

Article

# Multidisciplinary Analysis of *Cystoseira sensu lato* (SE Spain) Suggest a Complex Colonization of the Mediterranean

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**Abstract:** *Cystoseira sensu lato* (sl) are three genera widely recognized as bioindicators for their restricted habitat in a sub-coastal zone with low tolerance to pollution. Their ecological, morphological and taxonomic features are still little known due to their singular characteristics. We studied seven species of *Cystoseira sl* spp. in Cabo de las Huertas (Alicante, SE Spain) and analyzed their distribution using Permutational Analysis of Variance (PERMANOVA) and Principal Component Ordination plots (PCO). A morphological cladogram has been constructed using fifteen phenotypic taxonomic relevant characters. We have also developed an optimized *Cystoseira sl* DNA extraction protocol. We have tested it to obtain amplicons from mt23S, tRNA-Lys and psbA genes. With these sequence data, we have built a phylogenetic supertree avoiding threatened *Cystoseira sl* species. Cartography and distribution analysis show that the response to hydrodynamism predicts perennial or seasonal behaviors. Morphological cladogram detects inter-specific variability between our species and reference studies. Our DNA phylogenetic tree supports actual classification, including for the first-time *Treptacantha sauvageauana* and *Treptacantha algeriensis* species. These data support a complex distribution and speciation of *Cystoseira sl* spp. in the Mediterranean, perhaps involving Atlantic clades. The high ecological value of our area of study merits a future protection status as a Special Conservation Area.

**Keywords:** *Cystoseira*; algal cartography; abrasion platforms; SE Mediterranean; phylogeny supertree; DNA sequencing

## 1. Introduction

The family *Sargassaceae* Kützing (*Phaeophyceae*) inhabits all oceans, from polar waters to the warmest tropical seas [1]. The *Cystoseira sensu lato* (sl) species have their maximum diversity in the Mediterranean Sea, with two thirds of all species described found there [2–4]. Some of them have habitats as reduced as coastal platforms [5]. Outside the Mediterranean Sea, they are mainly found in the Northeast Atlantic. This may explain why they were reintroduced six million years ago into the Mediterranean Sea. During the Zanclean deluge, after the Messinian desiccation crisis, they may have been dragged by the currents [2,6,7], starting a new colonization process. Recent research corroborates the polyphyletic nature of these algae, distinguishing three genera [8–10]. They comprise *Cystoseira sensu stricto*, *Carpodesmia* and *Treptacantha*.

As an engineering species they form dense meadows on rocky substrates up to 100 m deep [2,5,11,12]. They are widely recognized as bioindicators for their restricted habitat in the

sub-coastal zone and low tolerance to pollution [13,14]. Most Mediterranean species are protected by the Barcelona (Annex II, COM/2009/585) and Bern Conventions (Annex I) and the INDEMARES project [15], a contributor to the expansion of the Natura 2000 Network. They are also used to assess the ecological quality of the coast (CARLIT), a requirement under the Water Framework Directive (2000/60/EU) for the conservation of good water status [13].

*Cystoseira* spp. have a high morphological plasticity which, with recurrent hybridization processes [2,16], makes taxonomic assignment of some species rather difficult [10,17,18]. *Cystoseira sl* communities are currently declining due to anthropogenic pressures [10,19–22]. Reforestation projects have been developed [20,22,23]. Even their economic value has been quantified to promote their preservation [24]. However, there is little public knowledge on the value of these ecosystems outside the phylogenetic community.

SE Spain has a great diversity of *Cystoseira sl* populations due to the presence of rocky platforms from the Quaternary Period, which generate adequate niches for their development [25,26]. However, there is little research on the distribution patterns of *Cystoseira sl* in these areas, since most studies of Spanish Mediterranean populations have been carried out on the coasts of Catalonia and the Balearic Islands [27–33]. Without light limitations, the main factor modifying the abundance of coastal communities is nutrient availability, which depends largely on hydrodynamism [13,34]. Geomorphological characteristics of the substrate (lithology, slope, depth) may account for the environmental heterogeneity of the system, a key factor in algal distribution [35]. Inclination of the substrate can affect vertical zonation [36]. Previous studies indicate that the type of substrate and depth can also affect the distribution of *Cystoseira sl*. Decimetric blocks and pebbles displaced by storms can affect these communities and lead to their replacement by other species [37]. These authors also reported variation in patterns of distribution with the degree of exposure to waves. On the other hand, intraspecific variability and environmental conditions to which they are exposed may cause variations in the concentration of polyphenols, polysaccharides and pigments among other primary and secondary metabolites. These compounds can affect DNA extraction protocols [38]. Sequencing of various genes (e.g., mt23S, tRNA-Lys, psbA, COI) has clarified the phylogenetic relationships of these genera [2,9,10,39,40].

Our hypothesis stands that the width and the location of the platform of *Cystoseira sl* communities, and the degree of wave exposure, will affect their distribution. These factors are directly related to hydrodynamics, and therefore to nutrient availability. There will be a differentiation in horizons depending on the width of the platform and the degree of exposure to waves to which it is subjected. The aim of this study is to increase our knowledge of *Cystoseira sl* in SE Spain using ecological, morphological and molecular tools. We have chosen El Cabo de las Huertas, a well preserved natural coast amidst largely touristic developed shores. This area has been a Site of Community Importance since 2001 (ESZZ16008) because of the presence of a sandy seabed with well-preserved seagrasses (*Posidonia oceanica*, *Zostera marina* and *Cymodocea nodosa*), which despite the extensive touristic development indicates a good water status. This makes this site interesting to reevaluate its degree of protection [41]. Unfortunately, a management plan for this area does not exist nor has it progressed its declaration as a Specially Protected Area [42]. In conclusion, our work could be a sound foundation to develop an ambitious *Cystoseira sl* protection plan in South-East (SE) Spain.

## 2. Materials and Methods

### 2.1. Cartography of *Cystoseira Sensu Lato*

Our sampling method consisted of a walk along 14 km of the Alicante city coast (38°21'26.48" N, 0°24'31.37" W–38°19'29.64" N, 0°30'40.41" W). We divide the coastal strip into 3 horizons parallel to the coastline: the proximal is next to the midlittoral zone, the distal horizon is hit by waves and it is sometimes emerged; the medium horizon is between these two. *Cystoseira sl* species have been identified in situ and their semi-quantitative abundance scored visually, as in Ballesteros et al. (2007).

The lowest value (1) corresponds to isolated individuals. Several individuals forming no patches score 2. For isolated patches, the abundance value is 3. For patches forming a discontinuous horizon, the value is 4. A continuous horizon of the same species of *Cystoseira sl* scores 5. Sixty-one linear transects (30–80m) were performed along the coastline of study (2018, May–July), recording the abundance of *Cystoseira sl* communities per horizon.

Trails were georeferenced using GPSies<sup>+</sup> (Klaus Bechtold, ©2017) and distribution maps drawn using QGIS v 2.18 with the WGS84 (EPSG:4326) coordinate system. An orthophoto of the region provided by the National Plan for Aerial Orthophotography (PNOA) of the National Geographic Institute [43] was used as model to draw a map according to the real geography.

## 2.2. Abiotic Factors and Spatial Variability of *Cystoseira Spp.*

Platform width, wave exposure and the sublittoral horizons were recorded as the main hydrodynamism variables (Table S1). Geomorphological characteristics of the substrate (lithology, slope, presence of pools or rifts) were also scored. Records have been analysed with Primer software (v.6.1) [44]. A three fixed factor PERMANOVA analysis has also been carried out with the Bray Curtis similarity matrix to study the influence of the main variables related to hydrodynamism on the abundance of *Cystoseira sl* species. A reduced model with 4999 permutations has been chosen. The distribution patterns of the samples have been analysed with a Principal Component Ordination Analysis (PCO), built with the same Bray–Curtis matrix.

## 2.3. Morphological Characterization

Specimens were collected in spring (2018) using chisel and hammer, avoiding damaging the basal structure and kept in 10% alcohol in seawater until analysis. A qualitative matrix using Primer 7 software [45] with 15 phenotypic characters of 37 *Cystoseira sl* was constructed (Table S2). Morphological data from samples described in Gómez-Garreta et al. (2000) [45], Cormaci et al. (2012) [46] and Orellana et al. (2019) [9] were recorded as reference algal groups. A cladogram was constructed using a dissimilarity Bray–Curtis matrix with the ‘simple matching’ method and a SIMPROF test carried out to distinguish statistical differences between individuals, adding a ‘dummy variable’ to improve the robustness of the cladogram.

## 2.4. DNA Extraction

Individuals collected were kept in cold seawater. They were cleaned of epiphytes and lyophilized in less than 24 h. Fine lyophilized thallus ground in liquid nitrogen was used for DNA extraction. DNA extractions were performed using a protocol based on the pre-treatment of Lane et al. (2006) [47] in combination with the cleaning steps of Rogers and Bendich (1989) [48]. All treatments were performed on ice to avoid DNA degradation. Lyophilized thallus is added to Buffer A (1.65 M sorbitol, 50 mM MES (sulphonic acid) pH 6.1, 10 mM EDTA, 2% (w/v) PVP-40, 0.1% (w/v) BSA (Bovine Serum Albumin) and 5 mM β-mercaptoethanol) while stirring for 2–3 min. The mixture is filtered with Miracloth<sup>®</sup> and centrifuged at 3000× g for 2 min. Buffer A is removed, the pellet is resuspended in Buffer B (Buffer A without PVP) and centrifuged at 3000× g for 2 min. Buffer B is discarded, and the pellet is resuspended in DNA extraction buffer [48]. Samples were incubated on ice for 1 h then centrifuged at 15,000× g for 10 min. Aqueous phase is transferred into new tubes for phenol, chloroform and isoamyl alcohol extraction for 5 min and then centrifugation. This step was performed again without phenol for 2 min. DNA is treated with –20 °C isopropyl alcohol on ice for 20 min. After centrifugation for 10 min, the supernatant is discarded and the pellet washed with ethanol at –20 °C. Pellets containing DNA are resuspended in nuclease free water and stored at –80 °C.

## 2.5. Gene Amplification, Sequencing and Phylogenetic Analysis

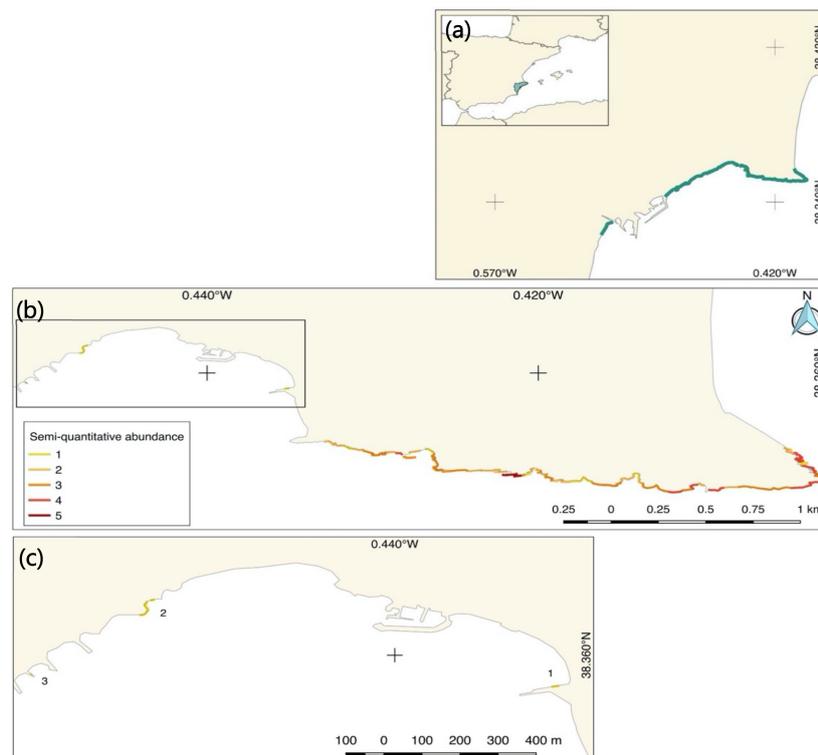
Six sets of primers from previous work were used (Table S3). Some of them (psbA-FR2 and psbA-F2R) can be used in three different combinations [2]. PCR reactions included a preheating stage

of 2 min at 92 °C, nine cycles of 30 s at 94 °C, 1 min at 45 °C with a final extension of 1 min at 72 °C plus 29 cycles of 30 s at 94 °C, 30 s at 50 °C with a final extension of 1 min at 72 °C. With the psbA-FR primer, final extensions were increased from 1 to 2 min. PCR reactions were repeated when required to supply enough DNA for Sanger sequencing. Amplicons were run in 2% agarose gels for quality testing, then treated with a DNA purification kit (Qiagen). Sequencing was carried out by Macrogen Inc. (Korea). Consensus sequences were determined using Bioinformatics ‘Reverse complement’ [49] and Omega Cluster tools [50]. A sequence database has been set up based on previous studies [2,9]. Phylogeny analyses were performed using Mega X software [51], through a Muscle type alignment [52]. Both supertree and isolate trees for individual genes (mt23S, tRNA-Lys and psbA) have been built using the ‘Neighbor-Joining’ method [53,54] and phylogenetic test ‘Bootstrap’ with 1500 interactions [55]. All taxa used in the phylogenetic analyses are listed in Supplementary Table S4. Sequences were obtained from Draisma et al. (2010) [2], Orellana et al. (2019) [9] and Bruno de Sousa et al. (2019) [10], among others.

### 3. Results

#### 3.1. Cartography of Communities Associated with the Coastal Fringe

*Cystoseira sl* species were found over more than 4 km of the 14 km sampled (Figure 1a,b), in nearly uninterrupted communities at Cabo de las Huertas (Cape area) and separate individuals or patches on La Almadraba beach, Paseo Marítimo and La Playita bay (Figure 1c). *Cystoseira compressa*, *C. humilis*, *C. foeniculacea*, *Carpodesmia amentacea* var. *stricta*, *C. brachycarpa* var. *balearica*, *Treptacantha algeriensis* and *T. sauvageauana* were the species found in the area of study.



**Figure 1.** (a) Area of study: El Cabo de las Huertas (Alicante, Valencian Community, Spain). (b) Semi-quantitative abundance found of *Cystoseira sensu lato* in El Cabo de las Huertas. Legend: 1: One individual (isolated algae). 2: Several isolated individuals. 3: *Cystoseira sensu lato* patches. 4: Discontinuous belts of at least one species. 5: Continuous belts of one or more species. (c) Individuals or isolated patches found near El Cabo de las Huertas. 1: La Almadraba beach. 2: Paseo Marítimo. 3: La Calita beach.

### 3.2. Distribution of *Cystoseira Sensu Lato*

*Cystoseira sl* communities are frequent in the area of study, in rocky shores with high hydrodynamism (Figure 2a). They usually disappear abruptly when the rock substrate changes from platform to boulders (Figure 2b).



**Figure 2.** (a) Exposed platform of El Cabo de las Huertas with *C. amentacea* var. *stricta* and *T. algeriensis* community. (b) Boulders without presence of *Cystoseira sl* in front of the exposed platform.

*Cystoseira sl* communities on narrow platforms and medium wave exposure are different from those under low or high wave exposure ( Tables 1 and 2 and S5). In wide platforms, the degree of wave exposure conditions *Cystoseira sl* communities. For instance, *Treptacantha sauveageauana* likes low wave exposure because it is the third most abundant species under these conditions. On the contrary, other species such as *Carpodesmia amentacea* var. *stricta*, *Treptacantha algeriensis* or *Cystoseira compressa* prefer large wave exposure. The abundance of *Cystoseira sl* species depends on their location at the platform, since populations from proximal and distal horizons also differ significantly.

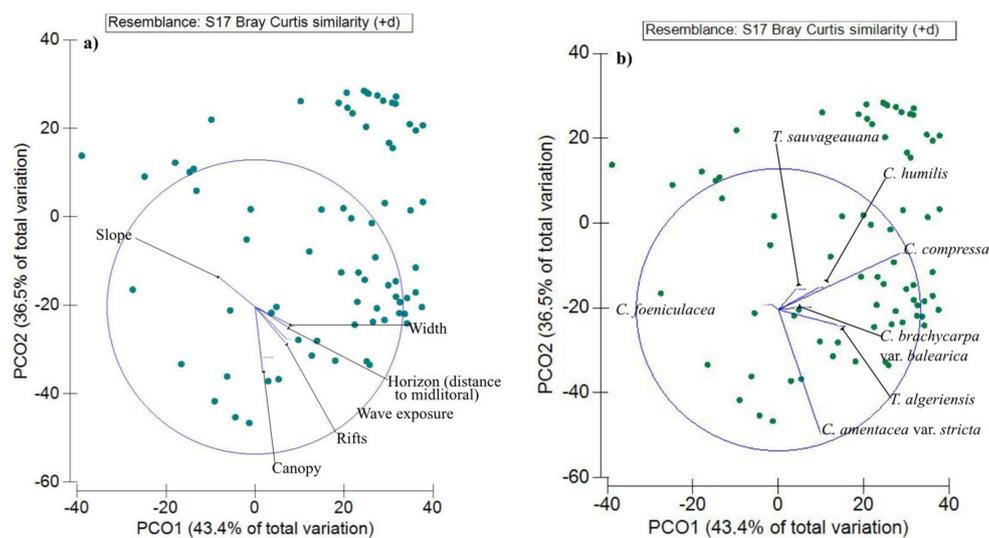
**Table 1.** PERMANOVA analysis of variables related with hydrodynamism (*p*-value < 0.05).

Source	df	SS	MS	Pseudo-F	P (perm)	Uniq. Perms
Width	3	15,532	5177.3	3679	0.0002	4986
Wave exposure	2	14,298	7148.9	5.08	0.0002	4983
Horizon	2	10,849	5424.7	3.8548	0.0016	4985
Width*WaveExp	5	20,474	4094.9	2.9098	0.0002	4972
Width*Horizon	6	5638.4	939.73	0.66778	0.8234	4974
Horizon*WaveExp	4	6531.8	1632.9	1.1604	0.3108	4982
Width*WaveExp*Horiz	10	6083.7	608.37	0.43231	0.9948	4982
Res	150	2.1109 × 10 <sup>5</sup>	1407.3			

**Table 2.** A posteriori PERMANOVA analysis of significant interactions of variables related with hydrodynamism ( $p$ -value < 0.05).

Width*Wave Exposure			
Wave Exposure	$t$	$P(perm)$	$perms$
Width = 0 (No platform)			
Med-Low	1.9482	0.0438	2246
Width = Narrow			
Med-Low	1.8362	0.0408	4981
Med-High	2.5084	0.0008	4990
Low-High	1.0787	0.3138	4983
Width = Medium			
Med-Low	1.2407	0.2272	4994
Med-High	1.7067	0.0532	4989
Low-High	1.0416	0.3604	4992
Width = Wide			
Med-Low	2.1585	0.0034	4985
Med-High	2.1066	0.0052	4993
Low-High	2.7538	0.0002	4992
Horizon			
Horizon	$t$	$P(perm)$	$perms$
Prox-Med	1.4607	0.0978	4985
Prox-Distal	2783	0.0004	4986
Med-Distal	1314	0.1656	4987

A PCO of *Cystoseira sl* abundance with environmental factors was analysed using 183 samples from 61 transects recorded (Figure 3). Axes explain 79.9% of the total variability and vectors with high correlation are represented ( $cor > 0.2$ ). Main hydrodynamism variables vectors are located to the lower right quadrant indicating the direction of higher values of hydrodynamism. Two geomorphologic variables have close correlation with hydrodynamism, ‘Inclination’ negatively and ‘Rifts’ positively. Canopy height is also directly linked. The lowest heights of *Cystoseira sl* have been located in La Calita, which is a cove with high anthropogenic impact (Figure S1). Thus, *Cystoseira sl* general abundance cannot be explained by a single environmental factor.



**Figure 3.** (a) Ordination Principal Component Ordination (PCO) plot of *Cystoseira sl* communities in SE Spain related to environmental variables. (b) Ordination PCO plot of *Cystoseira sl* communities in SE Spain with *Cystoseira sl* species ( $n = 183$ ).

When *Cystoseira* *sl* individual species are considered, different patterns of distribution appear (Figure 4). For instance, *C. compressa* has a wide distribution, since this species is the most environmentally tolerant of all found. With the largest ecological range, it is the most abundant and is nearly homogeneously distributed in all horizons of El Cabo de las Huertas (Figure 4a). *C. amentacea* var. *stricta* and *T. algeriensis* are distributed positively with vectors, therefore to hydrodynamism. They have a slightly smaller ecological range, with irregular distribution (Figure 4b,c). Meanwhile, *C. humilis*, *T. saugeauana* and *C. foeniculacea* have less correlation with hydrodynamism, with reduced distribution usually located at proximal horizon (low wave exposure) (Figure 4d–f). The proximal horizon has a discontinuous presence of *C. compressa*, *C. amentacea* var. *stricta*, *T. algeriensis*, *T. saugeauana* and *C. humilis* while more exposed horizons have a continuous community of these species (Figure S2).

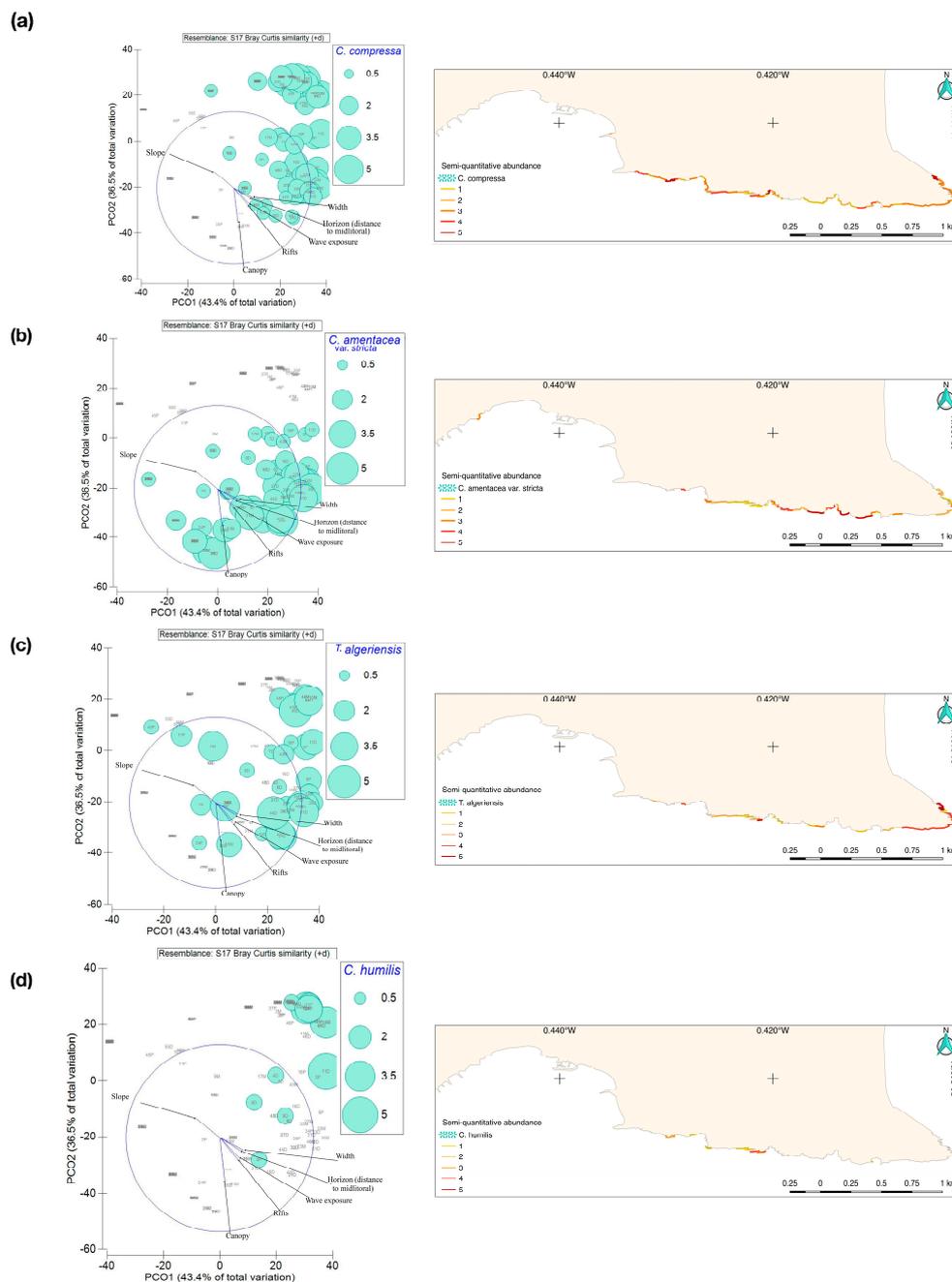
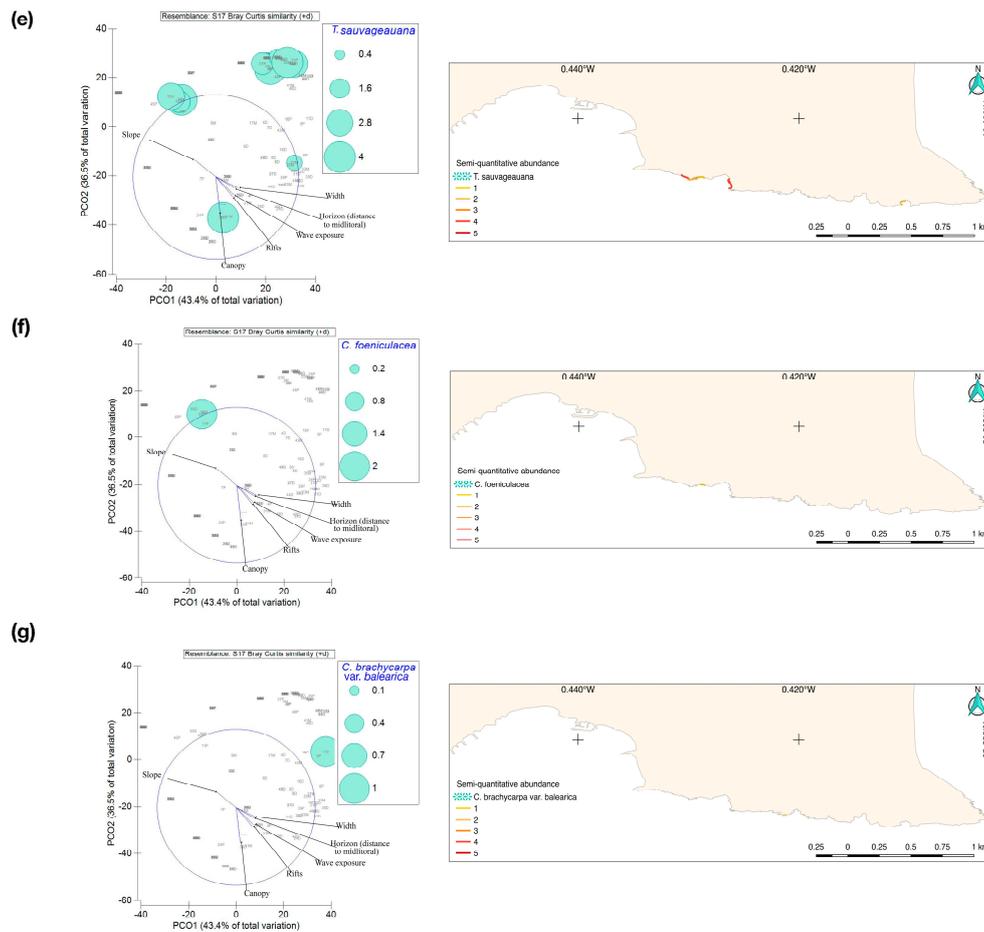


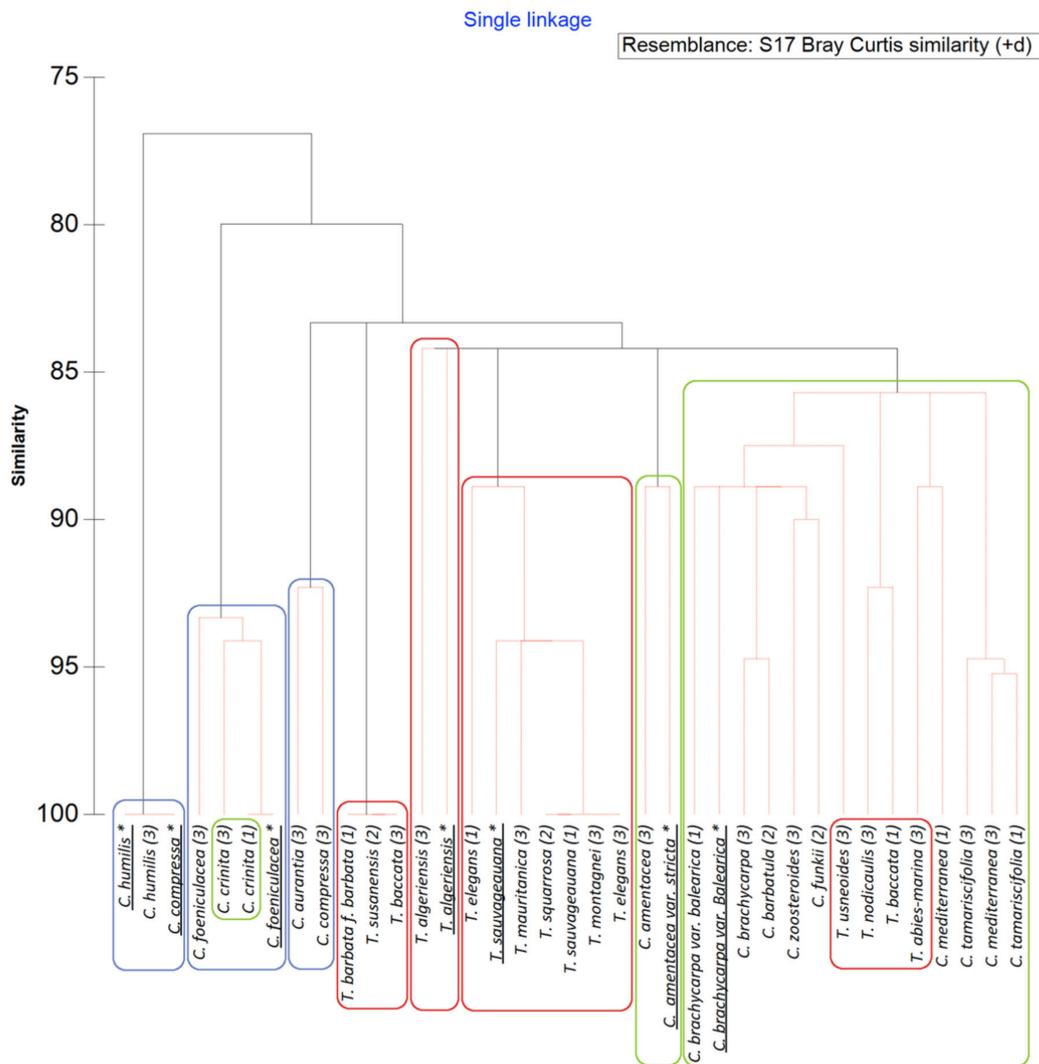
Figure 4. Cont.



**Figure 4.** Bubble plots overlaying PCO plot of *Cystoseira sl* in El Cabo de las Huertas and cartography. The size of the bubbles indicate the abundance of *Cystoseira sl* in each sample. (a) *C. compressa*. (b) *C. amentacea* var. *stricta*. (c) *T. algeriensis*. (d) *C. humilis*. (e) *T. sauvageauana*. (f) *C. foeniculacea*. (g) *C. brachycarpa* var. *balearica*.

### 3.3. Morphological Analysis

Our morphological cladogram includes eight clades (*Cystoseira* I–VIII) (Figure 5). *Cystoseira* VIII is the clade with the least similarity, followed by *Cystoseira* VII. From *Cystoseira* VI to I, branches can be differentiated with increasing similarity values. Similarities of more than 85% prevent species assignments. Most of our samples lay close to their counterparts included in previous reference studies [9,45,46]. However, several species (*T. sauvageauana*, *C. foeniculacea*, *C. compressa*) display more variability within a given clade or are located in different clades.



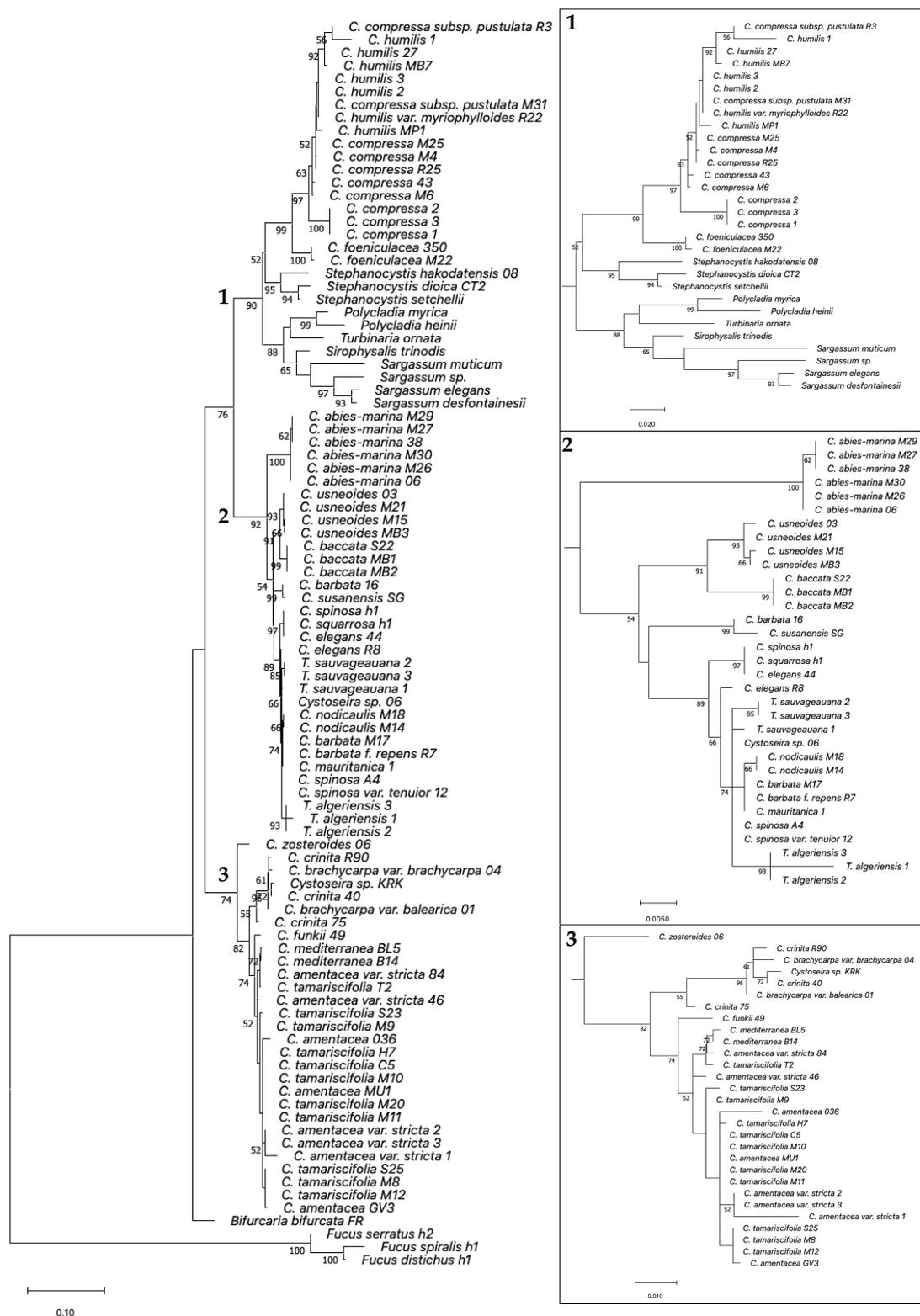
**Figure 5.** Single linkage cladogram based on data from *Cystoseira sl* built using the Bray–Curtis similarity matrix. Boxes correspond to current genus classification by Orellana et al., 2019 [9]: Blue = *Cystoseira sensu stricto* or Cystoseira-I; Red = *Treptacantha* or Cystoseira-II. Green = *Carpodesmia* or Cystoseira-III. Label legend: (1): Gómez-Garreta et al., 2010 [45]. (2): Cormaci et al., 2012 [46]. (3): Orellana et al., 2019 [9]. (\*) Underlined: This study.

### 3.4. Phylogenetic Analysis

Our DNA protocol completely removed *Cystoseira sl* secondary metabolites and allowed template amplification with all primers used (Figures S3–S6). In this study, 30 *Cystoseira sl* DNA samples have been sequenced, corresponding to 3 genes. We have built a concatenated tree (supertree) with a total of 98 *Fuaceae* sequences from 41 species; 22 of these are *Cystoseira sl* species (Figure 6). The supertree is more robust (higher node stats values) than those trees built using single gene sequences (Figures S7–S9).

Three clades (I–III) have been obtained. Cystoseira-I comprises *C. foeniculacea*, in a separate subclade, *C. compressa* and *C. humilis* together in a further subclade. Cystoseira-II includes four differentiated branches with *Treptacantha* spp. species (*T. abies-marina*, *T. baccata*, *T. usneoides*, *T. susanensis* and *T. barbata*). The latter two species clustered in a separate subclade. Cystoseira-II includes sequences of *T. sauvageauana* and *T. algeriensis* for the first time. Both sequences appear separated from the rest. Cystoseira-III includes *C. amentacea*, *C. brachycarpa*, *C. crinita*, *C. funkii*, *C. mediterranea*, *C. tamariscifolia*, and *C. zosteroides*, this last species as an outlier. Within clade III, *C. crinita* and *C. brachycarpa* can

be clearly differentiated from the rest. Cystoseira-I and Cystoseira-II appear closer phylogenetically, unlike Cystoseira-III.



**Figure 6.** Maximum likelihood phylogenetic subtree obtained with Nearest Neighbor Interaction on concatenated mt23S-psbA-tRNA-Lys sequences of samples from the *Sargassaceae* family. Values of branches represent maximum likelihood bootstrap support values (>50%). Samples sequenced in this study labelled as 1, 2 or 3. Labels: 1. Cystoseira-I. 2. Cystoseira-II. 3. Cystoseira-III.

#### 4. Discussion

Hydrodynamism plays a key role in the *Cystoseira sl* population distribution from the SE Spanish coast. This has also been found in previous works [13,31,34,56]. In our study, *Cystoseira sl*, in general terms, is most abundant and widely distributed in zones with large exposure to waves. For instance, *C. amentacea* var. *stricta*, *T. algeriensis* and *C. compressa*, with large productive potential, require light saturation [57] and high hydrodynamism [13,27,31,37,58,59]. Consequently, they are frequently found in rifts and other exposed places. There are seasonal species which have their optimal development during spring [13]. The widespread distribution of *C. compressa* may reflect its high ecological tolerance, even to anthropogenic impact. This is perhaps the reason why it is the only *Cystoseira sl* species found in urban areas such as La Almadraba beach [13,19,60]. Other species (e.g., *T. sauvageauana*, *C. foeniculacea*) are distributed preferentially in more sheltered environments [61,62] where hydrodynamism is less relevant. They have a perennial behavior, maintaining their thalluses all year [30,63]. Although *C. brachycarpa* inhabits sheltered environments [45,64], in our study it was found in an abrasion platform. The orientation on the coast, facing south, receives less impact from the dominant eastern waves [65] allowing *C. brachycarpa* to survive under these conditions. A coastline slope does not favor the presence of *Cystoseira sl* populations, as found in the Tyrrhenian islands [66]. Slope degree has a close inverse relationship with those populations, since above 60° can highly reduce the probability of settlement of these communities. Human trampling is to be considered because it takes place on coastal platforms during the summer season. Those coves with a high tourist influx have lower values of abundance and canopy of *Cystoseira sl*, indicating that they are very sensitive to this anthropogenic disturbance. Even low intensities of trampling can highly affect the spatial distribution of algal communities [60,67], causing the simplification of the platform communities [12]. Therefore, future efforts could be applied studying this relation in order to apply management plans for *Cystoseira sl* protection.

Recent studies show that natural hybridization is operating in seaweed forests of *Cystoseira sl* [2,8,16]. The high variability of *T. sauvageauana*, *C. foeniculacea*, *C. compressa* in our morphological cladogram would agree with this. Each *Cystoseira sl* gender has morphological characters with various phenotypes [9], usually one of them more common than the rest. So, perhaps species that exhibit uncommon morphotypes could not be classified appropriately in the cladogram. Numerical taxonomy techniques are useful to tackle this intraspecific variability. For instance, the lack of spines in secondary and higher order branches of *C. crinita* would lead the transfer of this species from *Cystoseira*-III into *Cystoseira*-I, in which all species are characterized by the absence of this type of appendages. The latest studies indicate that there are many exceptions to this character, reinforcing the need to combine morphological with phylogenetical studies [9]. Like any other method of morphological identification, it needs to rely on molecular taxonomy to clarify the classification. Therefore, morphological data has been completed with phylogenetic studies [2,10].

Our molecular supertree of sequences of psbA, mt23S and tRNA-Lys spacer gene from *Cystoseira sl* from SE of Spain mostly agrees with previous studies [2,9,10]. In agreement with Orellana et al. [9], our clades *Cystoseira*-II (*Treptacantha*) and *Cystoseira*-I (*Cystoseira sensu stricto*) are closer phylogenetically and with other genera such as *Polycladia*, *Stephanocystys*, *Sargassum* and *Sirophysalis*, and far from *Cystoseira*-III (*Carpodesmia*). This supports the lack of a common ancestor of these genera [2,9,10]. *Cystoseira*-III (*Carpodesmia*) is the most chemically complex genus [68,69] and most members are Mediterranean [2,70], suggesting that the seasonality of this sea [71] may be driving a pressure on these algae enhancing the production of their metabolites to deal with stressors such as UV and temperature [56]. Neither Bruno de Sousa et al. [9] nor this study have succeeded in the resolution on *C. tamariscifolia*/*C. amentacea* clade. Therefore, future studies should be aimed to resolve these phylogenetic relationships. We have generated for the first-time sequence data from *T. algeriensis* and *T. sauvageauana* which support that both species are well differentiated and separated from the rest. This would also agree with their different morphology and ecological preferences [45,46]. The challenge of understanding their taxonomy may reside in the recent and

continuous speciation of these genera in Mediterranean Sea [2,61,72], their adaptative convergence or possible genetic constraints [10]. There is an urgent need to keep investigating to understand their evolution and ecology in order to enhance their protection and maintain conservation efforts that help to preserve marine ecosystems for future generations.

This study provides the first bionomic cartography and evaluation of conservation of *Cystoseira sl* populations in SE Spain. Out of the 14 *Cystoseira sl* species cited in this area [73], half have been found in this study in a coastal fringe of just 4 km. In view of the diversity and abundance found, this region displays a relevant ecological quality [74]. The relative continuous algal canopy would also imply a good water status, as reported [75]. Therefore, because of its environmental characteristics and high algal diversity in the shores, this place should be a Special Conservation Area (SCA), integrated in the Natura 2000 Network (EU Directive 92/43/EEC). The inclusion of *Cystoseira*, *Treptacantha* and *Carpodesmia* genera in El Cabo de las Huertas Community Importance Site would also be a great achievement for the conservation of marine natural habitats of the Spanish Levant coast. The site may be useful for future extraction of specimens for transplants to former habitats which have undergone local extinctions [23]. There is also a pressing need to develop a management plan in view of the increasing disappearance of the prairies of eastern Mediterranean *Fucales* [19–22]. Long-term monitoring of these biocenosis would be desirable, which could be carried out using the CARLIT methodology, that employs *Cystoseira sl* populations as a key species establishing the health of the water body [13]. *Cystoseira sl* evolution data would generate time series to know the state of these communities, thus evaluating the health of our coast. This type of study is already being carried out in different areas of the Mediterranean Sea [20,31,59,76].

## 5. Conclusions

The bionomic cartography of *Cystoseira sl* assesses the good ecological quality and good water body status of El Cabo de las Huertas. Distribution analysis shows two levels of relation to hydrodynamism which predicts perennial or seasonal behaviors. Morphological cladogram detects inter-specific variability between our species and previous reference studies of these genera. Our phylogenetic tree supports actual classification. Previously unpublished sequences of psbA, mt23S and tRNA-Lys of *T. algeriensis* and *T. sauvageauana* confirm those are included in Bruno de Sousa's *Cystoseira* II group (2019), in agreement with morphological studies.

**Supplementary Materials:** The following are available online at: <http://www.mdpi.com/2077-1312/8/12/961/s1>. Table S1: Geomorphological characteristics of the substrate and its levels selected to PERMANOVA (\*) and Principal Component Analysis (PCO) analyses. Table S2: List of qualitative phenotypical characters used for the building of Bray–Curtis dissimilarity matrix. Table S3: List of primers used for phylogenetic analysis. Table S4: GenBank accession numbers used in this study. Table S5: Abundance of *Cystoseira sl* dominant species attending on Wave exposure, Width of the platform and Horizons of the platform. Percentage of contribution of each species to the dissimilarity. Figure S1: Canopy height of *Cystoseira sl* recorded in the area of study. Figure S2: Semiquantitative abundance of *Cystoseira sl* by horizons in the area of study. (a) Proximal horizon. (b) Medium horizon. (c) Distal horizon. Legend: 1: One isolated algae. 2: Several isolated individuals. 3: *Cystoseira sl* patches. 4: Discontinuous belts of at least one specie. 5: Continuous belts of one or more species. Figure S3: Quality electrophoresis DNA gel on 2% agarose. Legend: CA: *T. algeriensis*. CC: *C. compressa*. CH: *C. humilis*. CS: *T. sauvageauana*. CST: *C. amentacea* var. *stricta*. C-: Negative control. Figure S4: (a) Quality electrophoresis DNA gel of mt23S primer. (b) Quality electrophoresis DNA gel of mt23SB primer. Legend: CA: *T. algeriensis*. CC: *C. compressa*. CH: *C. humilis*. CS: *T. sauvageauana*. CST: *C. amentacea* var. *stricta*. Figure S5: Quality electrophoresis DNA gel of tRNA-LysB primer. Legend: CA: *T. algeriensis*. CC: *C. compressa*. CH: *C. humilis*. CS: *T. sauvageauana*. CST: *C. amentacea* var. *stricta*. Figure S6: (a) Quality electrophoresis DNA gel of psbA-FR primer. (b) Quality electrophoresis DNA gel of psbA-FR2 primer. (c) Quality electrophoresis DNA gel of psbA-F2R primer. Legend: CA: *T. algeriensis*. CC: *C. compressa*. CH: *C. humilis*. CS: *T. sauvageauana*. CST: *C. amentacea* var. *stricta*. Figure S7: Maximum likelihood phylogenetic tree obtained with Nearest Neighbour Interaction on mt23S sequences of samples from *Sargassaceae* family. Values of branches represent maximum likelihood bootstrap support values (>50%). *Cystoseira sl* samples sequenced in this study labelled with 1 or 2. Figure S8: Maximum likelihood phylogenetic tree obtained with Nearest Neighbour Interaction on tRNA-Lys spacer sequences of samples from *Sargassaceae* family. Values of branches represent maximum likelihood bootstrap support values (>50%). Samples sequenced in this study labelled with 1. Figure S9: Maximum likelihood phylogenetic tree obtained with Nearest Neighbour Interaction on psbA sequences of samples from *Sargassaceae* family. Values of branches represent maximum likelihood bootstrap support values (>50%). Samples sequenced in this study labelled with 1, 2 or 3.

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## References

1. Cánovas, F.; Mota, C.; Serrão, E.; Pearson, G. Driving south: A multi-gene phylogeny of the brown algal family *Fucaceae* reveals relationships and recent drivers of a marine radiation. *Evol. Biol.* **2011**, *11*, 371. [[CrossRef](#)] [[PubMed](#)]
2. Draisma, S.; Ballesteros, E.; Florence, R.; Thibaut, T. DNA Sequence Data Demonstrate the Polyphily of the Genus *Cystoseira* and Other *Sargassaceae* Genera (*Phaeophyceae*). *J. Phycol.* **2010**, *46*, 1329–1345. [[CrossRef](#)]
3. García-Fernández, A.; Bárbara, I. Studies of *Cystoseira* assemblages in Northern Atlantic Iberia. *An. Jard. Bot. Madr.* **2016**, *73*, e0352016. [[CrossRef](#)]
4. Guiry, M.D.; Guiry, G.M.; World-Wide Electronic Publication, National University of Ireland, Galway. AlgaeBase. Available online: <https://www.algaebase.org> (accessed on 6 June 2020).
5. Thibaut, T.; Blanfuné, A.; Markovic, L.; Verlaque, M.; Boudouresque, C.F.; Perret-Boudouresque, M.; Macic, V.; Bottin, L. Unexpected abundance and long-term relative stability of the brown alga *Cystoseira amentacea*, hitherto regarded as a threatened species, in the north-western Mediterranean Sea. *Mar. Pollut. Bull.* **2014**, *89*, 305–323. [[CrossRef](#)]
6. Hsü, K.J. *The Mediterranean Was a Desert: A Voyage of the Glomar Challenger*; Princeton University Press: Princeton, NJ, USA, 1982; p. 197. ISBN -10.
7. Boudouresque, C. Marine biodiversity in the mediterranean status of species populations and communities. *Sci. Rep. Port Cros Nat. Park* **2004**, *20*, 97–146.
8. Bermejo, R.; Chefaoui, R.M.; Engelen, A.H.; Buonomo, R.; Neiva, J.; Ferreira-Costa, J.; Pearson, G.A.; Marbà, N.; Duarte, C.M.; Airoidi, L.; et al. Marine forests of the Mediterranean-Atlantic *Cystoseira tamariscifolia* complex show a southern Iberian genetic hotspot and no reproductive isolation in parapatry. *Sci. Rep.* **2018**, *8*, 10427. [[CrossRef](#)]
9. Orellana, S.; Hernández, M.; Sansón, M. Diversity of *Cystoseira sensu lato* (Fucales, *Phaeophyceae*) in the eastern Atlantic and Mediterranean based on morphological and DNA evidence, including *Carpodesmia* gen. emend. and *Treptacantha* gen. emend. *Eur. J. Phycol.* **2019**, *54*, 447–465. [[CrossRef](#)]
10. Bruno de Sousa, C.; Cox, C.J.; Brito, L.; Pavão, M.M.; Pereira, H.; Ferreira, A.; Ginja, C.; Campino, L.; Bermejo, R.; Parente, M.; et al. Improved Phylogeny of Brown Algae *Cystoseira* (Fucales) from the Atlantic-Mediterranean Region Based on Mitochondrial Sequences. *PLoS ONE* **2019**, *14*, e0210143. [[CrossRef](#)]
11. Cheminée, A.; Sala, E.; Pastor, J.; Bodilis, P.; Thiriet, P.; Mangialajo, L.; Cottalorda, J.M.; Francour, P. Nursery value of *Cystoseira* forests for Mediterranean rocky reef fishes. *J. Exp. Mar. Biol. Ecol.* **2013**, *442*, 70–79. [[CrossRef](#)]
12. Bulleri, F.; Benedetti-Cecchi, L.; Acunto, S.; Cinelli, F.; Hawkins, S.J. The influence of canopy algae on vertical patterns of distribution of low-shore assemblages on rocky coasts in the northwest Mediterranean. *J. Exp. Mar. Biol. Ecol.* **2002**, *267*, 89–106. [[CrossRef](#)]
13. Ballesteros, E.; Torras, X.; Pinedo, S.; García, M.; Mangialajo, L.; De Torres, M. A new methodology based on littoral community cartography dominated by macroalgae for the implementation of the European Water Framework Directive. *Mar. Pollut. Bull.* **2007**, *55*, 172–180. [[CrossRef](#)]

14. Badreddine, A.; Abboud-Abi Saab, M.; Gianni, F.; Ballesteros, E.; Mangialajo, L. First assessment of the ecological status in the Levant Basin: Application of the CARLIT index along the Lebanese coastline. *Ecol. Indic.* **2018**, *85*, 37–47. [[CrossRef](#)]
15. Oceana: Protecting the World's Oceans. Available online: <https://europe.oceana.org/en/home> (accessed on 17 March 2019).
16. Roberts, M. Active speciation in the taxonomy of the genus *Cystoseira* C. Agard. In *Modern Approaches to the Taxonomy of Red and Brown Algae*; Irvine, D.E.G., Price, J.H., Eds.; Academic Press: London, UK; New York, NY, USA, 1978; Volume Systematics.
17. Ballesteros, E.; Catalán, J. Flora y vegetación marina y litoral del Cabo de Gata y el Puerto de Roquetas de Mar (Almería): Primera aproximación. *An. Univ. Murcia* **1981**, *42*, 237–277.
18. Ballesteros, E.; Pinedo, S. Los bosques de algas pardas y rojas. In *Praderas y Bosques Marinos de Andalucía*; Luque, A.A., Templado, J.C., Eds.; Consejería de Medio Ambiente, Junta de Andalucía: Sevilla, Spain, 2004; Volume 336, pp. 199–222.
19. Mangialajo, L.; Chiantore, M.; Cattaneo-Vietti, R. Loss of furoid algae along a gradient of urbanization, and structure of benthic assemblages. *Mar. Ecol. Prog. Ser.* **2008**, *358*, 63–74. [[CrossRef](#)]
20. Sales, M.; Cebrian, E.; Tomas, F.; Ballesteros, E. Pollution Impacts and Recovery Potential in Three Species of the Genus *Cystoseira* (Fucales, Heterokontophyta). *Estuar. Coast. Shelf Sci.* **2011**, *92*, 347–357. [[CrossRef](#)]
21. Thibaut, T.; Blanfuné, A.; Boudouresque, C.F.; Verlaque, M. Decline and local extinction of Fucales in the French Riviera: The harbinger of future extinctions? *Mediterr. Mar. Sci.* **2015**, *16*, 206–224. [[CrossRef](#)]
22. Susini, M.; Thibaut, T.; Meinesz, A.; Forcioli, D. A preliminary study of genetic diversity in *Cystoseira amentacea* (C. Agardh) Bory var. *stricta* Montagne (Fucales, Phaeophyceae) using random amplified polymorphic DNA. *Phycologia* **2007**, *46*, 605–611. [[CrossRef](#)]
23. Gianni, F.; Bartolini, F.; Airoidi, L.; Ballesteros, E.; Francour, P.; Guidetti, P.; Meinesz, A.; Thibaut, T.; Mangialajo, L. Conservation and restoration of marine forests in the Mediterranean Sea and the potential role of Marine Protected Areas. *Adv. Oceanogr. Limnol.* **2013**, *4*, 83–101. [[CrossRef](#)]
24. De La Fuente, G.; Asnaghia, V.; Chiantorea, M.; Thrushb, S.; Poveroa, P.; Vassalloa, P.; Petrilloa, M.; Paoli, C. The effect of *Cystoseira* canopy on the value of midlittoral habitats in NW Mediterranean, an emergy assessment. *Ecol. Model.* **2019**, *404*, 1–11. [[CrossRef](#)]
25. Zazo, C.; Goy, J.L.; Dabrio, C.J.; Bardají, T.; Hillaire-Marcel, C.; Ghaleb, B.; González-Delgado, J.A.; Soler, V. Pleistocene raised marine terraces of the Spanish Mediterranean and Atlantic coasts: Records of coastal uplift, sea-level high-stands and climate changes. *Mar. Geol.* **2003**, *194*, 103–133. [[CrossRef](#)]
26. Terradas-Fernández, M.; Botana Gómez, C.; Valverde Urrea, M.; Zubcoff, J.; Ramos-Esplá, A.A. The dynamics of phytobenthos and its main drivers on abrasion platforms with vermetids (Alicante, Southeastern Iberian Peninsula). *Mediterr. Mar. Sci.* **2018**, *0*, 58–68. [[CrossRef](#)]
27. Ballesteros, E. Structure and dynamics of the *Cystoseira caespitosa* Sauvageau (Fucales, Phaeophyceae) community in the North-Western Mediterranean. *Sci. Mar.* **1990**, *54*, 155–168.
28. Pena-Martín, C.; Juan, A.; Crespo, J.M. Evaluación del estado de conservación de comunidades fitobentónicas en el litoral de Alicante (España). In *Oceanos III Milenio*, 2nd ed.; Editorial C.P.D.: Madrid, Spain, 2002; Volume 1, p. 142.
29. Hereu, B.; Garcia-Rubies, A.; Linares, C.; Navarro, L.; Bonaviri, C.; Cebrian, E.; Diaz, D.; Garrabou, J.; Teixidó, N.; Zabala, M. Impact of the Sant Esteve's storm (2008) on the algal cover in infralittoral rocky photophillic communities. In *Assessment of the Ecological Impact of the Extreme Storm of Sant Esteve's Day (26 December 2008) on the Littoral Ecosystems of the North Mediterranean Spanish Coasts*; Mateo, M.A., Garcia-Rubies, T., Eds.; Centro de Estudios Avanzados de Blanes, Consejo Superior de Investigaciones Científicas: Blanes, Spain, 2012; pp. 123–143, Final Report (PIEC, 200430E599).
30. Mariani, S.; Cefali, M.E.; Chappuis, E.; Terradas-Fernández, M.; Pinedo, S.; Torras, X.; Jordana, E.; Medrano, A.; Verdura, J.; Ballesteros, E. Past and present of Fucales from shallow and sheltered shores in Catalonia. *Reg. Stud. Mar. Sci.* **2019**, *32*, 100824. [[CrossRef](#)]
31. Sales, M.; Ballesteros, E. Shallow *Cystoseira* (Fucales: Ochrophyta) assemblages thriving in sheltered areas from Menorca (NW Mediterranean): Relationships with environmental factors and anthropogenic pressures. *Est. Coast. Shelf Sci.* **2009**, *84*, 476–482. [[CrossRef](#)]
32. Medrano, A. Macroalgal Forests Ecology, Long-Term Monitoring, and Conservation in a Mediterranean Marine Protected Area. Ph.D. Thesis, Universitat de Barcelona, Barcelona, Spain, 2020.

33. Terradas-Fernández, M. Caracterización de las Fitocenosis de las Plataformas de Abrasión con Vermétidos del Sureste Ibérico. Master's Thesis, Universidad de Alicante-Universidad Miguel Hernández, Alicante, Spain, 2014.
34. Ballesteros, E. *Els Vegetals i la Zonació Litoral: Espècies, Comunitats i Factors que Influeixen en la Seua Distribució*; Arxius Secció Ciències; Institut de Estudis Catalans: Barcelona, Spain, 1992; Volume 101, p. 1.
35. Ballesteros, E. Production of seaweeds in Northwestern Mediterranean marine communities: Its relation with environmental factors. *Sci. Mar.* **1989**, *53*, 357–364.
36. Menconi, M.; Benedetti-Cecchi, L.; Cinelli, F. Spatial and temporal variability in the distribution of algae and invertebrates on rocky shores in the northwest Mediterranean. *J. Exp. Mar. Biol. Ecol.* **1999**, *233*, 1–23. [[CrossRef](#)]
37. Sangil, C.; Sansón, M.; Afonso-Carrillo, J. Spatial variation patterns of subtidal seaweed assemblages along a subtropical oceanic archipelago: Thermal gradient vs herbivore pressure. *Est. Coast. Shelf Sci.* **2011**, *94*, 322–333. [[CrossRef](#)]
38. Davis, T.A.; Volesky, B.; Mucci, A. A review of the biochemistry of heavy metal bio-absorption by brown algae. *Water Res.* **2003**, *37*, 4311–4330. [[CrossRef](#)]
39. Cho, G.Y.; Lee, S.H.; Boo, S.M. A new Brown algal order, *Ishigeales* (*Phaeophyceae*) established on the basis of plastid protein-coding *rbcl*, *psaA*, and *psbA* region comparisons. *J. Phycol.* **2004**, *40*, 921–936. [[CrossRef](#)]
40. Coyer, A.; Hoarau, G.; Le-Secq, M.; Stam, W.; Olsen, J.L. A mtDNA-based phylogeny of the brown algal genus *Fucus* (*Heterokontophyta*; *Phaeophyta*). *Mol. Phylogenet. Evol.* **2006**, *39*, 209–222. [[CrossRef](#)]
41. Ministerio Para la Transición Ecológica y el Reto Demográfico, Gobierno de España. Available online: [https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/biodiversidad-marina/espacio-s-marinos-prottegidos/red-natura-2000-ambito-marino/bm\\_emprot\\_rednat2000\\_marino\\_LIC.aspx](https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/biodiversidad-marina/espacio-s-marinos-prottegidos/red-natura-2000-ambito-marino/bm_emprot_rednat2000_marino_LIC.aspx) (accessed on 17 July 2020).
42. European Commission: Natura 2000 Network. Available online: <https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=ESZZ16008#6> (accessed on 5 August 2020).
43. Ministerio de Transportes, Movilidad y Agenda Urbana. Gobierno de España. Plan Nacional de Ortofotografía Aérea: Instituto Geográfico Nacional. Available online: <http://www.ign.es/wms/pnoa-historico?request=GetCapabilities&service=WMS> (accessed on 7 August 2019).
44. Anderson, M.J.; Gorley, R.N.; Clarke, K.R. *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods*; PRIMER-E: Plymouth, UK, 2008.
45. Gómez-Garreta, A. *Flora Phycologica Iberica. Vol. 1. Fucales*; Gómez-Garreta, A., Ed.; Universidad de Murcia: Murcia, Spain, 2000.
46. Cormaci, M.; Furnari, G.; Catra, M.; Alongi, G.; Giaccone, G. Flora marina bentonica del Mediterraneo: *Phaeophyceae*. *Boll. Accad. Gioenia Sci. Nat.* **2012**, *45*, 1–508.
47. Lane, C.; Mayes, C.; Druehl, L.; Saunders, G. A multi-gene molecular investigation of the kelp (*laminariales*, *Phaeophyceae*) supports substantial taxonomic re-organization. *J. Phycol.* **2006**, *42*, 493–512. [[CrossRef](#)]
48. Rogers, S.; Bendich, A. Extraction of DNA from plant tissues. In *Plant Molecular Biology Manual*; Gelvin, S.B., Schilperoort, R.A., Verma, D.P.S., Eds.; Springer: Dordrecht, Netherlands, 1989.
49. Stothard, P. The sequence manipulation suite: JavaScript programs for analyzing and formatting protein and DNA sequences. *BioTechniques* **2000**, *28*, 1102–1104. [[CrossRef](#)] [[PubMed](#)]
50. Madeira, F.; Park, Y.M.; Lee, J.; Buso, N.; Gur, T.; Madhusoodanan, N.; Basutkar, P.; Tivey, A.R.N.; Potter, S.C.; Finn, R.D.; et al. The EMBL-EBI search and sequence analysis tools APIs in 2019. *Nucleic Acids Res.* **2019**, *47*, 636–641. [[CrossRef](#)]
51. Kumar, S.; Stecher, G.; Tamura, K. MEGA7: Molecular Evolutionary Genetics Analysis Version 7.0 for Bigger Datasets. *Mol. Biol. Evol.* **2016**, *33*, 1870–1874. [[CrossRef](#)]
52. Edgar, R.C. MUSCLE: Multiple sequence alignment with high accuracy and high throughput. *Nucleic Acids Res.* **2004**, *32*, 1792–1797. [[CrossRef](#)]
53. Saitou, N.; Nei, M. The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Mol. Biol. Evol.* **1987**, *4*, 406–425. [[CrossRef](#)]
54. Tamura, K.; Nei, M.; Kumar, S. Prospects for inferring very large phylogenies by using the neighbor-joining method. *Proc. Natl. Acad. Sci. USA* **2004**, *101*, 11030–11035. [[CrossRef](#)]

55. Felsenstein, J. Confidence Limits on Phylogenies: An Approach Using the Bootstrap. *Evolution* **1985**, *39*, 783–791. [CrossRef]
56. Celis-Pla, P.S.M.; Bouzon, Z.L.; Hall-Spencer, J.M.; Schmidt, E.C.; Korbee, N.; Figueroa, F.L. Seasonal biochemical and photophysiological responses in the intertidal macroalga *Cystoseira tamariscifolia* (Ochrophyta). *Mar. Environ. Res* **2016**, *115*, 89–97. [CrossRef]
57. Steneck, R.; Dethier, M. A Functional Group Approach to the Structure of Algal-Dominated Communities. *Oikos* **1994**, *69*, 476–498. [CrossRef]
58. Falace, A.; Zanelli, E.; Bressan, G. Morphological and reproductive phenology of *Cystoseira compressa* (Esper) Gerloff & Nizzamuddin (*Fucales*, *Fucophyceae*) in the Gulf of Trieste (North Adriatic Sea). *Ann. Hist. Sci. Soc.* **2005**, *15*, 71–78.
59. Mancuso, F.P.; Strain, E.M.A.; Piccioni, E.; De Clerck, O.; Sarà, G.; Airoidi, L. Status of vulnerable *Cystoseira* populations along the Italian infralittoral fringe, and relationships with environmental and anthropogenic variables. *Mar. Pollut. Bull.* **2018**, *129*, 762–771. [CrossRef] [PubMed]
60. Thibaut, T.; Pinedo, S.; Torras, X.; Ballesteros, E. Long-term decline of the populations of *Fucales* (*Cystoseira* spp. and *Sargassum* spp.) in the Albères coast (France, North-western Mediterranean). *Mar. Pollut. Bull.* **2005**, *50*, 1472–1489. [CrossRef]
61. Roberts, M. Studies on marine algae of the British Isles. 6. *Cystoseira foeniculacea* (Linnaeus) Greville. *Br. Phycol. Bull.* **1968**, *3*, 547–564. [CrossRef]
62. INPN: Inventaire National du Patrimoine Culturel. Muséum National d’Histoire Naturelle. Available online: <https://inpn.mnhn.fr> (accessed on 5 August 2019).
63. Devescovi, M. Effects of bottom topography and anthropogenic pressure on northern Adriatic *Cystoseira* spp. (*Phaeophyceae*, *Fucales*). *Aquat. Bot.* **2015**, *121*, 26–32. [CrossRef]
64. Pizzuto, F. On the structure, typology and periodism of a *Cystoseira brachycarpa* J. Agardh *emend.* Giaccone community and of a duby community from the eastern coast of Sicily (Mediterranean Sea). *Plant Biosyst.* **1999**, *133*, 15–35. [CrossRef]
65. Puertos del Estado. Predicción de viento y oleaje: Boyas y Mareógrafos. Available online: <http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx> (accessed on 22 August 2019).
66. Jona Lasinio, G.; Tullio, M.A.; Ventura, D.; Ardizzone, G.; Abdelahad, N. Statistical analysis of the distribution of infralittoral *Cystoseira* populations on pristine coasts of four Tyrrhenian islands: Proposed adjustment to the CARLIT index. *Ecol. Ind.* **2017**, *73*, 293–301. [CrossRef]
67. Milazzo, M.; Badalamenti, F.; Riggio, S.; Chemello, R. Patterns of algal recovery and small-scale effects of canopy removal as a result of human trampling on a Mediterranean rocky shallow community. *Biol. Cons.* **2004**, *117*, 191–202. [CrossRef]
68. Piattelli, M. Chemistry and taxonomy of Sicilian *Cystoseira* species. *New J. Chem* **1990**, *14*, 777–782.
69. Valls, R.; Piovetti, L.; Praud, A. The use of diterpenoids as chemotaxonomic markers in the genus *Cystoseira*. *Hydrobiol.* **1993**, *260*, 549–556. [CrossRef]
70. Gallardo, T.; Bárbara, I.; Afonso-Carrillo, J.; Bermejo, R.; Altamirano, M.; Gómez-Garreta, A.; Barceló Martí, C.; Rull-Lluch, J.; Ballesteros, E.; De la Rosa, J. Nueva lista crítica de las algas bentónicas marinas de España. *Bol. Soc. Esp. Ficol.* **2016**, *51*, 7–52.
71. Bosc, E.; Bricaud, A.; Antoine, D. Seasonal and inter-annual variability in algal biomass and primary production in the Mediterranean Sea, as derived from 4 years of SeaWiFS observations. *Global Biogeochem. Cycl.* **2004**, *18*. [CrossRef]
72. Amico, V.; Giaccone, G.; Colonna, P.; Mannino, A.M.; Randazzo, R. Un nuovo approccio allo studio della sistematica del genere *Cystoseira* C. Agardh (Phaeophyta, Fucales). *Bol. Sed. Accad. Gioenia Sci. Nat. Catania* **1985**, *18*, 887–985.
73. Pla, M.; Gómez-Garreta, A. Chorology of the genus *Cystoseira* C. Agardh (Phaeophyceae, Fucales). *An. Jard. Bot. Madr.* **1989**, *46*, 89–97.
74. Mangialajo, L.; Ruggieri, N.; Asnaghi, V.; Chiantore, M.; Povero, P.; Cattaneo-Vietti, R. Ecological status in the Ligurian Sea: The effect of coastline urbanization and the importance of proper reference sites. *Mar. Pollut. Bull.* **2007**, *55*, 30–41. [CrossRef]

75. Díaz-Valdés, M.; Abellán, E.; Izquierdo, A.; Ramos-Esplá, A.A. Estudio preliminar de comunidades de macroalgas de la franja litoral rocosa de la Comunidad Valenciana dentro de la Directiva Marco del Agua. In Proceedings of the XIV Simposio Ibérico de Estudios de Biología Marina, Barcelona, Spain, 12–15 September 2006.
76. Blanfuné, A.; Boudouresque, C.F.; Verlaque, M.; Thibaut, T. The fate of *Cystoseira crinita*, a forest-forming Fucale (*Phaeophyceae*, *Stramenopiles*): In France (North Western Mediterranean Sea). *Estuar. Coast. Shelf Sci.* **2016**, *181*, 196–208. [[CrossRef](#)]

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