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RESEARCH ARTICLE

The alien alga *Caulerpa taxifolia* (Vahl) C. Agardh var. *distichophylla* (Sonder) Verlaque, Huisman and Procaccini move their northern and western limits

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Abstract

Caulerpa taxifolia (Vahl) C. Agardh var. *distichophylla* (Sonder) Verlaque, Huisman and Procacini is an invasive green alga recently reported in the Mediterranean Sea. The first record was in Turkey in 2007 and later it has been reported in Sicily (2009), Cyprus (2013), Malta (2015), Rhodes (2016) and Libya (2017). In the current study we present additional records of this species expanding its range into the Eastern and Western Mediterranean Sea (Eastern and Western Sicilian shoreline, Calabrian Tyrrhenian coast, Sardinia and Tunisia) as well as in the eastern Mediterranean basin. Our specimens were collected on various substrates and identified morphologically.

Keywords: *Caulerpa taxifolia* var. *distichophylla*, alien species, Mediterranean Sea, Italy, Tunisia

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Introduction

In the Mediterranean basin the green algae by genus *Caulerpa* is represented by seven taxa: *C. prolifera* (Forsskål) J.V. Lamouroux, *C. chemnitzia* (Esper) J.V. Lamouroux [as *Caulerpa racemosa* var. *occidentalis* (J.Agardh) Børgesen], *C. mexicana* Sonder *ex* Kützing, *C. scalpelliformis* (R. Brown *ex* Turner) C. Agardh, *C. taxifolia* (M. Vahl) C. Agardh, *C. cylindracea* Sonder, and *C. racemosa* var. *lamourouxii* f. *requienii* (Montagne) Weber van Bosse (Cormaci *et al*. 2014; Guiry and Guiry, 2018; Verlaque *et al*. 2000; Verlaque *et al*. 2003). Only the species *C. prolifera* is considered indigenous while the others are considered as alien species (Zenetos *et al*. 2010).

Caulerpa taxifolia var. *disticophylla* was first reported in 2007 in the Eastern Mediterranean Sea from the southern coast of Turkey (Cevik *et al*. 2007) and later from the southern coast of Sicily (Cormaci and Furnari 2009; Meinesz *et al*. 2010; Jongma *et al*. 2013; Musco *et al*. 2014), Cyprus (Çicek *et al*. 2013; Tsiamis *et al*. 2014; Aplikioti *et al*. 2016), Malta (Schembri *et al*. 2015), Rhodes (Aplikioti *et al*. 2016) and Libya (Shakman *et al*. 2017).

In this paper, it has been shown the advancing of *Caulerpa taxifolia* var. *disticophylla* towards the Pillars of Hercules at the Gibraltar Strait.

Materials and Methods

The sampling was realized between fall 2015 and spring 2017. The samples were collected in six places of Sicily (Brucoli Bay, Augusta Harbour, Terrauzza Bay, Vendicari Natural Reserve, Scala dei Turchi Beach and Stagnone di Marsala), in one place of southern Sardinia (south east of Cagliari) and in three different sites in Tunisia (Alataya Harbour, Djerba and Tabarka) (Di Martino and Stancanelli 2018), as shown in Figure 1. The last report of the species regards a southern station of the Calabrian Tyrrhenian coast, close to the harbor of Scilla (Reggio Calabria). The geographical coordinates of the samplings are shown in Table 1.

In each site, five different samples were collected within a sampling area of 40 x 40 cm. The sampling was supplemented by statistical studies related to the vegetation that forms the floristic cohort of an assemblage dominated by *C. taxifolia* var. *disticophylla*. The samples were collected by snorkeling and/or scuba diving at a depth between 0.2 and 2.0 m. Then, the specimens were preserved in a solution of seawater and formaldehyde at 4% and, after washing in seawater, they were frozen and stored in the CNR/ISAFOM herbarium of Catania (Italy).

The samples were assessed for the morphological identification of taxon through measurement of the diagnostic structural features used by Jongma *et al*. (2013) to characterize specimens from Sicily. They have got stolon width, shape, width and length of fronds and pinnules, the number of rhizoidal pillars and pinnules, the morphology and the width of midribs, virtually equal to samples of the same species described by others for the Mediterranean basin (Cevik *et al*. 2007).

Results

As resumed in Table 1, we report new populations of *C. taxifolia* var. *distichophylla* in six places of Sicily (Brucoli Bay, Augusta Harbour, Terrauzza Bay, Vendicari Natural Reserve in the Ionian Sea, Scala dei Turchi Beach in southern Sicily and Stagnone di Marsala in western Sicily), in a southern station

of the Calabrian Tyrrhenian coast (Scilla, Reggio Calabria), in the south of Sardinia (south east of Cagliari) and in three different sites in Tunisia (Alataya harbour, Djerba and Tabarka) (Figure 1). The samples collected in Calabria, Sardinia and Tunisia are the first report of *C. taxifolia* var. *distichophylla* for these areas.

All of the surveyed *C. taxifolia* var. *distichophylla* meadows were located in shallow waters and form non-continuous cords running parallel to the coastline. Except for Vendicari, the site surveyed supported pleasure boating activities or were located within of major port areas, as is the case of Augusta in Eastern Sicily and Scilla in Western Calabria (Figure 1).

The first sample of *C. taxifolia* var. *distichophylla* was collected in fall 2015 off Vendicari on a seabed covered by "*matte*" of dead *Cymodocea nodosa* and *Posidonia oceanica* to a depth of between 1.0 and 3.0 m. Other samples collected along the eastern coast of Sicily were found at various depths between 0.2 and 2.5 m on rocky and sandy bottoms.

At "Scala dei Turchi", near Agrigento (Sicily) *C. taxifolia* var. *distichophylla* formed very dense stands distributing parallel to the shoreline. The specimens collected at "Stagnone di Marsala" were located at a depth of 0.20 - 0.50 m on a sandy bottom having rocky outcrops in places and *Ruppia maritima* bed. The Calabrian samples collected in autumn 2016, close to Scilla harbor, at a depth of 3-4 m, were present at the borders of a *P. oceanica* meadow. Specimens collected in Sardinia, off Cagliari at locality called "Faro", were present on a mixed bottom of coarse sand and rocky substratum in the vicinity of a *P. oceanica* bed. At three places along the Tunisian coasts, *C. taxifolia* var. *distichophylla* was present as continuous and patchy stands at the periphery of *P. oceanica* meadows and/or sandy bottoms.

In general, where present, *C. taxifolia* var. *distichophylla* was more abundant and had longer fronds (ca 14/16 cm) where present in sheltered areas, on "*matte*" of dead *P. oceanica* and at the periphery of *P. oceanica*, where the alga was less dense.

On rocky seabed covered with fine debris the most common algal species present along with *C. taxifolia* var *distichophylla* were *Padina pavonica* (Linnaeus) Thivy, *Dasycladus vermicularis* (Scopoli) Krasser, *Flabellia petiolata* (Turra) Nizamuddin, *Dictyota dichotoma* (Hudson) J. V. Lamouroux, *Halopteris scoparia* (Linnaeus) Sauvageau and *Lophocladia lallemandii* (Montagne) F. Schmitz. On sandy and / or muddy bottoms *C. taxifolia* var *distichophylla* was almost always the only species present.

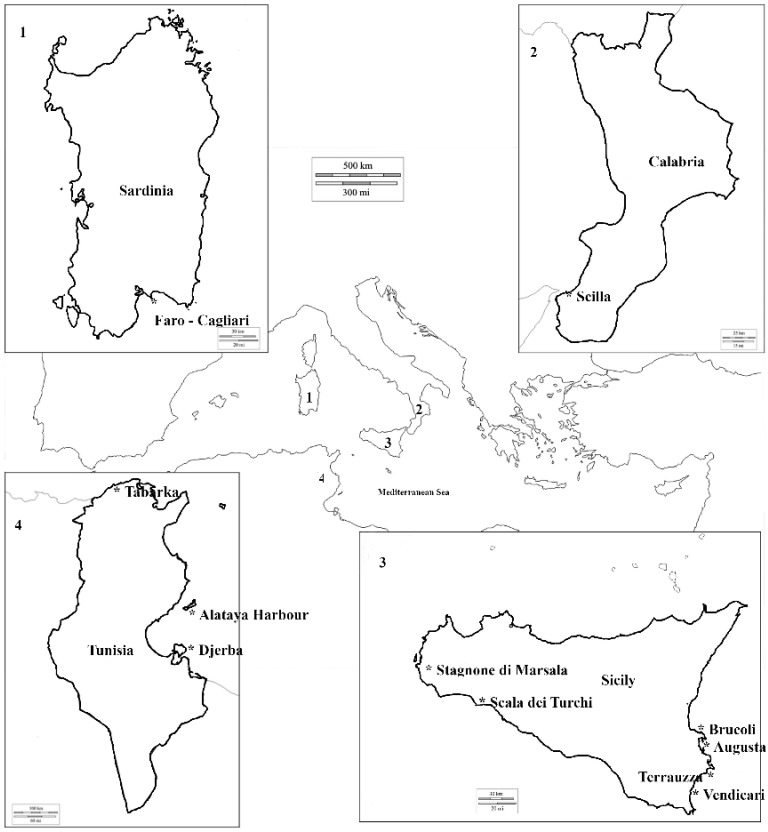

Figure 1. Map showing the new sampling site of *Caulerpa taxifolia* (Vahl) C. Agardh var. *distichophylla* (Sonder) Verlaque, Huisman and Procacini in Mediterranea Sea.

Discussion

In all sites surveyed, *C. taxifolia* var. *distichophylla* was always found in rheophile environments like stretches of coastline protected by rocky reef and / or seagrass meadows. Furthermore, *C. taxifolia* var. *distichophylla* appeared to prefer reduced light conditions; where *C. taxifolia* var. *distichophylla* was present in places where light was abundant, the alga had short (< 6/7 cm) fronds while in sciaphilous places the thallis exceeded 16/18 cm in height.

Whereas *Caulerpa taxifolia* var. *disticophylla* occupies the substrate of seagrass beds, it shares the available space with other species normally present in the meadows. Also in this case, the thallis of *Caulerpa taxifolia* var. *disticophylla*

are very long where *P. oceanica* leaves are more crowded and provide more shadow.

With regard to the interactions between *C. taxifolia* var. *distichophylla* and the associated biota, data drawn by the published literature are conflicting. For example, according to Musco *et al.* (2015) the presence of *C. taxifolia* var. *distichophylla* on the Sicilian seabed colonized by this species greatly influences the taxonomic composition and the abundance of associated macro and meiobenthos. On the other hand, according to Cevik *et al.* (2012), the introduction of this alien species enhances the habitat structure for local biota already present. This condition could support an increase in biodiversity, as it happens otherwise a bare bottom is colonized by vegetation. In all surveyed sites, it has been noted that the diversity in plant and animal species appears indifferent to the new host but these conditions are very uncertain and must be confirmed by further quantitative studies on this debated issue. Thus it is difficult to establish the driving factors leading to the spread of *C. taxifolia* var. *disticophylla* in the Mediterranean Sea. However, it is possible to envisage, according to Mannino and Balistreri (2017) and literature cited therein, that this invasive species arrived in the Mediterranean Sea via aquarium trade and, above all, shipping traffic. The results of this research highlight that the spreading of *Caulerpa taxifolia* var. *disticophylla* is following the same expanding pattern as those of many other Lessepsian species that in recent times have invaded the Mediterranean.

Conclusions

The process of tropicalization of Mediterranean biota is a serious environmental hazard with more than three hundred alien species, from faunal to floristic ones, entering into the basin. Amongst these, 128 are macrophytes (Zenetos *et al.* 2010) and this trend is actually ongoing in the Western area. In this scenario, it is difficult to foresee if the introduction of *Caulerpa taxifolia* var. *disticophylla* could increase the diversification of local biota or, instead, threaten the native structure of macro-algal assemblages. This state of biological variability and uncertainty suggests to realize on time a sound and complete mapping of coastal ecosystems so to protect the Mediterranean endemic species.

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Table 1. Sampling sites with geographical coordinates and indication of the type of seabed on which has settled *Caulerpa taxifolia* (Vahl) C. Agardh var. *distichophylla* (Sonder) Verlaque, Huisman and Procacini

		SITES										
		SICILY						**CALABRIA**	**SARDINIA**	**TUNISIA**		
		Brucoli Bay (SR)	Augusta harbour (SR)	Terrauzza Bay (SR)	Vendicari (SR)	Scala dei Turchi (AG)	Stagnone di Marsala (TP)	Scilla (RC)	Cagliari	Alataya Harbour	Djerba	Tabarka
	Latitude	*37° 17′ 0,49″ N*	*37° 13′ 09,65″ N*	*37° 00′ 49,00″ N*	*36° 48′ 09,41″ N*	*37° 17′ 21,95″ N*	*37° 50′ 24,94″ N*	*38°15'25.43'' N*	*39° 11′ 05,00″ N*	*34° 43′ 37,11″ N*	*33° 49′ 50,77″ N*	*36° 57′ 38,41″ N*
	Longitude	*15° 11′ 42,15″ E*	*15° 12′ 29,81″ E*	*15° 18′ 06,35 E*	*15° 05′ 58,85″ E*	*13° 28′ 26,89″ E*	*12° 26′ 53,36″ E*	*15°42'51.71'' E*	*9° 08′ 43,02″ E*	*11° 18′ 06,24″ E*	*11° 01′ 34,58″ E*	*8° 45′ 07,95″ E*
HABITAT	Posidonia bed			*	*			*		*	*	*
	Cymodocea bed	*			*							
	Ruppia bed				*		*					
	Rocky shore			*	*	*	*		*	*	*	
	Sand bottom				*	*	*			*	*	*
	"Matte"	*		*	*				*			*
	Muddy bottom	*	*									