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The Invasion of *Caulerpa cylindracea* Sonder 1845 in the Calabria Coastal Seas

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Abstract: *Caulerpa cylindracea*, Indo-Pacific and thermophilic macroalgal species, have spread in Italian coastal waters, especially in the western Mediterranean Sea. Also, along the Calabria coastline, this Invasive Alien Species (IAS) was able to colonize most of the western and eastern seasides of the region. This research was conducted between 1999 and 2021 through a detailed cost-effective citizen science program. The novelty of this research was to determine the overall distribution of *Caulerpa cylindracea* along Calabria seawaters from the Tyrrhenian to the Ionian coasts. The results of the monitoring survey highlighted the presence of *Caulerpa cylindracea* in 45 collecting stations throughout the Calabrian coastline. This regional assessment showed the extensive adaptability of the species to different environmental conditions: from exposed to sheltered sites, in shaded and sunny coastal areas and also throughout pristine and polluted waters. The rapid and increasing spread of the species could affect the structure of Mediterranean biota or, otherwise, could lead in time to new ecological niches. As highlighted in the most recent literature, it is necessary to update monitoring and mapping plans for the protection of marine biodiversity through close coordination between scientists, citizens and policy makers, all engaged to ensure effective management of invasive processes.

Keywords: *Caulepa cylindracea*; invasive alien species; Calabria; Mediterranean Sea

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1. Introduction

1.1. The Entrance of Non-Indigenous Species

Non-Indigenous species (NIS) are faunal and plant species introduced in the Mediterranean Sea by shipping activities, pet commerce and aquarium trade crossing the Strait of Gibraltar and the Suez Canal. In particular, the building of this waterway in 1869 and its following doubling, accomplished in 2015, between the western zone of the Levantine basin and the Gulf of Suez in the eastern area, linked the Atlanto-Mediterranean region with the Indo-Pacific one. As a result, the Mediterranean Sea changed from a semi-enclosed basin to an important hub of shipping activities coming from the Red Sea and, at the same time, it became sensitive to biological invasions arriving into the basin through fouling communities and/or ballast waters. This process was enhanced, also, for entrance into the Mediterranean Sea for some larval stages carried into the basin by the active migrations of many animal and plant species. Some of the NIS, after progressive steps of dispersal and colonization processes [1,2], established themselves in the basin and expanded their populations, becoming Invasive Alien Species (hereafter IAS) able to threaten marine biodiversity and the functioning of coastal ecosystems, having also high impacts on ecosystem services [3–7]. In this way, IAS could affect, in time, native biota, leading to critical changes in coastal ecosystems [8–12]. As mentioned above, the enlargement of the Suez Canal has increased the introduction of NIS from the Red Sea to the Mediterranean [13,14], favoured also by the increased temperatures **in** the basin [15]. To date, there are a total of 247 alien taxa in the Mediterranean Sea, of which 25 are exotic macrophytes [16,17].

1.2. The Invasive Genus Caulerpa

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 (known 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. Only the species *C. prolifera* is considered indigenous, while the others are regarded as alien species. Amongst them, the green macroalga *Caulerpa cylindracea* Sonder (hereafter *C. cylindracea*) is one of the most invasive species in the Mediterranean [18–20], and the species has been included in the 100 worst invaders of the basin [9]. The systematic history of *C. cylindracea* has been long debated in the scientific community. In fact, this invasive taxa, native to south-western Australian waters, was first reported, as *Caulerpa racemosa*, along the coasts of Tunisia in 1983 [21]. Afterwards, the species was identified, through a morphological and genetic study, as *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque and Boudouresque [22]. Finally, molecular investigations stated the genetic independence of the taxa and established the reinstatement of the original binomial as *Caulerpa cylindracea* Sonder [23]. This Indo-Pacific and thermophilic macroalga is able to colonize every kind of substrate, from sandy to muddy and rocky bottoms [24] and even areas affected by sedimentation [25]. Moreover, the species is widely distributed from surface waters to a depth of 70 m [18], but it is more common in shallow waters sheltered from wave motion [26]. Indeed, *C. cylindracea* can spread in sunny and shaded locations but also under different environmental conditions such as in pristine and polluted seawaters. Therefore, the high adaptability of the species to different kinds of coastal environments has allowed its rapid spread in the basin [19], having severe effects on marine biodiversity and coastal ecosystems [7,16,27,28]. Along the Italian coast, *C. cylindracea* has settled all along its coastline, especially in the western Mediterranean Sea [18]. The species was first sighted along the Sicilian coasts [29]. Afterwards, *C. cylindracea* showed an impressive expansion along the western coasts of Italy, invading many coastal regions such as: Liguria [30], Tuscany [31,32], Sardinia [33], Campania [34] and Sicily [35]. The effects of this invasive trend are not predictable across either short or long time scales. It is difficult to foresee if the presence of *C. cylindracea* within Mediterranean biota could over time increase marine biodiversity or impact Mediterranean ecosystems. This state of great uncertainty and biological variability suggests the necessity of management directed towards risky situations and suggests the development of a monitoring program and up-to-date mapping of this invasive seaweed. This goal could be realized only through close coordination between the technical, scientific, civil and political sectors, altogether engaged in problem solving.

1.3. Aims and Objectives of the Study

In the Calabria region, the species was first recorded in 1999 [36] and afterwards it showed a rapid expansion to twenty-two stations along the Calabria Tyrrhenian coast [37]. The present study aims to provide the first assessment on a regional scale relating to the presence of *C. cylindracea* along the entire Calabria coastal region.

2. Materials and Methods

An overall study, concerning the spread of *C. cylindracea* across the Calabria coast, was conducted between 1999 and 2022 along 788 km of coastline. The 23 years of planned research were divided in two periods. In the first stage, between 1999 and 2009, surveys of *C. cylindracea* were carried out over 242 km of coastline. Between 2014 and 2022, a survey program was conducted to identify the presence of the species along 546 kms of the Calabrian Ionian coast. The first step of the study was conducted by qualified staff, composed of researchers, technicians and professional divers, through repeat monitoring of sampling stations used for a local program of macroalgal census. Twenty-two sampling sites were chosen in the infralittoral zone from surface waters to a depth of 10 m, where samples were collected by SCUBA diving. The collecting stations were chosen not only for the wide spatial coverage but also for the narrow range of surveyed depths [37]. Between 2010 and 2013, there was a temporary break in the monitoring program due to a lack of financing. Therefore, in the second stage of the study, between 2014 and 2022, surveys were conducted to establish the presence of the species on the Ionian coast using citizens, divers, fishermen and tourists, as a typical model of citizen science. The aim of the second temporal stage of the research was to complete the regional survey of this invasive species along the eastern coastline of the region using a cost-effective citizen science approach. In fact, just from the second half of the 2010s, this new kind of collective approach has become a useful tool for academic and scientific trials, as highlighted by some research programs directly involving citizens, fishermen, divers and tourists working towards the same purpose. So, starting from 2014, many reports, sometimes supplemented with photographic elements produced by citizen scientists, began to inform systematic experts about alien species entering the Mediterranean Sea. Such trend represents a real turning point in the research of marine taxonomists, contributing to the understanding of some ecological processes of difficult comprehension. This novel approach, recently tested in some Mediterranean coastal regions [38,39], involved citizen scientists in the search of *C. cylindracea* and other alien species along the Calabria Ionian coasts. These spatial data were, afterwards, amended and validated by the authors, confirming the important role of citizen science in the knowledge of this invasive process. To obtain a good spatial representation of the collected information and processed data, the geographical locations, relating to the study area, were collected in various ways such as aerial photographs, GPS points, field surveys, coastal information and other relevant spatial datasets, enabling a complete baseline for cartographic representation to be developed. In this regard, the collected data from diverse sources enable careful processing and integration using ArcGIS software. In particular, spatial data like depths, coastal features and locations were georeferenced and transformed into a standardized coordinate system (WGS 83, UTM 33) to ensure a proper alignment of all data layers, enabling consistent mapping representation. This cartographic environment enabled the monitoring of the study area and its dynamic updates, ensuring that the maps accurately reflected the most current state of the marine environment for future forecasts. Finally, in the graphical representation of the resulting data, a list of abbreviations was used which are more suitable to describe the different kinds of bottoms, specimens and marine areas analysed in the study, as highlighted in the following table (Table 1).

Table 1. List of abbreviations concerning the type of marine bottoms, specimens and marine areas colonized by *C. cylindracea*.

Type of Marine Bottoms	
Abbreviations	**Meanings**
RMB	Rocky and Muddy Bottoms
SB	Sandy Bottoms
SMB	Sandy and Muddy Bottoms
RSB	Rocky and Sandy Bottoms
BS	Breakwaters with Sediments
MB	Muddy Bottoms
BPO	Borders of *Posidonia oceanica*
DM	Dead Matte

Table 1. *Cont.*

Type of Specimens	
Abbreviations	**Meanings**
SI	Stolons Isolated
SS	Small Spots
SSM	Small and Sparse Meadows
Type of Marine Areas	
Abbreviations	**Meanings**
NASB	Natural Areas with Submerged breakwaters
NA	Natural Areas
ABSB	Anthropized Beaches with Submerged Breakwaters
ZSC	Zones of Special Conservation
MRP	Marine Regional Parks
MPA	Marine Protected Areas
TM	Touristic Marina
HA	Harbour Areas

3. Results

The collecting stations of *C. cylindracea* were numbered in an increasing order and in the anticlockwise direction from the northern limit of the western Calabrian coast to the northern boundary of eastern regional coastline. In Table 2, the observational data have been tabulated, indicating the names of the sites where *C. cylindracea* was observed, relating coordinates, years of their first reporting, density of the meadows, depths of each sighting, habitats, bibliographic references and types of environment detected.

Table 2. Summary table of *C. cylindracea* stations in Calabrian coastal waters. (Legend: * first Calabrian report of *C. cylindracea*).

N.	Locations	Latitudes	Longitudes	Years	Type of Specimens	Depths	Habitats	Notes	Type of Areas
1	Island of Dino (Cs)	39,870	15,786	2004	Small and Sparse Meadows	6–7 m	Borders of *P. oceanica* meadows	[37]	Marine Regional Park
2	S. Nicola Arcella (CS)	39,848	15,783	2004	Small Spots	3–4 m	Borders of *P. oceanica* meadows	[37]	Touristic Marina
3	Capo Scalea (CS)	39,831	15,773	2003	Stolons Isolated	7–9 m	Borders of *P. oceanica* meadows	[37]	Natural Area
4	Island of Cirella (CS)	39,699	15,804	2003	Small Spots	2–10 m	Dead Matte	[37]	Marine Regional Park
5	Diamante (CS)	39,670	15,829	2009	Small and Sparse Meadows	4–5 m	Borders of *P. oceanica* meadows	[37]	Natural Area
6	Marina di Belvedere Marittimo (CS)	39,621	15,845	2003	Small Spots	7–9 m	Borders of *P. oceanica* meadows	[37]	Zone of Special Conservation

Table 2. *Cont.*

N.	Locations	Latitudes	Longitudes	Years	Type of Specimens	Depths	Habitats	Notes	Type of Areas
7	Cittadella del Capo (CS)	39,554	15,874	2004	Small Spots	5–6 m	Rocky and Sandy Bottoms	[37]	Touristic Marina
8	Marina di Cetraro (CS)	39,537	15,902	2004	Small and Sparse Meadows	4–5 m	Rocky and Sandy Bottoms	[37]	Natural Area
9	San Lucido (CS)	39,304	16,046	2005	Stolons Isolated	6–7 m	Rocky and Sandy Bottoms	[37]	Natural Area
10	Gizzeria Lido (CZ)	38,948	16,158	2005	Stolons Isolated	4–6 m	Sandy Bottoms	[37]	Natural Area
11	Pizzo Calabro (VV)	38,739	16,164	2006	Small Spots	2–8 m	Rocky and Sandy Bottoms	[37]	Marine Regional Park
12	Marina di Vibo Valentia (VV)	38,721	16,139	2006	Small and Sparse Meadows	5–6 m	Sandy Bottoms	[37]	Marine Regional Park
13	Tropea (VV)	38,685	15,917	2002	Stolons Isolated	4–5 m	Rocky and Sandy Bottoms	[37]	Marine Regional Park
14	S. Domenica (VV)	38,667	15,857	2002	Stolons Isolated	6–10 m	Borders of *P. oceanica* meadows	[37]	Marine Regional Park
15	*Torre Ruffa (VV)	38,642	15,835	1999	Small and Sparse Meadows	1–2 m	Rocky and Sandy Bottoms	[37]	Marine Regional Park
16	Capo Vaticano (VV)	38,617	15,825	2001	Small Spots	9–10 m	Borders of *P. oceanica* meadows	[37]	Marine Regional Park
17	Marina di Joppolo (VV)	38,572	15,896	2008	Stolons Isolated	5–6 m	Rocky and Sandy Bottoms	[37]	Natural Area
18	Marina di Gioia Tauro (RC)	38,437	15,883	2007	Small and Sparse Meadows	8–10 m	Sandy and Muddy Bottoms	[37]	Harbour Area
19	Marina di Palmi (RC)	38,352	15,835	2001	Stolons Isolated	6–7 m	Borders of *P. oceanica* meadows	[37]	Marine Regional Park
20	Bagnara Calabra (RC)	38,296	15,812	2009	Small Spots	4–5 m	Sandy and Muddy Bottoms	[37]	Touristic Marina
21	Chianalea (RC)	38,254	15,717	2000	Stolons Isolated	5–6 m	Sandy and Muddy Bottoms	[37]	Touristic Marina
22	Scilla (RC)	38,257	15,714	2000	Small Spots	3–4 m	Borders of *P. oceanica* meadows	[37]	Touristic Marina
23	Melito di Porto Salvo (RC)	37,916	15,774	2016	Stolons Isolated	4–10 m	Rocky and Muddy Bottoms	Personal Communication	Natural Area with Submerged Breakwaters
24	Marina di S. Lorenzo–Straci (RC)	37,918	15,840	2014	Small Spots	10 m	Sandy Bottoms	Personal Communication	Natural Area

Table 2. *Cont.*

N.	Locations	Latitudes	Longitudes	Years	Type of Specimens	Depths	Habitats	Notes	Type of Areas
25	Bova Marina (RC)	37,928	15,913	2021	Small and Sparse Meadows	10–15 m	Sandy and Muddy Bottoms	Personal Communication	Anthropized Beach and Submerged Breakwaters
26	Palizzi (RC)	37,917	15,991	2019	Stolons Isolated	5–15 m	Rocky and Sandy Bottoms	Personal Communication	Natural Area with Submerged Breakwaters
27	Capo Spartivento Village (RC)	37,930	16,071	2022	Small Spots	5–15 m	Sandy and Muddy Bottoms	Personal Communication	Zone of Special Conservation
28	Capo Bruzzano (RC)	38,040	16,148	2019	Small and Sparse Meadows	2–10 m	Rocky and Sandy Bottoms	Personal Communication	Marine Regional Park
29	Marina di Bovalino (RC)	38,152	16,187	2019	Small Spots	2–15 m	Rocky and Sandy Bottoms	Personal Communication	Anthropized Beach and Submerged Breakwaters
30	Roccella Jonica (RC)	38,321	16,409	2018	Small and Sparse Meadows	2–10 m	Breakwater with Sediments	Personal Communication	Anthropized Beach and Submerged Breakwaters
31	Roccella Jonica Village (RC)	38,328	16,435	2021	Small Spots	2–3 m	Sandy and Muddy Bottoms	Personal Communication	Touristic Marina
32	Marina di Catanzaro (CZ)	38,827	16,632	2021	Small Spots	2–3 m	Sandy and Muddy Bottoms	Personal Communication	Touristic Marina
33	S. Leonardo di Cutro (KR)	38,934	16,973	2021	Stolons Isolated	5–15 m	Rocky and Sandy Bottoms	Personal Communication	Natural Area
34	Le Castella (KR)	38,907	17,020	2020	Stolons Isolated	1–5 m	Rocky and Sandy Bottoms	Personal Communication	Marine Protected Area
35	Le Castella Village (KR)	38,911	17,028	2020	Small and Sparse Meadows	1–3 m	Sandy and Muddy Bottoms	Personal Communication	Touristic Marina
36	Le Castella S. Domenica (KR)	38,916	17,038	2020	Stolons Isolated	5–10 m	Rocky and Sandy Bottoms	Personal Communication	Natural Area
37	Capo Rizzuto West (KR)	38,905	17,093	2020	Stolons Isolated	5–10 m	Rocky and Sandy Bottoms	Personal Communication	Marine Protected Area
38	Capo Rizzuto East (KR)	38,899	17,096	2020	Small Spots	3–15 m	Sandy Bottoms	Personal Communication	Marine Protected Area
39	Marina di Isola Capo Rizzuto (KR)	38,942	17,148	2021	Stolons Isolated	0.5–2 m	Muddy Bottoms	Personal Communication	Touristic Marina

Table 2. *Cont.*

N.	Locations	Latitudes	Longitudes	Years	Type of Specimens	Depths	Habitats	Notes	Type of Areas
40	Isola di Capo Rizzuto Punta Cannone (KR)	38,951	17,161	2021	Stolons Isolated	1–3 m	Rocky and Sandy Bottoms	Personal Communication	Marine Protected Area
41	Marina di Crotone (KR)	39,080	17,137	2021	Small and Sparse Meadows	1–3 m	Muddy Bottoms	Personal Communication	Touristic Marina
42	Capo Colonna South (KR)	39,021	17,203	2020	Small Spots	2–6 m	Rocky and Sandy Bottoms	Personal Communication	Marine Protected Area
43	Marina di Cirò (KR)	39,370	17,135	2019	Small and Sparse Meadows	1–3 m	Sandy and Muddy Bottoms	Personal Communication	Touristic Marina
44	Cariati (CS)	39,687	16,963	2018	Stolons Isolated	3–5 m	Rocky and Sandy Bottoms	Personal Communication	Zone of Special Conservation
45	Marina di Cariati (CS)	39,506	16,940	2018	Small and Sparse Meadows	2–5 m	Sandy and Muddy Bottoms	Personal Communication	Touristic Marina

These reports were summarized in a geographical map of Calabria, showing all the collecting stations of *C. cylindracea* reported along the regional coastline (Figure 1). In this way, the biological invasion of *C. cylindracea* in the Calabria coastal waters showed an impressive increase from its first regional report from 1999 [36] until now. During the survey, the presence of the species was confirmed in some locations of the western Calabrian coast where it was previously recorded, while new sightings were registered in the eastern regional coastline. As a matter of fact, after a long temporal gap of about twenty years, the species was surveyed in 45 collecting sites along the Calabrian coastline, both on the western and eastern seaside of the region (Figure 1).

From a morphological point of view, the samples collected in Calabria coastal waters were characterized by a greater length of their fronds and by shorter branchlets when compared with Indo-Pacific and Mediterranean specimens (Table 3).

Table 3. Comparison of the median morphometric data of *C. cylindracea* in three biogeographical sectors (Indo-Pacific [22], Mediterranean Basin [40] and Calabria region [36]).

Morphometric Features	Samples		
	Indo-Pacific	Mediterranean	Calabria
Stolon widths (mm)	2.5–3.0	1.0–2.0	0.7–0.8
Frond heights (cm)	3.0–6.0	2.0–3.0	7.0–8.0
Branchlet lengths (mm)	1.5–2.0	4.0–5.0	1.8–2.0
Vesicle widths (mm)	1.5–8.0	2.0–3.0	1.2–1.5

Moreover, the branchlets were clavate, poorly ramified and distichously arranged around the main central axis (Figure 2).

Figure 1. Geographical map of Calabrian coastline reporting the collecting stations of *C. cylindracea*.

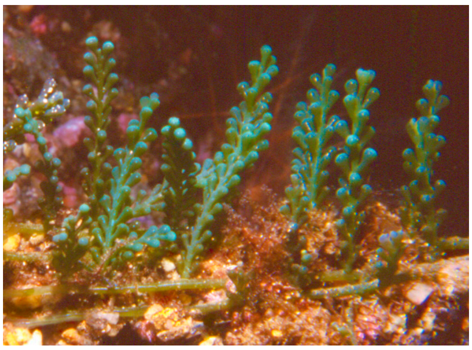

Figure 2. Habitus of *C. cylindracea* in Calabrian coastal waters.

The samples were collected in shallow depths between the surface water and 15 m deep, but the species appeared to be mostly present between 5 and 6 m (Figure 3).

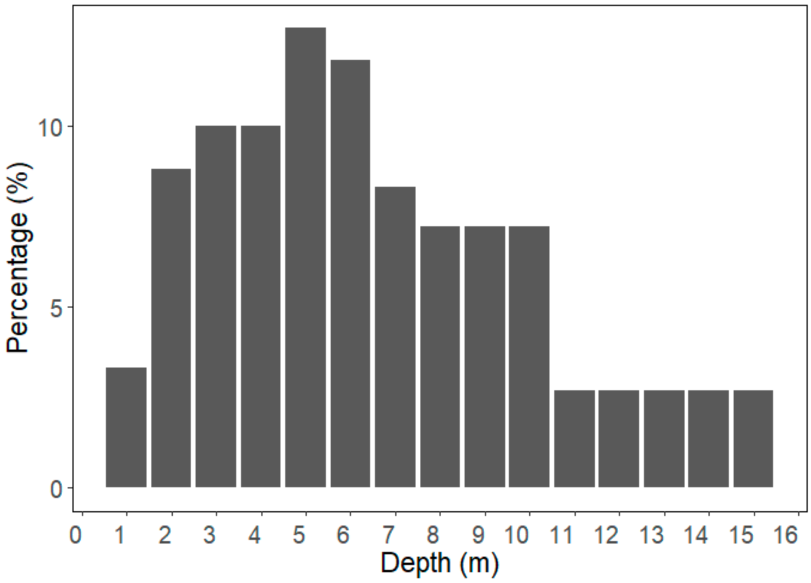

Figure 3. Bathymetric distribution of *C. cylindracea* in the collecting sites.

Moreover, this invasive species was able to colonize every kind of substrata from rocky to sandy and muddy bottoms but also the borders of *Posidonia oceanica* meadows (Figure 4).

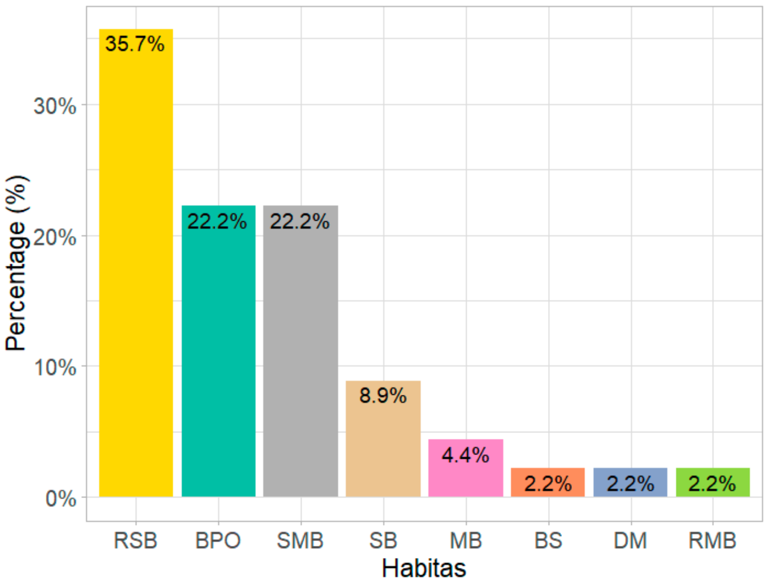

Figure 4. Types of substrata colonized by *C. cylindracea* in the collecting sites.

In particular, *C. cylindracea* showed, in the collecting stations, different population densities, including single stolons which were loosely scattered, small patches, and even dense meadows (Figure 5).

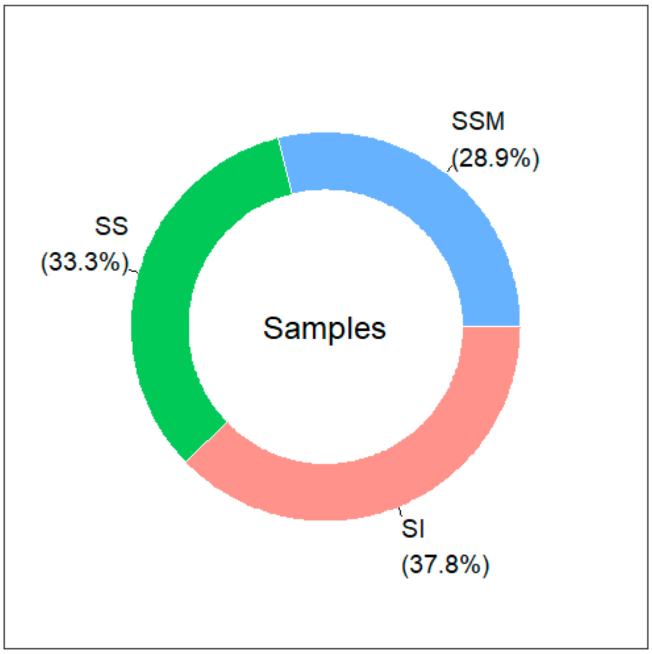

Figure 5. Kind of specimens in the collecting sites colonized by *C. cylindracea*.

The great adaptability of the species was confirmed, also, by its capability to colonize every type of marine area, from highly anthropized coastal areas and touristic marinas to natural areas, including marine regional parks and marine protected areas (Figure 6).

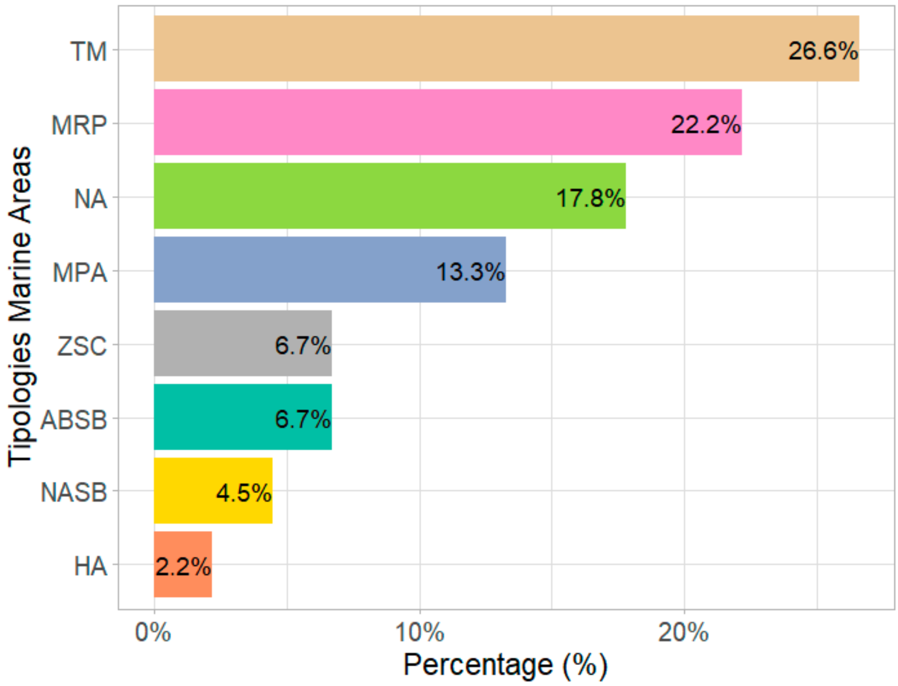

Figure 6. Type of marine areas invaded by *C. cylindracea*.

In summary, *C. cylindracea* was able to spread along the coastal strip of Calabria and it thrived both in exposed and sheltered sites, in shaded and sunny marine waters, and in uncontaminated areas and in polluted waters, demonstrating a great ability to adapt to variable and extreme environmental conditions.

4. Discussion

Since the first regional report in 1999, *C. cylindracea* has spread along the entire Calabria coastline, where it has been recorded in 45 collection stations. The observation of the morphological characteristics of *C. cylindracea* highlighted its great morphological plasticity, especially regarding the length of the phyllodes. In the Calabrian samples, they appear longer than the Mediterranean samples and Indo-Pacific ones (Table 3). As already hypothesized by other authors, this high morphological variability seems to be strictly connected to the environmental conditions of the areas colonized by *C. cylindracea* [19,29,35]. The analysis of the bathymetric distribution of *C. cylindracea* meadows, observed in Calabria, made it possible to highlight that they are more frequently present between depths of 5 and 6 m (Figure 3), where it colonizes large areas of bottoms, replacing the native biota of these coastal habitats. Therefore, the species causes significant changes in the structure of benthic populations with a reduction in algal diversity, especially in algal landscapes characterized by *Cystoseira* sp., *Padina* sp., *Dictyota* sp., etc. These conditions, as already reported by the scientific literature, lead to a reduction in macroalgal abundance and to a lower species diversity in ecosystems colonized by *C. cylindracea* [19,41–43]. The observations in Calabria coastal waters confirm the scientific hypothesis [18,44] that this species is able to colonize variable substrata even if the most colonized seabeds were sandy and rocky bottoms covered by sediments, as the 35.7% of the sites surveyed indicate (Figure 4). Further data resulting from the observations regard the density of *C. cylindracea* meadows. In this case, meadows of very different textures were observed, from simple isolated stolons and small patches to the presence of dense and well-structured meadows (Figure 5). In such conditions, Stolons Isolated (SI = 37.8%) were the most observed along the entire coastal perimeter of Calabria. Indeed, the presence of *C. cylindracea*, related to coastal regions, highlights a strong correlation between the areas most affected by the colonization of *C. cylindracea* and the presence of tourist ports and marine areas strongly impacted by human activities (26.6%) such as anchoring, coastal fishing and local navigation [37]. These conditions confirm the high capacity of the species to spread both on seabeds characterized by hypertrophic marine waters and eutrophic environments. At the same time, the species was observed in pristine seawaters but also in Marine Regional Parks (MRP, 22.2%), Natural Areas (NA, 17.8%) and Marine Protected Areas (MPA, 13.3%) (Figure 6). Anyway, the species' ability to thrive on different seabeds appears closely linked to the structure of local benthic communities. In fact, in degraded habitats, *C. cylindracea* was able to spread rapidly, forming compact mats that negatively affected macroalgal and infaunal associations [45,46]. Probably, this invasive process was possible thanks to the effective vegetative reproduction of the species, with rates of stolon growth varying from 4.4 mm day^{-1} to 20.0 mm day^{-1} [32,47–49]. In contrast, when *C. cylindracea* tries to establish itself in well-structured ecosystems, such as *Posidonia oceanica* meadows in good health conditions, it is not able to affect the native communities, as stated by the scientific literature [38,47]. As regards the rapid spread and the heavy impact of the species on the ecosystem's structure, it was considered as "ecosystem engineering" [50,51] or as a "habitat modifier" [52]. Finally, citizen science was a useful tool able to support traditional methods in the monitoring of *C. cylindracea* along the Calabria coasts. In fact, after the first stage of the survey performed through personal diving activities conducted on the western Calabrian coast, the second step of the research was launched, aiming to complete this regional assessment along the eastern coastline of the region. This stage was accomplished through citizen science activities, involving divers, fishermen, tourists, citizens and local people able to complete the monitoring of alien seaweeds in the Calabrian coastal region, as has also been conducted recently in other marine areas of the Mediterranean Sea, even concerning some marine invasive fishes [39,53,54]. The combined approach between scientific data and citizen science has the dual purpose of improving public awareness of the monitoring of Invasive Alien Species (IAS) [55,56] but also providing important information of their distribution, diffusion dynamics and on the paths of their introduction into the basin. So, citizen science has become very useful to complement scientific data and support decision-making processes in coastal management. This new type of marine planning could help managers, scientists and policy makers to implement preventive and mitigating actions [6,57].

5. Conclusions

The rapid and increasing spread of *C. cylindracea* observed over the last twenty years in Calabrian coastal waters is further evidence of the current tropicalization of the Mediterranean biome. From the beginning of this long history, the entry of invasive and alien species was supported by the expansion of the Suez Canal. This process, still ongoing, has caused the spread of 122 tropical macrophytes in the Mediterranean Sea which are well adapted to the warmer coastal waters of the basin. Among these thermophilic species, 97 taxa are fully established in Mediterranean waters [58]. Also, climate change can enhance the spread of thermophilic species, decreasing the thermal resistance of native ones. This trend could modify the structure of Mediterranean biota, causing a loss of its biodiversity or, on the contrary, could increase its biological variety, contributing to create new coastal habitats. In reality, the effects of the process are not predictable in the long term and, therefore, it is very important, for effective protection and conservation of Mediterranean ecosystems, to adopt regularly updated monitoring and mapping plans. An example of this are the collective reports produced every two years by the research group coordinated by Katsanevakis [16,17]. Researchers from all Mediterranean countries are involved in this working group, where they report both observations collected by themselves and data provided by citizen scientists. These reports are validated by the same research group in a published data base. Citizen science is essential for IAS monitoring, not only to support decision-making processes but also to provide potential solutions and mitigating actions against the present trend of biological invasions in the Mediterranean Sea [39,59,60]. So, this kind of collective approach could become an important tool to make people aware of marine resources. In conclusion, it is necessary to realize a close coordination between scientists, citizens and policy makers to better understand the spread of this alien species, ensuring effective management of its invasive process.

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