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The Fucalean Forests of the Island of Lampedusa (Pelagie Islands Marine Protected Area, Central Mediterranean): Past and Present Diversity and Distribution

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Abstract

This study explored the occurrence, density, and distribution of Fucales along the island of Lampedusa, almost 30 years after the latest studies conducted on the marine vegetation of this island. To carry out this study, we conducted a monitoring activity in 18 sites through both scuba dives and snorkeling. During this study, a total of 13 species (three belonging to *Cystoseira* sensu strictu (s.s.), five to *Ericaria*, two to *Gongolaria*, and finally three to *Sargassum*) were observed. Nine species were previously reported, four taxa (*E. brachycarpa*, *E. funkii*, *E. giacconei*, and *S.* cf *furcatum*) were reported here for the first time in Lampedusa, and six species have not been found anymore. *Ericaria giacconei* may have always been present on Lampedusa Island, but it might have been misidentified in the past. The record on the island of Lampedusa extends the known distribution range of this species. The presence of *S.* cf *furcatum*, a non-indigenous species that is recently expanding in the Mediterranean Sea, could be considered further proof of ongoing seawater warming. In conclusion, we found that the predominant species' association described in the past for the island of Lampedusa has remained unchanged in terms of species and biodiversity found in the studied sites. Nevertheless, we observed some changes in the Fucalean species, in particular a reduction in the canopy density values of some deep species. Therefore, we believe that the zonation pattern of the MPA should be revised, paying more attention to the conservation of fucalean species. Moreover, it will be important to manage and control the populations of the rabbitfishes, mitigating their impacts on the fucalean stands of the island.

Keywords: biodiversity; Fucales; *Cystoseira*; *Ericaria*; *Gongolaria*; *Sargassum*; Pelagie Islands; Marine Protected Areas

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1. Introduction

The Pelagie Islands Marine Protected Area (hereinafter MPA) is located in the Sicily Channel and comprises the islands of Lampedusa and Linosa, as well as the small, inhabited island of Lampione (Figure 1A–C). It extends over an area of 4136 ha. This MPA was established in 2002 to protect the marine and terrestrial flora and fauna (in particular reptiles and marine mammals), as well as to preserve the biological and geomorphological resources.

The MPA comprises three zones (A, B, and C) with varying degrees of protection. Zone A: an integral reserve area where only access and mooring for service boats carrying out surveillance and rescue tasks, as well as scientific research activities authorized by the managing body, are allowed. Bathing is allowed exclusively in Lampedusa's Isola dei Conigli, and only in manners and times regulated by the managing authority. Zone B: a general reserve area, where bathing, scuba diving with diving centers, sailing, mooring, anchoring, and fishing for residents of the municipality of Lampedusa and Linosa are allowed. Zone C: a partial reserve area where all the activities are allowed with fewer restrictions. On the island of Lampedusa, all the protection zones are present (see Figure 2). Moreover, this island is an Oriented Natural Reserve called "Riserva Naturale Isola di Lampedusa", established in 1995 to protect the natural environment of the southern part of the island, particularly endangered species, such as *Caretta caretta* (Linnaeus, 1758) that each year lays eggs at Isola dei Conigli (southern coast). Moreover, Lampedusa is part of the Natura 2000 network. In particular, it falls in the Site of Community Interest (SIC) and Special Conservation Area (ZSC) "Lampedusa Island and Lampione (ITA040002)", in the Special Protection Zone (SPA) "Pelagie Archipelago—marine and terrestrial area (ITA040013)", and in the Special Conservation Area (SAC) "Seabed of the Pelagie Islands (ITA040014)".

The first data on the marine hard substrate vegetation of the islands of the Sicily Channel were provided by Giaccone et al. [1]. Subsequently, Giaccone et al. [2] published an update on the Sicilian marine flora, including also Lampedusa among the explored islands. In 1990, some samplings were carried out at three stations of Lampedusa (Punta Cappellone, Capo Grecale, and Capo Ponente) by Alongi et al. [3]. The last study on the marine flora and vegetation of this island, which included samples collected at several stations between 1991 and 1992, was conducted by Scammacca et al. [4]. All these studies reported the presence of a well-defined and characteristic community of brown macroalgae belonging to the order Fucales (see in particular [3,4]). The order Fucales in the Mediterranean Sea is mainly represented by the species *Cystoseira sensu lato* (s.l.) (comprising the genera *Cystoseira* C. Agardh, *Ericaria* Stackhouse, and *Gongolaria* Boehmer) and *Sargassum* C. Agardh [5,6]. They form underwater forests, which are comparable to the Atlantic laminarian forests [7]. Moreover, thanks to the structural three-dimensionality of their branches, they modify the colonized environment and promote biological diversity by providing settlement substrate, food, and shelter for a highly diverse biota [8,9]. Due to their sensitivity to anthropogenic impacts, they are useful indicators of water quality, according to the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC) [10]. However, in the last decades, these species have suffered a severe decline in many Mediterranean areas, especially near the urbanized areas [11,12]. Despite their high value, vulnerability, and ongoing suffering, exacerbated by climate change [13], data on the distribution and conservation status of these species are still limited [14] or quite outdated [15]. Therefore, it is essential, especially for MPAs, which are regarded as vital conservation tools for safeguarding and restoring marine ecosystems [16], to provide up-to-date information on the distribution and status of these species. This will enable more effective protection measures and ensure their long-term survival.

Taking this into consideration, this study aimed to assess the current occurrence, status, and distribution of *Cystoseira* s.l. and *Sargassum* species around the Island of Lampedusa, about 30 years after the latest study carried out on the marine vegetation of the island. The obtained data were then compared with those of previous studies.

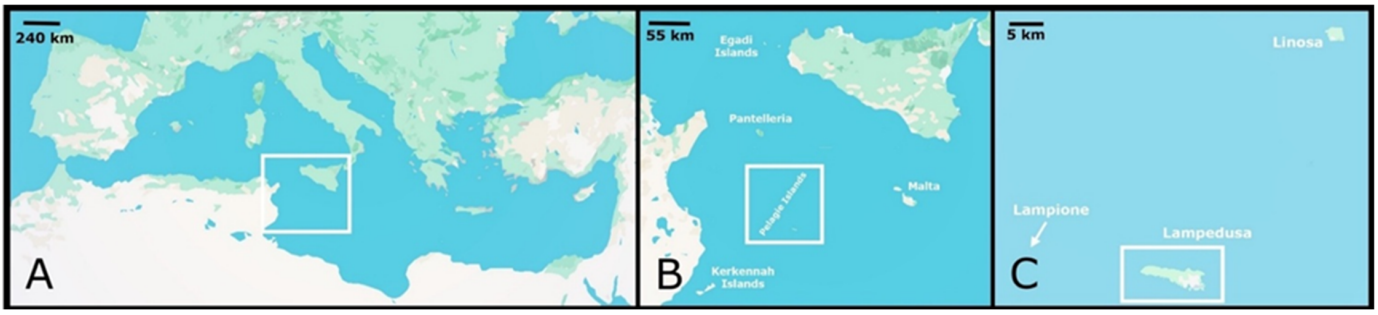

Figure 1. (**A**) Location of the study area (white box) in the Mediterranean Sea; (**B**) position of the Pelagie Islands MPA (white box) in the Sicily Channel; (**C**) the Pelagie islands: Lampedusa (white box), Linosa and Lampione. Maps were created with Google My Maps.

Figure 2. Zonation pattern of Lampedusa island: Zone A (red polygons), Zone B (yellow polygons), Zone C (blue polygons); and study sites represented with numbers (the corresponding sites are reported in Table 1). Map was created with Google My Maps.

Table 1. Details of study sites, including their corresponding number (Figure 2), protection zone, side of the island, GPS coordinates, date, and activity.

Site	Site Number	Protection Zone	Side	GPS Coordinates	Date	Activity
Grotta dell'Acqua	1	Zone B	north-east	35°31′20.0″ N 12°37′06.7″ E	7 July 2025	Scuba dive
Grotta Santa	2	Zone B	north	35°31′19.7″ N 12°35′39.6″ E	7 July 2025	Scuba dive
Baia di Taccio Vecchio	3	Zone B	north	from 35°31′18.6″ N 12°35′41.6″ E to 35°31′18.1″ N 12°35′46.8″ E	7 July 2025	Snorkeling
Muro Vecchio	4	Zone C	north	35°31′33.9″ N 12°33′35.2″ E	8 July 2025	Scuba dive

Table 1. *Cont.*

Site	Site Number	Protection Zone	Side	GPS Coordinates	Date	Activity
Scoglio Pignata	5	Zone C	north-west	35°31′37.9″ N 12°31′24.3″ E	8 July 2025	Scuba dive
Baia di Capo Ponente	6	Zone C	west	from 35°31′22.5″ N 12°31′13.0″ E to 35°31′18.3″ N 12°31′07.2″ E	8 July 2025	Snorkeling
Capo Grecale	7	Zone B	east	35°30′55.6″ N 12°37′58.6″ E	9 July 2025	Scuba dive
Fortino	8	Zone B	east	35°30′50.3″ N 12°37′44.3″ E	9 July 2025	Scuba dive
Costa Sud di Capo Grecale	9	Zone B	east	from 35°30′55.5″ N 12°37′55.0″ E to 35°30′53.8″ N 12°37′43.8″ E	9 July 2025	Snorkeling
Panettone	10	Zone B	south	35°30′26.0″ N 12°33′33.2″ E	10 July 2025	Scuba dive
Madonnina	11	Zone B	south	35°30′28.1″ N 12°33′24.2″ E	10 July 2025	Scuba dive
Tabaccara	12	Zone C	south	from 35°30′39.8″ N 12°34′07.3″ E to 35°30′27.6″ N 12°34′11.5″ E	10 July 2025	Snorkeling
Punta Parrino	13	Non-protected zone	east	35°30′02.6″ N 12°38′04.5″ E	11 July 2025	Scuba dive
Punta Iavuta	14	Non-protected zone	east	35°29′49.0″ N 12°38′02.2″ E	11 July 2025	Scuba dive
Baia di Punta Sottile	15	Non-protected zone	east	from 35°29′50.0″ N 12°37′58.2″ E to 35°29′46.2″ N 12°37′51.6″ E	11 July 2025	Snorkeling
Cala Spugne	16	Non-protected zone	south-east	from 35°29′35.3″ N 12°36′29.9″ E to 35°29′43.5″ N 12°36′38.3″ E	12 July 2025	Snorkeling
Cala Maluk	17	Non-protected zone	south-east	from 35°29′41.2″ N 12°36′42.5″ E to 35°29′36.1″ N 12°36′52.0″ E	12 July 2025	Snorkeling

Table 1. *Cont.*

Site	Site Number	Protection Zone	Side	GPS Coordinates	Date	Activity
Cala Francese	18	Non-protected zone	south-east	from 35°29′40.6″ N 12°37′26.6″ E to 35°29′43.6″ N 12°37′30.7″ E	12 July 2025	Snorkeling

2. Materials and Methods

2.1. Study Area

Lampedusa is the biggest and southernmost island among the Pelagie Islands, with an area of approximately 20 km^2, a coastline of 40 km, and a maximum altitude of 133 m above sea level (at Monte Albero Sole). From a geological point of view, Lampedusa belongs to the African continental shelf and is only 128 km away from Tunisia and 210 km from Sicily. The island, looking like a flat limestone plateau with an elongated shape, narrow and slightly elongated from north-west to south-east, consists of white stratified limestone of Miocene origin [17]. It represents an emergent flap of the African shelf, once connected to North Africa during the Pontian-Pliocene period [18].

The northern coast of Lampedusa, from Capo Grecale to Capo Ponente, consists of vertical rocky cliffs with variable height. On the contrary, the southern coast is generally low and rocky with numerous inlets. These areas represent the sea outlets of valleys which cut more or less deeply into the surface of most of the island [17]. The bathymetric profile follows this configuration: to the north, the cliff drops abruptly to a depth of 30 m, while elsewhere the seabed slopes gently towards the open sea [4].

2.2. Sampling

To carry out this research, a monitoring activity along the coasts of Lampedusa was conducted from 7 to 12 July 2025. A total of 18 sites (zones B and C), covering all sides of the islands (Figure 2; Table 1), were surveyed using an underwater visual census method involving both scuba diving and snorkeling activities. Since was needed a formal request for permission to enter Zone A, we decided to exclude this Area from our survey. The sites were selected in consultation with the staff from the diving center, considering the prevailing sea weather conditions. In particular, ten scuba dives and eight snorkeling activities were performed, each lasting from 40 min to 1 h, covering an area of approximately 250 m^2.

The visual census activity was conducted through the technique of random courses, which allows for exploring different habitats and depths [19–21]. The dives were carried out perpendicular to the coastline, following the seabed's geomorphology from the surface to a depth of around 40 m, depending on the site. Meanwhile, snorkeling activities were performed along the coastline at the same depth (0–1.5 m). During the visual census, Fucalean species were identified in situ, and their diacritical characters were photographed (i.e., apex, frond, base, receptacles, tophules) using two underwater cameras, Olympus TG-6 and TG-4 (Olympus Corporation, Tokyo, Japan). This approach is useful to minimize the impact of sampling on these threatened species, especially in MPAs [15,22,23]. Moreover, the canopy density was visually estimated taking into account the classes proposed by Thibaut et al. [24]: absence of individuals (1), scattered individuals (2), abundant patches (3), and almost continuous to continuous stands (4). Data on the depth and seawater temperature were taken through a Suunto D6i dive computer. When species examination

was not possible in the field, a few fragments of thalli were taken and stored in *exsiccata* for later identification with a stereomicroscope. The stored material was deposited in the authors' private collection, and some fragments were taken for future molecular analyses.

2.3. Data Analysis

All taxa were identified at specific and infraspecific level (hereinafter referred to as species) following Gómez-Garreta et al. [25], Cormaci et al. [26], Rodríguez-Prieto et al. [27], Blanfuné et al. [28], and the most recent taxonomic studies. The presence of mature individuals was also reported. For the taxonomy and nomenclature of species, we followed AlgaeBase [29].

The obtained data were compared with those of previous studies conducted on the island: Giaccone et al. [1,2], Alongi et al. [3], and Scammacca et al. [4]. Such reports were updated according to modern taxonomy and nomenclature to enable comparison.

3. Results

3.1. Current Diversity of Fucales in Lampedusa

During the visual census activity, a total of 13 fucalean species were found: three belonging to *Cystoseira* sensu strictu (s.s.) (*C. compressa*, *C. compressa* f. *rosetta* and *C. pustulata*), five to *Ericaria* (*E. amentacea*, *E. brachycarpa*, *E. dubia*, *E. funkii* and *E. giacconei*), two to *Gongolaria* (*G. montagnei* and *G. montagnei* var. *compressa*), and finally three to *Sargassum* (*S.* cf *acinarium*, *S.* cf *furcatum* and *S. vulgare*). Four species, precisely *E. brachycarpa*, *E. funkii*, *E. giacconei*, and *S.* cf *furcatum*, are reported for the first time on the island of Lampedusa.

The site with the highest number of species (nine species) was Muro Vecchio, located on the northern coast, in zone C. No fucalean species were found at Punta Iavuta and Cala Maluk, located on the east and south-east coast, respectively, in non-protected areas. While, at Capo Grecale and Fortino (on the east coast and in zone B), or at Cala Francese (on the south-east coast and in non-protected areas), only one fucalean species was found. As concerns the north and north-western coasts, a higher number of species (six) were found, precisely at Grotta Santa and Scoglio Pignata, located in zone B and C, respectively. Generally, in non-protected areas, the number of species was lower (1.67 ± 0.62) than in protected areas. Moreover, in zone C overall the number of species was higher (5.5 ± 1.32) than in zone B (3.25 ± 0.73) (Figure 3).

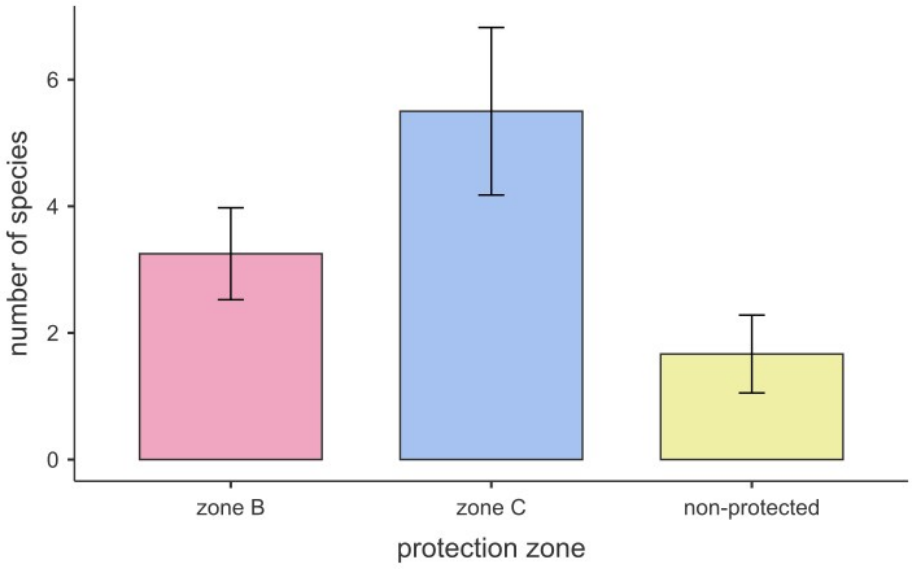

Figure 3. Number of species for protected and non-protected zones. Data are reported as mean ± standard error.

The species most frequently found in the study sites of the island were *S. vulgare* and *E. amentacea*, while those more rarely found were *E. brachycarpa*, *E. dubia*, and *S.* cf *acinarium*.

In Table 2 are reported the information on the occurrence and distribution of the species found in the study sites, their range of depth, presence of receptacles, and the classes of canopy density according to Thibaut et al. [24].

3.2. Comparison with Previous Studies

Three species (*E. amentacea*, *G. montagnei,* and *S. vulgare*), already reported by Giaccone et al. [1,2], were also found by Scammacca et al. [4]. Moreover, eight species (*C. crinita*, *C. foeniculacea*, *C. foeniculacea* f. *latiramosa*, *C. foeniculacea* f. *tenuiramosa*, *C. platyclada*, *S. acinarium*, *S. hornschuchii*, and *S. trichocarpum*) reported in Giaccone et al. [1,2] were not found by Alongi et al. [3], and Scammacca et al. [4]. Instead, Alongi et al. [3] and Scammacca et al. [4] reported seven species (*E. barbatula*, *C. compressa*, *C. compressa* f. *rosetta*, *E. dubia*, *C. humilis*, *G. montagnei* var. *compressa*, *G. montagnei* var. *tenuior*) that were not previously recorded by Giaccone et al. [1,2].

The comparison of our data with those from previous studies highlighted a greater closeness to those reported by Scammacca et al. [4] than to those from other studies (Table 3). Indeed, apart from the four species already reported by Giaccone et al. [1,2] (*E. amentacea*, *G. montagnei, S. acinarium* and *S. vulgare*), we found five species (*C. compressa*, *C. compressa* f. *rosetta*, *C. pustulata*, *E. dubia* and *G. montagnei* var. *compressa*) already reported by Scammacca et al. [4]. On the contrary, we did not find five species reported by Giaccone et al. [1,2]: *C. foeniculacea*, *C. foeniculacea* f. *latiramosa*, *C. foeniculacea* f. *tenuiramosa*, *S. hornschuchii*, and *S. trichocarpum*. However, the only species reported by Alongi et al. [3] and Scammacca et al. [4] that we did not find was *G. montagnei* var. *tenuior* (Table 3). Regards the complex of species *E. crinita/E. barbatula*, a more detailed discussion will be provided in the remarks section of *E. giacconei*.

Table 2. Distribution of the reported species at the sites (see Table 1), with information on the finding-depth range (in meters), presence of receptacles (*), and the canopy density (in brackets: 1—absence of individuals; 2—scattered individuals; 3—abundant patches; 4—almost continuous to continuous stands, according to Thibaut et al. [24]).

Site Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**N. Sites for Each Species**
Side of the Island	**North-East**	**North**	**North**	**North**	**North-West**	**West**	**East**	**East**	**East**	**South**	**South**	**South**	**East**	**East**	**East**	**South-East**	**South-East**	**South-East**	
Protection Zone	**B**	**B**	**B**	**C**	**C**	**C**	**B**	**B**	**B**	**B**	**B**	**C**	**Non-Protected**	**Non-Protected**	**Non-Protected**	**Non-Protected**	**Non-Protected**	**Non-Protected**	
C. compressa			0.1–0.3 m (4) *	0.3–15 m (3) *		0.1–0.3 m (4)			0.1–0.3 m (3)	0.1–0.2 m (4)		0.1–0.3 m (3) *	8 m (3)						7
C. compressa* f. *rosetta			0.1–0.3 m (2) *												0.1–0.3 m (2) *	0.1–0.3 m (2) *		0.1–0.3 m (2) *	4
C. pustulata		14 m (2)		11–15 m (2)				6 m (2)				0.3 m (2) *	7–9 m (3)		0.3–0.5 m (3) *				6
E. amentacea	0–0.1 m (3) *		0–0.1 m (4) *		0–0.1 m (4) *	0–0.1 m (4)*			0–0.1 m (4)	0–0.1 m (4)	0–0.1 m (4)	0–0.1 m (4)							8
E. brachycarpa			0.1–0.2 m (3)																1
E. dubia				23–24 m (3)									35 m (3)						2
E. funkii	26–28 m (2)	13–20 m (2)		19–27 m (3)	16–24 m (3)														4
E. giacconei					0.1–0.3 m (3)							0.1–0.3 m (3)				0.1–0.3 m (2)			3
G. montagnei		12–16 m (2)		14–19 m (2)	16–22 m (3)					17 m (2)									4
G. montagnei* var. *compressa	25 m (2)	14–17 m (3)		16–19 m (2)	16–20 m (3)					16 m (2)									5
S.* cf. *acinarium		16 m (2)		23–27 m (3)															2
S.* cf. *furcatum				12–13 m (2)	18 m (2)		14 m (2)												3
S. vulgare	0.1–15 m (3) *	15 m (2)	0.1–0.5 m (4) *	13–20 m (2)		0.1–0.3 m (4) *			0.1–0.3 m (3) *	0.2–0.4 m (3) *					0.1–0.3 m (3) *	0.1–0.3 m (3) *			9
Number of species x site	4	6	5	9	6	3	1	1	3	5	1	4	3	0	3	3	0	1	

Table 3. Comparison of previous and current data on the Fucales of Lampedusa. For each species, details on taxonomic information, morphological description, local habitat, and distribution, as well as further remarks, are given.

Taxa	Giaccone et al. [1]	Giaccone et al. [2]	Alongi et al. [3]	Scammacca et al. [4]	Present Study
Ericaria amentacea (C. Agardh) Molinari & Guiry	x (as *Cystoseira stricta*)	x (as *Cystoseira stricta* v. *stricta*)	x (as *Cystoseira amentacea*)	x (as *Cystoseira amentacea* v. *amentacea*)	x
Ericaria barbatula (Kützing) Molinari & Guiry			x (as *Cystoseira barbatula*)	x (as *Cystoseira barbatula*)	
Ericaria brachycarpa (J. Agardh) Molinari & Guiry					x
Cystoseira compressa (Esper) Gerloff & Nizamuddin				x (as *Cystoseira compressa*)	x
Cystoseira compressa f. *rosetta* (Ercegović) Cormaci, G. Furnari, Giaccone, B. Scammacca & Serio				x (as *Cystoseira compressa* f. *rosetta*)	x
Ericaria crinita (Duby) Molinari & Guiry	x (as *Cystoseira crinita*)	x (as *Cystoseira crinita*)			
Ericaria dubia (Valiante) Neiva & Serrão				x (as *Cystoseira dubia*)	x
Cystoseira foeniculacea (Linnaeus) Greville		x (as *Cystoseira ercegovićii* f. *ercegovićii*)			
Cystoseira foeniculacea f. *latiramosa* (Ercegović) A. Gómez Garreta, M. C. Barceló, M. A. Ribera & J. R. Lluch	x (as *Cystoseira ercegovićii* f. *latiramosa*)				
Cystoseira foeniculacea f. *tenuiramosa* (Ercegović) A. Gómez Garreta, M. C. Barceló, M. A. Ribera & J. R. Lluch	x (as *Cystoseira ercegovićii* f. *tenuiramosa*)				
Ericaria funkii (Gerloff & Nizamuddin) Molinari & Guiry					x
Ericaria giacconei D. Serio & G. Furnari					x
Cystoseira pustulata (Ercegović) Neiva & Serrão				x (as *Cystoseira humilis*)	x
Cystoseira platyclada Sauvageau (taxon inquirendum)	x				
Gongolaria montagnei (J. Agardh) Kuntze	x (as *Cystoseira spinosa*)	x (as *Cystoseira spinosa* v. *spinosa*)	x (as *Cystoseira spinosa* v. *spinosa*)	x (as *Cystoseira spinosa* v. *spinosa*)	x
Gongolaria montagnei var. *compressa* (Ercegović) Verlaque, Blanfuné, Boudouresque & Thibaut				x (as *Cystoseira spinosa* v. *compressa*)	x
Gongolaria montagnei var. *tenuior (Ercegović) Molinari & Guiry*			x (as *Cystoseira spinosa* v. *tenuior*)	x (as *Cystoseira spinosa* v. *tenuior*)	
Sargassum acinarium (Linnaeus) Setchell	x				x
Sargassum hornschuchii C. Agardh	x	x			
Sargassum trichocarpum J. Agardh	x	x			
Sargassum cf *furcatum* Kützing					x
Sargassum vulgare C. Agardh	x	x		x	x
Total number of species	10	7	4	10	13

For each species, details on taxonomic information, morphological description, local habitat, and distribution, as well as further remarks, are given.

3.3. Species Found During This Study

***Cystoseira compressa* (Esper) Gerloff et Nizamuddin (Figure 4A)**

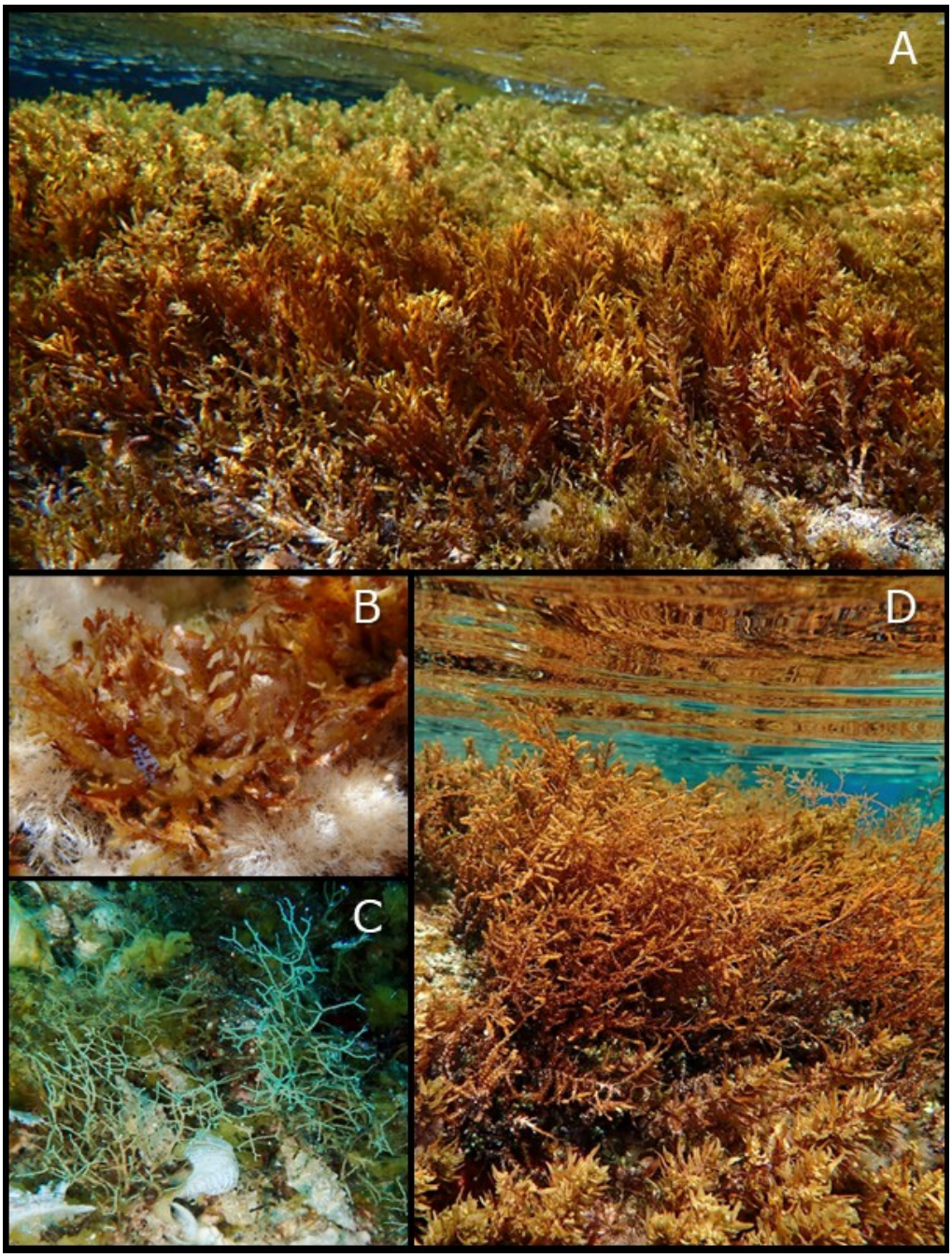

Figure 4. (**A**) *Cystoseira compressa*; (**B**) *Cystoseira compressa* f. rosetta; (**C**) *Cystoseira pustulata*; (**D**) *Ericaria amentacea*.

Basionym: *Fucus compressus* Esper

Synonyms: *Cystoseira flicina* Bory, *Cystoseira abrotanifolia f. fmbriata* Sauvageau, *Fucus fmbriatus* Desfontaines, *Cystoseira fmbriata* Bory

Morphological description of specimens: thalli are caespitose, attached to the substrate by a small discoid base. The apex is smooth and slightly protruding. Primary branches are flattened, covered by evident cryptostomata, and with a distichous arrangement; higher-order branches are flattened or cylindrical and with an alternate and distic-

hous disposal. During this study, some thalli showed lanceolate-fusiform receptacles, often associated with aerocysts.

Habitat: this species is widely distributed throughout the island, both on the southern and northern coasts, in zones B and C, and even in a non-protected zone (Punta Parrino). In shallow waters (0.1–0.3 m), it forms almost continuous stands that often go with those of *S. vulgare* and are underneath the E. *amentacea* belts, while in deeper waters (8–15 m), it establishes abundant patches.

Remarks: the association of the species *C. compressa*, *S. vulgare* and *E. amentacea* was already reported by Scammacca et al. [4]. This could indicate that the environmental conditions remained unchanged over time allowing the maintenance of this association.

***Cystoseira compressa* f. *rosetta* (Ercegovic) Cormaci, G. Furnari, Giaccone, B. Scammacca & Serio (Figure 4B)**

Basionym: *Cystoseira compressa* subsp. *rosetta* Ercegovic

Synonym: *Cystoseira compressa* subsp. *rosetta* Ercegovic

Morphological description of specimens: thalli are shorter than the other form and entirely flattened. Primary branches are foliaceous with a rosette arrangement. Cryptostomata are not very prominent and are disposed in longitudinal series along the branches. Receptacles are pedicellate and fusiform, not sustained by areocysts.

Habitat: this species was observed as scattered thalli in shallow areas (0.1–0.3 m) not exposed to wave motion, like bays or coves, such as Baia di Taccio Vecchio (on the northern coast, zone B) and Baia di Punta Sottile, Cala Spugne e Cala Francese (on the eastern and southern coasts, non-protected zones).

Remarks: this form was previously reported by Scammacca et al. [4].

***Cystoseira pustulata* (Ercegović) Neiva et Serrão (Figure 4C)**

Basionym: *Cystoseira abrotanifolia* subsp. *pustulata* Ercegovic

Synonym: *Cystoseira compressa* subsp. *pustulata* (Ercegovic) Verlaque

Morphological description of specimens: thalli are slender, caespitose, and attached to the substrate by a small discoid base. Apex is smooth and not prominent. Primary branches are cylindrical to slightly flattened with a distichous disposition. Higher-order branches are cylindrical. The name "*pustulata*" is derived from the protruding cryptostomata that cover the branches, giving them a pustulate appearance. Receptacles are simple, tiny, and lanceolate.

Habitat: this species is present on the northern coasts (Grotta Santa, Muro Vecchio, in zones B and C, respectively) as scattered thalli and on the south (Tabaccara, zone C) and east (Punta Parrino and Baia di Punta Sottile, non-protected zones) coasts, where it forms dense patches. It colonizes different habitats: from shallow (0.3–0.5 m) to deeper waters (up to 15 m).

Remarks: this species was previously reported for Lampedusa island by Scammacca et al. [4] as *Cystoseira humilis*. However, Neiva et al. [30] recently pointed out that previous records of *C. humilis* may have been misidentified and could refer to *C. pustulata*, a species that has been recognized as separate and distinct.

***Ericaria amentacea* (C. Agardh) Molinari et Guiry (Figure 4D)**

Basionym: *Cystoseira ericoides* var. *amentacea* C. Agardh

Synonyms: *Cystoseira stricta* var. *amentacea* (Bory) Giaccone, *Halerica amentacea* (C. Agardh) Kützing, *Carpodesmia amentacea* (C. Agardh) Orellana & Sansón

Morphological description of specimens: thalli are caespitose and attached to the substrate by a large and encrusting base. The apex is not prominent. Primary branches are cylindrical and robust. Higher-order branches are slender and more flexible. All branches are covered with spinose appendages. Receptacles are compact, cylindrical, and with deciduous spines.

Habitat: this species forms continuous or almost continuous belts in the infralittoral fringe (0–0.1 m) in waters exposed to wave motion, at north (Grotta dell'Acqua, Baia di Taccio Vecchio, Scoglio Pignata, in zones B and C, respectively), east (Costa Sud di Capo Grecale, zone B), west (Baia di Capo Ponente, zone C), and south (Panettone, Madonnina and Tabaccara, zones B and C, respectively) coasts of Lampedusa.

Remarks: *E. amentacea* has been reported for Lampedusa island since Giaccone et al. [1]. In particular, Scammacca et al. [4] observed that *E. amentacea* stands were well structured and widely distributed across the island. We can confirm that the density of the canopy has not changed since that time.

***Ericaria brachycarpa* (J. Agardh) Molinari et Guiry (Figure 5A,B)**

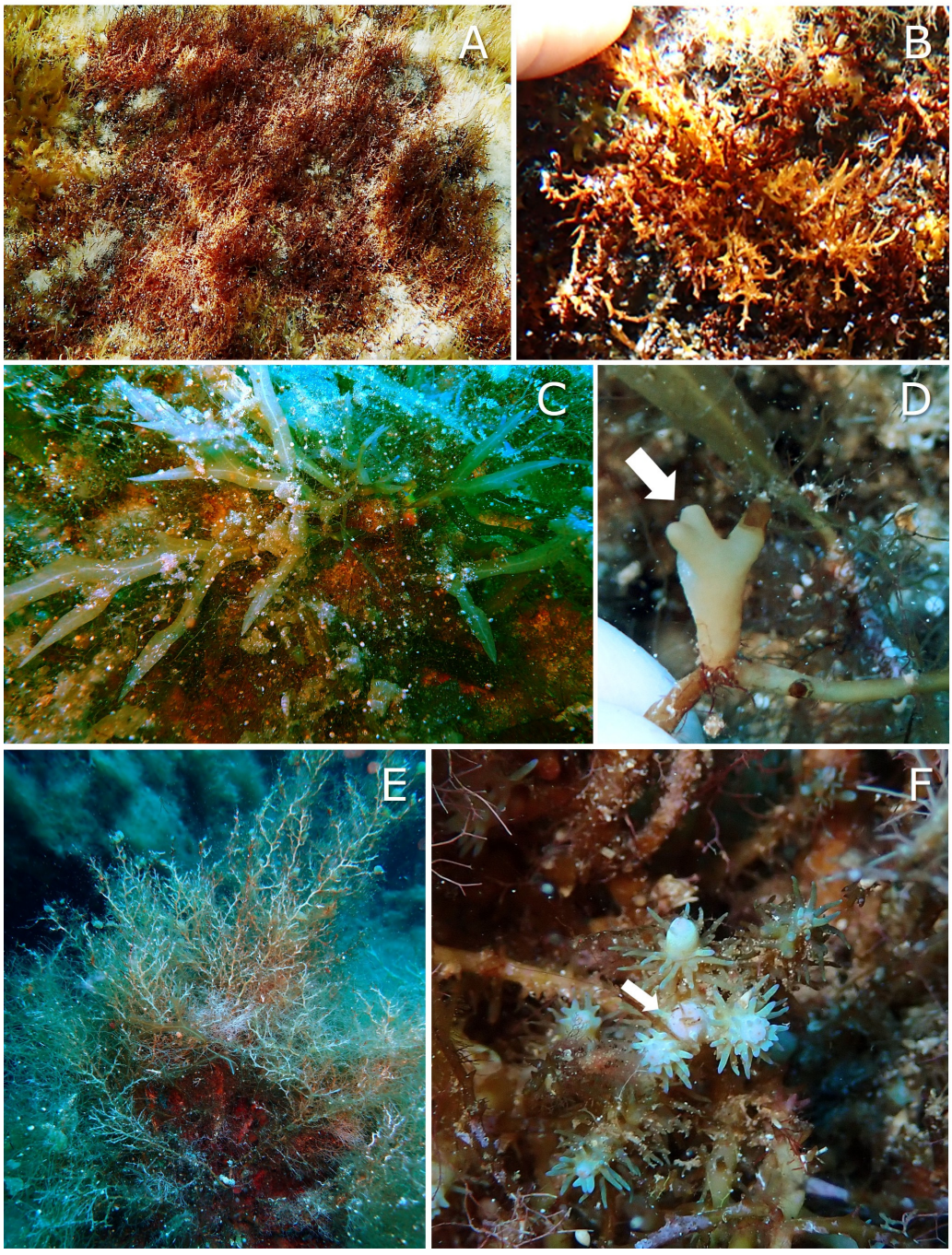

Figure 5. (**A,B**) *Ericaria brachycarpa;* (**C**) *Ericaria dubia;* (**D**) The apex of a thallus of *E. dubia* (white arrow)*;* (**E**) *Ericaria funkii;* (**F**) The apex of a thallus of *E. funkii* (white arrow).

Basionym: *Cystoseira brachycarpa* J. Agardh

Synonyms: *Cystoseira caespitosa* Sauvageau, *Carpodesmia brachycarpa* (J. Agardh) Orellana & Sansón

Morphological description of specimens: during the monitoring period, we only found very small thalli of this species, probably eroded by the wave motion. Thalli are characterized by a brown coloration, are caespitose, and are attached to the substrate by a large, compact discoid base. Apex is smooth and not prominent. All branches are cylindrical and can bear spinose appendages. Receptacles were not observed.

Habitat: this species formed dense patches in only one study site, Baia di Taccio Vecchio (on the northern coast, zone B) at 0.1–0.2 m of depth.

Remarks: this species has never been previously reported for the island of Lampedusa. Since it is present in only one site, we believe it may be a recent arrival from neighboring areas, such as Tunisia [31].

***Ericaria dubia* (Valiante) Neiva & Serrão (Figure 5C,D)**

Basionym: *Cystoseira dubia* Valiante

Morphological description of specimens: thalli are stoloniferous with a holdfast entirely buried in the substrate. It usually has a creeping habit. Apex is smooth and prominent. Primary branches are initially cylindrical and then become foliaceous with an evident midrib and acute margin. Receptacles were not observed during this study.

Habitat: this species was observed at two sites in Lampedusa island: Muro Vecchio (in the north, zone C) at 23–24 m, and Punta Parrino (in the east, non-protected zone) at 35 m, forming dense patches. It has always been found on gravelly-sandy substrates.

Remarks: this species was previously found by Scammacca et al. [4] in one site located in the northern coast of the island (Taccio Vecchio). This might indicate that *E. dubia* has shown a stable trend on the island over time.

***Ericaria funkii* (Gerloff & Nizamuddin) Molinari & Guiry (Figure 5E,F)**

Basionym: *Cystoseira funkii* Schiffner ex Gerloff & Nizamuddin

Synonym: *Carpodesmia funkii* (Schiffner ex Gerloff & Nizamuddin) Orellana & Sansón

Morphological description of specimens: thalli are pseudo-caespitose, with a single axis that divides creating with the tophules a coralloid-looking system. They are attached to the substrate by a digitiform base. Apex is smooth and not prominent. Primary branches and higher-order branches are cylindrical and bear spines. The tophules are oblong, rough, or covered with spinose appendages. Receptacles were not observed during this study.

Habitat: this species was found in four sites (Grotta dell'Acqua, Grotta Santa, Muro Vecchio, and Scoglio Pignata) located along the northern coast of the island, in both zones B and C, as scattered individuals or forming dense patches in a range of depth from 13 to 28 m.

Remarks: this species had never previously been reported off the coast of Lampedusa.

***Ericaria giacconei* D. Serio & G. Furnari (Figure 6A,B)**

Synonym: *Cystoseira hyblaea* Giaccone

Morphological description of specimens: thalli are caespitose, attached to the substrate by a compact basal disk. Axes are robust and slightly rough due to the scars left by old deciduous primary branches. Apex is smooth and not prominent. Primary and higher-order branches are cylindrical, without spiniform appendages. Receptacles were not observed during this study.

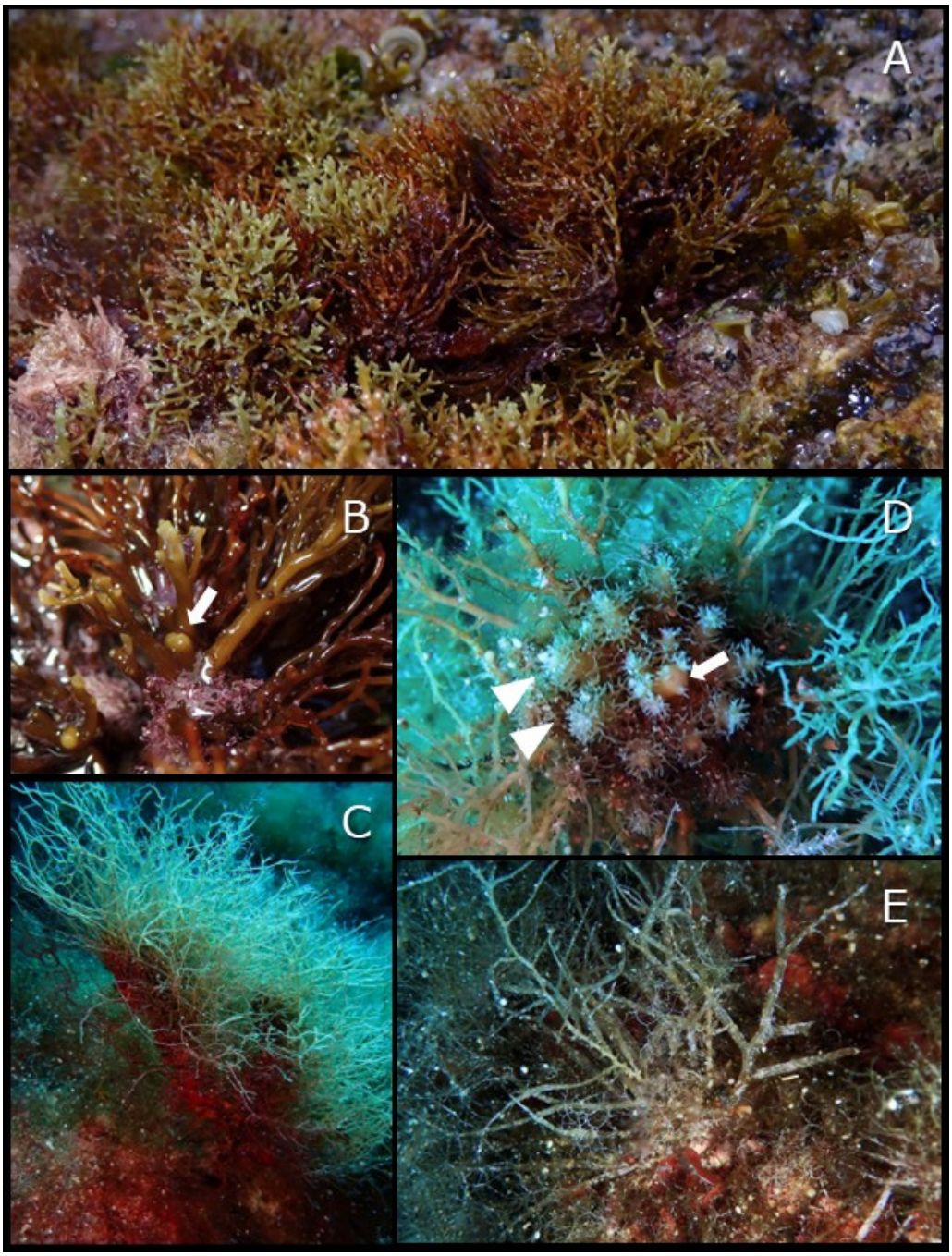

Figure 6. (**A**) *Ericaria giacconei*; (**B**) The apex of a thallus of *E. giacconei* (white arrow); (**C**) *Gongolaria montagnei*; (**D**) The apex (white arrow) and spinose tophules (white arrowheads) of a thallus of *G. montagnei*; (**E**) *Gongolaria montagnei* var. *compressa*.

Habitat: this species was found in three sites, Scoglio Pignata, Tabaccara (zone C) and Cala Spugne (non-protected zone), located along both the northern and southern coasts of Lampedusa, respectively, forming dense patches from 0.1–0.3 m. As described by Giaccone et al. [32], this species is usually vicariant of *E. amentacea*. However, in two sites (Scoglio Pignata and Tabaccara), stands of *E. giacconei* are found just below the infralittoral fringe, which is characterized by *E. amentacea* belts.

Remarks: this might represent the first record of *E. giacconei* in Lampedusa. However, it is interesting to note that Giaccone et al. [1,2] reported the presence of *E. crinita*, while Alongi et al. [3] and Scammacca et al. [4] found *E. barbatula* in this island. As stated by Serio and Furnari [33], *E. giacconei* is morphologically similar to *E. crinita* and *E. barbatula*, but

it differs from them for the base that is compact and robust, and the apex that is smooth, not prominent, and never surrounded by spinose appendages. Therefore, we believe that the past reports of *E. crinita* and *E. barbatula* on the island might be misidentifications attributable to *E. giacconei*. In particular, we found this species in locations very close to those where *E. barbatula* was found by Scammacca et al. [4]: Capo Ponente, which is located near Scoglio Pignata, Isola dei Conigli and Baia dei Conigli, which are close to Tabaccara.

***Gongolaria montagnei* (J.Agardh) Kuntze (Figure 6C,D)**

Basionym: *Cystoseira montagnei* J. Agardh

Synonyms: *Cystoseira spinosa* Sauvageau, *Cystoseira adriatica* Sauvageau, *Phyllacantha montagnei* (J. Agardh) Kützing, *Treptacantha montagnei* (J. Agardh) Orellana & Sansón, *Treptacantha ballesterosii* Orellana & Sansón

Morphological description of specimens: thalli are not caespitose and attached to the substrate by a compact discoid base. Apex is smooth and not prominent, usually covered by ovoid and spinose tophules. These last are distributed along the length of the thallus and especially on the upper part. Primary and higher-order branches are cylindrical or slightly flattened and bear bifid and multifid spinose appendages. Receptacles were not observed during this study.

Habitat: this species was found in four sites of the island, Grotta Santa (zone B) Muro Vecchio (zone C) and Scoglio Pignata (zone C) located in the north, and Panettone (zone B) located in the south of the island, forming dense patches or as scattered thalli from 12 to 22 m.

Remarks: this species has been reported in Lampedusa since Giaccone et al. [1] and was always recorded in sites located along the northern coast by Alongi et al. [3] and Scammacca et al. [4].

***Gongolaria montagnei* var. *compressa* (Ercegovi) Verlaque, Blanfuné, Boudouresque & Thibaut (Figure 6E)**

Basionym: *Cystoseira adriatica* subsp. *compressa* Ercegovic

Synonyms: *Cystoseira adriatica* subsp. *compressa* Ercegovic, *Cystoseira platyramosa* Ercegovic, *Cystoseira adriatica* subsp. *intermedia* Ercegovic, *Cystoseira adriatica* var. *intermedia* (Ercegovic) Giaccone, *Cystoseira spinosa* var. *compressa* (Ercegovic) Cormaci, G. Furnari, Giaccone, Scammacca & D. Serio, *Cystoseira montagnei* var. *compressa* (Ercegovic) M. Verlaque, Blanfuné, Boudouresque, Tibaut & Sellam.

Morphological description of specimens: thalli are not caespitose and attached to the substrate by a basal disk. Apex is smooth and not prominent. Tophules are oblong and spinose and are distributed near the base. Primary branches are initially cylindrical near the base and tend to become flattened. Higher-order branches are flattened with a central midrib. Receptacles were not observed.

Habitat: this species was found in five sites in Lampedusa: four along the northern coast (Grotta dell'Acqua, Grotta Santa, in zone B, and Muro Vecchio and Scoglio Pignata, in zone C) and one along the southern one (Panettone, in zone B). It was observed as scattered individuals or forming dense patches from 14 to 25 m.

Remarks: this species was reported for the first time in Lampedusa by Scammacca et al. [4] in only one site (Taccio Vecchio) located in the northern coast of the island.

***Sargassum* cf *acinarium* (Linnaeus) Setchell (Figure 7A)**

Figure 7. (**A**) *Sargassum* cf *acinarium*; (**B**) *Sargassum* cf *fucatum*; (**C**) *Sargassum vulgare* with receptacles (white arrows).

Basionym: *Fucus acinarius* Linnaeus

Synonyms: *Fucus acinarius* S. G. Gmelin, *Fucus linariifolius* Turner, *Fucus linifolius* Turner, *Sargassum linifolium* C. Agardh, *Sargassum linifolium* f. *gibraltica* Grunow, *Sargassum vulgare* var. *linifolium* (C. Agardh) Zanardini

Morphological description of specimens: thalli are not caespitose and attached to the substrate by a discoid base. Axis is cylindrical, rough, or knotty. Primary branches are cylindrical and bear narrow foliaceous branches with wavy or toothed margins, an acute and slightly rounded apex, and a central midrib. Aerocysts are brought by a cylindrical pedicel, are spherical, and are located particularly on the upper portion of the thallus. Receptacles were not observed during this study.

Habitat: this species was found as scattered individuals (16 m) or forming dense patches (23–27 m) in two sites located along the northern coast of Lampedusa: Grotta Santa (zone B) and Muro Vecchio (zone C).

Remarks: this species was reported for the first time in Lampedusa by Giaccone et al. [1], precisely in the northern coast of the island. However, it has not subsequently been found by the other authors. Unfortunately, the identification at the species level is not certain because we did not find fertile specimens during this study.

***Sargassum* cf *furcatum* Kützing (Figure 7B)**

Synonym: *Sargassum vulgare* f. *furcatum* (Kützing) J. Agardh

Morphological description of specimens: thalli are not caespitose and are characterized by a creeping habit. They are attached to the substrate by a discoid base. Axis is knotty and divides, forming spaced branches with a fan shape. Primary branches are knotty and bear lanceolate leaves, branched up to four times, with toothed or wavy margins, and are crossed by an evident midrib, which is dichotomously divided 1–4 times. Moreover, they are often characterized by a blue-green iridescence surrounding the midrib and almost covering it. The apex of foliose branches is acute or rounded. Aerocysts and receptacles were not observed during this study.

Habitat: this species was found in a range of depths of 12–18 m as scattered individuals in three sites: two located in the northern coast (Muro Vecchio and Scoglio Pignata, zone C), and one in the eastern coast (Capo Grecale, zone B) of the island.

Remarks: this species has never been found before in the island of Lampedusa. Unfortunately, the identification at the species level was not certain since we did not find fertile individuals during this study. This species, present both in the western Atlantic and Pacific Ocean, was first reported in the Mediterranean in 1995 on the Chafarinas Islands [34], which are one of Spain's territories in North Africa, located off the Moroccan coast. The species was then reported in several locations around Sicily, including the islands of Lipari and Vulcano (Aeolian Islands) [23] and the island of Marettimo (Egadi Islands) [15]. *Sargassum* cf *furcatum* is increasingly spreading, most likely due to the tropicalization process [35].

***Sargassum vulgare* C. Agardh (Figure 7C)**

Synonyms: *Fucus salicifolius* S. G. Gmelin, *Sargassum megalophyllum* Montagne, *Sargassum coarctatum* Kützing, *Sargassum vulgare* var. *megalophyllum* (Montagne) Vickers.

Morphological description of specimens: thalli are not caespitose and attached to the substrate by a discoid base. Axis can be smooth or knotty. Primary branches are cylindrical and smooth, and bear lanceolate leaves with a distichous arrangement, a toothed margin, an evident midrib, and an acute apex that is slightly rounded. Aerocysts were not observed during this study. Receptacles are composed of a sterile pedicel that is located at the leaf axis, and are simple or bifid, warty, and slightly flattened.

Habitat: this species was found at north-east (Grotta Santa, zone B), north (Grotta Santa and Baia di Taccio Vecchio, in zone B and Muro Vecchio, zone C), west (Baia di Capo Ponente, zone C), east (Costa Sud di Capo Grecale, zone B, and Baia di Punta Sottile, non-protected zone), south (Panettone, zone B) and south-east (Cala Spugne, non-protected zone) coasts, both in shallow and in deeper waters. In particular, as mentioned above, in shallow areas, it forms almost continuous stands or dense patches in association with *E. amentacea* and *C. compressa*, while only scattered individuals are present in deeper environments (13–20 m).

Remarks: this species was always reported in the island of Lampedusa in association with the abovementioned species [1,2,4].

4. Discussion

During this study, we monitored the occurrence, distribution and status of fucalean species in Lampedusa island, about 30 years after the last studies conducted on the marine vegetation of the island. A total of 13 species were found along the coasts of the island: three belonging to *Cystoseira*, five to *Ericaria*, two to *Gongolaria,* and three to *Sargassum*. Four species, precisely *E. brachycarpa*, *E. funkii*, *E. giacconei,* and *S.* cf *furcatum*, were reported for the first time along the coasts of Lampedusa. We believe that *E. brachycarpa*, *E. funkii,* and *S.* cf. *furcatum* are more recent arrivals on the island, whereas *E. giacconei* may have always been present in Lampedusa island, but it was misidentified in the past. Indeed, as mentioned above, *E. giacconei* is morphologically similar to *E. crinita* (reported by Giaccone et al. [1,2] and *E. barbatula* (reported by Alongi et al. [3] and Scammacca et al. [4]). As pointed out by Serio and Furnari [33], *E. giacconei* is distinguished by its base, which is robust and compact (more irregular in the other two species), and by its apex that is smooth, not prominent, and without spiniform appendages (while in *E. barbatula* it is smooth and prominent, and in *E. crinita* it is spinose and prominent). Moreover, Serio and Furnari [33] studying the specimens hosted in the CAT Herbarium, collected in a southernmost site of Sicily (Isola delle Correnti, Portopalo di Capo Passero) and identified by Pizzuto et al. [36] as *E. crinita*, observed smooth apices in all these samples. Therefore, they concluded that *E. giacconei* had been present in that locality since that time. In that instance, we believe that also the samples from Lampedusa may have been misidentified in the past. Therefore, this report on the island of Lampedusa extends the known distribution range of this species, including Portopalo di Capo Passero [33] and Kelibia (Tunisia) [37]. From a molecular point of view, these three species are currently included in the same complex, *E. crinita* s.l. [30]. Nevertheless, we believe that further analyses would be necessary to better understand and deepen the relationship, the distribution ranges, and the biogeographic boundaries of these three entities.

As concerns *E. brachycarpa*, *E. funkii* and *S.* cf *furcatum*, we believe that these species arrived in Lampedusa from neighboring areas (e.g., north Africa, Sicily) [28] most likely by means of currents. Among these species, *S.* cf *furcatum* deserves special attention since it is a non-indigenous species, present in both the western Atlantic and the Pacific Ocean, which is recently expanding in the Mediterranean Sea [35]. Indeed, after the first Mediterranean record in 1995 in the Chafarinas Islands (Spain) by Flores-Moya and Conde [34], this species was found in 2021 in several locations of the eastern coast of Sicily, in two sites along the French Mediterranean coastline and Corsica [28], and more recently, it was documented in some Sicilian islands, such as Lipari and Vulcano [23], and Marettimo [15]. The expanding trend of *S.* cf. *furcatum*, which is a non-indigenous species with warm affinity, could be considered a further proof of ongoing seawater warming and the tropicalization of Mediterranean waters.

By comparing our data with the most recent studies by Alongi et al. [3] and Scammacca et al. [4], we observed that *G. montagnei* var. *tenuior* was never found in the sites monitored during this study. According to Alongi et al. [3] and Scammacca et al. [4], this species showed high canopy density values in the low horizon of the infralittoral, both in sites located along the northern and southern coasts of the island. During our study, instead, we did not find this species anymore, and even the other varieties (*G. montagnei* and *G. montagnei* var. *compressa*) presented low canopy densities, being observed always as scattered individuals or patches. Even other deep species, such as *E. funkii* and *E. dubia*, were found with low canopy density values. One of the primary drivers of *Cystoseira* s.l. decline is the ocean warming and the effects of climate-driven impacts [38]. In particular, Capdevila et al. [39] demonstrated through a controlled laboratory experiment that warming effects on the early stages of deep species (e.g., *Ericaria zosteroides* (C. Agardh) Molinari & Guiry)

could impair the ability to rebound after major disturbances and, thus, the stands of these species might become more vulnerable to further stress. Even thermal anomalies, such as marine heatwaves (MHW), can compromise, particularly the vitality and survival of early stages, as observed by Verdura et al. [40]. This could seriously threaten endemic species with a restricted distribution, such as *Gongolaria rayssie* (Ramon) Molinari & Guiry, which has a limited, narrow geographical distribution in the Levantine basin and, thus, might become globally extinct due to seawater warming [41].

Moreover, another climate-induced cause of *Cystoseira* s.l. decline is the overgrazing by the Lessepsian fish [38]. In this regard, we believe that one important cause of the decrease in the canopy density of deep species in Lampedusa might be connected to the presence in this island of the rabbitfishes *Siganus luridus* (Rüppell, 1828) and *Siganus rivulatus* (Forsskål & Niebuhr, 1775). These two fish entered the Mediterranean from the Red Sea through the Suez Canal and colonized first the Levantine coast [42], where they profoundly transformed the shallow rocky reefs by removing habitat-building macroalgae and hindering the establishment of new erect algae [43]. *Siganus luridus* was first reported at the Pelagie Islands (in the island of Linosa) in 2003 [44], while S. *rivulatus* was found for the first time in this area (in the island of Lampedusa) in 2017 [45]. Nowadays, these species are well-established in the Sicily Strait [45,46]. Even during our monitoring activities, we observed dense populations of both species, together with another Lessepsian alien fish, *Fistularia commersonii* Rüppell, 1838. The presence of these invasive alien fish might represent another indicator of the tropicalization of Mediterranean waters [47]. During our study, we observed that the seawater temperature was around 26–27 °C from 0 to 15 m, and between 19 and 21 °C from 20 to 30 m of depth. Data collected in July by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) [48] at the site of Cala Madonna (Lampedusa) shows that the surface seawater temperature increased from 23.5 °C in 2010 to 26.7 °C in 2025. Therefore, this increase of approximately 3 °C in the seawater temperature may have favored the expansion and establishment of these Lessepsian species in Lampedusa.

The comparison with the past studies highlighted a greater closeness to the data reported by Scammacca et al. [4] than to those of the other studies, not only in terms of species, but also in terms of biodiversity found along the sides of the island. In our study, as also observed by Scammacca et al. [4], the sites located along the northern and western coasts showed a higher number of species than that found along the southern and eastern coasts. In particular, we found that the site of Muro Vecchio, located on the northern coast, had the highest number of species (nine), while many sites along the eastern and southern coasts (such as Capo Grecale, Fortino, Madonnina, and Cala Francese) had only one species. No fucalean species were found in two sites in the south-eastern coast of Lampedusa: Cala Maluk and Punta Iavuta. This difference in the fucalean biodiversity along the island could be connected to the diverse geomorphology of the coasts, which are characterized by rocky cliffs in the north-west, and bays and coves in the south-east. Moreover, as concerns the zonation pattern, we found a higher number of species in zone C than in zone B, where there should be more restrictions and a regime of greater protection for flora and fauna. Mannino et al. [49] discussed that in many Mediterranean MPAs, the zonation is often arbitrary, and the zones' boundaries, in particular those of zone A, are frequently chosen for reasons that are different from those of a scientific nature. From that point of view, we believe that the zonation pattern of Lampedusa should be revised, and in particular, two species, *E. giacconei* and *E. dubia*, which are currently distributed in zone C or in non-protected zones, should benefit from greater protection.

Overall, as already reported by Scammacca et al. [4] and observed also during this study, the predominant species' association at Lampedusa is formed by *Halopteris scoparia*

(Linnaeus) Sauvageau, *H. filicina* (Grateloup) Kützing, and *Padina pavonica* (Linnaeus) Thivy. According to Scammacca et al. [4], this species' association together with the presence of a well-defined and characteristic community of Fucales at Lampedusa is connected to: the friable limestone substrate that causes a high sedimentation rate (this does not allow the establishment of species with greater light requirements), and to the seabed configuration and coasts' exposure that characterize this island.

This species' association is completely different from that of another nearby island, Pantelleria, which has a volcanic origin [50] and shows a higher fucalean diversity (19 species) [22].

5. Conclusions

In conclusion, through this study, it was observed that overall, the predominant species' association described in the past for the island of Lampedusa has remained unchanged in terms of species and biodiversity found in the sites. However, we did not find any more *G. montagnei* var. *tenuior*, and we observed that many deep species, such as *G. montagnei*, *G. montagnei* var. *compressa*, *E. dubia*, and *E. funkii* had low canopy density values.

Therefore, in the future, it will be necessary to plan periodic monitoring activities to follow up on the health status of the fucalean canopies and all the possible impacts on the canopy density of fucalean species such as the rabbitfishes. In this regard, it will be important, for instance, to find effective strategies, such as commercial fishing, to manage and control the populations of these fish, mitigating their impacts on the Mediterranean biota.

Author Contributions: Conceptualization, G.M. and A.L.; methodology, G.M. and A.L.; validation, D.S. and A.M.M.; data curation, G.M., D.S. and A.M.M.; writing—original draft preparation, G.M. and A.L.; writing—review and editing, D.S. and A.M.M.; supervision, D.S. and A.M.M.; funding acquisition, D.S. and A.M.M. All authors have read and agreed to the published version of the manuscript.

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