

Distribution of *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini in the Mediterranean Sea

Anna Maria Mannino¹, Francesco Cicero², Marco Toccaceli²,
Maurizio Pinna³, Paolo Balistreri⁴

1 Department of Biological, Chemical and Pharmaceutical Sciences and Technologies, University of Palermo, Via Archirafi 38, 90123 Palermo, Italy **2** Cooperativa CREA, Via Guardione 30, 90139 Palermo, Italy **3** Department of Biological and Environmental Sciences and Technologies, University of Salento, S.P. Lecce-Monteroni, 73100 Lecce, Italy **4** C. Bio&Tec Soc. Coop., Trapani, Italy

Corresponding author: A.M. Mannino (annamaria.mannino@unipa.it); M. Pinna (maurizio.pinna@unisalento.it)

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Abstract

The Non-Indigenous Species (NIS) *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman & Procaccini has been reported for the first time in the Mediterranean Sea along the coast of South Turkey. This NIS is actively expanding into the Eastern and Western Mediterranean Sea. In this paper, we present an overview of the current distribution of this alga in the Mediterranean Sea, based on relevant scientific publications, grey literature and personal observations. New records from the Sicilian coast (Italy) are also reported. *Caulerpa taxifolia* var. *distichophylla* was found over a wide range of environmental conditions (depth, light and substratum), suggesting a broad ecological plasticity of this alga which makes it a potential threat for the Mediterranean benthic communities. In this respect, artificial structures, often linked to harbours and maritime traffic, seem to provide suitable habitats for this NIS. Since maritime traffic is intense in the Mediterranean Sea, further expansion of *C. taxifolia* var. *distichophylla* in this region is to be expected. For this reason, it is very important to build up an overview on the current distribution of the species and its possible pattern of colonisation in relation to environmental conditions, as well as in view of future climate change scenarios.

Keywords

Non-Indigenous species (NIS), *Caulerpa taxifolia* var. *distichophylla*, Sicily coast, artificial marine infrastructures, Mediterranean Sea

Introduction

The spread of Non-Indigenous Species (NIS, i.e. organisms introduced outside of their natural, past or present range and outside of their natural dispersal potential) has been pointed out as a major threat to biodiversity (Wallentinus and Nyberg 2007; Katsanevakis et al. 2014; Vergés et al. 2016). NIS may become invasive (Invasive Alien Species “IAS”) and may cause biodiversity loss and ecosystem service changes (Brunel et al. 2013; Giakoumi 2014; Vergés et al. 2014, 2016), thus representing a serious concern for nature conservation and economic activities (Occhipinti-Ambrogi and Galil 2010). In the Mediterranean, the number of recorded NIS has been currently reaching around 1000, of which 134 species are macrophytes (24 Chlorophyta, 79 Rhodophyta, 30 Ochrophyta and 1 Tracheophyta; Zenetos et al. 2012; Galil et al. 2015; Verlaque et al. 2015; Alós et al. 2016).

Amongst the NIS recorded in the Mediterranean Sea, *Caulerpa* taxa (*Caulerpa cylindracea* Sonder, *Caulerpa taxifolia* (M. Vahl) C. Agardh and *Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque, Huisman and Procaccini) have raised serious concern due to their potential or ascertained impact on the native communities (Boudouresque et al. 1995; Klein and Verlaque 2008; Katsanevakis et al. 2014).

Jongma et al. (2013) proposed the name *C. taxifolia* var. *distichophylla* for a gracile form of *C. taxifolia* reported in 2006 from the coasts of South Turkey (first Mediterranean record, Cevik et al. 2007) and one year later from Sicily (Cormaci and Furnari 2009; Meinesz et al. 2010). Morphologically, this form is very close to *Caulerpa distichophylla* Sonder, a species described from Western Australia, but differed from *C. taxifolia*. However, slight genetic differences observed between these two species led Jongma et al. (2013) to propose the new combination, which is currently accepted taxonomically (Guiry and Guiry 2019).

Later, *C. taxifolia* var. *distichophylla*, has been reported from other Sicilian sites (Musco et al. 2014; Antoci et al. 2015; Picciotto et al. 2016; Mannino and Balistreri 2017; Di Martino et al. 2018), Calabria, Sardinia (Di Martino et al. 2018), Cyprus (Çicek et al. 2013; Tsiamis et al. 2014; Aplikioti et al. 2016), Malta (Schembri et al. 2015), Rhodes Island (Aplikioti et al. 2016), Lebanon (Bitar et al. 2017), Libya (Shakman et al. 2017) and Tunisia (Chartosia et al. 2018) (for details on localities see Fig. 1 and Table 1).

This invasive alien taxon, whose plausible pathway of introduction and spread is maritime traffic, has been pointed out as a potential threat for the indigenous communities but also for fishing activities (Jongma et al. 2013; Musco et al. 2014) and as potentially invasive by Aplikioti et al. (2016).

In the Mediterranean, maritime traffic plays an important role in the introduction and spread of NIS (Katsanevakis et al. 2014). The fact that many colonised areas are near harbours and exposed to human activities (e.g. shipping, tourism, fishing), would support this hypothesis (Mannino and Balistreri 2017). Since knowledge of distribution and spread dynamics of NIS within the Mediterranean Sea is of great importance, for management and conservation purposes as well as in view of future climate change scenarios, the aim of the present paper is to draw the current distribution and spread

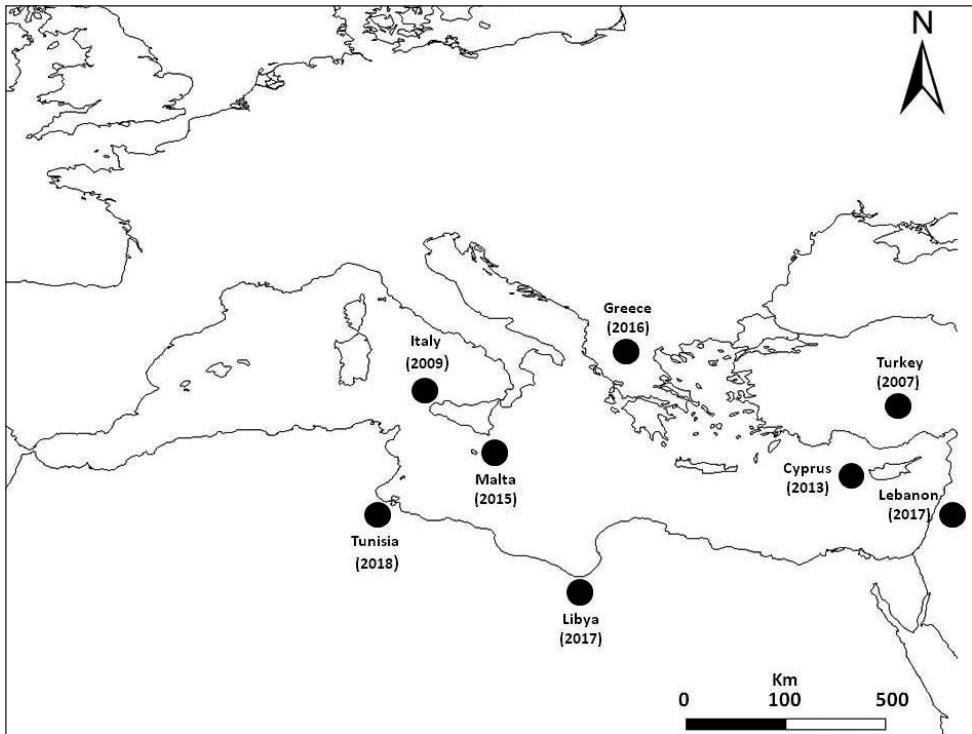


Figure 1. Map showing countries in the Mediterranean Sea where *Caulerpa taxifolia* var. *distichophylla* has been recorded (see Table 1 for localities and detailed references).

dynamics of *C. taxifolia* var. *distichophylla* into the Mediterranean Sea and to provide additional records from the Sicilian coasts (North-Western Mediterranean Sea), together with some environmental and biological variables.

Materials and methods

Field surveys were carried out (summer 2015 and 2017) by the authors in six localities along the coast of Sicily (North-western Mediterranean) (see Fig. 2). In particular, two sites were located along the Northern coast: Termini Imerese (PA, 2015) and Cefalù (PA, 2017) and four along the southern coast: Isola delle Correnti (SR, 2015), Portopalo di Capo Passero (SR, 2015), Punta delle Formiche-Pachino (SR, 2015) and Concerie-Pachino (SR, 2015).

At each site, specimens ($n = 20$) of the alga were collected by snorkelling, at a depth of 0–10 m. Specimens were identified in the laboratory as *C. taxifolia* var. *distichophylla* on the basis of morphological characters (stolon, fronds, pinnules, rhizoidal pillars, midrib) used by Jongma et al. (2013) to characterise specimens from Sicily. Moreover, some environmental (depth, substrate) and biological variables (percentage cover) were registered. Depth was measured using a waterproof watch. Different classes of sub-

Table 1. Known sites of occurrence of *Caulerpa taxifolia* var. *distichophylla* in the Mediterranean Sea.

Country	Locality	Substrate	Depth (m)	Coverage level	Benthic assemblage	References
Turkey	Gulf of Iskenderun	silted sand	11	m.d.	m.d.	Cevik et al. (2007)
Italy	Punta Braccetto	rock	0.5–20	m.d.	m.d.	Cormaci and Furnari (2009)
	Capo Passero, Isola delle Correnti, Punta Braccetto	rock	m.d.	m.d.	m.d.	Meinesz et al. (2010)
	Punta Braccetto	rock	0.5–20	m.d.	m.d.	Jongma et al. (2013)
Turkey	Kas, Antalya, Gulf of Iskenderun	m.d.	m.d.	m.d.	m.d.	Jongma et al. (2013)
Cyprus	Agios Philon Church Bay, Dipkarpaz	rock	6–8	m.d.	<i>Cystoseria</i> spp., <i>Posidonia oceanica</i>	Çicek et al. (2013)
	Cavo Greco, Famagusta	rock	m.d.	m.d.	m.d.	Tsiamis et al. (2014)
Italy	San’Ambrogio, Donnalucata, Ragusa, Punta Secca, Torre di Mezzo, Punta Braccetto, Marina di Torre Salsa	dead matte, sand with pebbles, cobbles and boulders, rock	0–5	from < 10 to > 50%	<i>Caulerpa cylindracea</i> , <i>Cymodocea nodosa</i> , <i>Posidonia oceanica</i> , macroalgae	Musco et al. (2014)
Malta	White Rocks, Exiles in Sliema	rock and sediment	3–15	patches from 0.35 × 0.35 m to 22.0 × 4.0 m	<i>Posidonia oceanica</i>	Schembri et al. (2015)
Italy	Isola delle Correnti, Foce Fiume Irminio, Punta Braccetto, Marina di Acate, Malerba, Realmonte	dead matte, sand, sabellaria	3–9	from 10 to 5584 filloid*m ²	Macroalgae, <i>Posidonia oceanica</i> , Sabellaria, <i>C. cylindracea</i>	Antoci et al. (2015)
	Termini Imerese, Portopalo di Capo Passero, Isola delle Correnti	rock, sand, shipwreck	1–10	from 1 to 50% and > 50%	<i>Cymodocea nodosa</i>	Present study (2015)
Cyprus	Cavo Greco, Agios Philon Church Bay, Rizokarpaso (Dipkarpaz), Sunrise Bay	biogenic sand, mud, biogenic hard substrate	< 1, 22, 34, 42, 48	99–100%	<i>Caulerpa cylindracea</i> , <i>Caulerpa prolifera</i> , <i>Codium bursa</i> , <i>Cymodocea nodosa</i> , <i>Halophila stipulacea</i>	Aplikioti et al. (2016)
Rhodes Island (Greece)	Lindos Bay, Charaki Bay, Karakonero Bay, Lahania	sand, sand/mud, mud, rock, pebbles/shells	9–18, 20, 35, 50, 100	99–100%	m.d.	Aplikioti et al. (2016)
Italy	San Saba- Acqualadrone-Tono	sand	3–6	from < 8 to 26%	<i>Halophila stipulacea</i> , <i>Penicillus capitatus</i> , <i>Posidonia oceanica</i>	Picciotto et al. (2016)
Lebanon	El Madfoun and Byblos	sand and gravels	16–48	m.d.	m.d.	Bitar et al. (2017)
Libya	Tripoli	sand	m.d.	m.d.	Seagrass meadow	Shakman et al. (2017)
Italy	Termini Imerese	sand	9–10	from 1 to 50% and > 50%	<i>Cymodocea nodosa</i>	Mannino and Balistreri (2017)
	Cefali, Punta delle Formiche-Pachino and Concerie-Pachino	sand, rock	2–5	from 20 to 50% and > 50%	<i>Posidonia oceanica</i>	Present study (2017)
Tunisia	Alataya Harbour, Djerba, Tabarka	sand, rock, dead matte	0.2–2	m.d.	<i>Posidonia oceanica</i>	Chartosia et al. (2018)
Italy	Stagnone di Marsala, Terrauzza Bay, Brucoli Bay, Augusta Harbour, Vendicari Natural Reserve, Scala dei Turchi Beach, Scilla (Calabria), Cagliari (Sardegna)	dead matte, sand, rock	0–4	m.d.	<i>Cymodocea nodosa</i> , <i>Posidonia oceanica</i>	Di Martino et al. (2018)

m.d.: missing data

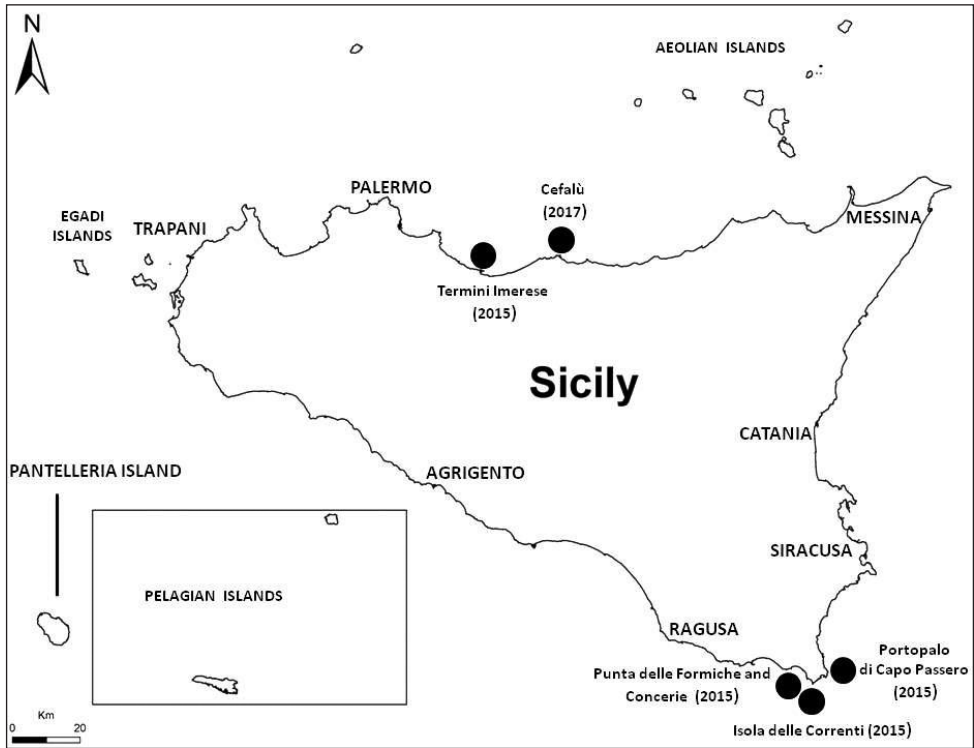


Figure 2. Map showing localities surveyed in the present study.

strate were examined: natural (rock, sand, sand and rock) or both natural and artificial (sand, rock and shipwreck). The percentage cover was visually estimated (*in situ* and by using photographs of the frames) by placing a 20 × 20 cm frame (three replicates) (Mangialajo et al. 2008) and three classes were considered: 1 (cover < 20% and > 1%), 2 (cover < 50% and > 20%) and 3 (cover > 50%).

All the relevant publications, grey literature and reports dealing with *C. taxifolia* var. *distichophylla* in the Mediterranean, from its first record in the area and updated till 2018, were also searched and analysed. A search, based on the following string: *Caulerpa* AND *taxifolia* AND “var. *distichophylla*” AND Mediterranean*, was performed using standard scientific databases (Scopus, Web of Science) (Marrocco et al. 2019).

Results

Field surveys

During the surveys, three new records of *C. taxifolia* var. *distichophylla* have been registered: Concerie-Pachino and Punta delle Formiche-Pachino, located along the southern coast and Cefalù located along the Northern coast. The alga was growing on both

natural (mainly on rock) and artificial substrates, from 1 to 10 m depth (mainly in shallow waters). In all sites, only sterile specimens were found. We report below detailed information for each surveyed site.

Concerie-Pachino: the alga (fronds about 10 cm long) was found in shallow waters (at a depth of about 3 m) both on rocky substrate, forming patches of class 2 or 3 and on sandy substrate, forming patches of class 2.

Punta delle Formiche-Pachino: the alga (fronds not exceeding 10 cm in length) was recorded on rocky substrate in very shallow waters (at a depth of about 2 m), forming patches of class 2 or 3.

Isola delle Correnti (Figs 3A–D): the alga was found in shallow waters (at a depth of about 3 m and 300 m distant from the coastline) flourishing on a shipwreck, a boat sunk about 30 years ago on sandy substrate. Rocky and sandy substrates were both present around the shipwreck, but the alga was present only on rocky substrate. On the external surfaces of the shipwreck, *C. taxifolia* var. *distichophylla* (erect fronds not exceeding 5 cm in length) formed patches of class 1 or 2. On the internal surfaces of the shipwreck, the alga (erect fronds about 10–15 cm long) formed patches of class 1 or 3.

Portopalo di Capo Passero: the alga, with fronds not exceeding 10 cm in length, settled on rocky substrate in very shallow waters (at a depth of about 1–2 m), forming patches of class 2.

Cefalù: the alga, with fronds 5–10 cm long, was found at a depth of about 4–5 m on rocky substrate and at the base of *Posidonia oceanica* (L.) Delile, forming patches of class 2.

Termini Imerese: the alga, with fronds 5–10 cm long, was found on sandy substrate at a depth of about 9–10 m, forming patches of class 1 along the borders of a *Cymodocea nodosa* (Ucria) Ascherson meadow (Fig. 3E–F).

Literature data

The analysis of literature data also highlighted that *C. taxifolia* var. *distichophylla* is able to thrive under a wide range of environmental conditions (see Table 1 for details on records). It grows mainly in shallow waters, even though it was found from the surface down to 100 m depth. It is mainly found on sand, but it can also grow on biogenic substrates, calcareous algae, pebbles, cobbles, sand, rock, mud and artificial substrates. It can grow both under low and high light conditions, though in shaded conditions, it is more abundant and with longer fronds. It occurs alone but also intermingled with other NIS (*C. cylindracea* and *Halophila stipulacea* (Forsskål) Ascherson) or native macroalgae, on dead mat of *P. oceanica* and *C. nodosa*, as well as along the borders or in vicinity of *P. oceanica* meadows. The level of colonisation ranged from sparse individuals to patches (from 0.35 × 0.35 m to 22.0 × 4.0 m), the number of filloid ranged from 10 to 5584 m² and the substratum cover (%) ranged from 8% to 100%.

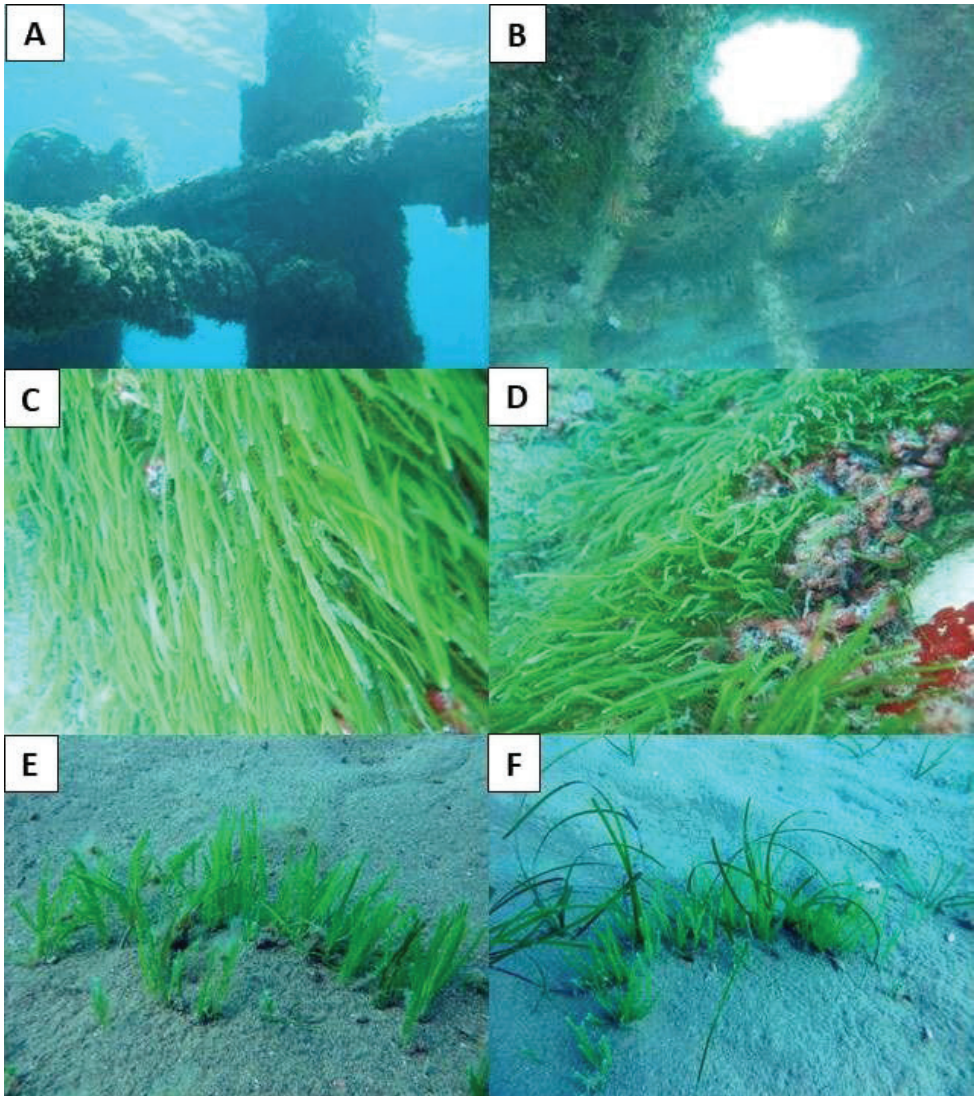


Figure 3. *Caulerpa taxifolia* var. *distichophylla* **A–D** patches on the shipwreck at Isola delle Correnti (photos by Francesco Cicero) **E–F** small patches at Termini Imerese (photos by Marco Toccaceli).

Discussion

Though there is a certain limitation in the collection of data by snorkelling, this technique allows the gathering of useful data and information on NIS, mainly in shallow waters (Imbert 2014). Field surveys confirmed the presence of *C. taxifolia* var. *distichophylla* in sites where it was previously recorded (Mannino and Balistreri 2017), but also allowed us to register new populations both in the southern and in the northern coast

of Sicily, suggesting the spread of this alga is an on-going process along the Sicilian coasts. Along the southern coast, it was recorded in very shallow waters (between 1 and 3 m), whereas in the northern coast, it was found both in shallow and deeper waters (between 4 and 10 m). In reduced light conditions (e.g. on the inside surfaces of the shipwreck), the alga had longer fronds.

Moreover, it seems to prefer rocky and artificial substrates (patches of class 3) more than sandy bottoms. In particular, the alga really flourished on the structures of the shipwreck. *Caulerpa taxifolia* var. *distichophylla*, as well as the congeneric *C. cylindracea*, seem to grow well on artificial structures (e.g. shipwrecks, present study and Ragonese and Rizzo 2017), which may provide suitable habitat for marine NIS but also enhance their further spread, by functioning either as stepping stones or even corridors for their expansion (e.g. Bulleri and Airoidi 2005; Ruiz et al. 2009; McNeill et al. 2010; Mineur et al. 2012). In this respect, artificial structures could act as sentinel places for monitoring the appearance of new NIS (Ruiz et al. 2009; Peirano 2013). The analysis of literature data highlighted how, in colonised areas, *C. taxifolia* var. *distichophylla* is able to adapt well to different environmental conditions (e.g. light, depth, substrate) more than in native areas where it is found on sand up to 6 m depth (Womersley 1984). The alga is also able to grow in deeper waters than the congeneric *C. cylindracea* (Klein & Verlaque, 2008); indeed it was found to at least 100 m depth, even though the presence at 100 m depth still needs to be confirmed (Aplikioti et al. 2016). Certainly, the ability to adapt well to different environmental conditions makes *C. taxifolia* var. *distichophylla* a potential threat for the indigenous communities (Musco et al. 2014; Aplikioti et al. 2016). However, its impact on Mediterranean habitats and associated communities (i.e. *P. oceanica*, hard bottoms) has not yet been ascertained (Cevik et al. 2012; Musco et al. 2014, 2015).

The recent records of *C. taxifolia* var. *distichophylla* along the Sicilian coasts, in Rhodes Island (Aplikioti et al. 2016), Lebanon (Bitar et al. 2017), Libya (Shakman et al. 2017), Tunisia, Sardinia and southern coast of Italy (Chartosia et al. 2018; Di Martino et al. 2018) confirm that *C. taxifolia* var. *distichophylla* is actively spreading into the Mediterranean Sea, expanding beyond its northern and western limit (Musco et al. 2014). Sicilian populations of *C. taxifolia* var. *distichophylla*, probably entered independently from the Turkish one. The regular and intense maritime traffic between Sicily and other Mediterranean countries could be responsible for the introduction of this alga along the Sicilian coasts but also for a secondary introduction from Sicily to other regions such as Malta, Sardinia and Calabria (Schembri et al. 2015; Di Martino et al. 2018). Since maritime traffic can produce a constant spill-over of new invaders into surrounding areas, Sicily and Turkey could have played and are still playing an important role as receiver, transit and probably sources for secondary dispersal of NIS, respectively within the Eastern and Western basin of the Mediterranean Sea. Therefore, knowledge of spread dynamics of NIS in these areas is of great importance for all the Mediterranean Sea, as well as for management purposes.

Sicily and circum-Sicilian Islands are inhabited by a rich biota (e.g. Domina et al. 2018) and have a high number of Marine Protected Areas (MPAs). As a consequence of their geographic position and by virtue of the intense maritime traffic volumes cross-

ing the region, they are particularly vulnerable to biological marine invasions (Occhipinti-Ambrogi et al. 2011a, b; Coll et al. 2012; Katsanevakis et al. 2014; Mannino et al. 2014, 2015, 2017, 2018; Mannino and Balistreri 2017). Therefore, this area should be regularly and carefully monitored.

Moreover, a warmer and drier Mediterranean region, as forecast for the 21st century (Ben Rais Lasram et al. 2010), will certainly facilitate the further expansion of *C. taxifolia* var. *distichophylla*. Its occurrence, in association with tropical-subtropical macrophytes (e.g. *H. stipulacea* and *Penicillus capitatus* Lamarck), suggests that a re-organisation of benthic communities as a consequence of global change is already underway within the Mediterranean Sea (Evagelopoulos et al. 2008; Picciotto et al. 2016).

For a better understanding of the invasive potential and spread dynamics of NIS, a quick sighting of any newly colonised area (Klein and Verlaque 2008), together with good knowledge of environmental and biological factors enhancing their spread, is fundamental. Therefore, the establishment of regular monitoring programmes, including public awareness campaigns, citizen science initiatives and online databases or networks, are necessary in areas at risk, such as Sicilian coasts (included MPAs), particularly areas located in proximity to ports, marinas and transitional waters (e.g. Orfanidis et al. 2007), in order to increase knowledge on distribution and spread dynamics of IAS (Mannino and Balistreri 2018). Moreover, the identification of threatening NIS at the earliest stages of their introduction increases the chances for effective control (Bieler et al. 2017).

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