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Seagrasses along the Sicilian coasts

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All seagrass species known from the Mediterranean basin have been recorded along the Sicilian coast, where studies have been carried out at a very local scale and information is fragmented or confined to the grey literature. The objective of this article is to summarise and evaluate current knowledge on seagrass species on the Sicilian coasts, providing an overview of species distribution, genetic diversity, biology and ecology, based on the literature and unpublished data. Most literature studies have been carried out on *Posidonia oceanica* meadows because of their wide distribution, complexity and ecological importance. In this study, the analyses carried out on *P. oceanica* structural and functional features show that the Sicilian meadows are in good condition with respect to the Mediterranean average, probably because of relatively low anthropogenic pressure and favourable ecological conditions. The available data on this species summarised in this article represent an important starting point from which to build effective plans for understanding levels of environmental threats and for supporting conservation strategies for these important ecosystems. Conversely, the limited information available on other seagrasses only allows the description of some structural and functional features, and does not permit to drive overall conclusions on their general health status.

Keywords: seagrass; Mediterranean; Sicily; distribution; status

1. Introduction

Although seagrasses include relatively few species globally (∼60), they are now known to play a key functional, ecological and economic role in coastal ecosystems worldwide [1,2]. Seagrasses are considered 'ecosystem engineers' because they build up and support complex ecosystems. Seagrasses exert important 'ecosystem services', being important primary producers, performing physical functions of filtering coastal waters, dissipating wave energy preventing the erosion of sandy shores, stabilising and structuring the seabed and providing habitat and nursery areas for many organisms (including commercially caught species) [1].

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In the last few decades, natural disturbances and human activities have caused a worldwide decline in seagrass ecosystems [3–5] and their protection and conservation are becoming of primary importance in the environmental legislations of many countries. Seagrass meadows, have, in fact, already been proposed as a priority habitat under the European Union Habitats and Species Directive (H&SD 92/43/EEC). Moreover, the Water Framework Directive (WFD 2000/60/EU), establishng a framework for the protection and improvement of costal waters, considers seagrasses as biological quality elements, useful in order to assess the ecological status of coastal water bodies.

In the Mediterranean Sea, four native and one invasive true marine seagrass species are present. Native *Posidonia oceanica* (Linnaeus) Delile and *Cymodocea nodosa* (Ucria) Ascherson are widely distributed forming extensive meadows, while *Nanozostera noltii* (Hornemann) Tomlinson & Posluszny and *Zostera marina* Linnaeus are less common. The invasive *Halophila stipulacea* (Forsskål) Ascherson is a Lessepsian species spreading from the Red Sea to the eastern and western Mediterranean where it has its northernmost distribution in the harbour of Palinuro (Salerno, Campania) [6].

All five Mediterranean seagrasses have been recorded in the infralittoral zone of Sicily, the largest island in the Mediterranean with a surface area of $\sim$25,000 km^2. Sicily is located in the middle of the basin and is surrounded by 14 small islands, which are mainly part of three archipelagos. The coastline of Sicily, including its small islands, is $\sim$1600 km long, representing more than 1/50th of the Italian coastal perimeter.

In Sicily, the beginning of a modern approach for studying seagrasses dates back to the middle of the twentieth century with studies by Molinier and Picard [7]. In particular, these authors, coupling observations of the meadows of Sicily with those of meadows along the French and Algerian Mediterranean coasts, were able to drive general conclusions and to build general hypothesis, giving rise to the modern Mediterranean seagrass ecology [8,9].

Studies have evolved from an initially qualitative [7,10,11] to a current quantitative level [12–19]. This transition has been paralleled by a diversification in research topics and implied the use of new approaches and tools (remote sensing and acoustic techniques, molecular ecology) [20–23].

Here, we summarise here the data available from multiple and diverse information sources, i.e. scientific literature, reports, web sites. Sources were identified by conducting a web research using the following search term: (Sicily* or Mediterranean*) and (seagrass* or *Halophila stipulacea** or *Nanostera noltii** or Z*ostera noltii** or *Zostera marina** or *Cymodocea nodosa** or *Posidonia oceanica**). However, studies are at a very local scale and the knowledge of seagrasses at a large scale along Sicilian coasts is prevalently confined to the grey literature. In an attempt to fill this gap, we integrated the literature data with a only partially published data coming from a databank built in the framework of monitoring programs performed in the last 20 years.

Such information will help us to understand the levels of the environmental threat to seagrasses in a regional context, which will support the seagrass conservation actions by regional agencies.

2. Species distribution

The five Mediterranean seagrasses show different degrees of spread and cover in in the infralittoral zone of Sicilian coasts (Figure 1).

The Lessepsian immigrant seagrass *Halophila stipulacea* [24] was first found in the eastern Mediterranean in 1894 [25], remaining restricted to this basin for several decades. The first record in Sicily (and Italy) dates back to 1988 in Riposto Harbour (Catania) by Villari [26], although local fishermen claimed that the species was already present on the Ionian coast (Giardini Naxos–Messina) before 1975 [27]. Later, *H. stipulacea* showed a progressive colonisation pattern along

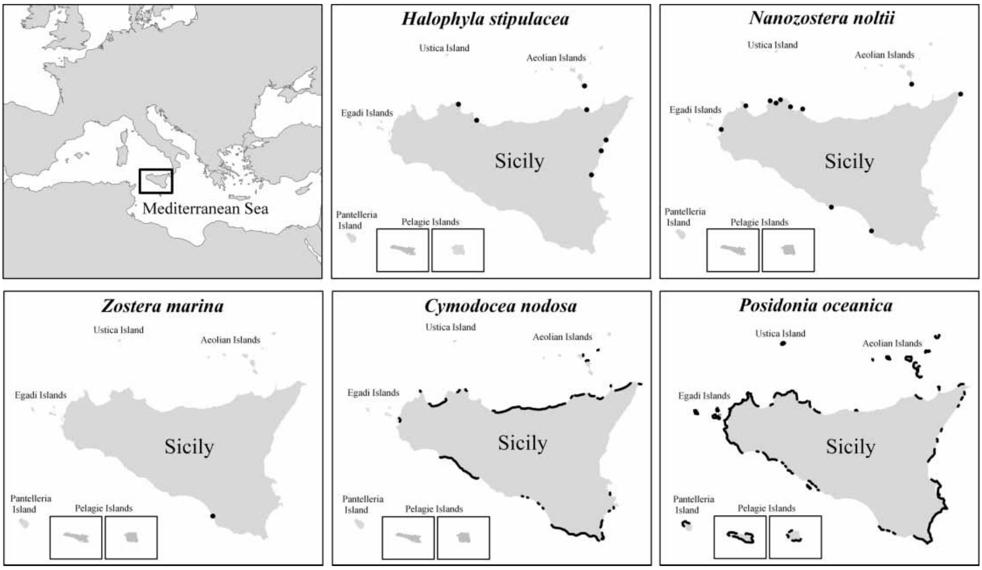

Figure 1. Seagrasses distribution in Sicily.

the Ionian coasts of Sicily [22,28–31]. In the southern Tyrrhenian Sea it was first observed in 1995 off the island of Vulcano, in the Aeolian Archipelago [32], and at Oliveri-Tindari (Messina) [30], forming dense prairies ~2 ha wide, extending from 1 to 27 m depth [27,33]. *H. stipulacea* is also common today, mainly in small harbours and sheltered bays along the Tyrrhenian coast and the Egadi islands, although it is not common along the southern coast of Sicily (author's observation). The recent rapid spread of the species has likely been mediated by pleasure boat traffic and anchoring, and favoured by an increase in seawater temperature [6].

Nanostera noltii is a Zosteracea widely distributed along the coasts of Europe and northern Africa [2], but not common along the Sicilian coasts, where only small patches of $<10\,\mathrm{m}^2$ have occasionally been observed. The species was recorded in a few localities along the north-western [34] and south-eastern coasts [35] and in a coastal lagoon, the Stagnone di Marsala [36], as well as the coastal lakes of Ganzirri and Faro [37]. Recently, it has been found in a salt mine near Marsala (western coast, author's observation), where high salinity ($\sim$60–70 $\mathrm{g \cdot L^{-1}}$) can be detected in summer.

The eel-grass *Zostera marina*, a species adapted to the cold waters of the North Atlantic and North Pacific, can be found in the Mediterranean in more or less sheltered areas on soft mud or firm sand [38]. It occurs rarely in Sicily and was detected only near Gela (south-eastern coast), which is up to date the only location where the species has been recorded in Sicily [35].

Extensive mapping surveys by acoustic instruments (side scan sonar), combined with airborne and satellite remote sensing methods and true control inspections (remote-operated vehicle; ROV) have been used to estimate *Cymodocea nodosa* and *Posidonia oceanica* coverage and distribution along Sicilian coasts [39].

Prairies of *C. nodosa* are frequently observed along the coast of Sicily and colonise ~19,000 ha. In term of species coverage, the northern (~40%) and southern (~44%) coasts show the higher values, while the Aeolian Islands host >90% of the *C. nodosa* prairies of the small Sicilian islands. Moreover, *C. nodosa* reaches edaphic climax characterised by dense, extensive prairies at 7–15 m depth [40,41] in some areas of the southern (Gulf of Gela) and northern coasts (Gulfs of Castellammare and Termini Imerese). This ecological condition is due to peculiar sedimentologic

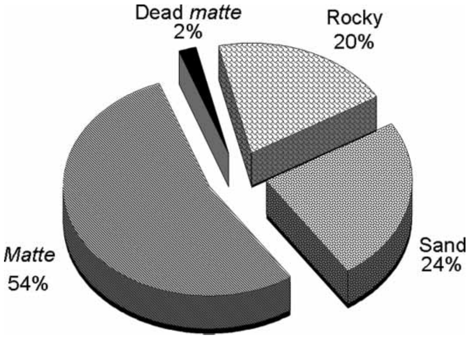

Figure 2. Distribution of *Posidonia oceanica* meadows per substratum type in Sicily.

and physiographic factors such as: (1) sea floor morphology features, (2) dominance of muddy and unstable sediments, and (3) low water transparency [41].

Posidonia oceanica is the most common seagrass along Sicilian coasts, covering ∼76,000 ha of coastal areas, which corresponds to 18.5% of the sea bottom at depths between 0 and 50 m [39]. In Sicily, *P. oceanica* meadows show the most extensive bottom coverage of all the Italian regions after Sardinia [42]. Settlement and development of *Posidonia* meadows along Sicilian coasts has been affected by composition and structure of the substratum. About 54% of meadows settle on *matte*, 24% on sand and 20% on rocky bottom and only 2% is dead *matte* (Figure 2).

The distribution of *P. oceanica* meadows in term of species coverage shows the presence of dense, extensive beds growing along the western (55%) and south-eastern (19%) coasts of Sicily, corresponding to the most important carbonatic and calcarenitic outcrops of the island (Figure 1). In particular, along the western coast of Sicily favourable ecological conditions and highly pristine natural conditions have allowed the settlement and development of one of the largest *P. oceanica* meadows in the Mediterranean [41]. Moreover, the development of the meadow near the shoreline, facilitated by extensive shallow bottoms, gave rise to peculiar *P. oceanica* reef formations (*plateau-récifale* and *récif-barrière*) [43,44] and contributed to building and maintaining natural (Stagnone di Marsala) and artificial (salt mines) lagoon ecosystems. Because if its peculiar environmental and geomorphological characteristics, the Stagnone di Marsala can be considered as a ‘natural laboratory’, in which remote sensing techniques have been tested to map phytobenthic communities and evaluate biomass density distribution [45,46].

P. oceanica meadows show a discontinuous distribution along the Tyrrhenian and north-eastern Ionian coasts, characterised by rugged mountains crossed by torrent-like rivers and metamorphic, igneous, sedimentary (Peloritani Units) and volcanic rocks (Mount Etna).

Wide and dense *P. oceanica* meadows are present on the sea floor of the calcareous Egadi Archipelago (where over 70% of the *P. oceanica* beds mapped in the small Sicilian islands have been described) and the island of Lampedusa, while in the volcanic islands (Aeolie, Ustica, Pantelleria and Linosa) *P. oceanica* beds settle on rock or volcanic sands mixed with biogenic calcareous detritus.

On the whole, *P. oceanica* is commonly found in a good condition along Sicilian coasts, except for meadows close to the main urban and industrial areas [19,47–49], where signs of evident regression up to complete disappearance have been found (Gulfs of Palermo and Augusta).

The typology of the lower depth limit of *P. oceanica* meadows [50,51] is considered an important descriptor to evaluate extension/regression balancing conditions of the meadows, allowing us to detect the principal local factors controlling the bathymetric distribution of the plant along Sicilian coasts.

Analysis of 319 ROV profiles showed that the progressive limit typology [39,52] is the most frequent along Sicilian coasts (60.8%), whereas sharp and erosive limits are, respectively, 31.4 and 7.8%. The mean lower limit depth varies with typology, ranging from 23.0 m (sharp limit) to 31.4 m (progressive limit) (Figure 3). In particular, the progressive depth limit of *P. oceanica* meadows was from 11.1 m (Brucoli, Catania) to 44.0 m (Panarea, Aeolie archipelagos), and is more frequent along the coasts of Sicily than in the small islands, where the sharp limit is the most frequent (47.2%) [52]. Moreover, owing to the high water transparency, the lower limits of *P. oceanica* meadows observed along the small islands are deeper than those found along the Sicily coasts.

Depth records of progressive limit were classified by K mean cluster analysis in four classes [52] (Table 1) and converted into seawater transparency levels according to Pergent et al. [53]. The class 'very transparent waters' is the most frequent in the north-western area of Sicily, while the class 'very little transparent waters' is detected only near the urban centre of Palermo and the petrochemical industry of Augusta, where *P. oceanica* does not colonise bottoms deeper than 14 m. Along the southern coasts of Sicily morphology and composition of the bottom and swell exposure frequently limit water transparency; consequently the meadow depth limit rises.

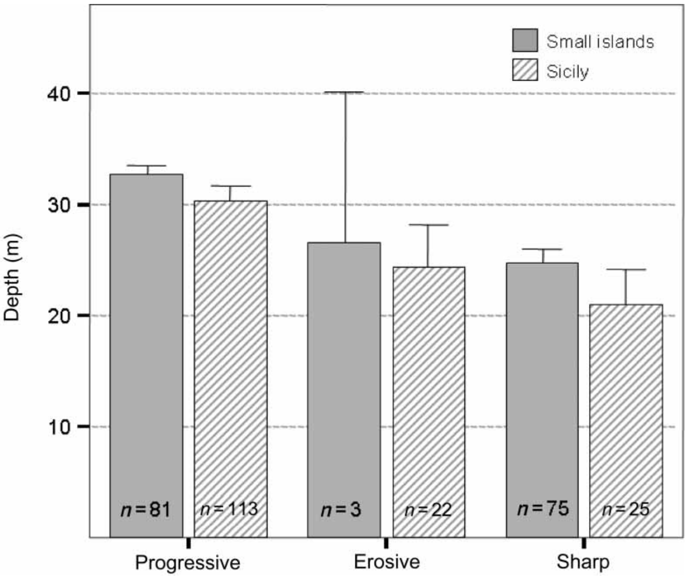

Figure 3. Mean different lower depth limit typology (±SE) along the coasts of Sicily and small islands (n = number of observations).

Table 1. Water transparency classification of meadows along the coasts of Sicily and small islands, based on mean values of progressive depth limit of *Posidonia oceanica* meadows.

Class	No. observations	Minimum depth (m)	Maximum depth (m)	Mean depth (m)	Evaluation quality
1	50	33.1	40.0	35.6	Very transparent waters
2	39	26.0	33.0	30.4	Transparent waters
3	19	18.5	25.3	21.0	Few transparent waters
4	5	11.1	15.8	13.6	Very few transparent waters

3. Genetic structure and variability

Sicily is in a particular position, in the centre of an acknowledged biogeographic transition separating the western and eastern Mediterranean basins [54,55]. It has been considered by different authors to belong entirely or partially to either the western or eastern Mediterranean basin [55]. The Strait of Sicily, separating Sicily from the Tunisian coast, underwent drastic changes during and after glaciation [56], affecting levels and patterns of gene flow among populations located on the two sides of the basin. Moreover, Sicily represents the gate for the westward expansion of Lessepsian migrants [55], which enter the Mediterranean basin through the Strait of Sicily or the narrow Strait of Messina. The distribution of the seagrass flora along the Sicilian coasts and the intraspecific population genetic structure of Mediterranean seagrass species reflect this peculiarity.

An example of westward expansion of a putative Lessepsian migrant, is given by *Halophila stipulacea*. The introduction in the Mediterranean basin via the Suez Channel was confirmed by rDNA sequencing data, which recorded almost complete identity of the ribosomal cistron ITS1-5.8S-ITS2, between the west Mediterranean and Red Sea genotypes [57]. High variability in random amplified polymorphic DNA (RAPD) markers was found both in a population located near the harbour of the island Vulcano (Eolian Archipelago) and in mainland populations located in the semi-enclosed marine lakes of Oliveri-Tindari (Messina) [22]. Only male flowers were recorded for this study, as well as for most of the west Mediterranean sites where the species has been recorded [6,22,29]. Female flowers have been recorded only once on the south-east coast of Sicily [58]. This seems to suggest that few sexually reproducing populations support the high level of genotypic diversity found in the recently colonised areas through fragmentation and re-attachment of mature thalli.

The role of phylogeographic transition zone played by the Strait of Sicily has been demonstrated for many different marine organisms (e.g. fishes and molluscs) [59,60]. This has been confirmed recently for the two Mediterranean seagrass species *C. nodosa* and *P. oceanica*. In both species, strong genetic divergence in the allelic distribution of microsatellite markers has been found between populations growing in the eastern and western basins [54,61]. The only two *C. nodosa* meadows sampled in Sicily come from the south-eastern tip of the island (Porto Palo and Marzamemi) and both fall in an intermediate position between western and eastern population groups in the Neighbour Joining and Multidimensional Scaling analysis [61]. Although the lack of other *C. nodosa* sampling stations in Sicily does not allow us to locate precisely the west/east transition for this species, recent analysis performed on *P. oceanica* seems to identify the south-eastern tip of Sicily as the real west/east transition zone [54,62,63]. The meadow near Marzamemi (south-eastern coast), in particular, appears to play a central role, defined by its betweenness centrality, in the *P. oceanica* population's network built over the whole Mediterranean, and to be a key population shaping the structure of the network [64].

P. oceanica shows high genetic and genotypic polymorphism in most of the localities analysed along the coasts of Sicily [23,54,63], which is a strong indication of the good health of the meadows [65,66]. This is also fits with the frequent record of flowers and beached fruits along the coasts of the island. Flowering intensity seems to increase in a eastward direction [67], which fits nicely with the presence of more genetically diverse meadows in the south-east tip of the island [55]. Although not fully acknowledged in *P. oceanica*, the contribution of sexual reproduction in enhancing meadows' genetic diversity has been shown by Orsini et al. [68]. Nonetheless, very low genotypic richness has been found in meadows which are either isolated from the main patterns of local gene flow (*Posidonia* shoals populations, of the Sicily banks) [63] or at the extremes of the environmental tolerance of the species (Stagnone di Marsala) [23]. The atoll-like shaped *P. oceanica* patches growing within the Stagnone di Marsala, in particular, seem to suffer from both the extreme salinity and temperatures reached within the lagoon, particularly in summer, and the recent isolation from the adjacent coastal meadows due to the almost complete closure of the northern entrance of the lagoon [23].

Here we present the most acknowledged descriptors of the meadows, most of which have been traditionally used to assess the status of seagrass meadows [51]. Because of its recognised ecological importance and wide distribution, most of the data available in the literature have been obtained on *Posidonia oceanica*.

4. Density

P. oceanica density is considered an important descriptor of the vitality and dynamics of a meadow and it is very sensitive to the human impact [51].

Altogether, 1584 counts (5–12 counts per station) of *P. oceanica* shoot density were made in 174 stations along Sicilian coasts from 1 to 28 m depth (see Supplementary Table – online only). Mean density values were from 121.1 to 931.3 shoot·m^{-2} and the 99% confidence interval (CI) of the mean was estimated at between 370.6 and 425.3 shoot·m^{-2}. On average, shallow and deep *P. oceanica* meadows show the highest and lowest density values respectively. This pattern is well described by a semi-logarithm regression model in which depth accounts for 30% of total density variability ($p < 0.01$) (Figure 4). These results are in agreement with the model proposed by Pergent et al. [53] for the Mediterranean scale, confirming the value of the link between density and depth also on a regional scale.

Based on the standardised scale for density classification [53], about two-thirds of the Sicilian *P. oceanica* meadows, mainly located along the western and south-eastern Sicilian coasts and small islands, belong to the best classes (‘Higher Sub-normal Density’ and ‘Normal Density’). The abnormal class (‘Abnormal Density’) represents 16.5% of cases and is mainly detected close to

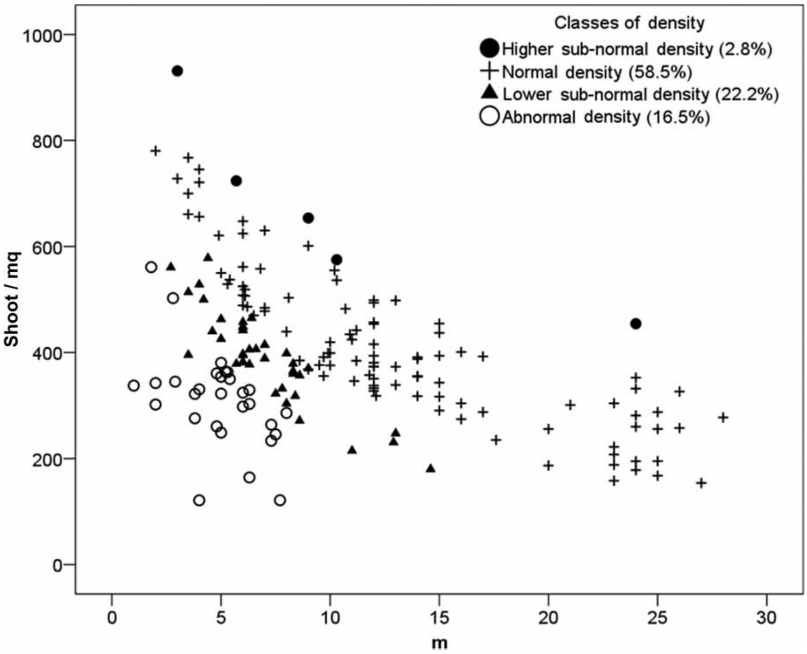

Figure 4. Relationship between density and depth; the classification according to Pergent et al. [53] is superimposed.

man-induced disturbance sources (harbours and urban and industrial sewage) and along southern and north-eastern coasts of Sicily, due to natural edaphic factors.

5. Leaf biometry

Shoot phenology and leaf biometry are often used to characterise *P. oceanica* meadows [51,69]. However, to avoid any confounding effect of seasonality these descriptors should be sampled during a fixed period of the year [70]. In the current study, summer (June–July) foliar biometry values were selected from data collected in the framework of several research projects of the last two decades (see Supplementary Table – online only). Altogether, 5372 *Posidonia oceanica* shoots were selected in 119 sampling stations from 1 to 27 m depth and $>$25,000 leaves were examined (see Table 2).

Mean leaf surface area for Sicilian coasts was from 249.0 ± 89.4 to $306.7 \pm 108.2\ \mathrm{cm}^2 \cdot \mathrm{shoot}^{-1}$ (99% CI = 267.1–274.6). The mean number of leaves per shoot ranged from 4.7 ± 1.1 to 5.2 ± 1.2 (99% CI = 4.8–4.9).

Leaf biometry values were comparable among different sectors except for the western coast of Sicily, where the means were generally $\sim$10–20% higher than in the other sectors. This is

Table 2. Mean values (SD) of *Posidonia oceanica* leaf biometry variables in different sectors of Sicilian coasts: 1, western and north-western; 2, southern; 3, south-eastern; 4, eastern and north-eastern; 5, small islands. Confidence interval (bold) at 99% of the grand mean for each variable was estimated with sample size = total n stations, leaves or shoots sampled.

Sector	No. stations	Depth (m)	No. adult leaves measured	Adult leaf length (cm)	No. intermediate leaves measured	Intermediate leaf length (cm)	No. shoots	No. leaves per shoot (Ad+Int)	Shoot surface (cm^2)
1	38	10.8	5340	68.5 (25.6)	2841	65.9 (32.4)	1660	4.9 (1.0)	306.7 (108.2)
2	3	7.0	763	62.2 (26.6)	406	54.9 (35.7)	225	5.2 (1.2)	276.3 (95.5)
3	17	7.2	2231	68.3 (27.6)	1206	53.3 (33.3)	724	4.7 (1.1)	261.2 (94.1)
4	24	8.7	2295	60.0 (23.9)	1314	57.2 (29.8)	756	4.8 (1.1)	249.0 (89.4)
5	37	10.2	6421	64.0 (25.9)	3045	51.9 (32.9)	2007	4.7 (1.1)	252.2 (110.3)
Grand mean	119	8.3	17,050	**64.8–65.8**	8,812	**56.6–58.5**	5372	**4.8–4.9**	**267.1–274.6**

Table 3. Mean values of *Posidonia oceanica* leaf biometry variables observed in the literature. The confidence interval (bold) at 99% of grand mean for each variable was calculated by using all mean values recorded per station.

Locality	No. stations	Depth (m)	Adult leaf length (cm)	Intermediate leaf length (cm)	No. shoots	No. leaves per shoot (Ad+Int)	Shoot surface (cm^2)	Ref.
South of France	9	7	39.1	34.1	189	4.6	155.3	[75]
Port-Cros (France)	5	13.7	53.3	45.4	200	4.4	–	[76]
Banjuls sur Mer (France)	4	8.3	29.5	31.3	160	4.8	–	
Urla-Iskele (Turkey)	4	1.8	41.7	22.9	160	5.5	–	
Fanals Point (Spain)	1	15	–	–	30	–	354.7	[77]
Platja de Mitjorn (Formentera, Balearic Islands)	6	1.8	–	–	60-180	–	153.5	[78]
Liguria (Italy)	2	5	–	–	54	–	183.3	[79]
Laganas Bay (Zakynthos, Greece)	3	10	–	–	30	–	196.6	[80]
Lacco Ameno (Ischia, Italy)	3	16.7	–	–	75	–	207.3	[81]
Grand mean		7.8	**30.5–47.7**	**25.6–42.6**	976–1096	**4.4–5.1**	**148.7–213.8**	

consistent with Calvo et al. [41], who recorded the maximum mean shoot surface of Sicilian coasts in the same sector.

A comparison between our data and those available from the Mediterranean basin at comparable depth and period indicates that the average values of Sicilian sectors (except for leaf number) are generally greater than in the rest of the basin. Consequently, the confidence intervals are different and no overlapping boundaries are present (Table 3).

Studies focusing on *P. oceanica* plasticity provide evidence that leaf biometry variations are affected by different factors (excluding depth and period) operating on different spatial scales, from several kilometres to a few metres [71]. It is likely that the large-scale *P. oceanica* heterogeneity observed in this study reflects the variability in climatic conditions [72], because there is very high latitudinal and longitudinal variation between the two macro areas considered (Sicily vs. Mediterranean coasts).

Recent studies of multivariate analysis performed on several *P. oceanica* descriptors indicate that shoot surface is one of the best candidates to asses meadow status [70,73,74]. The data compilation in this study provides evidence of the good condition of Sicilian meadows.

6. Growth performance

During the last decade more attention has been given to the use of reconstructive ageing techniques, because there is growing evidence that these methods provide reliable estimates of seagrass growth performance, on large temporal and spatial scales [51,82]. In Sicily, most dating measurements were made on a local scale to assess the influences of site-specific conditions (hydrodynamism, urban and fish farm pressure) and endogenous factors (ageing and sexual reproduction) on *P. oceanica* growth performance [18,19,23,83,84]. On a regional scale, information on *P. oceanica* growth is limited to the analysis of the effect of depth on spatial synchrony [85].

In this study, the history of *P. oceanica* growth performance of >10,500 shoots, sampled in 238 stations spread around all the Sicilian coasts from 1 to 32 m depth was reconstructed by lepidochronology [86] (Table 4). These new records were obtained from ~67,000 annual rhizome segments belonging to temporal series ranging from 1 to 48 years per shoot. The temporal range explored varies across different sectors from the 1951–2005 window to the 1986–2005 window.

Mean vertical rhizome elongation ranges from 7.6 ± 3.3 to 10.9 ± 5.2 $\mathrm{mm \cdot shoot^{-1} \cdot yr^{-1}}$ and the confidence interval of the grand mean for Sicilian coasts was estimated at 99% between 9.6 and 9.9 $\mathrm{mm \cdot shoot^{-1} \cdot yr^{-1}}$. The mean number of leaves produced per year ranged from 7.2 ± 0.8 to 7.8 ± 0.9 (99% CI of grand mean 7.47–7.52).

A previous study of growth performance data from a series of Mediterranean localities estimated that 6.8–8.3 leaves were produced annually and that 5.9–8.9 $\mathrm{mm \cdot yr^{-1}}$ of vertical rhizome growth can be considered ‘normal’ for this species [53]. The new, more extensive estimates presented

Table 4. Mean values (SD) of the examined growth performance variables of *Posidonia oceanica* in different sectors of Sicilian coasts (see Table 2). The confidence interval (bold) at 99% of the grand mean for each variable was estimated.

Sector	Temporal range	No. stations	No. shoots	No. rhizome segments	Rhizome elongation ($\mathrm{mm \cdot shoot^{-1} \cdot yr^{-1}}$)	Leaf production ($n \cdot \mathrm{shoot^{-1} \cdot yr^{-1}}$)
1	1951–2005	84	4744	34,067	10.9 (5.2)	7.4 (0.9)
2	1986–2005	13	421	2167	7.6 (3.3)	7.2 (0.8)
3	1974–2005	28	1203	8461	10.2 (4.4)	7.4 (0.7)
4	1973–2005	62	1166	6729	9 (4.1)	7.6 (0.8)
5	1970–2005	51	3025	15,641	10 (5.1)	7.8 (0.9)
Grand mean	1951–2005	238	10,559	67,065	**9.6–9.9**	**7.47–7.52**

in this study provide evidence that one of the two growth performance parameters estimated for Sicilian coasts, the mean rhizome elongation, is above the normal Mediterranean range: indeed on the basis of the standardised scale the rhizome elongation in Sicily can be considered as 'superior–sub-normal' [53]. Several factors may explain this strong difference, such as the relatively low anthropic pressure present along the Sicily coasts and the different sedimentation rate [77] and different temperature and photoperiod linked to longitudinal and latitudinal variations [86,87]. In the last case, further studies will be necessary to implement an evaluation scale that take into account natural variations induced by geographical gradient.

7. Flowering

Fragmentation and vegetative stolonisation seem to represent the dominant reproductive mode in the Mediterranean population of *Halophila stipulacea* [6]; male flowers show low frequency and female ones were never recorded in the studies by Cancemi et al. [29] and Procaccini et al. [22], probably because they do not find in west Mediterranean favourable conditions to ripen [6]. Although in Sicily, Famà et al. [30] also observed only male flowers, it is worth noting here that, in September 1988, Villari [26] recorded specimens bearing immature fruits and 10 years later near Syracuse (Ionian Sea) Di Martino et al. [58] found many flowers, both male and female, suggesting that, although rare, female flowers are present in the west Mediterranean meadows of *H. stipulacea*.

Native Mediterranean seagrass species flower between late spring (*C. nodosa and N. noltii*) and summer (*Zostera marina*), except for *P. oceanica*, which flowers in autumn (September–November).

Flowerings of *Z. marina* and *N. noltii* have never been observed along the Sicilian coasts, probably because of their very limited distribution and the lack of continuous monitoring, while *C. nodosa* flowering has been observed rarely (Stagnone di Marsala; Calvo, pers. obs.).

However, flowering of *P. oceanica* in Sicily [88] is more frequent than previously thought, as indicated by both increased field observations [89] and the use of reconstructive methods that allow detection and dating of past flowering episodes [82,90]. Thanks to that, flowering has been detected almost every year from 1978 to 2005 along the entire Sicilian coast, as documented by direct and retrospective observations from the last three decades.

The number of flowering shoots varies greatly depending on year, depth and location, from 1 to 200 per m^2 [91]. The percentage of flowering shoots estimated by direct observation reached a maximum of 30% in 1995 in the Egadi islands [41], followed by 10.1% recorded in 1997 by backdating methods in the south-eastern coast of Sicily [18] and confirmed by the unusually massive fruiting in the area in the same year [92].

The fraction of meadows flowering in any one year shows that on the western coast of Sicily [23] flowering was more prevalent in the years 1987 (50%), 1991 (67%), 1996 (56%) and 2003 (50%). The massive flowering recorded in 2003 along the coast of western Sicily, in particular, coincided with the most widespread flowering event ever recorded in the Mediterranean, when $>80\%$ of the investigated meadows flowered [67]. This outstanding flowering followed the warmest year in past centuries across Mediterranean regions, suggesting that positive thermal anomalies may play an important role in driving synchronous *P. oceanica* flowering on a large scale [67,93].

Recently, a new set of flowering performance indices [67] applied to the meadows of western Sicily [23] showed that: the probability of finding a flowering annual rhizome segment in the total number of annual segments analysed (Pf) was 0.0072 inflorescences per shoot per year, the fraction of years that a given meadow has flowered (FF) was 0.196 and the fraction of shoots presenting stalks within a particular year (FI) was on average 0.026 ± 0.007 inflorescences per shoot. The most important dataset of flowering occurrences reported for the western Mediterranean

[67] compared with the flowering performance estimated in Sicily showed that the latter area has higher averages values [23]. However, in sites where *P. oceanica* grows near its upper limit of thermal tolerance (Stagnone di Marsala lagoon), no flowering events have ever been detected over a 24 year time series.

Flowering probability increases with age, reaching a maximum in 15-year-old shoots (with an inflorescence frequency per age of 12.7%), as observed in Sicilian meadows [18]. Fifteen years thus represents the ageing point at which the probability that a shoot can perform sexual reproduction declines. This pattern partially confirms the conclusions of a study by Balestri and Vallerini [87] on the north-western coast of Italy, but is not in agreement with data recorded in other localities of western Mediterranean [67], showing that optimal age for flowering may change with geographic area in the Mediterranean. However, the latter suggestion should be taken with caution because the partial agreement could be derived from the difference in the time-length series used in the literature (16–32 years old). It would be interesting to assess whether the threshold age for sexual reproduction applies to single shoots or to the entire genotype from which the shoot eventually branched. More insights in this direction could help in clarifying the observed differences.

Previous studies suggest that flowering has a negative effect on leaf biometry [94,95], determining also a reduction in rhizome elongation and production lowered to $\sim$27 and 38%, respectively [18]. According to these calculations, it is possible that the cost associated with sexual reproduction may be difficult to sustain for older shoots, suggesting that the species' capacity to regulate its internal resource economy to support flowering may be limited by other physiological stresses linked to ageing.

8. Associated communities

Seagrass epiphytes play an important role in ecosystem functioning contributing significantly to the primary production of the meadow [96,97] and representing an important food resource for many organisms [98,99]. Furthermore, the abundance and composition of assemblages of seagrass epiphytes are considered sensitive indicators of natural and anthropogenic disturbance [100,101]. Only studies on *H. stipulacea* and *P. oceanica* epiphyte assemblages have been carried out along Sicilian coasts over the last 30 years.

The first study of the macroalgal epiphytic community on *H. stipulacea*, dating back to 1993 [28], was carried out on a meadow in Catania harbour. A total of 30 species (22 Rhodophyta, 3 Ochrophyta and 5 Chlorophyta) were found. From a qualitative point of view, the epiphytic community on *H. stipulacea* results are very similar to those on *P. oceanica* leaves [13]. Among the epiphytes identified the presence of *Chondria pygmaea* Garbary *et* Vandermeulen, described in the Red Sea as epiphytic on *H. stipulacea* leaves [102], is noteworthy. This leads us to suppose that this species migrated into the Mediterranean together with its host species [103].

Some years later, a meadow of *H. stipulacea* occurring near the harbour of the island of Vulcano (Aeolian Islands) was studied to assess the associated community [32]. In that study, only nine species of macroalgae were reported as epiphytic on *H. stipulacea* leaves.

Further data is provided by Di Martino et al. [58] in a study of a meadow of *H. stipulacea* present at Capo Meli (Syracuse). In this article the authors report a total of 61 and 39 species of macroalgal epiphytic on both rhizomes and leaves in autumn and spring, respectively. More recently, Di Martino et al. [104] studied temporal variations in the algal assemblage associated with a *H. stipulacea* meadow in the Maddalena Peninsula (Syracuse). A total of 110 species (5 Cyanophyta, 81 Rhodophyta, 19 Ochrophyta and 5 Chlorophyta) epiphytic on *H. stipulacea* leaves were found.

The animal communities associated with *H. stipulacea* were studied by Cancemi et al. [29] and Acunto et al. [105]. The former study, dealing with vagile fauna, was carried out in a meadow occurring in Giardini Naxos harbour (Messina). Mollusca, Amphipoda and Decapoda with 18, 21 and 14 species, respectively, were the most abundant groups. The latter study, dealing with groups of macrozoobenthos, was carried out in the meadow near the harbour of the island of Vulcano, where Polychaeta, Crustacea and Mollusca with 23, 15 and 6 families, respectively, were the most abundant.

The first studies on epiphytic algal communities on *P. oceanica* leaves were those carried out on two *P. oceanica* meadows off Capo Passero (Syracuse): one near the island of Correnti, the other near the island of Capo Passero. The studies were conducted in spring [13] and autumn [106]. A total of 54 taxa at specific and infraspecific levels (later named species) (18 Rhodophyta, 8 Ochrophyta and 1 Chlorophyta) were found in the island of Correnti meadow, while 90 species (51 Rhodophyta, 17 Ochrophyta and 4 Chlorophyta) were found in the island of Capo Passero meadow. Because the largest number of species are found on the oldest leaves, the significantly lower number of species recorded in the island of Correnti meadow is due to the greater exposure to water movement at that station, which causes more shedding of the oldest leaves. A further 10 years passed before a new study on epiphytic algal communities on *P. oceanica* leaves was made [107]. Here the epiphytic flora of the *P. oceanica* meadow of Vendicari island (Syracuse) was examined. A total of 78 species (7 Cyanophyta, 47 Rhodophyta, 16 Ochrophyta and 8 Chlorophyta) were found.

About 10 years later, the epiphytic algal flora of the meadow of the Marine Protected Area ‘Isole Ciclopi’ (Catania) was studied [108]. Epiphytic macroalgae on both leaves and rhizomes were considered. A total of 73 species (54 Rhodophyta, 13 Ochrophyta and 6 Chlorophyta) were recorded, of which only 14 (10 Rhodophyta and 4 Ochrophyta) were found on leaves. This number appears very low compared with those recorded in the above-mentioned meadows occurring along south-east coast of Sicily, although this is similar to that found in the meadow off Lacco Ameno (Ischia, Gulf of Naples), where only 19 species were recorded [109].

Finally, patterns of variability in epiphytes of *P. oceanica* leaves at various spatial scales around Sicily were investigated [110]. Encrusting red and brown algae, filamentous algae, encrusting bryozoans, erect bryozoans, hydroids and Foraminifera were the most abundant taxa. Significant differences in the abundance of taxa were detected among geographical regions (more abundant on the western coast than the northern and southern coasts of Sicily), although no significant differences were found between Sicily and the small islands. At smaller scales, variability was concentrated mostly among leaves 100s of centimetres apart and among meadows a few kilometres apart. These results suggest that both geographical and local processes are important in structuring the epiphytes of *P. oceanica* leaves in this area of the Mediterranean basin.

9. Trophic role

Despite their wide distribution and ecological importance, seagrass ecosystems are still incompletely studied in terms of organic matter pathways and food web structure. The information available on the trophic ecology of seagrass ecosystems (e.g. the role of herbivory and detritus, the contribution to littoral fish production, exportation to other ecosystems) is mainly based on new insights derived from the application of stable carbon and nitrogen isotope analysis. Using this technique, the role of seagrasses was studied in a semi-enclosed coastal area (Stagnone di Marsala) [16,111] and adjacent saltworks [112] in the Egadi Archipelago [113] and the island of Ustica (Vizzini, unpublished data) and along the south-western [114]) and south-eastern [17] coasts of Sicily. Most of the available information is on *P. oceanica* because of its large extension, biomass and associated biodiversity.

The results of these studies are in line with the findings of other articles on the Mediterranean (e.g. [115–117]). Seagrass abundance seems to be generally controlled by abiotic limitations more than by biotic activities (i.e. herbivory), and bottom-up effects are recognisable in food webs where seagrasses limit the herbivory level because of their low nutritional quality. True and exclusive herbivores are not clearly recognisable: although a few species undoubtedly ingest and also assimilate seagrass tissues, they exploit other items to meet their nutrient requirements mainly in terms of nitrogen. In the interaction seagrass–epiphyte–herbivores a major role seems to be played by epiphytes, although the spatial and temporal variability of this process needs further study.

Because seagrass beds function as nursery and feeding areas for many fish species of commercial value, an important task is the recognition of the trophic role of these plants in supporting ichthyofauna. Indeed, the basal energy supply for fish potentially originates from different organic matter sources, mainly seagrass living tissues and detritus, phytoplankton, epiphytes on seagrass leaves and rhizomes and epilithic macroalgae. Vascular tissues contribute significantly to sedimentary organic matter in seagrass beds, especially in those sites with high plant density and fine sediments and where seagrass detritus is channelled through sedimentary organic matter to higher trophic levels in food webs.

One of the most important ecological services provided by seagrass ecosystems is certainly the support to food webs. However, several areas of seagrass ecology still need to be explored in greater depth to understand food web dynamics, the spatio-temporal variability of specific processes (herbivory intensity, the role of detritus and detritivores, exportation of organic matter and so on) and the rules and mechanisms that determine such variability.

10. Conclusion

Seagrasses are very common along Sicilian coasts where they play an essential naturalistic and ecological role in the balance of the coastal zone. Although all the Mediterranean seagrasses have been described, only *P. oceanica* and *C. nodosa* show significant coverage. Currently, *H. stipulacea* spreads easily in sheltered areas although it does not compete strongly against natural communities, while *N. noltii* is not at all widespread and *Z. marina* has been reported only in one location.

Most studies have focused on *P. oceanica* meadows because of their wide distribution, complexity and ecological importance. Studies on the ecology of this seagrass have looked at the structural and functional attributes at different organisational levels (physiological, individual, population). Further studies and environmental monitoring of Sicilian seagrass ecosystems are required in order to provide integrated coastal zone management actions and protect and prevent environmental damage to aquatic ecosystems. According to a European directive (WFD 2000/60/UE) and an Italian law (152/2006), Biological Quality Elements (BQE) based on seagrass descriptors will, in the immediate future, be considered as ecological indicators for the determination of the Ecological Quality status (EcoQ) [118]. The aim will be to use phenological and lepidochronological descriptors to identify and validate a multivariate synthetic biometric index for *P. oceanica*.

Although it is not always possible to drive overall conclusions for the different species and for the different aspects which have been studied on the seagrass meadows along the Sicilian coasts, we can assess that *P. oceanica* meadows are in a good health in respect to average Mediterranean conditions. This is demonstrated by the high levels of productivity, leaf biometry and flowering performance which have been recorded. Overall genetic diversity is also high, with the exception of isolated meadows such as the *Posidonia* banks and the Stagnone of Marsala [23,63]. Several factors may explain the health status of Sicilian meadows, such as relatively low anthropogenic pressure, sedimentation rate and favourable temperature and photoperiod, linked to longitudinal and latitudinal variations. However, it is very difficult to assess which is the predominant factor, because they are often cross-correlated. An extensive monitoring of selected parameters from *Posidonia* meadows would be necessary, including traditionally acknowledged and new generation indicators, in particular from the southern and eastern Mediterranean basin, for assessing the existence of latitudinal and/or longitudinal spatial patterns and at which scale they operate.

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