Chemistry and Ecology
Vol. 26, Supplement, June 2010, 91–104

Distribution and bio-ecological features of *Posidonia oceanica* meadows along the coasts of the southern Adriatic and northern Ionian Seas

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(*Received 13 July 2009; final version received 15 February 2010*)

An update of the spatial distribution and bio-ecological features of *Posidonia oceanica* (L.) Delile meadows spread along the coasts of the southern Adriatic and northern Ionian Seas (Apulia region, southern Italy) is reported. Mapping carried out in 2004 indicated a remarkable reduction in the spatial distribution of *P. oceanica* meadows in the southern Adriatic Sea, mostly northwards of Bari, when compared with 1991 data. By contrast, in the northern Ionian Sea, the spatial distribution seems to be more stable. The *P. oceanica* meadows covered $\sim$330 km^2 distributed along a total of 320 linear km coastline, mostly on the southern side of Apulia. Within natural variability, the differences in bio-ecological features could be due mainly to the presence of anthropic disturbance (urban, industrial and tourist pressure) rather than a significant geographical gradient between the Adriatic and Ionian Seas. However, the mean density values recorded in almost all the Adriatic stations fall within the 'lower sub-normal density' (LSD) range. By contrast, the mean density values observed in the Ionian meadows were generally within the 'normal density' (ND) range.

Keywords: *Posidonia oceanica*; mapping; GIS; status of health; southern Adriatic Sea; northern Ionian Sea; Apulia

1. Introduction

According to Dayton [1], *Posidonia oceanica* can be considered a 'foundation species' in shallow marine habitats because it is able to build a complex structural and functional system, increasing and stabilizing biodiversity [2]. Corals and canopy-forming plants, able to provide habitats for different species can be considered as other important foundation species. The disappearance of these species from the sea represents a serious problem for other associated species because of the consequent decline in ecosystem services. *P. oceanica* is very sensitive to environmental changes and has therefore been proposed as a 'biological indicator' [3] of changes in the coastal environment. Conservation strategies for this seagrass require a combined approach because all the species living together receive great benefit from their associates [4].

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ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757541003705484
http://www.informaworld.com

In the Mediterranean Sea, *P. oceanica* is the most important living flowering marine plant. The current extension of this seagrass is more restricted than in the past as a consequence of different human and natural impacts. *P. oceanica* meadows are distributed in shallow coastal areas and its decline is recorded throughout the Mediterranean basin as a result of different processes such as a decrease in the quality of seawater, physical damage connected to dumping or fishing activities [5]. The effects of this decline on the distribution of seagrasses in the Mediterranean Sea are very serious, and include coastal erosion, a decrease in primary production, loss of biodiversity and loss of ecosystem function. For these reasons, it is very important to map the real extension of *P. oceanica* meadows and to monitor their spatial distributions annually on both local and wider geographic scales.

The first mapping of *P. oceanica* meadows carried out at a national level in Italy was financed by the ex-Ministry of Merchant Navy (1991) [6]. Since then, increasing interest in *P. oceanica* in the EU (Habitats Directive 92/43/CEE) has driven the Apulia Region to finance (P.O.R. Puglia 2000–2006) an update in mapping of the species along the Apulian coasts, as well as mapping its bio-ecological features in 2004–2005.

Surveys were carried out to evaluate the quality and conservation status of *P. oceanica* meadows at 10 selected sites, 5 in the southern Adriatic Sea and 5 in the northern Ionian Sea. A research consortium was formed (CRISMA, Coop. NAUTILUS, ASSOPESCA Molfetta, Coop. COISPA) and coordination of its activities was entrusted to a scientific committee with experts from the University of Bari, University of Salento (Lecce) and Zoological Station of Naples.

Actually, *P. oceanica* meadows along the southern Adriatic coasts generally extend from ∼8 to 18 m in depth, almost continuously from Bari southwards to Otranto. In addition, residual areas with dead matte and scattered shoots of *Posidonia* were observed for ∼ 50 km north of Bari. In the northern Ionian Sea, *P. oceanica* meadows were generally isolated and extended from ∼10 to 25 m in depth.

The Tremiti Islands, Torre Guaceto (southern Adriatic Sea) and Porto Cesareo (northern Ionian Sea) are Marine Protected Areas (MPAs), established in the region and characterized by the presence of *P. oceanica* meadows. In particular, the meadow distributed around the Tremiti Islands represents the most northerly along the Italian coasts of the Adriatic Sea, with the exception of those bordering the Croatian coasts in the Trieste Gulf [7,8].

Finally, assessment of the quality and conservation status of the *P. oceanica* meadows represents a fundamental prerequisite for management of the coastline, mostly considering the heavy impact of industrial activities and increasing tourist development in the region. For these reasons, it is important to promote and carry out monitoring which allows the detection of any changes over time, and also changes related to environmental conditions. Fortunately, the currently available technologies for submarine investigations provide a higher reliability and more detailed monitoring of the spatial distributions and extension of *P. oceanica* meadows on both local and wider geographic scales than in the recent past.

Thus, the aim of this article is to update the knowledge on the Apulian *Posidonia* meadows as well as to compare the current and previous status as a basic measure in the management of these coastal ecosystems.

2. Materials and methods

2.1. *Mapping*

Surveys were carried out in the southern Adriatic and northern Ionian Seas along the Apulian coasts from September 2004 to April 2005 using a vessel equipped with:

- A Side Scan Sonar EG&G 272-TD with double frequency and image correction;
- an echosounder single-beam with double frequency (30 and 200 kHz);
- a remotely operated underwater vehicle (ROV; Hydrovision-mod. Hyball) with a high-resolution video camera;
- GPS at metric level precision; and
- a PC with PDS-2000-RESON navigation software and Hydro module of Trimble-Navigation installed.

A total area of $\sim$700 km^2 was investigated with 433 line transects realized in the coastal range between 3 and 40 m depth, along a total route of 2000 linear km. A Side Scan Sonar with 100 kHz operative frequency and range of 200 m was used to produce images with a resolution of 0.5 m and overlap of 50 m. In addition, 34 underwater line transects perpendicular to the coast were carried out by means of ROV for a total of 32 h of video recording.

Photomosaic interpretation and cartographic reproduction supported by ROV surveys were carried out using Autocad Map 3D software. Processing of the collected data provided digitalized maps (scale 1:25,000 and 1:10,000) and the realization of a dedicated GIS database on the ArcGis 9.1 platform, containing bio-ecological parameters, underwater videos and photos. Additional methodological details for the sampling design, data treatment and mapping are reported at http://www.pescapuglia.it/.

2.2. *Biological sampling and laboratory analysis*

A total of 10 line transects were allocated in the southern Adriatic Sea (Tremiti Islands, Bari, Torre Guaceto, Le Cesine, Otranto) and northern Ionian Sea (Chéradi Islands, Campomarino, Torre Colimena, Gallipoli, Ugento) (Figure 1). In particular, transects were distributed along the

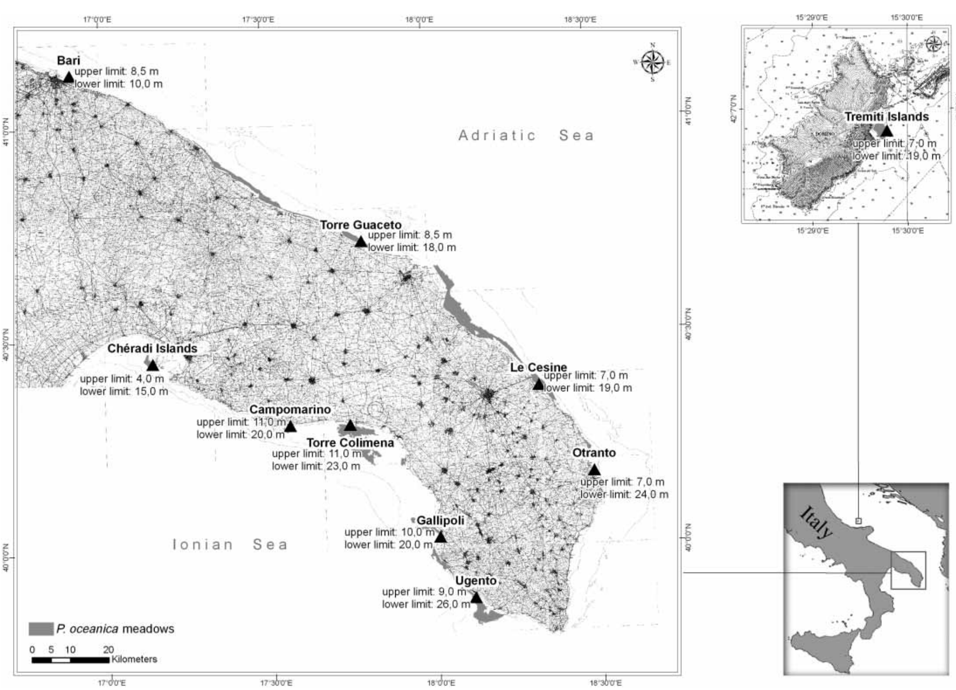

Figure 1. Map of *Posidonia oceanica* meadows along the Apulia region coasts, indicating sampling sites and related upper and lower limit depths.

Apulian coasts in order to consider different environmental conditions and human pressures (e.g. MPA and/or anthropised sites).

Sampling and scuba activities were carried out during August–December 2004. For each transect, three sampling sites were investigated by two scuba divers, corresponding to the upper limit, the middle zone and the lower limit of the meadow [9], for a total of 30 sampling stations. Ten replicates of shoot counting were carried out in each station using a 40 × 40 cm square. Estimates of covered surface (%) were carried out by each diver separately, considering a circular area with a 5 m radius on the bed [9]. For each station, 30 orthotropic (vertical) shoots were collected (900 shoots in total).

Laboratory analyses were conducted following standardized protocols [9–15] using the sampled biological material as follows: morphological and biometrical analysis, 20 shoots × 3 stations × 10 beds = 600 shoots; lepidochronological analysis, 30 rhizomes × 3 stations × 10 beds = 900 rhizomes; and epiphytic analysis, 10 shoots × 3 stations × 10 beds = 300 shoots.

Whenever possible, some types of the abovementioned analysis were conducted on the same shoot or rhizome, in order to minimize the impact of sampling and optimize the laboratory procedures. The data set for all these measurements consists of thousands of records.

A matrix of bio-ecological data (density, cover, coefficient 'A', epiphyte coverage %) was compiled using the mean values from each sampling station. Ordination of the stations according to the upper limit, the middle zone and the lower limit was performed by means of nonmetric multidimensional scaling (nMDS) based on Euclidean distance of the square root data (PRIMER 5 software) [16]. In addition, the differences between sites were tested by means of analysis of similarities (ANOSIM) using data of density, cover, coefficient 'A', epiphyte coverage % from the middle zones, adding the lower limit depth values to this bio-ecological matrix.

3. Results

The Apulian *P. oceanica* meadows measured in this survey cover ∼330 km^2, distributed along a total of 320 linear km of coastline, showing a colonization of 68.1% on matte, 6.6% on sand, 0.5% on rocky bottoms. In addition, the mosaic of *Posidonia* and hard substrates and the mosaic of *Posidonia* and dead matte showed cover values of 18.3 and 6.5%, respectively. The meadows generally showed wider extensions with deeper lower limits along the southern coast of the Adriatic and Ionian Seas (Salento peninsula) (Figure 1).

A summary of bio-ecological features collected in the investigated meadows is reported separately for the sites investigated in the southern Adriatic Sea (Table 1) and in the northern Ionian Sea (Table 2).

Along the Adriatic coast (Tremiti Islands, Bari, Torre Guaceto, Le Cesine, Otranto), meadow density varied at the upper limits (depth 7–8.5 m) between 312 shoots·m^{-2} (Tremiti Island) and 498 shoots·m^{-2} (Otranto); in the middle zone (depth 9–14) the density values were quite variable depending on the site, ranging between 189 shoots·m^{-2} (Tremiti Island) and 502 shoots·m^{-2} (Le Cesine); at the lower limits (depth 19–24 m) the density of beds decreased to a minimum of 74 shoots·m^{-2}(Otranto) and a maximum of 221 shoots·m^{-2}(Le Cesine). Because of the low depth of its lower limit (10 m), the density value measured in the Bari meadow (252 shoots·m^{-2}) was not comparable with density at other sites (Figure 2). The percentage cover of the *Posidonia* meadows varied from a minimum of 15% (Bari) to a maximum of 70% (Torre Guaceto) at the upper limits, whereas in both the middle zones and at the lower limits the values seem to be higher and stable (40–95%).

Considering the morphological parameters, the average number of leaves per shoot ranged between 6.4 and 6.9 in the upper limits, 6.6 and 7.5 in the middle zones and 6.2 and 7.6 at the

Table 1. Bio-ecological data (mean ± SD) recorded for the *Posidonia oceanica* meadows investigated in the southern Adriatic Sea.

	Tremiti Islands (sampling date 9 September 2004)			Bari (sampling date 11 November 2004)			Torre Guaceto (sampling date 18 November 2004)		
Station type	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit
Coordinates (° ’ WGS84): lat.	N 42° 06.850′	N 42° 06.840′	N 42° 06.820′	N 41° 07.542′	N 41° 07.569′	N 41° 07.608′	N 40° 43.431′	N 40° 43.699′	N 40° 43.827′
long.	E 15° 29.600′	E 15° 29.650′	E 15° 29.680′	E 16° 54.167′	E 16° 54.192′	E 16° 54.232′	E 17° 46.976′	E 17° 47.449′	E 17° 47.584′
Depth (m)	7	14	19	8.5	9	10	8.5	11	18
Density (shoots m^{-2})	312 ± 74	189 ± 47	173 ± 38	371 ± 68	301 ± 38	252 ± 53	443 ± 48	347 ± 39	196 ± 23
Cover (%)	60	65	50	15	40	45	70	80	80
Classification bed:	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed
(Giraud, 1977)	III Sparse	IV Very sparse	IV Very sparse	III Sparse	III Sparse	IV Very sparse	II Dense	III Sparse	IV Very sparse
(Pergent et al., 1995; Pergent & Pergent-Martini, 1996)	LSD Disturbed	LSD Disturbed	LSD Disturbed	LSD Disturbed	LSD Disturbed	LSD Disturbed	ND In equilibrium	ND In equilibrium	LSD Disturbed
Intermediate leaf mean length (cm)	13.0 ± 7.1	25.5 ± 17.7	21.3 ± 12.9	14.2 ± 5.9	12.3 ± 5.5	12.6 ± 5.3	22.2 ± 9.1	19.7 ± 9.7	21.7 ± 10.0
Adult leaf mean length (cm)	26.2 ± 7.3	46.3 ± 15.8	56.7 ± 17.0	24.0 ± 8.5	22.7 ± 9.5	23.7 ± 8.9	22.5 ± 5.0	24.3 ± 7.6	31.1 ± 10.0
No. leaves per shoot	6.9 ± 1.3	6.8 ± 1.4	6.8 ± 1.6	6.9 ± 1.0	6.9 ± 1.1	6.7 ± 1.4	6.4 ± 1.0	6.6 ± 1.0	6.9 ± 1.0
Total coeff. ‘A’ (%)	45.6	56.4	43.0	19.0	26.4	20.6	2.9	6.4	15.2
Leaf biomass (g dw · $shoot^{-1}$)	0.546 ± 0.26	1.015 ± 0.39	1.415 ± 0.49	0.470 ± 0.17	0.421 ± 0.12	0.384 ± 0.19	0.497 ± 0.13	0.481 ± 0.20	0.515 ± 0.15
Leaf surface (cm^2 · $shoot^{-1}$)	76.7 ± 26.4	176.6 ± 64.7	227.3 ± 71.6	85.0 ± 26.7	79.7 ± 22.1	73.1 ± 32.9	96.2 ± 22.9	99.4 ± 38.2	127.8 ± 33.4
Leaf standing crop (LSC) (g dw m^{-2})	150.9 ± 66.2	171.9 ± 65.7	216.1 ± 74.7	148.9 ± 51.6	107.7 ± 31.0	83.5 ± 41.6	191.4 ± 50.1	146.6 ± 59.5	88.9 ± 26.0
Leaf area index (LAI) ($m^2 m^{-2}$)	2.4 ± 0.8	3.3 ± 1.2	3.9 ± 1.2	3.2 ± 1.0	2.4 ± 0.7	1.8 ± 0.8	4.3 ± 1.0	3.4 ± 1.3	2.5 ± 0.7
LFR (no. leaves $shoot^{-1}$ $year^{-1}$)	5.0 ± 1.3	5.5 ± 0.9	5.2 ± 1.1	6.0 ± 1.2	5.6 ± 1.5	5.2 ± 1.4	5.7 ± 1.0	5.3 ± 1.3	5.6 ± 1.4
RhER (rhizome cm $year^{-1}$)	0.3 ± 0.1	0.5 ± 0.3	0.5 ± 0.2	0.8 ± 0.4	0.6 ± 0.3	0.5 ± 0.2	0.6 ± 0.2	0.5 ± 0.2	0.4 ± 0.2
RhP (rhizome g dw $year^{-1}$)	0.030 ± 0.025	0.063 ± 0.049	0.056 ± 0.029	0.084 ± 0.046	0.066 ± 0.038	0.048 ± 0.023	0.077 ± 0.099	0.047 ± 0.023	0.038 ± 0.024
No. flower stalks (paleo-flowering)	0	0	0	1	1	0	2	2	1
Epiphytes covering (%)	17.1	13.8	10.5	32.3	37.0	43.9	3.4	11.2	10.8

(*Continued*)

Table 1. Continued.

	Le Cesine (sampling date 14 December 2004)			Otranto (sampling date 23 September 2004)		
Station type	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit
Coordinates (° ’WGS84): lat.	N 40° 22.326′	N 40° 22.357′	N 40° 22.568′	N 40° 09.718′	N 40° 09.819′	N 40° 09.877′
long.	E 18° 19.838′	E 18° 20.522′	E 18° 20.936′	E 18° 29.256′	E 18° 29.284′	E 18° 29.338′
Depth (m)	7	10	19	7	14	24
Density (shoots m^{-2})	359 ± 49	502 ± 86	221 ± 40	498 ± 118	218 ± 62	74 ± 18
Cover (%)	50	70	40	45	95	75
Classification bed:	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed
(Giraud, 1977)	III Sparse	II Dense	IV Very sparse	II Dense	IV Very sparse	V Semi bed
(Pergent et al., 1995; Pergent & Pergent-Martini, 1996)	LSD Disturbed	ND In equilibrium	ND In equilibrium	ND In equilibrium	LSD Disturbed	LSD Disturbed
Intermediate leaf mean length (cm)	17.3 ± 7.3	18.3 ± 6.8	17.7 ± 7.0	9.1 ± 3.4	13.0 ± 5.8	14.6 ± 7.8
Adult leaf mean length (cm)	20.6 ± 7.1	21.4 ± 6.3	20.4 ± 6.3	26.2 ± 9.8	50.1 ± 22.4	51.9 ± 15.4
No. leaves per shoot	6.8 ± 1.0	6.7 ± 0.9	6.2 ± 0.8	6.8 ± 1.3	7.5 ± 1.1	7.6 ± 1.0
Total coeff. ‘A’ (%)	23.1	26.5	23.7	33.0	33.3	40.0
Leaf biomass (g dw · $shoot^{-1}$)	0.419 ± 0.14	0.370 ± 0.08	0.288 ± 0.10	0.521 ± 0.25	1.122 ± 0.42	0.954 ± 0.29
Leaf surface (cm^2 · $shoot^{-1}$)	82.3 ± 27.9	86.1 ± 18.1	76.3 ± 19.5	73.2 ± 39.1	184.5 ± 78.6	171.0 ± 51.8
Leaf standing crop (LSC) (g dw m^{-2})	131.7 ± 45.7	165.7 ± 36.6	55.9 ± 19.6	209.3 ± 105.8	207.5 ± 79.7	61.8 ± 19.2
Leaf area index (LAI) ($m^2 m^{-2}$)	3.0 ± 1.0	4.3 ± 0.9	1.7 ± 0.4	3.6 ± 1.9	4.0 ± 1.7	1.3 ± 0.4
LFR (no. leaves $shoot^{-1}$ $year^{-1}$)	5.6 ± 1.1	5.6 ± 1.2	5.8 ± 1.0	5.8 ± 1.1	5.6 ± 1.3	5.8 ± 1.0
RhER (rhizome cm $year^{-1}$)	0.9 ± 0.7	0.6 ± 0.3	0.7 ± 0.3	0.7 ± 0.3	0.4 ± 0.2	0.4 ± 0.2
RhP (rhizome g dw $year^{-1}$)	0.089 ± 0.068	0.055 ± 0.044	0.056 ± 0.027	0.080 ± 0.038	0.054 ± 0.028	0.044 ± 0.042
No. flower stalks (paleo-flowering)	22	0	1	1	0	0
Epiphytes covering (%)	16.4	14.9	18.9	33.8	19.4	26.6

Table 2. Bio-ecological data (mean ± SD) recorded for the *Posidonia oceanica* meadows investigated in the northern Ionian Sea.

	Cheradi Islands (sampling date 4 August 2004)			Campomarino (sampling date 10 August 2004)			Torre Colimena (sampling date 18 November 2004)		
Station type	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit
Coordinates (° ’ WGS84): lat.	N 40° 26.831′	N 40° 26.777′	N 40° 26.656′	N 40° 17.351′	N 40° 17.185′	N 40° 16.996′	N 40° 17.510′	N 40° 16.784′	N 40° 16.394′
long.	E 17° 08.790′	E 17° 08.682′	E 17° 08.557′	E 17° 33.771′	E 17° 33.841′	E 17° 33.598′	E 17° 44.697′	E 17° 44.230′	E 17° 44.035′
Depth (m)	4	9	15	11	15	20	11	16	23
Density (shoots m^{-2})	494 ± 96	306 ± 46	250 ± 47	343 ± 53	254 ± 30	221 ± 27	344 ± 69	349 ± 27	228 ± 51
Cover (%)	60	80	60	55	55	75	60	95	65
Classification bed:	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed	Class Bed
(Giraud, 1977)	II Dense	III Sparse	IV Very sparse	III Sparse	IV Very sparse	IV Very sparse	III Sparse	III Sparse	IV Very sparse
(Pergent et al., 1995; Pergent & Pergent-Martini, 1996)	LSD Disturbed	LSD Disturbed	ND In equilibrium	ND In equilibrium	ND In equilibrium	ND In equilibrium	ND In equilibrium	ND In equilibrium	ND In equilibrium
Intermediate leaf mean length (cm)	37.0 ± 20.9	29.5 ± 15.7	34.2 ± 19.9	23.2 ± 16.3	34.4 ± 21.3	32.6 ± 16.9	23.2 ± 12.8	24.0 ± 12.3	26.9 ± 12.7
Adult leaf mean length (cm)	39.5 ± 16.8	45.4 ± 19.5	65.7 ± 19.4	51.9 ± 14.7	69.8 ± 20.9	60.1 ± 18.7	42.9 ± 13.8	40.3 ± 14.9	40.9 ± 12.0
No. leaves per shoot	6.3 ± 1.5	5.9 ± 1.2	6.4 ± 1.1	6.7 ± 1.5	5.8 ± 1.1	7.0 ± 1.1	6.5 ± 0.8	6.5 ± 0.9	6.5 ± 0.7
Total coeff. ‘A’ (%)	64.7	47.7	22.6	41.2	29.5	27.7	16.3	12.0	16.3
Leaf biomass (g dw · $shoot^{-1}$)	0.797 ± 0.30	0.810 ± 0.36	1.166 ± 0.31	0.966 ± 0.35	1.121 ± 0.19	1.379 ± 0.44	0.608 ± 0.25	0.591 ± 0.28	0.605 ± 0.13
Leaf surface (cm^2 · $shoot^{-1}$)	125.2 ± 44.5	131.2 ± 50.1	205.8 ± 47.9	160.7 ± 54.5	202.7 ± 32.8	254.1 ± 74.7	134.8 ± 47.8	130.7 ± 58.2	128.6 ± 26.0
Leaf standing crop (LSC) (g dw m^{-2})	349.6 ± 136.9	218.3 ± 96.7	257.0 ± 65.9	286.7 ± 101.6	257.6 ± 45.5	270.2 ± 84.2	186.5 ± 79.7	184.6 ± 87.4	122.6 ± 28.1
Leaf area index (LAI) ($m^2 m^{-2}$)	6.2 ± 2.2	4.0 ± 1.5	5.1 ± 1.2	5.5 ± 1.9	5.2 ± 0.8	5.6 ± 1.6	4.6 ± 1.6	4.6 ± 2.0	2.9 ± 0.6
LFR (no. leaves $shoot^{-1}$ $year^{-1}$)	5.7 ± 1.3	6.0 ± 1.2	5.6 ± 0.9	5.9 ± 0.9	5.5 ± 1.1	5.7 ± 1.1	5.8 ± 1.1	5.3 ± 1.2	5.6 ± 1.2
RhER (rhizome cm $year^{-1}$)	0.7 ± 0.3	0.6 ± 0.2	0.5 ± 0.2	0.8 ± 0.5	0.7 ± 0.4	0.7 ± 0.3	0.8 ± 0.4	0.9 ± 1.2	0.9 ± 0.5
RhP (rhizome g dw $year^{-1}$)	0.055 ± 0.037	0.063 ± 0.043	0.042 ± 0.016	0.074 ± 0.051	0.045 ± 0.030	0.052 ± 0.027	0.062 ± 0.027	0.061 ± 0.040	0.081 ± 0.052
No. flower stalks (paleo-flowering)	0	0	0	2	0	8	7	3	1
Epiphytes covering (%)	20.6	42.5	28.8	11.7	20.6	15.4	2.1	3.1	3.4

(*Continued*)

Table 2. Continued.

	Gallipoli (sampling date 26 October 2004)			Ugento (sampling date 6 November 2004)		
Station type	Upper limit	Middle zone	Lower limit	Upper limit	Middle zone	Lower limit
Coordinates (° ’ WGS84): lat.	N 40° 01.177’	N 40° 01.196’	N 40° 01.133’	N 39° 52.944’	N 39° 52.599’	N 39° 52.052’
long.	E 18° 00.994’	E 18° 00.736’	E 18° 00.379’	E 18° 06.877’	E 18° 06.856	E 18° 06.207’
Depth (m)	10	13	20	9	14	26
Density (shoots m^{-2})	319 ± 30	341 ± 77	121 ± 18	458 ± 107	357 ± 74	117 ± 18
Cover (%)	70	68	55	75	80	40
Classification bed:	Class / Bed	Class / Bed	Class / Bed	Class / Bed	Class / Bed	Class / Bed
(Giraud, 1977)	III / Sparse	III / Sparse	V / Semi bed	II / Dense	III / Sparse	V / Semi bed
(Pergent et al., 1995; Pergent & Pergent-Martini, 1996)	LSD / Disturbed	ND / In equilibrium	LSD / Disturbed	ND / In equilibrium	ND / In equilibrium	ND / In equilibrium
Intermediate leaf mean length (cm)	16.7 ± 7.7	14.7 ± 6.0	10.9 ± 4.2	19.5 ± 9.5	24.8 ± 11.7	19.5 ± 8.8
Adult leaf mean length (cm)	34.7 ± 16.1	33.2 ± 14.3	28.0 ± 10.0	33.0 ± 13.4	37.6 ± 11.3	48.8 ± 15.9
No. leaves per shoot	6.6 ± 0.9	7.0 ± 1.3	7.6 ± 1.2	6.1 ± 0.6	6.2 ± 0.8	6.8 ± 0.8
Total coeff. ‘A’ (%)	27.0	21.7	31.2	14.9	23.2	22.6
Leaf biomass (g dw · $shoot^{-1}$)	0.573 ± 0.26	0.542 ± 0.22	0.575 ± 0.24	0.527 ± 0.18	0.588 ± 0.13	0.777 ± 0.26
Leaf surface (cm^2 · $shoot^{-1}$)	99.0 ± 43.7	103.3 ± 41.8	95.6 ± 42.0	104.2 ± 30.8	118.4 ± 22.8	161.0 ± 49.9
Leaf Standing Crop (LSC) (g dw m^{-2})	161.5 ± 73.5	162.2 ± 65.9	58.8 ± 25.1	214.8 ± 74.7	186.6 ± 38.4	80.2 ± 27.0
Leaf area index (LAI) ($m^2 m^{-2}$)	3.2 ± 1.4	3.5 ± 1.4	1.2 ± 0.5	4.8 ± 1.4	4.2 ± 0.8	1.9 ± 0.6
LFR (no. leaves $shoot^{-1}$ $year^{-1}$)	6.3 ± 1.4	5.4 ± 0.9	6.2 ± 1.4	5.6 ± 0.9	6.0 ± 0.8	5.8 ± 1.7
RhER (rhizome cm $year^{-1}$)	1.1 ± 0.5	0.4 ± 0.1	0.5 ± 0.2	0.7 ± 0.3	1.0 ± 0.4	0.4 ± 0.2
RhP (rhizome g dw $year^{-1}$)	0.104 ± 0.062	0.035 ± 0.058	0.053 ± 0.033	0.077 ± 0.041	0.088 ± 0.038	0.053 ± 0.040
No. flower stalks (paleo-flowering)	0	0	0	0	0	0
Epiphytes covering (%)	7.4	6.6	9.0	18.7	14.0	10.9

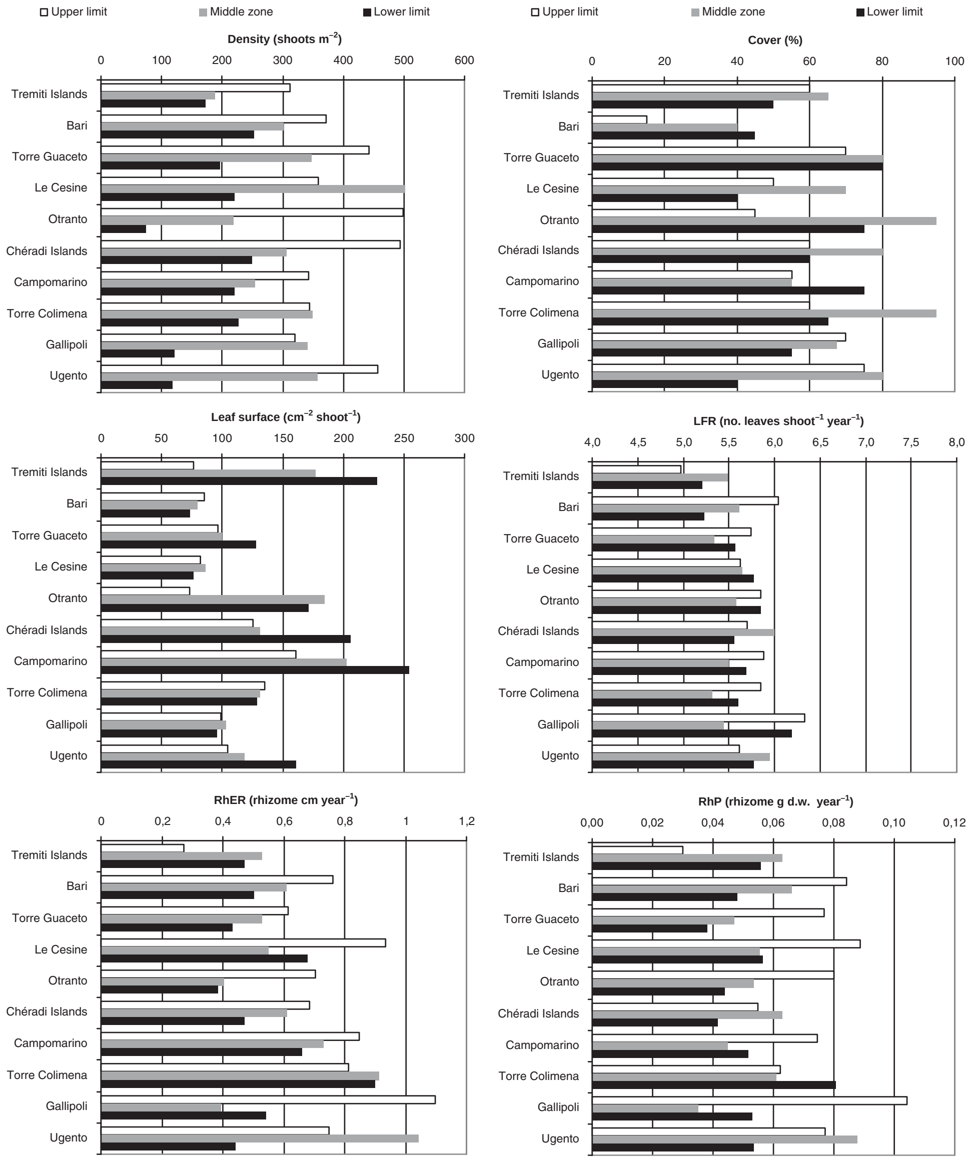

Figure 2. Bio-ecological features [density, cover, leaf surface, leaf formation rate (LFR), rhizome elongation rate (RhER) and rhizome production (RhP)] calculated for the *Posidonia oceanica* meadows distributed along the Apulian coasts in the southern Adriatic and northern Ionian Seas.

lower limits. The mean total length of intermediate leaves ranged between 9.1 and 22.2 cm in the upper limits, 12.3 and 25.5 cm in the middle zones, and 20.4 and 56.7 cm at the lower limits. The mean total length of adult leaves ranged between 20.6 and 26.2 cm in the upper limits, 21.4 and 50.1 cm in the middle zone, and 20.4 and 56.7 cm in the lower limits. In addition, the percentage of adult and intermediate leaves with broken apices (coefficient ‘A’), generally showed values ranging between 4.4 and 77.8% for adult leaves, and 0.0 and 21.1% for intermediate leaves. The leaf surface ($cm^2 \cdot shoot^{-1}$) showed mean values ranging from 73.2 to 96.2 cm^2 in shallower stands and 79.7 and 184.5 cm^2in the middle zones of the meadows (depth range 9–14 m) (Figure 2). Moreover, mean values between 73.1 and 227.3 cm^2 were recorded for shoots sampled at the lower limits. The leaf biomass (g dw·shoot^{-1}) showed mean values ranging from 0.419 to 0.546 g in upper limit stands, but very wide ranges between 0.370 and 1.122 g and 0.288 and 1.415 g were reported for the middle zones and lower limits, respectively. Correlated with the shoot density data, the Leaf Area Index (LAI) values calculated for the five Adriatic meadows ranged between 1.3 and 4.3 m^2·m^{-2}, while the Leaf Standing Crop (LSC) values varied from 55.9 to 216.1 g dw·m^{-2}. Concerning the other production data, the leaf formation rate (LFR) (leaves·shoot^{-1}·year^{-1}) indicates an average annual production of 5.0–7.6 leaves per shoot for investigated sites (Figure 2). The rhizome elongation rate (RhER; cm·shoot^{-1}·year^{-1}) showed an average value ranging between 0.3 and 0.9 cm at the upper limit stands, with a more restricted variability in growth rate (0.4 to 0.7 cm) observed for the rhizomes coming from the middle zones and from the lower limits. The rhizome production (RhP; g dw·shoot^{-1}·year^{-1}) showed average values ranging between 0.030 and 0.089 g at the upper limits, 0.047 and 0.066 g in the middle zones, and 0.038 and 0.056 g at the lower limits. Past flowering events were observed at the Le Cesine site where a total of 23 flower stalks were observed from 1992 to 2004. In particular, four, six and seven flower stalks were recorded in 1998, 1999 and 2003, respectively. In addition, seven flower stalks were detected at Torre Guaceto from 1998 and 2004. Finally, percentage cover of leaf epiphytes showed values between a minimum of 3.4% and a maximum of 43.9%.

Along the Ionian coast (Chéradi Islands, Campomarino, Torre Colimena, Gallipoli, Ugento), the meadow density varied at the upper limits (depth 4–9 m) between 319 shoots·m^{-2} (Gallipoli) and 494 shoots·m^{-2} (Chéradi Island). In the middle zone (depth 9–16 m) the density varied between 254 shoots·m^{-2} (Campomarino) and 357 shoots·m^{-2} (Ugento); at the lower limits (depth 15–26 m) the density was within the range 117 shoots·m^{-2}(Ugento) and 250 shoots·m^{-2}(Chéradi Islands) (Figure 2). The percentage cover of beds at the upper limits was significantly higher than on the Adriatic coast, varying from 55% (Campomarino) to 75% (Ugento). In the middle zones and at lower limits the values seem consistently high (55–95%).

Regarding the morphological measures, the average number of leaves per shoot ranged between 6.1 and 6.7 in the upper limits, 5.8 and 7.0 in the middle zones, and 6.4 and 7.6 in the lower limits. The mean total length of intermediate leaves ranged between 16.7 and 37.0 cm in the upper limits, 14.7 and 34.4 cm in the middle zones, and 10.9 and 34.2 cm at the lower limits. The mean total length of adult leaves ranged between 33.0 and 51.9 cm in the upper limits, 33.2 and 69.8 cm in the middle zones, and 28.0 and 65.7 cm at the lower limits. In addition, the percentage of adult and intermediate leaves with broken apices (coefficient 'A'), generally showed values ranging between 23.9 and 83.6% for adult leaves, and 0.0 and 16.7% for intermediate leaves. The leaf surface (cm^2·shoot^{-1}) showed mean values ranging between 99.0 and 160.7 cm^2 in shallower stands, and 103.3 and 202.7 cm^2 in the middle zones of the meadows (depth range 9–16 m) (Figure 2). Moreover, mean values between 95.6 and 254.1 cm^2 were recorded for shoots sampled at the lower limit stands. The leaf biomass (g dw·shoot^{-1}) showed mean values ranging between 0.527 and 0.966 g at the upper limit stands, 0.542 and 1.121 g for the middle zones, and 0.575 and 1.379 g at lower limits. Correlated with the density data, the LAI values calculated in five meadows in the northern Ionian Sea ranged between 3.2 and 6.2 m^2·m^{-2}, whereas the LSC values varied from 58.8 to 349.6 g dw·m^{-2}. Continuing evaluation of the other production parameters, also for the investigated sites in Ionian Sea the LFR (leaves·shoot^{-1}·year^{-1}) showed an average annual production of 5.3–6.3 leaves per shoot (Figure 2). However, the RhER (cm·shoot^{-1}·year^{-1}) showed an average value between 0.7 and 1.1 cm in the upper limit stands and a variable growth rate (0.4–1.1 cm) for the rhizomes collected in the middle zones and at the lower limits. RhP (g dw·shoot^{-1}·year^{-1}) showed average values ranging between 0.055 and 0.104 g at the upper limits, 0.035 and 0.088 g in the middle zones and 0.042 and 0.081 g at the lower limits. Paleo-flowering in the northern Ionian Sea was detected at Campomarino (10 flower stalks) from 1997 to 2000 and at Torre Colimena (11 flower stalks) from 1998 to 2000. Finally, percentage cover of leaf epiphytes generally ranged between 2.1 and 42.5%.

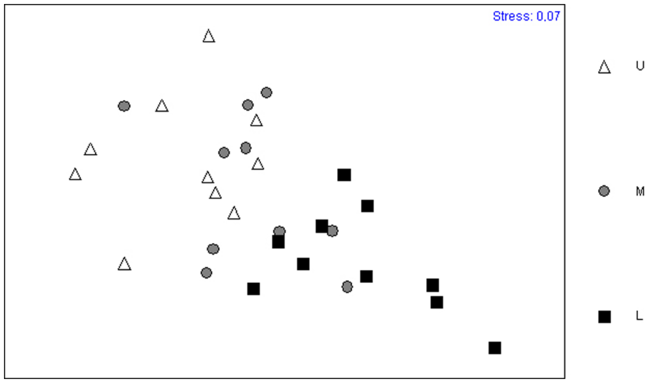

Figure 3. Ordination of sampling site (△, upper limit U; □, middle zone M; ■, lower limit L) performed by nonmetric multidimensional scaling.

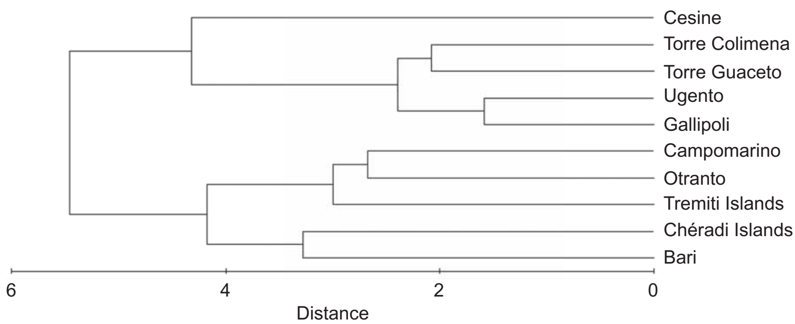

Figure 4. Dendrogram of the sampling site elaborated using bio-ecological data related to the middle zones.

The multivariate analysis by means of nMDS showed slight differences between the sampling stations ($R = 0.337$, $p = 0.001$) (Figure 3). In particular, the pairwise test only gave a significant difference between the upper and lower limit stations ($R = 0.646$, $p = 0.001$).

No significant geographical differences were observed in the bio-ecological features of the meadows distributed in the Adriatic and the Ionian Seas. However, two main groups seem to separate according to the different levels of anthropic disturbance observed in the Apulia region (Figure 4).

4. Discussion and conclusions

The spatial distribution and the bio-ecological data reported in this study provide an update of the knowledge available on the *P. oceanica* meadows along the coasts of the Apulia region, representing a fundamental contribution for the management of the regional coastline. The overall results −48 digitalized maps of *P. oceanica* meadows in the Apulia region (1:25,000); 12 maps (1:10,000) at the MPAs and creation of a dedicated GIS platform containing all the bio-ecological data and information – were collected in a DVD support published by the above mentioned Consortium (2006) [17], and currently available at http://www.pescapuglia.it.

The mapping carried out in 2004 indicated a remarkable reduction in the spatial distribution of the *P. oceanica* meadows along the coasts of the southern Adriatic Sea, mostly north of Bari, when compared with 1991 data. By contrast, along the northern Ionian Sea, the spatial distribution of the *P. oceanica* meadows seems to be more stable. Moreover, the depth limit of the meadows seems to be quite stable on both the Adriatic and Ionian coasts with the exception of Bari, where the reduction in both the upper and lower limits recorded in 1991 showed an increasing trend. However, the overlapping between the maps produced in 1991 and 2004 is not realible because of the great technogical gap between the studies and the different data treatment adopted.

Within the natural variability, the differences in the bio-ecological features observed in the meadows of the Tremiti Islands, Bari, Otranto, Chéradi Island and Campomarino could be mainly because of the higher presence of anthropic disturbance (urban, industrial and touristic pressure) in these areas than in Torre Guaceto, Le Cesine, Torre Colimena, Gallipoli and Ugento. No significant geographical gradient was observed in the differences of bio-ecological features for the meadows distributed in the Adriatic and the Ionian Seas. However, the mean density values recorded in almost all the Adriatic stations fall into the range of 'lower sub-normal density' (LSD) according to the classification proposed by Pergent-Martini [9,14]. By contrast, the mean density values observed in the Ionian meadows generally were in the range of 'normal density' (ND).

Some comparisons with previous investigations carried out in 1997 [18] and 2001 [19] are possible for the Tremiti Islands, Otranto and Chéradi Island meadows (Table 3). In particular, a quite stable condition was observed in the Chéradi Island meadows. However, in both the investigated meadows of the Tremiti Islands and Otranto a general decreasing trend was observed

Table 3. Comparison between bio-ecological data collected for the *Posidonia oceanica* meadows investigated during 1997, 2001 and the current study.

	Upper limit			Middle zone		Lower limit	
	1997	2001	Current study	2001	Current study	2001	Current study
Tremiti Islands							
Depth (m)	8	6	7	14	14	18	19
Density (shoots m^{-2})	445	308	312	236	189	244	173
Cover (%)	–	80	60	95	65	80	50
Leaf area index (LAI) (m^2m^{-2})	–	4.1	2.4	4.2	3.3	6.3	3.9
RhER (rhizome cm $year^{-1}$)	0.60 ± 0.13	0.40 ± 0.20	0.27 ± 0.13	0.60 ± 0.20	0.53 ± 0.29	0.60 ± 0.30	0.47 ± 0.18
RhP (rhizome g dw $year^{-1}$)	0.06 ± 0.02	0.03 ± 0.02	0.03 ± 0.03	0.05 ± 0.02	0.06 ± 0.05	0.05 ± 0.03	0.06 ± 0.03
Otranto							
Depth (m)	7	7	7	12	14	24	24
Density (shoots m^{-2})	633	349	498	323	218	115	74
Cover (%)	–	60	45	90	95	90	75
Leaf area index (LAI) (m^2m^{-2})	–	4.4	6.3	6.7	4.0	2.1	1.3
RhER (rhizome cm $year^{-1}$)	0.80 ± 0.20	1.30 ± 0.40	0.70 ± 0.32	0.90 ± 0.40	0.40 ± 0.15	0.50 ± 0.30	0.38 ± 0.23
RhP (rhizome g dw $year^{-1}$)	0.06 ± 0.02	0.12 ± 0.05	0.08 ± 0.04	0.09 ± 0.06	0.05 ± 0.03	0.04 ± 0.03	0.04 ± 0.04
Cheradi Islands							
Depth (m)	–	5	4	10	9	13	15
Density (shoots m^{-2})	–	356	494	310	306	224	250
Cover (%)	–	50	60	90	80	80	60
Leaf area index (LAI) (m^2m^{-2})	–	4.2	6.2	7.0	4.0	5.5	5.1
RhER (rhizome cm $year^{-1}$)	–	1.49 ± 0.58	0.69 ± 0.34	0.56 ± 0.21	0.61 ± 0.23	0.48 ± 0.25	0.47 ± 0.16
RhP (rhizome g dw $year^{-1}$)	–	0.12 ± 0.06	0.05 ± 0.04	0.05 ± 0.03	0.06 ± 0.04	0.04 ± 0.03	0.04 ± 0.02

in the bio-ecological features. The high tourist pressure on these areas may explain these results. In particular, concerning the meadow of the Tremiti Islands, no evident protective effect seems to have derived from the presence of the MPA. In particular, the repeated anthropogenic disturbance (anchorages) inside the less-protected zone (area C) seem to be the main threat to this meadow. Moreover, intrinsic vulnerability because of its geographic and genetic isolation could reduce the potential capability for renewal of this meadow [17].

It is important to highlight that any decline in *P. oceanica* meadows could have serious economic implications not only in terms of loss of biodiversity and ecosystem quality, but also related to a decrease in fishing resources and an increase in coastal erosion. In fact, *P. oceanica* meadows are considered as an 'essential fish habitat' for their role as a spawning and nursery area; thus, the value of the loss of fishing activity is greater than the cost of protection of this fundamental Mediterranean ecosystem.

Finally, the Millenium Ecosystem Assessment in 2005 defined 'ecosystem services' as the multiple benefits given by ecosystems to humans. In fact, changes in ecosystems are causing changes in human well-being. For these reasons, the loss of these services should involve a PSE (Payment for the Services of Ecosystems) by the government.

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