 2001). Ten years after its first observation, the species has colonized 22 locations for a total length of 62.8 km as a single report on 12.7 km of coastline (Fig. 1). The study was conducted, through single time observations, only in shallow habitats until 10 m depth in coastal waters easily detectable, even though the species can usually thrives until 40 m depth (Piazzi et al., 1997). In all the 22 sites, the species was collected in surface waters and, especially, from 4 to 6 m depth (Fig. 2).

In the study areas, the species has invaded rocky and sandy bottoms but, also and above all, the borders of *Posidonia oceanica* (L.) Delile meadows (Table 2, Fig. 3).

From the survey, *C. cylindracea* has thrived along the Calabrian Tyrrhenian coasts under different environmental conditions: in exposed and sheltered sites, at low and high light conditions, in pristine and in polluted areas. Besides, the collecting sites are subjected to high pressures for shipping and tourist activities, but the first ones are, certainly, prevailing (Fig. 4).

During the survey, *C. cylindracea* showed a very heterogeneous pattern of distribution and different densities from small patches, loosely scattered, to dense and continuous meadows. In particular, in the two study sites of Diamante and Torre Ruffa, the process of colonization by this invasive species has been realized according to different conditions. Really, the first observation of *C. cylindracea*, at Diamante station, dated back to April 2009 and showed small patches loosely scattered on the rock, whereas at Torre Ruffa station, the bottom was densely colonized since September 1999 when field observations began (Cantasano, 2001) and, actually, it is covered with a carpet of greenery in a stratified structure of about 10 cm depth (Fig. 5).

From personal observations made by authors, the biometric data of *C. cylindracea,* in the selected stations of Diamante and Torre Ruffa, showed longer fronds and shorter branchlets than the Mediterranean ones, sampled in Tuscan and Ligurian coasts (Table 3).

Besides, in the two study sites, a total of 27 macroalgal species were identified including 6 Chlorophyta, 6 Ochrophyta and 15 Rhodophyta, with their nomenclatural authorities (Table 4). Really, macroalgal assemblages are very important to evaluate the effects of *C. cylindracea* invasion. In fact, in the study sites invaded by the species, this biological invasion has caused a decrease in species richness. In particular, in Torre Ruffa station, a site characterized by an old stage of colonization by this invasive species, it has been highlighted a marked reduction in Ocrophyta taxa, well known as stenovalent species, while it has been noted a slight increase in opportunistic and tolerant ones owing to Rhodophyta and Chlorophyta taxa. Finally, the vegetation was structured in three macroalgal layers composed by Turf (T), Erect (E) and Encrusting (C) species, as highlighted in Table 4. Overall, a greater percent cover of turf species, related to *C. cylindracea* invasion, was found on the dense meadow of Torre Ruffa than on the patchy distribution pattern of Diamante station.

As regards the commercial traffic in the harbour of Vibo Valentia, mostly coming from Italian countries (94%), the annual trend in arrivals was equal to 166 ships. Besides, a lot of commercial arrivals were recorded in summer months, as 30% of the whole traffic. In particular, in 2015 year, it is noteworthy that the total number of ships involved in the yearly traffic was 620 units while the number of annual arrivals was 166 ones. Therefore, some ships entered into the harbour many times during the same year, even though specific data for each vessel are unknown. Generally, the trade exchanges regarded three macro areas as were Western Mediterranean Sea, Eastern Mediterranean Sea and Atlantic Ocean, but most of the commercial traffic (88%) came from the Italian region of Sicily. By this way, the world traffic was very small and restricted to some eastern countries as Turkey (1%), Croatia (1%), Egypt (1%), Lebanon (15) and Lybia (1%) while the outside traffic, from Atlantic Ocean, was limited to Belgium (1%) and Holland (1%). Finally, the vessel typologies, entering the harbour of Vibo Valentia, regarded two categories of commercial units, as Cistern and Container ships with the Cistern ones recording the highest percentage of 96% (Fig. 6).

Altogether, the general trend of the shipping navigation showed a local traffic mainly coming from the southern regions of the Western Mediterranean sea.

From the data released by the harbour authority of Vibo Valentia, it has been possible to distinguish, along the Calabrian Tyrrhenian coasts, three main harbour areas that, proceeding from north to south, are: Cetraro, Vibo Valentia and Gioia Tauro districts. These coastal regions are characterized by an intense shipping activity more important than other littoral areas distributed along the regional coastline. By this way, these regions are affected by the widespread presence of *C. cylindracea*, as shown in the following figure (Fig. 7) where it is highlighted the high statistical relationship between the presence of the species and the great commercial importance of these three harbors characterized by a leading sea trade and by a large shipping activity.

4. Discussion

In the Calabrian Tyrrhenian coasts, *C. cylindracea* has experienced an impressive development during the last years and the invasion seems to be related to an effective vegetative propagation mechanism for the fast stoloniferous growth of the alga between 4 and 20 mm/d (Piazzi et al., 1997; Piazzi and Cinelli, 1999; Ruitton et al., 2005) and for the allelopathic activity of a secondary metabolite, called “caulerpenine”, that could have an important role in the successful competition of this green alga with local macrophytes (Raniello et al., 2007) and against herbivorous feeding (Dumay et al., 2002). The species is, also, characterized by a high adaptability to every kind of substrata (Piazzi et al., 1997) where it

Table 2
Calabrian sites invaded by *C. cylindracea* from 1999 to 2009 years. * First Calabrian report (Cantasano, 2001). Substrate: PO = *Posidonia oceanica* meadow with low density; DM = dead "matte" of *Posidonia oceanica*; CS = Coarse sand; FS = Fine sand; RS = Rocky substratum.

Sites – geographical coordinates	Depth	Substrate	Date collections
1. Scilla – 38°15′25.43″N-15°42′51.71″E	3-4 m	PO	01/09/2000
2. Chianalea – 38°15′15.73″N-15°43′04.96″E	5-6 m	CS	10/09/2000
3. Bagnara Calabra – 38°17′45.00″N-15°48′41.73″E	4-5 m	CS	15/09/2009
4. Marina di Palmi – 38°21′08.06″N-15°50′07.35″E	6-7 m	PO	05/09/2001
5. Marina di Gioia Tauro – 38°26′11.56″N-15°53′00.57″E	8-10 m	CS	05/09/2007
6. Marina di Joppolo – 38°34′22.67″N-15°53′44.73″E	5-6 m	RS	10/09/2008
7. Capo Vaticano – 38°37′04.49″N-15°49′29.03″E	9-10 m	PO	15/09/2001
8. * Torre Ruffa - 38°38′31.65″N - 15°50′04.93″E	1-2 m	RS	30/09/1999
9. Santa Domenica – 38°40′02.53″N-15°51′23.73″E	6-10 m	PO	05/09/2002
10. Tropea – 38°41′04.53″N-15°55′01.16″E	4-5 m	RS	10/09/2002
11. Vibo Valentia Marina – 38°43′14.36″N-16°08′21.06″E	5-6 m	FS	03/09/2006
12. Pizzo Calabro – 38°44′20.78″N-16°09′50.27″E	2-8 m	RS	10/09/2006
13. Gizzeria Lido – 38°56′52.71″N-16°09′30.38″E	4-6 m	FS	01/10/2005
14. San Lucido – 39°18′15.14″N-16°02′44.60″E	6-7 m	RS	15/09/2005
15. Marina di Cetraro – 39°32′14.18″N-15°54′08.33″E	4-5 m	RS	10/09/2004
16. Cittadella del Capo – 39°33′12.88″N-15°52′25.50″E	5-6 m	RS	01/09/2004
17. Marina di Belvedere – 39°37′15.05″N-15°50′43.73″E	7-9 m	PO	03/09/2003
18. Diamante - 39°40′11.71″N-15°49′45.36″E	4-5 m	PO	30/10/2009
19. Isola di Cirella – 39°41′57.38″N-15°48′13.06″E	2-10 m	DM	01/10/2003
20. Capo Scalea – 39°49′50.37″N-15°46′24.07″E	7-9 m	PO	09/10/2003
21. San Nicola Arcella – 39°50′53.97″N-15°46′57.55″E	3-4 m	PO	20/09/2004
22. Isola di Dino – 39°52′13.18″N-15°47′09.66″E	6-7 m	PO	30/09/2004

Table 3
Comparison of morphometric data of *Caulerpa cylindracea* collected in Tuscan and Ligurian coasts (Piazzi et al., 1994, 2001; Modena et al., 2000) with Calabrian samples collected in Torre Ruffa (Cantasano, 2001), distinguished by longer fronds and shorter branchlets.

Morphological features	Mediterr.	Depth	Date	Authors	Calabria	Depth	Date	Authors
Stolon width (mm)	0.90–1.10 (2.00)	4	09/93	Piazzi et al., 1994	0.70–0.90 (1.00)	2	09/99	Cantasano 2001
	1.30	2	08/98	Modena et al., 2000				
	1.66	2	10/98	Piazzi et al., 2001				
Frond height (cm)	2.00–3.00 (5.00)	4	09/93	Piazzi et al., 1994	7.00–8.00 (9.00)	2	09/99	Cantasano 2001
	2.00	2	08/98	Modena et al., 2000				
	1.15	2	10/98	Piazzi et al., 2001				
Branchlet width (mm)	4.00–5.00 (6.00)	4	09/93	Piazzi et al., 1994	1.20–1.50 (1.80)	2	09/99	Cantasano 2001
	2.00	2	08/98	Modena et al., 2000				
	2.00	2	10/98	Piazzi et al., 2001				

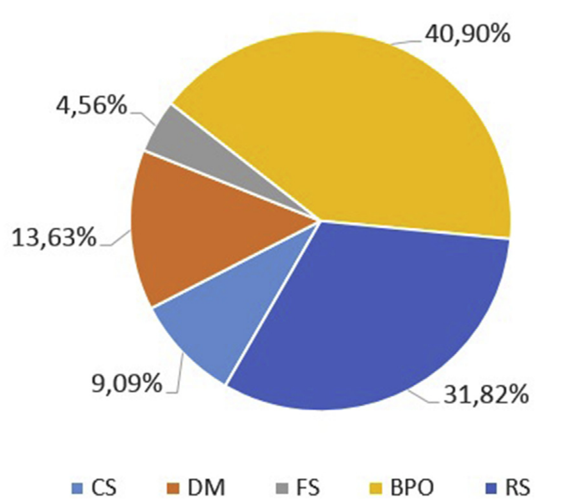

Fig. 3. Relative cover rates of substrata allocations in the spreading of *C. cylindracea* in collecting sites. CS=Coarse Sand; DM = Dead Matte of *Posidonia oceanica*; FS=Fine Sand; PO=*Posidonia oceanica* meadows; RS = Rocky Substrata.

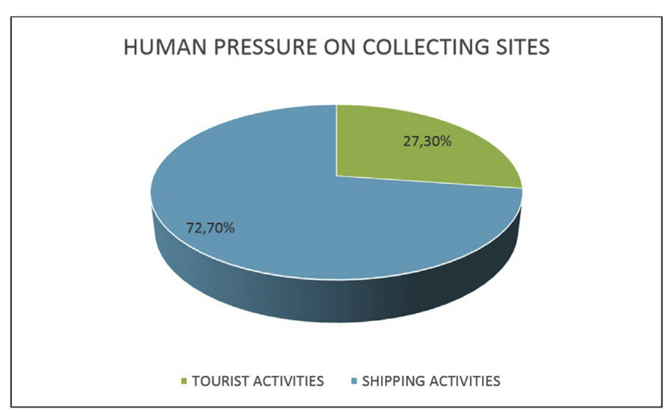

Fig. 4. Patterns of human pressure on collecting sites.

grows, generally in high light conditions, both in exposed and sheltered areas. These effects can inhibit the establishment of other sessile species and could be enhanced through sediment trapping (Piazzi et al., 2005a, 2007). On the Calabrian Tyrrhenian coast, the species thrives under a large array of environmental conditions and it is often found in the proximity of recreational harbours due to a special kind of dispersal mechanism, via boating traffic, attesting the great tolerance of the species to high levels of pollution and sedimentation (Airoldi and Cinelli, 1997; Piazzi et al., 2007). Really, most of the colonized areas are exposed to human activities as: fishing, coastwise navigation and anchorages close to harbour

Fig. 5. *C. cylindracea* growth on algal turf.

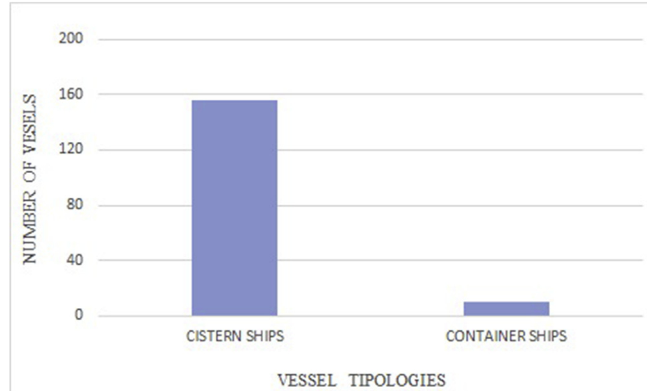

Fig. 6. Vessel typologies in the harbour of Vibo Valentia.

Table 4
List of taxa recorded in the two study sites. Presence or absence of species is indicated as + and − respectively. Vegetation layers for each species is given as T = Turf, E = Erect and C = Encrusting.

Layers	Taxa	Diamante	T. Ruffa
	Chlorophyta		
T	*Anadyomene stellata* (Wulfen) C. Agardh	+	−
T	*Caulerpa cylindracea* Sonder	+	+
T	*Cladophora nigrescens* Zanardini *ex* Frauenfeld	−	+
E	*Dasycladus vermicularis* (Scopoli) Krasser	+	+
E	*Flabellia petiolata* (Turra) Nizamuddin	+	+
E	*Halimeda tuna* (J. Ellis *et* Solander) J.V. Lamouroux	−	+
	Ochrophyta		
E	*Dictyota dichotoma* (Hudson) J.V. Lamouroux	+	+
E	*Halopteris filicina* (Grateloup) Kützing	+	−
E	*Padina pavonica* (Linnaeus) J.V. Lamouroux	+	−
T	*Sphacelaria plumula* Zanardini	+	−
T	*Sphacelaria tribuloides* Meneghini	−	+
E	*Zonaria tournefortii* (J.V. Lamouroux) Montagne	+	−
	Rhodophyta		
E	*Amphiroa beauvoisii* J.V. Lamouroux	+	−
E	*Amphiroa rigida* J.V. Lamouroux	+	−
T	*Antithamnion cruciatum* (C. Agardh) Nägeli	+	−
T	*Ceramium diaphanum* (Lightfoot) Roth	−	+
T	*Ellisolandia elongata* (Ellis *et* Solander) K.R. Kind *et* G.W. Saunders	+	+
T	*Dasya hutchinsiae* Harvey	−	+
E	*Halopithys incurva* (Hudson) Batters	−	+
T	*Herposiphonia secunda* (C. Agardh) Ambronn	−	+
T	*Jania rubens* (Linnaeus) J.V. Lamouroux	−	+
C	*Lithophyllum stictaeforme* (Areschoug) Hauck	+	−
C	*Peyssonnelia squamaria* (S.G. Gmelin) Decaisne	+	−
T	*Polysiphonia fibrillosa* (Dillwyn) Sprengel	−	+
T	*Ptilothamnion pluma* (Dillwyn) Thuret	−	+
T	*Spermothamnion repens* (Dillwyn) Rosenvinge	−	+
E	*Sphaerococcus coronopifolius* Stackhouse	+	−

structures and subjected to sedimentation. This high burial level, due to the presence of organic pollutants and to the increase in nourishing loadings, is the base for the development of this rhizophytic association, increasing the competitiveness of *C. cylindracea*, more tolerant than other native species to variations in sedimentation rate (Piazzi et al., 2005b). Besides, in the Calabrian samples, the stolons are very branched and, sometimes, come out from the same fronds covering other macroalgae and allowing a better and widespread expansion of the species.

As a result of this research, it is shown that the biological invasion of *C. cylindracea* produces, in the pattern of macroalgal assemblages, a decrease in species richness and a prevalence of opportunistic ones leading to a gradual decrease in macroalgal biodiversity. In the two study sites, invaded by *C. cylindracea*, some of the species listed in the table belonged to a phytosociological association named *Caulerpetum racemosae* Giaccone and Di Martino, mainly composed by rhizophytic species, described in southern Italy (Giaccone and Di Martino, 1995). This association, originally related to Eastern Mediterranean basin is, actually, spreading in the Western Mediterranean one (Di Martino and Giaccone, 1995). Overall, a greater cover, in percentage terms, of turf species was found on the dense meadow of Torre Ruffa station than on the patchy distribution pattern of Diamante station. Turfs, probably, assist the settlement of *C. cylindracea* by entrapment algal fragments (Bulleri et al., 2002) and enhancing anchoring of stolons (Ceccherelli and Piazzi, 2001; Bulleri and Benedetti-Cecchi, 2008), which form a multilayered structure trapping sediments, damaging native species and overwhelming the local benthic assemblages. Indeed, in the checklist of the two study sites, the turf species are about 50% of the whole macro-algal community (Table 4). By the way, facilitation of turf-forming species, in areas invaded by *C. cylindracea*, has been already described suggesting a synergism between invader, turfs and sedimentation (Ceccherelli et al., 2002; Piazzi and Ceccherelli, 2006; Piazzi et al., 2007). Anyway, in both cases, the absence of *Cystoseira* sp. and the ubiquitous presence of *Ellisolandia elongata* (J. Ellis *et* Solander) K.R. Kind *et* G.W. Saunders indicated a poor coastal water quality (Arevalo et al., 2007), whereas *C. cylindracea* is highly adapted also in polluted areas (Ballesteros et al., 1999; Ruitton et al., 2005).

Above all, the spreading of *C. cylindracea* is supported, also, by the commercial traffic coming from the southern part of the Western basin. By this way, the key-role of some Mediterranean harbours, such as Vibo Valentia (Calabria, Southern Italy), could explain the fast spreading of alien species along Italian coasts.

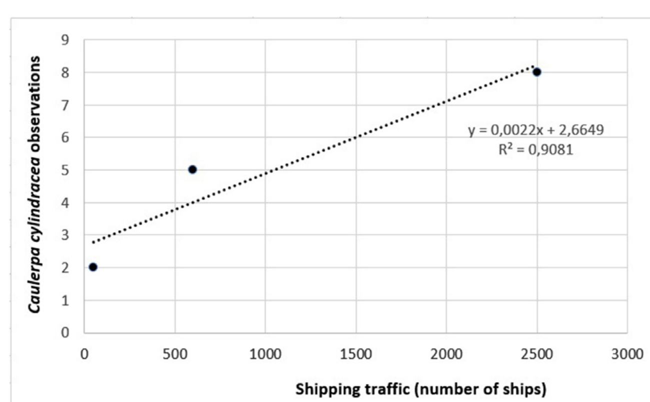

Fig. 7. Relationship between the shipping activities in harbour districts and the presence of *C. cylindracea*.

Really, some allochtonous and termophilic species, such as *C. cylindracea*, coming from warmer waters, should have higher probability to spread in the central part of the Western basin. This process could be enhanced by the highest harbour traffic occurring in summer months when water temperature is higher, reaching mean values of about 25 °C and favouring species entering from the warmer areas of the world.

The results of this survey confirm the widespread distribution of *C. cylindracea* on the Calabrian Tyrrhenian coasts, in areas closed to harbours and subjected to high rate of sedimentation.

5. Conclusions

The Mediterranean Sea is highly affected by biological invasions becoming in these last decades a "sea under siege" (Galil, 2000). In fact, 986 alien species have been introduced in the basin and, amongst them, 128 are macrophytes of which 97 taxa completely established (Zenetos et al., 2012). Currently, the introduction of alien species is one of the most serious environmental hazards affecting marine biodiversity (Wallentinus, 2003) and threatening the native structure and the good functioning of marine ecosystems (Mack et al., 2000; Williams and Smith, 2007). The settlement of a great number of alien and termophilic species of tropical origin is producing the "tropicalization" of Mediterranean Sea (Bianchi and Morri, 2003). This trend, towards a gradual change of Mediterranean biota, is, also, confirmed by the spreading of some allochthonous species, as the present case of *C. cylindracea*, which went up from the south-western Australian coasts to the Western Mediterranean basin and, in this case-study, from the southern to the northern part of the Calabrian Tyrrhenian coasts, according to a process of southing spreading, actually occurring in the basin (Andaloro et al., 2002). For decades, many tropical species have been entering in the Mediterranean Sea by ship transportation and, actually, the basin seems highly susceptible to ship-transported bioinvasions (Coll et al., 2010). In fact, one-fifth of the marine alien species, recorded in the Mediterranean Sea, is imported by commercial shipping (Flagella et al., 2006) and, particularly, in its Western basin, the 38% of the allochtonous species is introduced by vessels (Galil, 2009). Therefore, it is necessary to apply the obligations established between Mediterranean countries, as stated by the Convention on Biological Diversity (http://www.cbd.int/doc/legal/cbd_en.pdf), to manage some of the main impacts on marine biodiversity and, particularly, those associated with invasive non-indigenous species (Galil et al., 2015). Amongst these aliens, *C. cylindracea* is one of the most dangerous invaders for its fast spreading, that has few equivalents in other introduced macrophytes (Verlaque et al., 2004) and for its heavy impact on marine benthic ecosystems (Boudouresque and Verlaque, 2002). Really, its invasive trend affects allochtonous species producing, in time, conditions of biological pollution (Williamson, 1989). In fact, *C. cylindracea* successfully competes, for space, light and nutrients, against native algal species (Ceccherelli et al., 2002). So, the presence of this species could become a strong driving force in the future assessment of Mediterranean marine ecosystems because *C. cylindracea* is able to model coastal biocenosis producing changes in marine environments. By this way, it has been proposed a multi-scale model of four levels stating the various impacts of invasive species on the base of their adaptability to changing marine biota (Meinesz, 2007). In this range, *C. cylindracea* holds one of the highest level of environmental hazard for its strong impact on macroalgal assemblages and for its successful presence all the time. This high potential in *C. cylindracea* spreading could be caused by some factors as the high viability in covering bare bottoms and/or the capacity to support climatic, physical and edaphic stresses. Indeed, this species is able to exploit a big and fast vegetative growth supported by a high capacity in vegetative fragmentation and by a special persistence of their populations (Piazzi and Cinelli, 1999; Ceccherelli et al., 2000; Piazzi and Ceccherelli, 2006). The dramatic speed in the range expansion of the species in the Calabrian Tyrrhenian coasts is, clearly, shown by this study. Really, just ten years after its first report (Cantasano, 2001) nearly the whole coast has been affected by its invasion, especially in proximity to regional harbours.

In conclusion, this study highlights the fast spread of this invasive alien whose increasing success may lead to a profound alteration in the marine biodiversity of the Calabrian Tyrrhenian coasts and, more generally, confirms the extremely invasive behaviour of *C. cylindracea* that represents, at present, one of the most serious invasive events occurring in the Mediterranean Sea.

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