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Wetland monitoring: aquatic plant changes in two Corsican coastal lagoons (Western Mediterranean Sea)

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ABSTRACT

1. A monitoring system was developed in two Corsican coastal lagoons (Biguglia and Urbino; Corsica, Western Mediterranean).

2. Three species of seagrass (*Nanozostera noltii*, *Ruppia cirrhosa* and *Cymodocea nodosa*) were monitored by (i) measuring spatio-temporal changes in the seagrasses, using fixed structures, (ii) investigating temporal changes in the biological parameters of the seagrasses, and (iii) mapping their distribution by processing aerial images of both lagoons.

3. These investigations showed that, while the two lagoons exhibit, a priori, a certain structural homogeneity (ecosystems based on aquatic plants), they function in different ways that are specifically linked to environmental conditions.

4. At present, the estimated net production varies from 86 to 469 g C m⁻² yr⁻¹ at Biguglia and 190 to 1301 g C m⁻² yr⁻¹ at Urbino. These values confirm the richness of these two lagoons, and the interest of using seagrass, by means of regular monitoring, for the conservation and management of coastal lagoons.

KEY WORDS: coastal lagoon; Mediterranean; seagrass; monitoring; mapping; population dynamics

INTRODUCTION

Wetlands are important reservoirs for biodiversity. Wetlands perform various functions that are essential to the life of the organisms that are dependent on them (feeding, reproduction, shelter, refuge and rest). These biological functions give wetlands a distinctly higher productivity rate than other environments (Kjerfve, 2000). Wetlands also contribute to the maintenance and improvement of water quality by acting as a purifying filter, since they favour the deposition of sediments and the trapping of toxic elements, and are also a favoured site for biochemical degradation (Kjerfve, 2000).

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[†]egal contribution to the work

Aquatic macrophytes, in particular aquatic angiosperms, constitute a major component of lagoonal ecosystems (Millet and Guelorget, 1993; Sfriso and Ghetti, 1998; Sfriso *et al.*, 2001, 2003; Duarte *et al.*, 2002; Menéndez, 2002; Marzano *et al.*, 2003). These plants are of particular interest in view of their ecological (Tamisier and Boudouresque, 1994) and economic roles (Pearce and Crivelli, 1994; Skinner and Zalewski, 1995). They also contribute to the sedimentary balance (Skinner and Zalewski, 1995) and constitute a bioindicator of water quality (Succow and Reinhold, 1978 (in Blandin, 1986); Meriaux and Watez, 1980; Guilizzoni, 1991).

Currently, the development of various human activities (e.g. the exploitation of living resources, industrialization, urbanization and fishing) affects the stability and conservation of lagoonal ecosystems and, in some instances, seriously jeopardizes their future survival (Bacher *et al.*, 1995; Bettinetti *et al.*, 1996; Herrera-Silveira, 1996; De Casabianca *et al.*, 1997; Deslous-Paoli *et al.*, 1998; Kjerfve, 2000). Wetlands are extremely fragile and threatened; almost a million hectares have been destroyed over the past 50 years (Ramade, 1990). Although they are registered in Annexe I of the EU Habitats Directive as a priority habitat, and some of them are on the list of sites covered by the Ramsar Convention, Mediterranean lagoons are rarely truly protected, and their destruction continues. Numerous studies have reported the degradation of vegetation (Montague and Ley, 1993; De Casabianca *et al.*, 1997), the deterioration of physical and chemical parameters (e.g. salinity, turbidity, silting; Souchu *et al.*, 1997, 1998; De Casabianca and Posada, 1998), or even the infilling of lagoons (e.g. wetlands of St. Florent — Corsica, France). While a few lagoons enjoy specific protective measures (e.g. Camargue Natural Reserve — France, Ebro Natural Park — Spain, Ichkeul National Park — Tunisia; Carasp, 1997), this does not necessarily ensure their actual conservation. In addition, the few attempts at lagoon rehabilitation that have been undertaken over the past 20 years (Pergent and Ben Maïz, 2001), have shown that this involves long and costly procedures with a highly uncertain outcome (Vidy, 2001). It is thus vital to develop tools for the effective management and protection of these remarkable sites, before irreversible degradation occurs.

Within the Mediterranean Basin, Corsica (an island in the Western Basin) is of particular importance, with more than 50 coastal lagoons, covering 3000 hectares (Pergent-Martini *et al.*, 1997). Given the importance of aquatic angiosperms in these lagoons (i.e. *Cymodocea nodosa* (Ucria) Ascherson, *Nanozostera noltii* (Hornem.) Tomlinson, *Ruppia cirrhosa* (Petagna) Grande; Pergent-Martini *et al.*, 1997; Agostini *et al.*, 2003a), it seemed necessary to develop a monitoring system based on patterns of distribution and change in the seagrasses, for two of the major lagoons of the east coast of the island. The aims were (i) to diagnose the state of these lagoons in order to establish a baseline reference state, and (ii) to initiate an ongoing survey which will provide a basis for the proper management and conservation of these sites.

MATERIALS AND METHODS

The two sites chosen (Figure 1) show distinct differences regarding both their typology (depth, salinity) and the human pressures to which they are exposed (Table 1). The Biguglia lagoon (Figure 1) is linked to the sea by a channel to the north, and a channel to the south. A mesohaline type lagoon (Sacchi, 1985; Table 1), it is characterized by high inputs of freshwater in the southern part (e.g. 60% to 140%; Frisoni and Dutrieux, 1992). The sedimentological profile is classic, with fine sediment, rich in organic silt, in the centre and on the continental shore, and coarse sandy sediment, sometimes shelly and giving rise to beaches, near the lido (Agenc, 1989). The lagoon is mainly used for fishing, with a mean annual production of 180 t of fish (Boulmer *et al.*, 1997). The Urbino lagoon (Figure 1) is linked to the sea by a regularly maintained channel in the north-east (Clanzig, 1992). A euryhaline lagoon (Table 1; Sacchi, 1985), it is characterized by the high degree of homogeneity of its water mass (except at the river outlets, in the north-west sector). The bottom consists of silt, rich in organic matter (Longere *et al.*, 1972), sand and terrigenous or shelly sediments (Coerd'acier, 1987). The lagoon is mainly used for aquaculture, with a production rate that varies

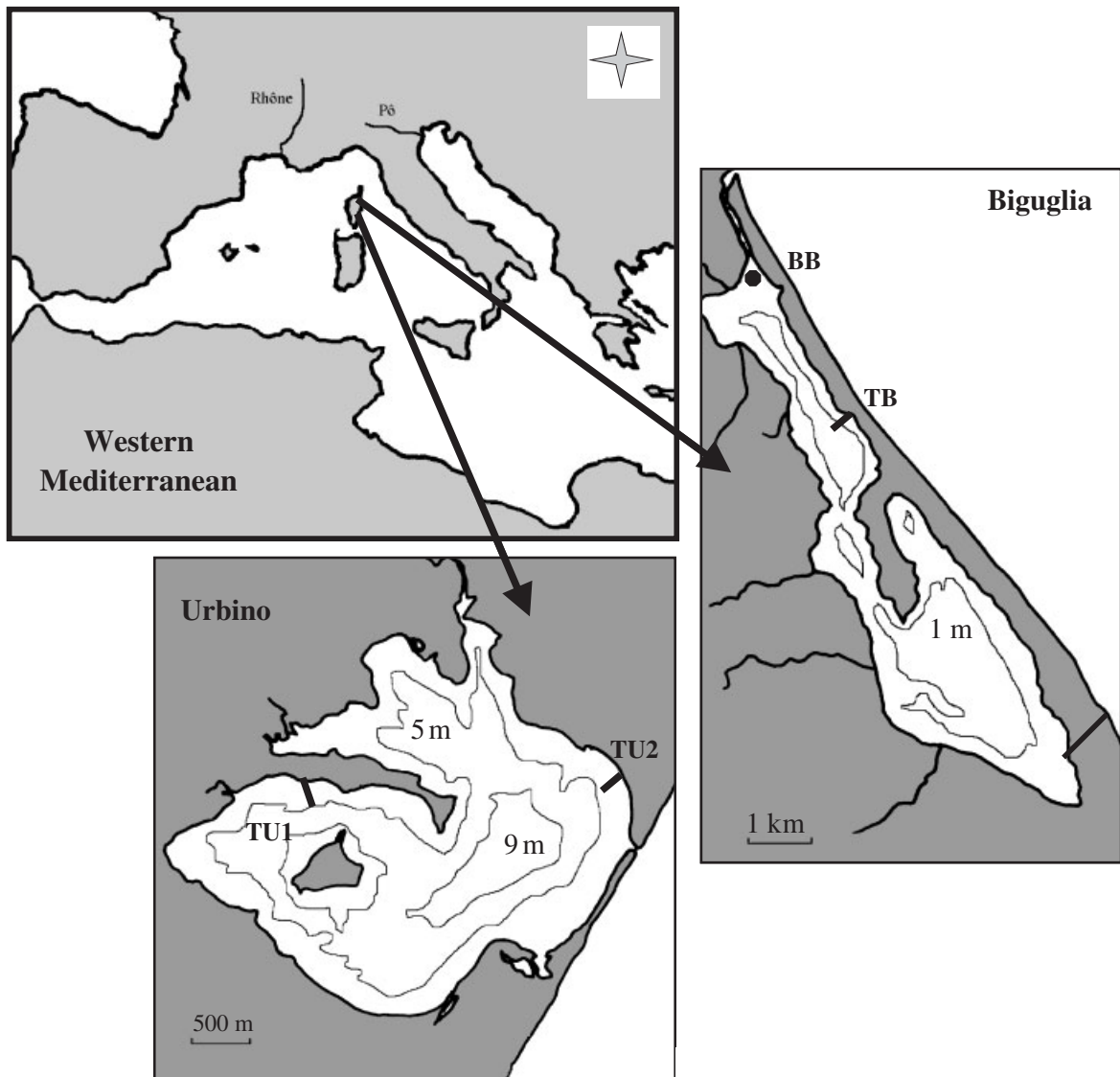


Figure 1. Situation of the Biguglia and Urbino lagoons and monitoring structures (BB, marked survey area Biguglia; TB, Transect Biguglia; TU1, Transect Urbino no. 1; TU2, Transect Urbino no. #2).

considerably from year to year, both quantitatively and qualitatively. Production rose from 162 t of shellfish and 20 t of fish in 1978, to 200–250 t of fish in the 1990s (Clanzig, 1992). Currently, production has declined, with an annual mean production of 50 t of fish (i.e. *Dicentrarchus labrax* and *Sparus aurata*) and 40 t of shellfish (i.e. *Crassostrea gigas*), together with fishing (seasonal small craft fishing) estimated at 100 t (Pergent-Martini *et al.*, 1997).

The spatio-temporal changes in the seagrasses were investigated by means of fixed structures. Monitoring was carried out using fixed markers, placed in the lagoon in April 1998 and regularly checked each season until April 1999. The markers (metal rods) were positioned along the outer limit of a meadow (marked survey area) or within a stand along a precise axis (transect). Whichever the technique chosen, the aim was

Table 1. General characteristics of the sites studied (Pergent-Martini *et al.*, 1997)

Lagoon	Biguglia	Urbino
<i>Abiotic parameters</i>		
Geographical coordinates	42°37'N; 9° 27'E	42°03'N; 9° 28'E
Surface area (ha)	1500	760
Maximum depth (m)	1.8	9.2
Mean depth (m)	1.5 m	5 m
Volume (millions of m ³)	38	33
Catchment area (km ²)	180	31
Temperature (°C)	5 to 26	9 to 29
Salinity (‰)	4 to 26	26 to 44
<i>Human pressure sources</i>		
Population of catchment area (ha)	18 528	245
Industrial and touristic activities in the catchment area	Effluent, wine-making, airport, oil tanks, boilerworks, hotels and restaurants, transport	None
Agricultural activities in the catchment area	Orchards, vineyards, pumpkins and squashes, stock-rearing	Orchards, vineyards (only in parts)
Activities at the 'lido'	Built-up area, holiday village, hotels and restaurants	None
Fishing and aquaculture	Fishing: 180 t yr ⁻¹ of fish	Limited fishing Aquaculture: 150 t yr ⁻¹ of fish; 40 t yr ⁻¹ of shellfish

to record accurately the existing meadows and bottom types in order to perform an accurate micro-cartographic survey (precision 20 cm). Survey markers and a permanent transect were set up in the Biguglia lagoon and two transects in the Urbino lagoon (Figure 1). The survey markers set up in Biguglia lagoon encompassed the unique zone containing *Nanozostera noltii* (nearness of the channel). Transects set up in both lagoons were established on the basis of the results of preliminary surveys in areas with representative seagrasses (cover, distribution, present species).

In parallel, *in situ* sampling (five replicates) was carried out by means of a cylindrical corer (15 cm in diameter and 50 cm in height), at a water-depth of 0.5 m, in order to record the seasonal patterns of change in the vegetation. For each sample, we took care to ensure that none of the leaves were cut, by sliding a hand into the corer and arranging them all vertically. These samples were collected from January 1998 to July 1999, in order to determine the state of the plant formations over an annual cycle (January 1998 to January 1999) and initiate a short-term survey (January 1999 to July 1999). In the laboratory, for each core, the density (number of shoots per m²) of each species present was determined, then the below-ground tissues (rhizomes and roots) and above-ground tissues (leaf shoots) were separated and oven-dried (48 hours at 60°C), and the biomass of each fraction was measured. A study of the main foliar biometric parameters of seagrasses (e.g. length, width, number of leaves; LAI: Leaf Area Index; Coefficient A: percentage of leaves having lost their apex owing to grazing by herbivores or to hydrodynamic action; Giraud, 1977) was added in order to complement the preceding observations.

The distribution of the aquatic angiosperms and bottom types was mapped by image processing of aerial photographs of the Biguglia and Urbino lagoons, according to the method defined by Pasqualini *et al.* (1997). The photographs, scale 1/10 000, were taken in June 1999 (Compagnia Generale Ripresaeree di Parma[®]). The resolution was adjusted in order to obtain a 2 m by 2 m pixel. The image-processing operation enabled the main meadows and bottom types to be identified, on the basis of the colours in the

aerial photographs and point-based field data; 150 point-based field data were obtained for each lagoon, from the surface by means of a Calpha bucket when the depth and turbidity allowed, or by scuba diving. The position of each point was recorded using differential GPS (Global Positioning System: Valsat MLR), giving a level of precision of less than the size of a pixel. These point-based field data were used to classify the image-processing and were generalized to the whole of the image, in order to produce the thematic map (Pasqualini *et al.*, 1997).

The comparisons of mean parameters as a function of site or species were processed by the Mann–Witney or Kruskal–Wallis tests (Zar, 1984). The relation between two parameters was analysed using simple linear regression (Zar, 1984). The correctness of the fit was tested by analysis of variance. The software used was Statgraphics plus (v2.1) for Windows.

RESULTS

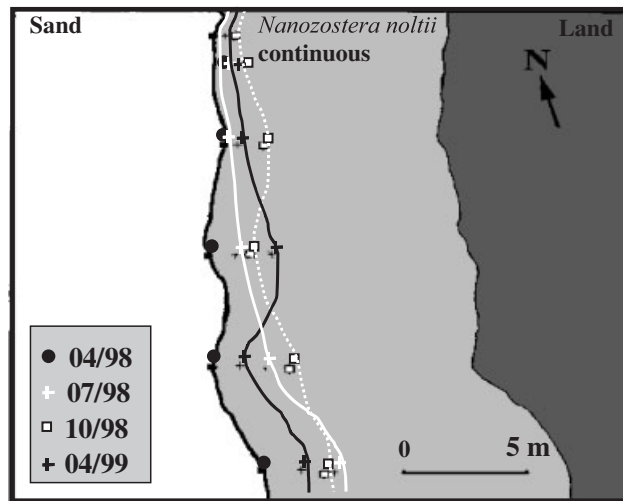
Local distribution and temporal changes

Four species of aquatic angiosperms were recorded in the Biguglia lagoon: *Nanozostera noltii*, *Ruppia cirrhosa*, *Ruppia maritima* Linneus and *Potamogeton pectinatus* Linneus. Monitoring in January 1999 was ruled out by these aquatic plants' lack of above-ground structures in winter. The survey markers (Figure 2(a)) were positioned at the limit of a monospecific *N. noltii* meadow, at a depth of -0.8 m. From April to October 1998, a decrease in *N. noltii* was observed. The limit of the meadow in April 1999 remained short of that observed one year previously (0.7 m in the north to 1.8 m in the south). The seasonal fluctuations were much more marked in the south of the survey area (maximum range of variation 3 m) than in the north (maximum variation range 1 m). For the transect (Figure 2(b)), in April 1998, a continuous relatively dense *Ruppia* sp. meadow was observed (up to 50 m from the shore), with a little *Ulva* sp. This plurispecific meadow comprised 90% *R. cirrhosa* and extended from -1.1 m to -1.6 m in depth. Below that, there was mainly silt colonized to a greater or lesser extent by *Ulva* sp., which can produce very dense (continuous) formations locally, from 50 to 75 m from the shore) with a little *R. cirrhosa*. This continuous *R. cirrhosa* meadow disappeared almost entirely, and only reappeared in spring 1999. It then occupied virtually the whole transect. Within this transect, a few specimens of *R. maritima* and *P. pectinatus* were observed.

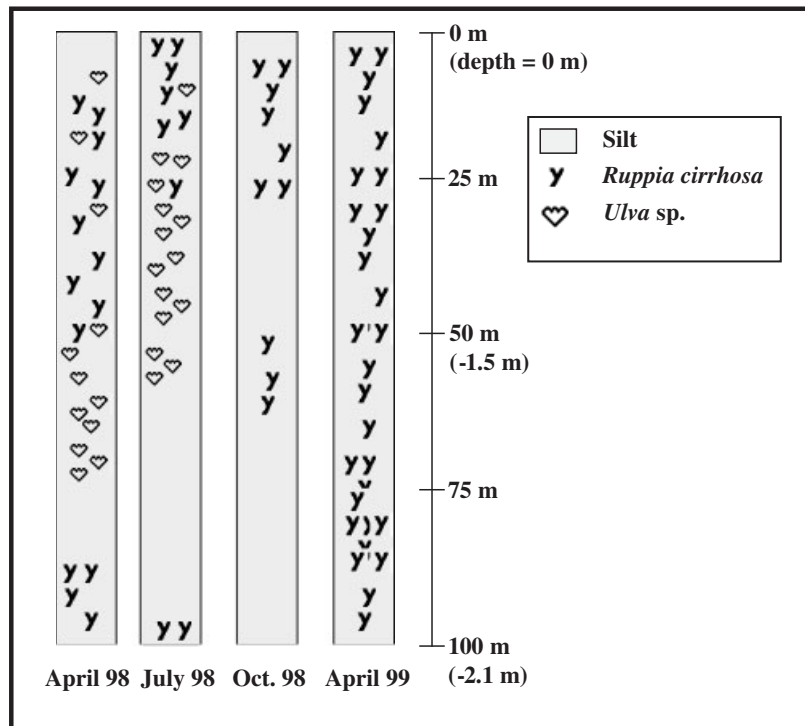
Three species of aquatic angiosperms were recorded in the Urbino lagoon: *Cymodocea nodosa*, *N. noltii* and *R. cirrhosa*. In April 1998, TU1 crossed a continuous *C. nodosa* meadow that progressively gave way, after 78 m, to a population of *Gracilaria dura* (C. Agardh), which became very dense beyond 90 m (Figure 3). This distribution pattern, and in particular the limit of the *Cymodocea/Gracilaria*, remained relatively constant throughout the study period (Figure 3). Over the whole study period, it was noted that the *C. nodosa* meadow generally occupied the depth range from -0.4 m to -4.5 m whereas the *Gracilaria dura* population generally started at -4.7 m and went beyond -5.5 m. In April 1998, the second transect (Figure 3) was mainly occupied by an extended monospecific *C. nodosa* meadow, which gave rise locally to a plurispecific formation of *N. noltii* (from 5 to 27 m from the shore). This meadow, which extended to a depth of -1.5 m, was preceded, at shore level, by a narrow monospecific strip of *N. noltii*. During the study period, these plant formations showed little change. There were only some fluctuations in the strip of *N. noltii* meadow. From October 1998, a new species was observed along the transect, with a few shoots of *R. cirrhosa*.

Characterization of aquatic angiosperms and temporal changes

Analysis of the density of different species of aquatic angiosperms showed that the values differed according to the species under consideration (Table 2). The densities varied significantly: from 679 to $12\,903$ shoots



(a)



(b)

Figure 2. Record of monitoring structures in the Biguglia lagoon, from April 1998 to April 1999. (a) marked survey area; (b) transect.

per m² for *R. cirrhosa* (at Biguglia; Kruskal–Wallis test, $t = 19.4$, $p < 0.05$), from 1358 to 21 902 shoots per m² for *N. noltii* (at Biguglia; Kruskal–Wallis test, $t = 28.3$, $p < 0.01$) and from 509 to 1471 shoots per m² for *C. nodosa* (at Urbino; Kruskal–Wallis test, $t = 16.9$, $p < 0.05$; Table 2). However, it should be noted that the

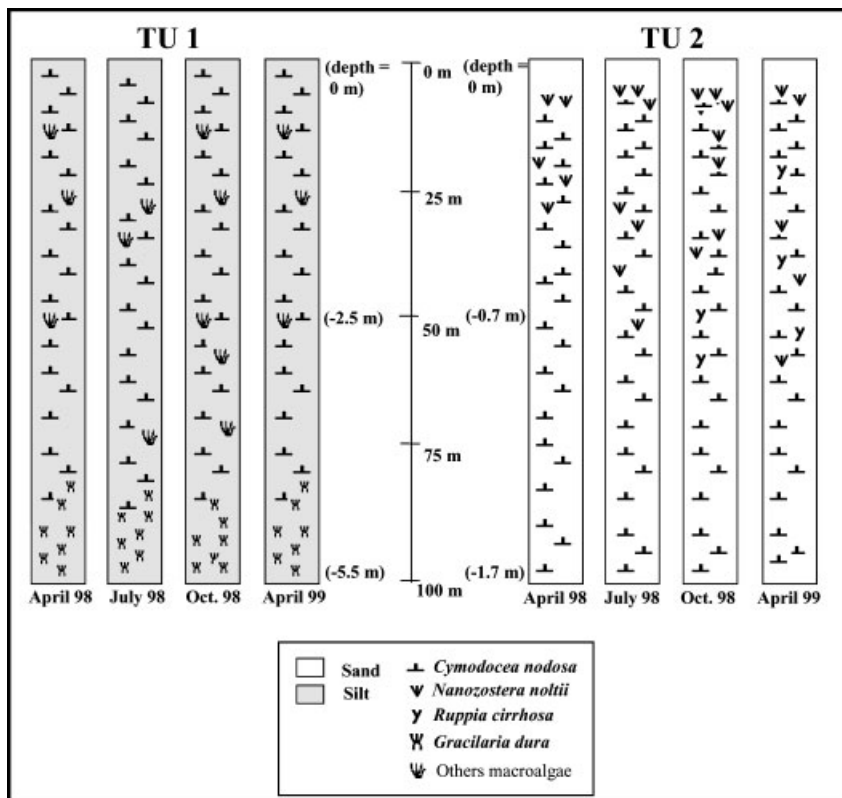


Figure 3. Record of monitoring structures in the Urbino lagoon, April 1998 to April 1999 (TU1, Transect 1; TU2, Transect 2).

density of *N. noltii* showed significant differences between the two lagoons, at least during certain periods of the year, with higher values at Biguglia (Mann–Witney tests, $p < 0.05$).

For *C. nodosa* and *N. noltii*, the below-ground fraction was dominant in relation to the above-ground fraction, whereas the opposite was true for *R. cirrhosa* (Figure 4). The ratio of below-ground biomass/above-ground biomass was high, both in *C. nodosa* (4.2) and in *N. noltii* (from 1.8 at Biguglia to 3.4 at Urbino). The below-ground biomass was higher in *R. cirrhosa* and *C. nodosa* than in *N. noltii*, regardless of the site considered (Kruskal–Wallis tests, $p < 0.05$; Figure 4). For the above-ground biomass, the differences between species, for both sites taken together, are significant, with the lowest values recorded for *R. cirrhosa*, and the highest for *C. nodosa* (tests Kruskal–Wallis, $p < 0.05$; Figure 4).

Phenological parameters were only considered for *C. nodosa* and *N. noltii*. The mean number of leaves per shoot varied little and the differences observed in the length and width of leaves were linked to the species under consideration, giving rise to a significantly different LAI (Table 2). Coefficient A is distinctly higher for *C. nodosa* (53%) than for *N. noltii* (24%). However, for *N. noltii*, there are significant differences in the total number of leaves, the width of adult leaves and the length of leaves, according to the site, but the LAI does not differ (Table 2; test Mann–Witney; $p < 0.05$).

In order to initiate a short-term survey, the 1998 data were compared with those from 1999. A decrease in the length and width of leaves was apparent between 1998 and 1999, at both sites and for both *C. nodosa* and *N. noltii* (test Mann–Witney, $p < 0.05$; Table 3). The shoot density was significantly lower in 1999 for *N. noltii* and *R. cirrhosa* whereas it was significantly higher for *C. nodosa* (Mann–Witney tests, $p < 0.05$). In

Table 2. Density and phenological data for different species of aquatic angiosperms during the year 1998 at the two sites studied (\pm confidence interval 95%)

	Urbino lagoon		Biguglia lagoon	
	<i>C. nodosa</i>	<i>N. noltii</i>	<i>N. noltii</i>	<i>R. cirrhosa</i>
Density per m ² (mean)	939.5 \pm 110.5	7456.1 \pm 1903.2	8849.4 \pm 3219.4	6457.3 \pm 1598.9
minimum	509.3	1924.2	1358.2	679.1
maximum	1471.4	15959.3	21901.5	12903.2
Number of leaves (mean)	3.9 \pm 0.1	3.6 \pm 0.1	3.5 \pm 0.1	
minimum	2.0	2.0	2.0	
maximum	6.0	5.0	5.0	
Length of adult leaves in mm (mean)	145.6 \pm 8.6	147.6 \pm 4.5	168.7 \pm 6.0	
minimum	24.0	20.0	16.0	
maximum	724.0	375.0	436.0	
Length of intermediate leaves in mm (mean)	80.7 \pm 7.8	71.4 \pm 4.7	87.08 \pm 6.15	
minimum	2.0	4.0	5.0	
maximum	371.0	317.0	352.0	
Width of adult leaves in mm (mean)	3.0 \pm 0.1	1.3 \pm 0.0	1.1 \pm 0.0	
minimum	1.0	0.5	0.5	
maximum	5.5	15.0	2.0	
Width of intermediate leaves in mm (mean)	2.4 \pm 0.1	1.2 \pm 0.0	1.1 \pm 0.0	
minimum	1.0	0.5	0.5	
maximum	4.5	2.5	1.5	
Coefficient A in % (mean)	52.5 \pm 3.0	22.4 \pm 2.2	25.4 \pm 2.5	
minimum	0.0	0.0	0.0	
maximum	100.0	100.0	100.0	
LAI in m ² .m ⁻² (mean)	1.3 \pm 0.4	3.9 \pm 1.3	4.0 \pm 0.4	
minimum	0.9	1.2	1.1	
maximum	1.6	5.3	6.6	

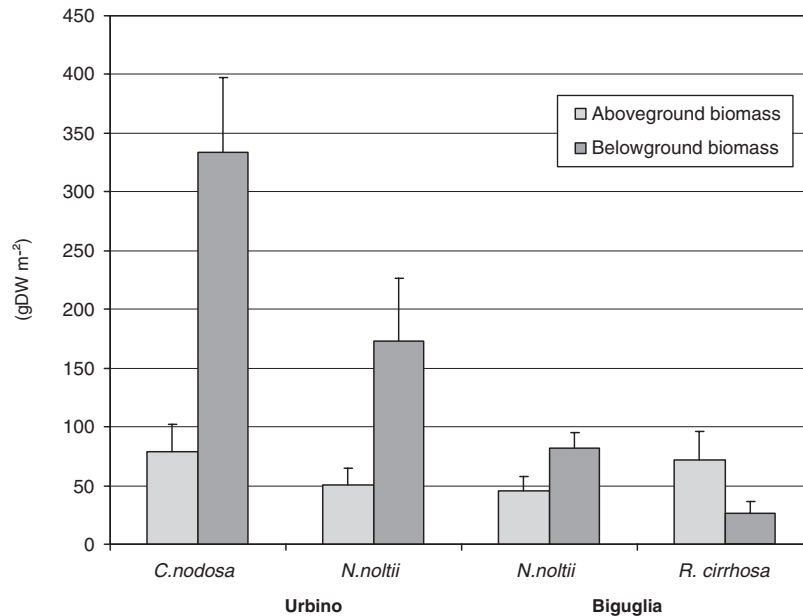


Figure 4. Biomass of different species of seagrasses, during 1998, at the two sites studied (\pm confidence interval 95%).

Table 3. Density, biomass and phenological data for different species of aquatic angiosperms, for January, April and July 1998 and for January, April and July 1999, at the two sites studied (\pm confidence interval 95%)

	Urbino lagoon		Biguglia lagoon	
	<i>C. nodosa</i>	<i>N. noltii</i>	<i>N. noltii</i>	<i>R. cirrhosa</i>
Density per m ² (mean)				
1998	871.5 \pm 127.5	8485.2 \pm 2238.2	10 675.9 \pm 393.1	7372.2 \pm 1795.6
1999	1512.9 \pm 447.0	2392.3 \pm 493.1	1705.3 \pm 371.8	4255.8 \pm 986.6
Above-ground biomass per g DW m ⁻² (mean)				
1998	85.7 \pm 29.9	61.4 \pm 15.6	56.1 \pm 12.4	92.7 \pm 24.4
1999	69.5 \pm 33.2	19.9 \pm 7.1	23.1 \pm 8.4	129.6 \pm 82.3
Below-ground biomass per g DW m ⁻² (mean)				
1998	286.2 \pm 68.6	185.5 \pm 63.6	79.2 \pm 15.8	33.1 \pm 12.4
1999	436.0 \pm 132.5	243.2 \pm 92.3	48.9 \pm 15.0	30.1 \pm 9.7
Number of leaves (mean)				
1998	4.0 \pm 0.1	3.7 \pm 0.1	3.6 \pm 0.1	
1999	4.0 \pm 0.1	3.4 \pm 0.1	3.5 \pm 0.1	
Length of adult leaves in mm (mean)				
1998	153.5 \pm 11.0	160.8 \pm 5.1	185.4 \pm 6.7	
1999	133.6 \pm 11.4	85.7 \pm 3.4	118.0 \pm 5.1	
Length of intermediate leaves in mm (mean)				
1998	94.5 \pm 10.4	78.3 \pm 5.6	95.9 \pm 7.4	
1999	75.0 \pm 9.7	41.5 \pm 3.2	78.9 \pm 6.3	
Width of adult leaves in mm (mean)				
1998	2.9 \pm 0.1	1.4 \pm 0.0	1.1 \pm 0.0	
1999	3.3 \pm 0.1	1.2 \pm 0.0	1.2 \pm 0.0	
Width of intermediate leaves in mm (mean)				
1998	2.4 \pm 0.1	1.3 \pm 0.0	1.1 \pm 0.0	
1999	2.5 \pm 0.1	1.1 \pm 0.0	1.1 \pm 0.0	
Coefficient A in % (mean)				
1998	50.8 \pm 3.6	22.5 \pm 2.5	26.2 \pm 2.8	
1999	60.5 \pm 3.0	29.8 \pm 3.2	37.3 \pm 3.1	
LAI in m ² .m ⁻² (mean)				
1998	1.3 \pm 0.5	4.8 \pm 1.5	5.0 \pm 1.2	
1999	1.6 \pm 0.5	0.7 \pm 0.2	0.7 \pm 0.4	

addition, with *N. noltii*, there was a significant decrease in the above-ground biomass, in the total number of leaves and thus in LAI, at both Urbino and Biguglia. On the other hand, Coefficient A showed a significant increase both for *N. noltii* (at both sites) and for *C. nodosa* (Mann–Witney tests, $p < 0.05$).

General distribution pattern

The mapping of the distribution, based on computer processing of aerial photographs, resulted in the identification of the main meadows and bottom types: silt, sand, aquatic angiosperms and macroalgae for the Biguglia lagoon (Figure 5), and silt, sand, aquatic angiosperms and pebbly bottom for the Urbino lagoon (Figure 6). Analysis of the map of the Biguglia lagoon revealed a predominance of silty bottoms (77.0% of total area), especially in the highly turbid central areas and in the south of the lagoon, and relatively small areas of aquatic angiosperms (13% of total area; Figure 5). These aquatic angiosperms were 95% *R. cirrhosa* meadows, *P. pectinatus* only occurring in the south-west part of the lagoon. There were large formations of macroalgae (6.5% of total area), which took the form of tufts within the *R. cirrhosa* meadows. *Posidonia oceanica* (L.) Delile, an exclusively marine species, was only found in the form of

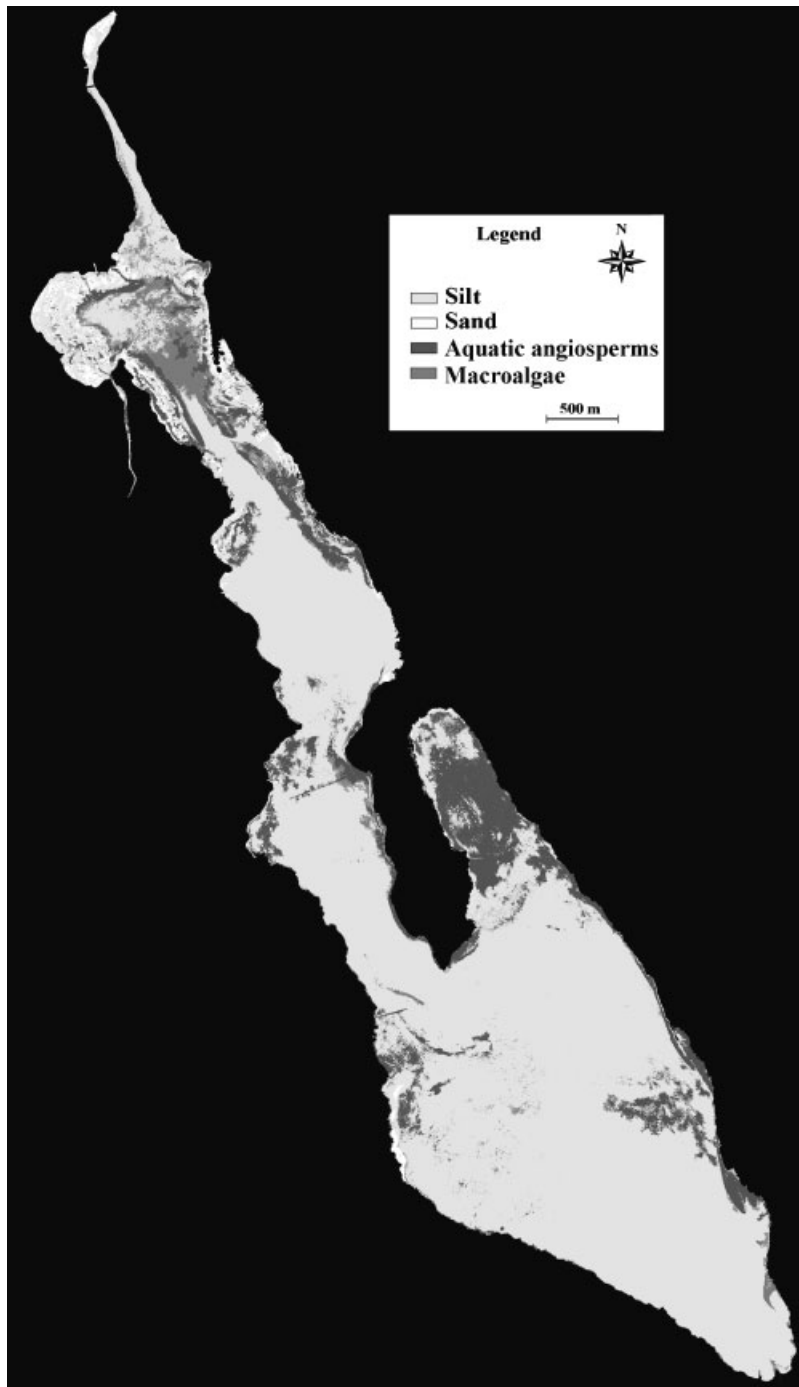


Figure 5. Localization of meadows and bottom types in the Biguglia lagoon.

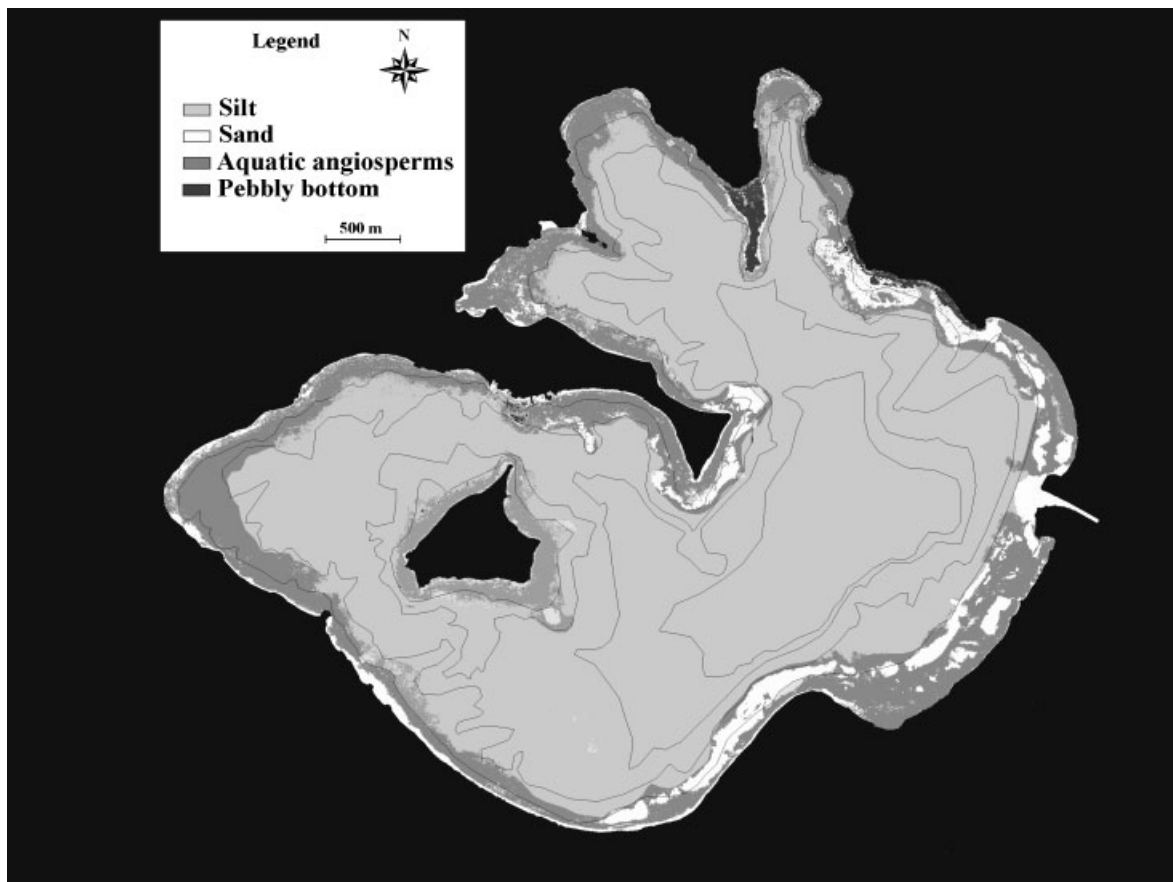


Figure 6. Localization of meadows and bottom types in the Urbino lagoon.

stranded litter, in the northern part, partly blocking the connecting channel. At the Urbino lagoon (Figure 6), silt predominated (70.0% of total area) and occupied the central part of the lagoon. The aquatic angiosperms formed a continuous belt around the outer rim of the lagoon (20.7% of total area) from the surface to -5 m. They were almost exclusively *C. nodosa* meadows (96%). The sand was also localized around the outer rim of the lagoon (7.5% of total area), whereas the pebbly bottom occupied only very small areas in the north of the lagoon.

DISCUSSION AND CONCLUSIONS

The mapping of the distribution of the plant communities and bottom types confirms the differences already reported between the two lagoons (Pergent-Martini *et al.*, 1997). Although silty substrates are well represented at both sites, there is a predominance of aquatic angiosperms (by percentage) at the Urbino lagoon. The distribution pattern within each lagoon varies, with the aquatic angiosperms restricted to the outer rim of the lagoon at Urbino (Figure 6) but scattered over virtually the whole area of the lagoon at Biguglia (Figure 5). In addition, the species differ, with a strong predominance of marine species at Urbino (e.g. *C. nodosa* and *N. noltii*) and species with freshwater affinities at Biguglia (e.g. *R. cirrhosa*, *R. maritime*,

P. pectinatus). Salinity is an important environmental factor that can affect the distribution of aquatic angiosperms. The distribution of *N. noltii* is restricted to the area around the channel at Biguglia, reflecting the salinity profile, in the lagoon showing a decreasing salinity gradient from the north to the south with an amplitude of 5 to 10. The north basin is under marine influence (high salinity) and the south basin is under freshwater influence (low salinity) (Orsoni *et al.*, 2001). On the other hand, *N. noltii* is more widely distributed throughout Urbino lagoon which has a homogeneous salinity throughout the water mass with values close to open-sea salinities (Orsoni *et al.*, 2001).

The higher nutrient levels in Biguglia (ammonium: 0.66 to 53.77 μM in Biguglia, 0.14 to 3.80 μM in Urbino; nitrites: 0.12 to 6.17 μM in Biguglia, 0.09 to 0.74 μM in Urbino; nitrates: 0.01 to 17.25 μM in Biguglia, 0.06 to 1.00 μM in Urbino) could cause indirect negative effects on the seagrasses, with the proliferation of macroalgal blooms (Sfriso *et al.*, 2003), *Lemna* sp. (personal observations) or phytoplankton. It is likely that the development of macroalgae or *Lemna* sp., or phytoplankton in the Biguglia lagoon resulted in a decline in the intensity of the light (by decreasing light by their shade or by increasing turbidity) reaching the seagrasses. Laugier *et al.* (1999) report that in the presence of macroalgae, *Zostera* increases leaf height in order to reduce the shading effect and that the number of leaves per shoot is positively correlated with light. To the extent that the length of leaves of *N. noltii* is significantly greater at Biguglia, and that the total number of leaves per shoot is lower, it would appear that this lagoon has more turbid waters, consistent with measurements reported by Orsoni *et al.* (2001) of between 0.9 and 11.8 NTU in Biguglia, compared with between 0.6 and 1.9 NTU in Urbino.

Temperature is an important environmental factor that can affect the morphology of seagrasses. The cause of the increased development of the above-ground biomass of *N. noltii* at Urbino is probably related to the higher temperature of this lagoon, similar to the Thau lagoon (Laugier *et al.*, 1999). In fact, the temperature data oscillate between 9.8 and 27.9°C in Biguglia and between 8.8 and 28.3°C in Urbino (Orsoni *et al.*, 2001).

It would appear that grazing levels differ between the two lagoons. Although it does not differ significantly throughout the year, coefficient A, for *N. noltii*, is higher at Biguglia. Several authors report an increase in the growth of the leaves of aquatic plants when they are exposed to heavy grazing (Cebrian *et al.*, 1996, 1998; Cebrian and Duarte, 1998). The Biguglia lagoon is a major haven for birds (Cemagref, 1982), for which *N. noltii* is the favoured food (Tamisier and Boudouresque, 1994). In contrast, at Urbino, the sea urchin *Paracentrotus lividus* is the major consumer of seagrasses and it is particularly abundant in *C. nodosa* beds (Fernandez *et al.*, 2001) which is a favourite food (Traer, 1980), as confirmed by the significantly higher coefficient A rate at Urbino for this species (53%).

An estimate of the mean annual biomass (above-ground + below-ground) of the aquatic plants may be calculated, on the basis of the surface area occupied by the meadows in each lagoon. Assuming that the Biguglia meadows are exclusively made up of *R. cirrhosa*, the biomass values range from 23 t (DW; October 1998) to 735 t (DW; July 1999), or an annual mean of 230 t (DW). The same calculation, at Urbino, on the basis of meadows made up of 95% *C. nodosa* and 5% *N. noltii*, gives a biomass that ranges from 244 t (DW; April 1999) to 1062 t (DW; July 1999), or an annual mean of 732 t (DW), which represents a biomass that is three times greater. Integrating the P/B ratio for each species, on the basis of data from the literature (Table 4), gives an estimation of the primary production for each lagoon. This ranges from 86 to 469 $\text{g C m}^{-2} \text{yr}^{-1}$ at Biguglia, and from 190 to 1301 $\text{g C m}^{-2} \text{yr}^{-1}$ at Urbino (depending on whether the P/B ratio is minimum or maximum for the species considered; Table 5). The availability of data on the primary production of *C. nodosa* for the Urbino lagoon (Agostini, 2001; Agostini *et al.*, 2003b) enables this estimation to be refined, with a production rate ranging from 1267 to 1301 $\text{g C m}^{-2} \text{yr}^{-1}$. Primary production is thus distinctly higher at Urbino than at Biguglia. The estimated values are comparable, for the Biguglia lagoon, to the production rate of coral reefs (Crossland *et al.*, 1991 (in Duarte and Chiscano, 1999)) or macroalgae (Charpy-Roubaud and Sournia, 1990 (in Duarte and Chiscano, 1999)) whereas, for

Table 4. Bibliographical data for biomass (below-ground + above-ground), net primary production and production/biomass ratio for the different species studied, in lagoonal environments

Site	Biomass (g DW m ⁻²)	Production (g C m ² yr ⁻¹)	Ratio production/ biomass	Reference
<i>C. nodosa</i>				
Mar Menor — Spain	68–220	206–505	2.3–3.0	Terrados and Ros, 1992
Venice lagoon — Italy	399–1841	826	0.5–2.1	Rismondo <i>et al.</i> , 1997
Urbino lagoon — France	777 (mean)	2470	3.2	Agostini, 2001/Agostini <i>et al.</i> , 2003b
<i>N. noltii</i>				
Thau lagoon — France	44–437	539	1.2–12.3	Laugier, 1998
Thau lagoon — France	45.8–95	197	0.2–4.3	Plus <i>et al.</i> , 2001
<i>R. cirrhosa</i>				
Camargues — France	50–160	59–141	0.9–1.2	Verhoeven, 1980
Santo André lagoon — Portugal	72–388	135	0.4–1.9	Calado and Duarte, 2000
Valle Smarlacca lagoon — Italy	150	594	4.0	Azzoni <i>et al.</i> , 2001
Ebro Delta — Spain	75–672	361	0.5–4.8	Menéndez, 2002

the Urbino lagoon, they are of the same order as that of temperate forests (Whittaker, 1975 (in Duarte and Chiscano, 1999)) or marsh plants (Woodwell *et al.*, 1973 (in Duarte and Chiscano, 1999)).

The full set of investigations carried out for this reference state survey show that while, a priori, the two lagoons are similar in structure (aquatic angiosperm-based ecosystems), they present functional differences, specifically linked to environmental conditions.

Comparing the biological parameters obtained from the Corsican lagoons with those recorded for the same species in other Mediterranean lagoons, it is apparent that the values are similar (Table 5). At the most, it may be noted that the values for the total biomass of *R. cirrhosa* at Biguglia are low, but close to those obtained in the Camargue natural reserve (Verhoeven, 1980). Similarly, the values for the above-ground biomass of *N. noltii* at the two sites studied are minimal in comparison with the data available for lagoons where there is greater human pressure (Table 5). The same is true for *C. nodosa*, for which the density values at Urbino are lower than those recorded in the Venice lagoon (Rismondo *et al.*, 1997; Sfriso and Ghetti, 1998). Although it is difficult solely on the basis of these observations to establish a comparative state of the Corsican lagoons, it would appear that, while human pressure does exist (Table 1), it cannot be compared with that occurring at other lagoons. The impact of human activities on the Corsican lagoons does not appear to alter the development of aquatic plants to a marked degree, whereas this is already the case for other lagoons that are exposed to greater human pressure, such as the Thau and Venice lagoons.

The observations carried out in the course of the monitoring and temporal survey of the Corsican lagoons show that considerable changes occurred between 1998 and 1999, both on the transects and with regard to the biological parameters.

The variations recorded at the Biguglia marked survey area are mainly linked to variations in abiotic parameters. Orsoni *et al.* (2001) show an increase in rainfall and turbidity from December 1998 to February 1999, which seems to be the cause of the regression in population of *N. noltii*, a species with marine affinities that is particularly sensitive to marked decreases in salinity and has poor tolerance of high turbidity (Riouall, 1972). Orsoni *et al.* (2001) also report strong increases in nitrite and nitrate content from November 1998 to May 1999, which would appear to correspond to the general disappearance of the *R. cirrhosa* meadows. This nutrient enrichment is likely to favour the development of macroalgae, to the detriment of aquatic angiosperms (Hartog Den, 1994; Coffaro and Bocci, 1997). So, the development of

Table 5. Bibliographical data for biological parameters in lagoonal environments

Site	Density (m ²)	Above-ground biomass (g DW m ⁻²)	Below-ground biomass (g DW m ⁻²)	Total biomass (g DW m ⁻²)	Number of leaves	Length of leaves (mm)	Width of leaves (mm)	LAI (m ² .m ⁻²)	Reference
<i>C. nodosa</i>									
Mar Menor — Spain	312–2314	18.0–170.0	50.0	68–220	1.8–4.0			0.2–1.8	Terrados and Ros, 1992
Ebre — Spain	1000–2000	20.0–200.0	396.0	416–596					Perez and Romero, 1994
Venice lagoon — Italy	860–2302	44.0–810.0	355–1031	399–1841	1.0–4.0	116–480		0.4–8.2	Rismondo <i>et al.</i> , 1997
Venice lagoon — Italy	1650–3377	526.0	129.7	655.7	2.1	601			Sfriso and Ghetti, 1998
<i>N. noltii</i>									
Thau lagoon — France	134–2272	25.0–291.0	19.0–146.0	44–437	2.4–3.7	12–271	1.1–3.2		Laugier <i>et al.</i> , 1999; Laugier, 1998
Venice lagoon — Italy	2030–14617	224.9	71.0	295.9	2.2	475			Sfriso and Ghetti, 1998
Thau lagoon — France	1061–3593	26.6–136.3	19.2–125	45.8–261.3	2.6–3	85–386	1.2–1.8	0.5–3.6	Plus <i>et al.</i> , 2001
<i>R. cirrhosa</i>									
Camargues — France				50–160					Verhoeven, 1980
Santo André lagoon — Portugal				72–388					Calado and Duarte, 2000
Valle Smarlicca lagoon — Italy				150					Azzoni <i>et al.</i> , 2001
Ebro Delta — Spain				75–672					Menéndez, 2002

Ulva sp. was observed along the transect at Biguglia, which has already been reported both for Biguglia (De Casabianca, 1979) and for other coastal lagoons (Coffaro and Bocci, 1997; De Casabianca *et al.*, 1997). Furthermore, the increase in these macroalgae, and their subsequent decomposition, results in the occurrence of anoxic conditions that may be responsible of degradation of the seagrasses (Hartog Den, 1994). Generally speaking, the decline in the biological parameters observed would appear to reflect a change in environmental conditions between 1998 and 1999. At the Urbino lagoon, alterations in the plant communities would appear to be more limited, but show the same trend towards a reduction in the biological parameters. It would thus appear that the explanation for this putative degradation in environmental conditions must be sought on a regional scale (e.g. unusually high runoff from catchment areas, climate change) rather than at the level of one of the lagoons. Significant inter-annual variations were observed for many biological parameters. These observations confirm the speed of inter-annual evolution in the lagoons as a function of changing environmental conditions (Kjerfve, 2000). While human responsibility cannot be ruled out, nor can it be the direct cause of these alterations. The greater range in the degradation of the biological parameters recorded at Biguglia (e.g. reduction in density by a factor of 1 to 20) must be due, in part at least, to the difference in the size of the catchment areas (180 km² for the Biguglia lagoon compared to 30 km² for the Urbino lagoon) and the more variable environmental characteristics. Furthermore, the lower depth range of this lagoon prevents it from absorbing these environmental fluctuations, as is certainly the case at Urbino.

The observations made in the course of the development of the monitoring survey of vegetation in the Corsican lagoons show the strong influence of abiotic conditions on the distribution patterns of the aquatic plants in semi-open environments, as well as the high productivity rate in these environments. While the existence of human activities (Table 1) can alter the way these lagoons function, it would appear for the time being that they only do so to a limited extent. Nevertheless, the evidence for alteration of environmental parameters at a regional level confirms the relevance of this monitoring survey with a view to providing an early warning of disturbances engendered by human activities. The methods adopted, whether it is the monitoring of the fixed marks, the permanent transects, the study of the morphological parameters and/or the use of the image processing of aerial photographs are all relevant in the implementation of a monitoring system. This work confirms the importance of more intensive and reliable surveillance of aquatic angiosperm meadows in the conservation and long-term management of coastal lagoons. Such long-term management has to (i) characterize potential sources of disturbances present in the catchment area and develop purification networks; (ii) manage openings to the sea, to maintain the exchanges of water between the marine and lagoonal environment; and (iii) manage the activities bringing out organic matters in the lagoonal environment (fish farming); with the aim of limiting concentrations in fatal nutriments to seagrasses, these species being characteristic of a good quality of the environment.

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