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Posted Date: 20 November 2024

doi: 10.20944/preprints202411.1520.v1

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## Article

# Diversity and Distribution of Intertidal *Cystoseira sensu lato* Species Across Protection Zones in a Mediterranean Marine Protected Area

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**Abstract:** This study investigates the diversity and distribution of intertidal *Cystoseira sensu lato* (s.l.) species across different protection zones within the “Capo Gallo-Isola delle Femmine” Marine Protected Area (MPA) in the central Mediterranean Sea. Five *Cystoseira* s.l. species (*Cystoseira compressa*, *C. foeniculacea*, *Ericaria amentacea*, *E. brachycarpa* and *E. crinita*) were observed on the intertidal rocky shores, with varied abundances across the MPA's protection zones. *Ericaria amentacea* was the only species found in all zones, with a much higher cover percentage in the most protected area (zone A). However, its morpho-functional traits showed an inverse trend, with the largest thalli found in the moderately protected zone B and C. The remaining *Cystoseira* s.l. species were only found in zone B and C probably due to their wider area and greater habitat diversity compared to zone A. The presence of two non-indigenous species, *Asparagopsis taxiformis* and *Caulerpa cylindracea*, was observed exclusively in the less protected zones B and C. Our findings highlight the complex interactions between MPA protection levels and *Cystoseira* s.l. species conservation, with protection having, in some respects, a positive influence on selected *Cystoseira* s.l. species, indicating the importance of careful consideration in MPA design and management. Furthermore, this study provides a baseline for future monitoring of *Cystoseira* s.l. populations in light of ongoing environmental changes in the Mediterranean Sea.

**Keywords:** biodiversity; macroalgal distribution; Marine Protected Areas; Mediterranean Sea; *Cystoseira sensu lato*; *Cystoseira*; *Ericaria*; *Gongolaria*

## 1. Introduction

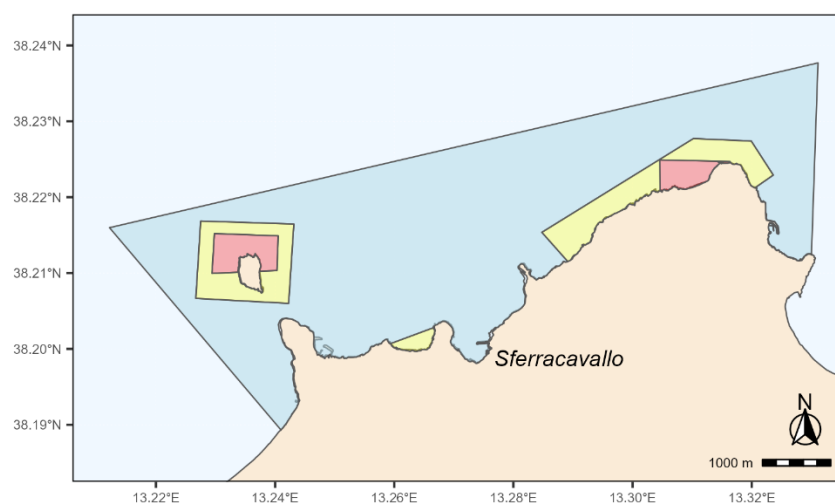
Marine Protected Areas (MPAs) have emerged as vital tools for biodiversity conservation and ecosystem management worldwide [1,2]. These protected zones serve as valuable resources for studying the effects of human activities on marine ecosystems and the potential for recovery when such pressures are reduced or eliminated [3]. Among the various indicators of ecosystem health in Mediterranean coastal waters, brown seaweeds of the genus *Cystoseira sensu lato* (s.l.) - including the genera *Cystoseira*, *Ericaria*, and *Gongolaria* [4,5] - have emerged as particularly significant.

In the Mediterranean rocky shores, seaweeds belonging to the genus *Cystoseira* s.l. play a valuable role as foundation species, forming complex three-dimensional habitats that support high biodiversity and provide numerous ecosystem services [6–8]. These seaweeds significantly enhance the structural complexity and productivity of coastal communities from the intertidal down to the upper circalittoral zone [9–12]. Additionally, they are considered useful indicators of water and ecosystem quality according to the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (2008/56/EC) [13,14].

Some species of *Cystoseira s.l.* are recognized as highly impacted, particularly near urban areas, due to the interplay effects of local anthropogenic pressures (e.g., pollution, urbanization, the introduction of non-native species, overfishing, coastal aquaculture), and global climate change [7,15–18]. Consequently, the decline or loss of *Cystoseira s.l.* populations has been observed on many rocky coasts, leading to a shift from complex and productive benthic communities to less structured assemblages dominated by turf-forming algae, mussels, or sea urchin barrens [19,20], and a decrease of valuable ecosystem services [21].

While MPAs can play a critical role in the conservation of *Cystoseira s.l.* forests by providing protection from various anthropogenic impacts [22], their effectiveness in preserving these foundation seaweeds remains understudied. The protective environment within MPAs may facilitate higher reproduction rates of *Cystoseira s.l.* populations by reducing local anthropogenic stressors, facilitating conditions to successful reproduction and the establishment of new individuals [22].

We investigated the diversity and distribution of *Cystoseira s.l.* populations on the intertidal rocky shore within the “Capo Gallo-Isola delle Femmine” MPA in the central Mediterranean Sea and tested whether the diverse protection zones within the MPA may affect their conservation differently. For *Ericaria amentacea* (C.Agardh) Molinari & Guiry 2020, one of the main species characterizing the intertidal zone, we also explored changes in key morpho-functional traits across the protection zones. Additionally, we documented the presence of non-indigenous seaweeds in the investigated area, providing crucial information for understanding current challenges to conservation efforts. With this study we provide a baseline understanding of *Cystoseira s.l.* population dynamics within the “Capo Gallo-Isola delle Femmine” MPA (Figure 1) by updating a previous research [23]. This data will be essential for the MPA to plan future monitoring activities, which are mandatory for effective conservation strategies in the face of global change.



**Figure 1.** The MPA of Capo Gallo – Isola delle Femmine. Red, yellow, and blue areas denote no-take (zone A), general (zone B), and limited (zone C) protection zones, respectively.

## 2. Results

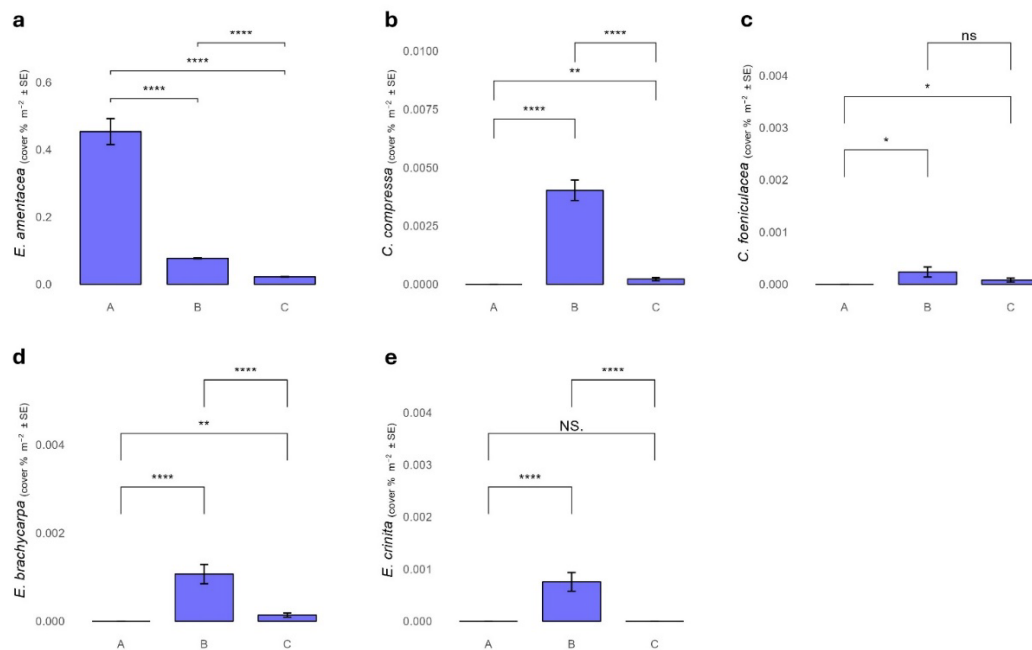
A total of 5 *Cystoseira s.l.* species (*Cystoseira compressa* (Esper) Gerloff & Nizamuddin 1975, *Cystoseira foeniculacea* (Linnaeus) Greville 1830, *E. amentacea*, *E. brachycarpa* (J.Agardh) Molinari & Guiry 2020 and *E. crinita* (Duby) Molinari & Guiry 2020) were identified along the intertidal rocky shore of the MPA of Capo Gallo – Isola delle Femmine (Figure 2).

*Ericaria amentacea* was mainly found on the outer edge of the vermetid reef. It was the only species among that discovered in this study, present in all the MPA protection zones. In particular, the cover percentage of *E. amentacea* was significantly higher in zone A, while decreased in the other protection zones, with the lowest values in zone C (Figure 2a, Table S1-S2).

*Cystoseira compressa* was mainly discovered within intertidal pools along the vermetid reef, or close to the external edge of the vermetid reef, where substitutes *E. amentacea*. It was rarely

associated with *E. amentacea*. *Cystoseira compressa* was found in B and in C zones with average cover of 2.6 % and 0.44%, respectively (Figure 2b).

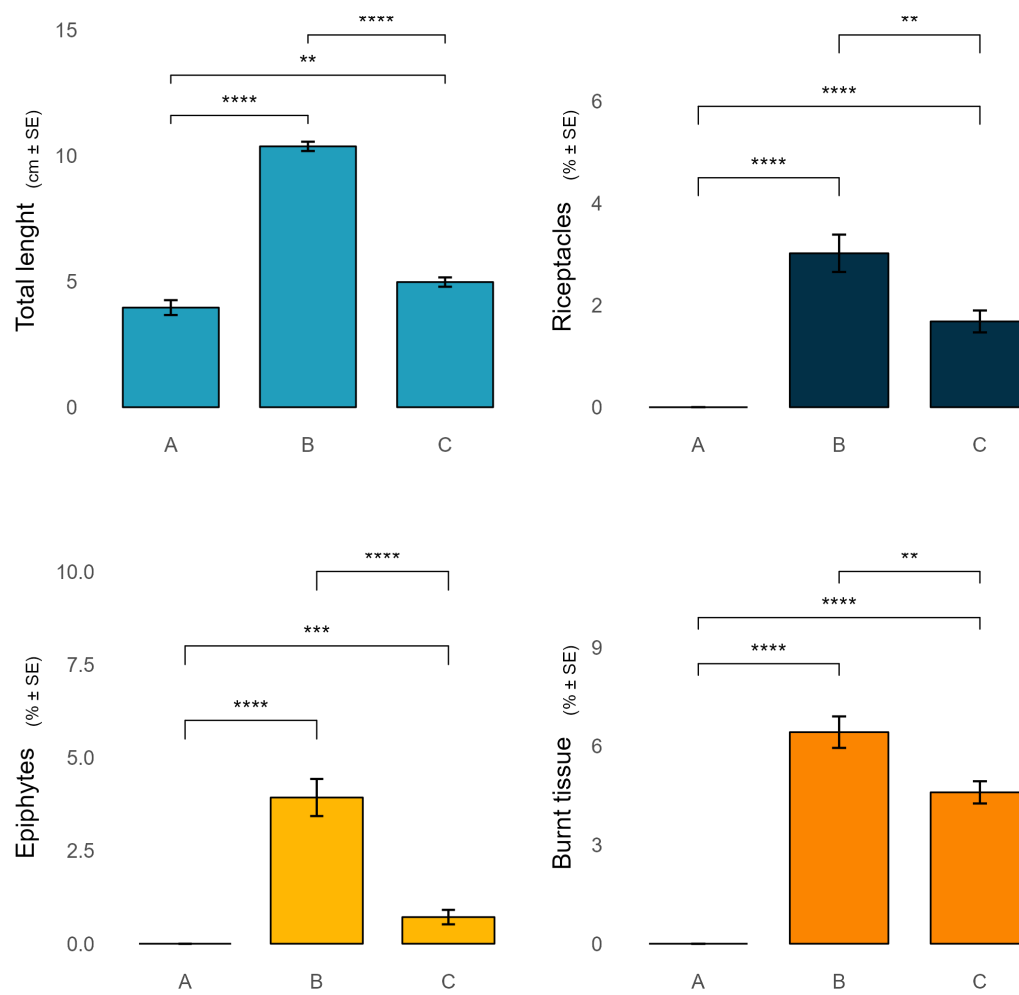
*Cystoseira foeniculacea*, *E. crinita* and *E. brachycarpa* were mostly found in the cuvettes of the vermetid platform. The three species, were absent in zone A, while are present in lower percentage in zones B and C. Specifically, *C. foeniculacea* is found in zone B with an average percentage of 0.25%, and in zone C with a percentage of 0.18%. *Ericaria brachycarpa* is present in zone B with an average percentage of 0.70%, and in zone C with an average coverage of 2% while *E. crinita* was found only in zone B with an average percentage of 0.48% (Figure 2c-e).



**Figure 2.** Cover percentage of *Ericaria amentacea* (a), *Cystoseira compressa* (b), *Cystoseira foeniculacea* (c), *Ericaria brachycarpa* (d), and *Ericaria crinita* (e) among the AMP protection zones.

### 2.1. Morpho-Functional Parameters of *Ericaria Amentacea*

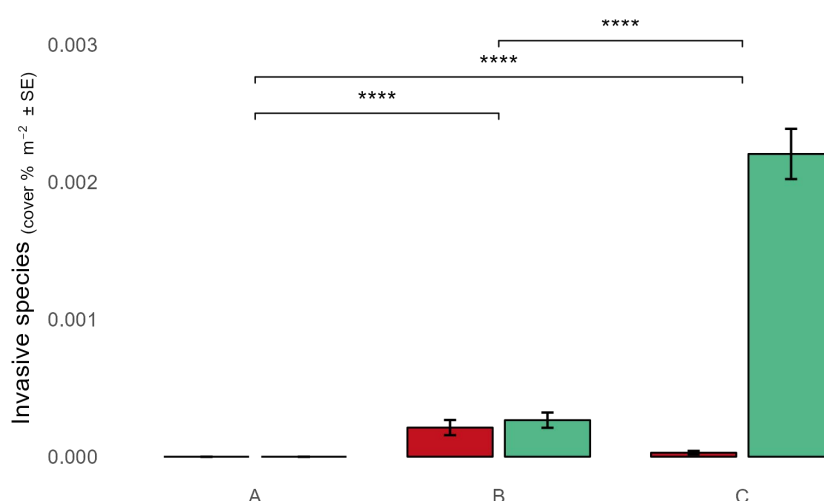
*Ericaria amentacea* presented bigger thalli in zone B, with a total length of about  $10.4 \pm 0.2$  cm, compared to zone C and A, where thalli were  $5 \pm 0.2$  cm, and  $4 \pm 0.3$  cm, length respectively (Figure 3). The percentage of receptacles, epiphytes and burnt tissue were in general more present in zone B ( $3 \pm 0.4$ ,  $4 \pm 0.5$ ,  $6.4 \pm 0.5$  %, respectively) than in zone C ( $1.7 \pm 0.2$ ,  $0.7 \pm 0.2$ ,  $4.6 \pm 0.3$  %, respectively), while were absent in zone A (Figure 3).



**Figure 3.** Variation of the morpho-functional parameters of *Ericaria amentacea* among the AMP protection zones.

## 2.2. Non-Native Species

Two species, *Asparagopsis taxiformis* (Delile) Trevisan 1845 and *Caulerpa cylindracea* Sonder 1845, were discovered, with the last one resulting more abundant (Figure 4). These species were found only in zones B and C, with *C. cylindracea* being more abundant in zone C (Figure 4). *Asparagopsis taxiformis* was found in intertidal pools or in the outer part of the external edge of the vermetid reef, while *C. cylindracea* was mainly found in the cuvettes of the vermetid platform with thalli not longer than 1-2 cm.



**Figure 4.** Cover percentage of *Asparagopsis taxiformis* (red), and *Caulerpa cylindracea* (green), among the AMP protection zones.

### 3. Discussion

Our findings reveal a diversified pattern of *Cystoseira s.l.* species distribution across different protection zones within the MPA of “Capo Gallo - Isola delle Femmine”, highlighting the potential effectiveness of MPAs in conserving these important foundation species. We identified five *Cystoseira s.l.* species (*C. compressa*, *C. foeniculacea*, *E. amentacea*, *E. brachycarpa* and *E. crinita*) on the intertidal rocky shores of the MPA. This diversity underscores the ecological importance of the MPA and aligns with previous studies documenting the richness of *Cystoseira s.l.* species in Mediterranean coastal ecosystems (Ballesteros et al., 2009; Thibaut et al., 2015; Mancuso et al., 2024). Compared to previous research carried out into the MPA, we observed changes in *Cystoseira s.l.* composition rather than in number of species. In fact, previous study highlighted the presence of *Cystoseira humilis* Schousboe ex Kützinger 1860 [23]. We believe the absence of this species in our study may be due to its restricted range in the intertidal zone, as it is usually confined to intertidal rocky pools. It's possible that during our survey, *C. humilis* may have been retracted or less visible due to high temperatures that intertidal pools can reach during the sampling season. However, this hypothesis requires further investigation to confirm. The discrepancy in our findings underscores the importance of considering temporal factors in surveys particularly for intertidal species that are highly subjected variation of environmental variables.

We found that the distribution of these species varied significantly across the MPA's protection zones, suggesting that the level of protection influences their abundance and composition. *Ericaria amentacea* was the widely distributed and abundant species and was the only species present in all protection zones, aligning with previous observation [23]. However, compared to previous research *E. amentacea* presented a significantly higher cover percentages in zone A (no-take/no-access), suggesting an improvement in its status and supporting the hypothesis that stricter protection measures can benefit *Cystoseira s.l.* populations, possibly by reducing direct human stressors and maintaining favorable environmental conditions [22]. The variable abundances of *Cystoseira s.l.* species across protection zones demonstrate the complex relationship between conservation measures and species-specific ecological needs. *Ericaria amentacea* thrived in the highly protected zone A, whereas *C. compressa*, *C. foeniculacea*, *E. brachycarpa*, and *E. crinita* were more abundant in the less strictly protected Zones B and C. The observed distribution patterns of *Cystoseira s.l.* species across protected zones are most likely the result of a complex interaction of factors such as species-specific environmental tolerances, anthropogenic stressors, and interspecific competition. The geomorphological properties of the seabed have an important influence in shaping coastal marine



ecosystems and, by extension, seaweeds distribution. In the intertidal zone, substrate composition, topographical features, and hydrodynamic conditions all have a significant influence on the formation and composition of macroalgal communities [24]. Substrate qualities have a direct impact on algal attachment and growth, with various species preferring specific substrate types [25,26].

Furthermore, hydrodynamic conditions influenced by wave exposure and water flow patterns promote the dispersion of reproductive propagules and nutrients, influencing the distribution and diversity of macroalgal assemblages [27]. While we did not specifically include geomorphological data in our analysis, we recognize its potential importance in understanding the observed differences in macroalgal distribution among protected zones. Future research incorporating extensive seabed geomorphology analysis will surely provide greater insights into the distribution patterns of *Cystoseira s.l.* populations, hence improving our understanding of these complex coastal ecosystems. The absence of some species (*C. foeniculacea*, *E. brachycarpa* and *E. crinita*) from zone A may be attributed to greater habitat variability (e.g., the presence of intertidal pools) and specific habitat requirements that are not met in the most strictly protected areas, rather than the level of protection.

The analysis of *E. amentacea*'s morpho-functional traits across protection zones reveals interesting patterns. Surprisingly, individuals in zone B exhibited the largest thalli, contrary to our expectation that the most protected area (zone A) would host the most well-developed specimens. This finding suggests that, while the higher cover percentage of *E. amentacea* in zone A may be facilitated by reducing human stressors such as trampling (especially during summer), which has been shown to have a negative impacts on its growth [28,29], the higher area covered by moderate levels of protection, combined with greater variation in geomorphological characteristics, may provide an optimal balance of environmental conditions for *E. amentacea* growth. The higher percentages of receptacles, epiphytes, and burnt tissue in zones B and C, compared to their absence in zone A, may indicate also in this case that greater variation in geomorphological characteristics of these less protected areas may experience greater environmental stress or disturbance. These factors could influence the reproductive strategies and overall health of *E. amentacea* populations. The presence of burnt tissue, in particular, may be an indicator of exposure to extreme temperatures or desiccation, which could be more pronounced in areas with higher human activity [18].

The detection of two non-native species, *Asparagopsis taxiformis* and *Caulerpa cylindracea*, exclusively in zones B and C may be concerning. However, their absence from zone A suggests that strict protection measures may help resist biological invasions, possibly by maintaining more intact and resilient native communities [30]. The higher abundance of *C. cylindracea* in zone C indicates that areas with lower protection levels may be more susceptible to invasion, potentially due to increased disturbance or altered competitive dynamics.

Our findings have important implications for the management of MPAs and the conservation of *Cystoseira s.l.* species. The effectiveness of strict protection (zone A) in supporting high cover of *E. amentacea* underscores the value of no-take/no-access areas in preserving key foundation species, especially for trampling related stressors. The variability in species responses to protection levels highlights the need for a diverse approach to MPA zoning to accommodate the requirements of different *Cystoseira s.l.* species, especially in terms of habitat suitability (e.g., intertidal pools). The presence of invasive species emphasizes the importance of monitoring and management strategies to prevent their spread.

This study provides a baseline for future monitoring of *Cystoseira s.l.* intertidal populations in the "Capo Gallo-Isola delle Femmine" MPA. Long-term studies are needed to track changes in species distribution, abundance, and traits over time, particularly in the context of global climate change. Additionally, investigating the specific mechanisms driving the observed patterns, such as water quality, herbivory pressure, or competitive interactions, would provide valuable insights for conservation strategies.

## 4. Material and Methods

### 4.1. Study Area

Sampling was performed on the intertidal rocky shore within the “Capo Gallo-Isola delle Femmine” MPA (Lat: 38.213961, Long: 13.277121) located in the northwestern coast of Sicily, Italy (Figure 1). The “Capo Gallo-Isola delle Femmine” MPA, established in 2002 by the Italian Ministry of Environment and Protection of Land and Sea, affects the sea stretch between the towns of Palermo and Isola delle Femmine. Covering approximately 22 km<sup>2</sup> of sea area and a coastline of about 16 km, it is bounded to the east by the gulf of Mondello and to the west by the bay of Carini. An imposing calcareous dolomitic mountain crest (Capo Gallo, 562 m a.s.l.) defines the coastal strip, resulting in a steep and rocky coastal morphology. Due to the limestone nature, flowing waters generate karst phenomena, leading to caves of high naturalistic value (Grotta dell’Olio and Grotta della Mazzara). Only towards the western part, the rocky coast assumes a flat conformation, enlivened by the presence, about 300 meters from the mainland, of the Isola delle Femmine (also known as Isola di Fuori), an isolated vestige of the aforementioned calcareous ridge.

The MPA is divided into three main zones (A, B and C), each with its own level of environmental protection (Figure 1). There are two no-take/no-access zones (zone A, total area of 1 km<sup>2</sup>, Figure 1), one in the north sector of Isola delle Femmine and the other in the stretch of sea at the west of Capo Gallo promontory, between the Puntazza and the Capo Gallo lighthouse. Zones B and C are buffer zones where human use restrictions, including fishing, become progressively lower. In particular, there are three general protection zones (zone B, total area of 2 km<sup>2</sup>, Figure 1), while the remaining sea within the MPA’s border includes a partial protection area (zone C, total area of 19 km<sup>2</sup>, Figure 1). The MPA area is also identified as Site of Community Importance (SCI, ITA020047 – Fondali di Isola delle Femmine Capo Gallo).

#### 4.2. Sampling

The MPA coastline was divided into sectors of 300 meters each, totaling 36 stations. Each station of 300 m was divided into 12 sectors of 25 meters where sampling was performed visually on 6 random replicates using a 20 x 20 cm quadrat, the minimum area recommended for sampling Mediterranean assemblages in the upper infralittoral zone [31]. In each quadrat the percentage coverage of *Cystoseira s.l.* species was estimated using the method proposed by Dethier et al. (1993), using a frame divided into 25 equal squares: we attributed a cover score from 0 to 4 to each square, and then summed up scores where the taxon was present. Organisms filling < 1/4 square were given the value of 0.5. For *E. amentacea* a series of morpho-functional characteristics (length of the cauloid, branch length, total length of the thallus, presence/absence and percentage of receptacles, and percentage of burned tissue) were also analysed. All surveys were carried out between May and June 2022, when the thalli of *Cystoseira s.l.* species in this area reach their maximum development [33].

#### 4.3. Data Analysis

Differences on *Cystoseira s.l.* species cover percentage among the MPA protection zones (fixed factor with 3 levels: zone A, zone B, and zone C) was tested using one-way Analysis of Variance (ANOVA). Assumptions of normality and homogeneity of variances were tested using Shapiro-Wilk and Levene’s tests, respectively. As regards the morpho-functional parameters of *E. amentacea*, a Draftsman Plot was first created to check for high correlations among the morpho-functional parameters. Total thallus length, cauloid length, and branch length were found to be highly correlated (cor. > 0.90), as were the presence and percentage of receptacles (cor. = 0.95) (Figure S1, Table S1). Consequently, the following parameters were selected for investigating variations among the MPA’s zones: total thallus length, percentage of receptacles, burnt tissue, and presence of epiphytes.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

**Author Contributions:** Conceptualization, F.P.M. and A.M.M.; methodology, F.P.M. and A.M.M.; data curation, F.P.M.; investigation, F.P.M. and A.M.M.; visualization, F.P.M.; laboratory analyses, F.P.M. and A.M.M.; writing—original draft, F.P.M., G.S. and A.M.M.; writing—review and editing, F.P.M., G.S. and A.M.M.;



supervision, G.S. and A.M.M.; funding acquisition, G.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Fondo europeo per gli affari marittimi e la pesca Misura: “1.40—Protezione e ripristino della biodiversità e degli ecosistemi marini e dei regimi di compensazione nell’ambito di attività di pesca sostenibili”, and by the European Union—NextGenerationEU; award number: Project code CN\_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, Project title: “National Biodiversity Future Center—NBFC”. the Ministero della transizione ecologica (MiTE) through the projects “Realizzazione di misure di conservazione del sito di interesse comunitario ITA 020047 “Fondali Isola delle Femmine-Capo Gallo”” and “Valutazione dello stato di conservazione della vegetazione algale nell’AMP di Capo Gallo-Isola delle Femmine and Ministero delle politiche agricole alimentari, forestali e del turismo (Mipaaf) FEAMP PO 2014– 2020

**Data Availability Statement:** We encourage all authors of articles published in MDPI journals to share their research data. In this section, please provide details regarding where data supporting reported results can be found, including links to publicly archived datasets analyzed or generated during the study. Where no new data were created, or where data is unavailable due to privacy or ethical restrictions, a statement is still required.

**Data Availability Statement:** Data are contained within the article and Supplementary Materials.

**Acknowledgments:** We thank Gabriella Lo Cicero for the assistance during the sampling.

**Conflicts of Interest:** The authors declare no conflict of interest.

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