ORIGINAL ARTICLE

# The effect of *Ruppia cirrhosa* features on macroalgae and suspended matter in a Mediterranean shallow system

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## Abstract

Relationships among chemical–physical features, total gross suspended organic matter, coverage of the seagrass *Ruppia cirrhosa* and its associated algal community in eight ponds of a saltworks system of western Sicily (Mediterranean Sea) were investigated in spring and summer 2004. All biological features varied both at different levels of seagrass coverage and between seasons. A low algal diversity (46 taxa, $14.75 \pm 1.41$ on average) was highlighted; algal coverage and species richness showed to be negatively correlated. *Ruppia cirrhosa* coverage was negatively correlated with algal coverage, but positively correlated with species richness. Moreover, a significant correlation among *R. cirrhosa* coverage, the availability of suspended matter in the water column and the chlorophyll *a* concentration was detected.

## Problem

The importance of shallow waters as a reservoir of biodiversity has been evidenced everywhere in the world both at temperate and tropical latitudes (Gray 1997; Duarte 2000; Raffaelli 2000; Pusceddu *et al.* 2003). Shallow waters function as a buffer system of interchange between open sea and land, and aquatic macrophytes represent key species regulating fluxes of energy and matter (Wetzel 1975). Dominant species in these systems are often seagrasses, which markedly colonize shallow habitats with extended meadows or beds (Short & Coles 2001).

The multi-niche habitats provided by seagrasses play an important role in regulating the biological cycle of aquatic organisms both as trophic *pabulum* and nurseries for resident fauna and migrating organisms. In the Mediterranean Sea, most of the studies on seagrass meadows are mainly focused on *Posidonia oceanica* (L.) Delile and *Cymodocea nodosa* (Ucria) Ascherson (Boudouresque *et al.* 1984, 1989; Pergent 1987; Pergent & Pergent-Martini 1988; Peduzzi & Vukovic 1990; Buia & Mazzella

1991; Rismondo *et al.* 1997; Sfriso & Ghetti 1998; Buia *et al.* 2000; Cancemi *et al.* 2002; Vizzini *et al.* 2002) while there is less information on *Zostera marina* L. (Caniglia *et al.* 1992; Buia & Mazzocchi 1995; Sfriso & Ghetti 1998) and only a few are dealing with *Ruppia cirrhosa* (Petagna) Grande (Calado & Duarte 2000; Menéndez 2002). This species is widespread in Mediterranean shallow systems with salinities higher than in marine environment, as saltwork basins or some marginal secondary shallow environments.

Emergent from the water for long periods, *R. cirrhosa* creates a multidimensional substrate for macro and microalgae. The latter are food sources, either directly or indirectly (through detritus), for a range of invertebrates (both marine and terrestrial) and small fish that represent food for migratory birds. Indeed, organic matter produced by seagrass and associated photosynthetic organisms, such as epiphytes and benthic algae, represents a direct trophic mechanism able to affect food availability to secondary consumers (Thom & Albright 1990; Mazzella & Zupo 1995). Nevertheless, *R. cirrhosa* is very common

in habitats undergoing a direct human influence, where the work of men can, even daily, alter the structure and dynamics of ecological processes triggered by features of the *R. cirrhosa* system. The particular location on the coast of these habitats and the abundance of available food, make *R. cirrhosa* environments among the most important 'ecological corridors' to allow wildlife to migrate from the African continent to Europe. Gathering knowledge on the ecological role of *R. cirrhosa* and its distribution can therefore trigger management decisions to limit the human impact.

This paper reports on some features of *R. cirrhosa* in the saltworks system of the western Sicily, where the seagrass is the most important plant, and its effect on suspended matter quantity and quality. The aims of the present paper were thus to identify: (i) whether temporal changes of *R. cirrhosa* features and coverage affect the occurrence of associated algal taxa and (ii) the extent to which *R. cirrhosa* coverage affects features of the suspended matter in the water column.

## Material and Methods

### Study area

The study was carried out in the Natural Reserve of Trapani and Paceco (Western Sicily, 37°52′ N; 12°28′ E) (Fig. 1). The area hosts the most important saltworks system of the Western Mediterranean. It is composed of 25 salt production ponds, covering a surface area of about 1000 ha. The whole system was created in the 15th century. There are

two types of ponds in saltworks: ponds receiving water directly from the sea (hereafter called cold ponds), with salinity similar or slightly higher than in the near sea water and 'crude' ponds that are fed by cold ponds. The research was carried on eight cold ponds (Fig. 1), representing about 60–65% of currently active salt production ponds of the area. Their muddy-sand bottoms are extensively colonized by stable meadows of *Ruppia cirrhosa* with a specialized macroalgal community (Sortino *et al.* 1981; Cinelli 1986). This *R. cirrhosa* system is probably the largest in the Mediterranean, functioning as the main ecological corridor in central–western Mediterranean for avifauna migrating from Africa to Europe (Sorci *et al.* 1991).

### Sample collection and analysis

The collection of samples (water and plants) was carried out in spring and summer (10th and 30th May, 23rd July and the 13th of August) 2004.

Sampling methods for each variable are summarized in Table 1. In the laboratory, water samples were filtered using pre-washed, pre-combusted (450 °C, 4 h) and pre-weighed Whatman GF/F filters to determine total suspended matter (TSM; mg l$^{-1}$) and photosynthetic pigments [chlorophyll *a* (CHL *a*); µg l$^{-1}$]. TSM determination was carried out gravimetrically after desiccation (60 °C, 24 h) using a Sartorius balance (A200; accuracy ± 1 µg). The organic fraction of seston (OSM; mg l$^{-1}$) was determined by ignition loss (450 °C, 4 h) and the material remaining after combustion was considered as its inor-
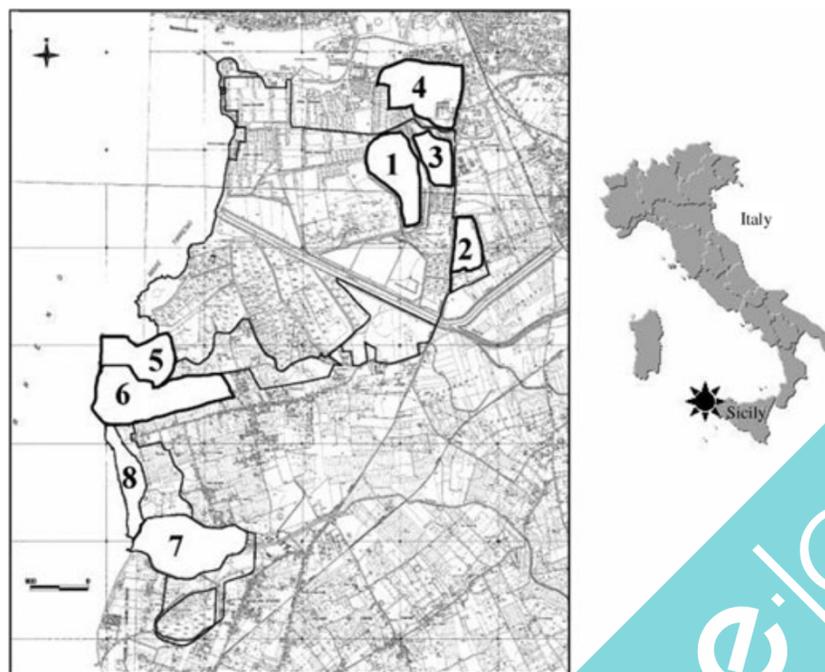


**Fig. 1.** Map of the saltworks system of western Sicily with the location of the studied ponds.

**Table 1.** List of the synthetic descriptors and sampling methods.

| | |
|---|---|
| Depth (m) | By hand with a depth meter |
| Temperature (°C) | Multiprobe in triplicate |
| Salinity | Multiprobe in triplicate |
| TSM/ISM/OSM (mg $l^{-1}$) | By hand in triplicate with a plastic bottle |
| CHL *a* ($\mu$g $l^{-1}$) | By hand in triplicate with a plastic bottle |
| Total macrophyte coverage (%) | Visual census: classified into two classes: >70% and <70% |
| *R. cirrhosa* coverage (%) | In triplicate using a 1 $m^2$ quadrate |
| Shoot density ($m^{-2}$) | In triplicate using a 400 $cm^2$ quadrate |
| Bottom algal coverage (%) | In triplicate using a 400 $cm^2$ quadrate |
| Bottom and epiphyte algal taxa (n) | In triplicate using a 400 $cm^2$ quadrate |

ganic fraction (ISM; mg $l^{-1}$). CHL *a* was determined according to Lorenzen & Jeffrey (1980). In each pond, the presence of seagrasses and macroalgae was recorded; the total plant coverage (seagrasses plus macroalgae, TC, %), *R. cirrhosa* coverage (*Ruppia* C, %) and shoot density (number of shoots per square metre), and macroalgal coverage (Algal C, %) were estimated in triplicates. Moreover, seagrass and macroalgae were entirely removed from quadrates (Table 1), and brought back to the laboratory for subsequent analysis. Then, the plant material was sieved and washed with tap water to remove sediment and large debris, and temporarily stored in a fridge (*c.* 4 °C). *Ruppia cirrhosa* density was recorded by counting the shoots inside the quadrates (20 × 20 cm); the value for each pond was reported as the mean among the replicates.

A qualitative analysis of bottom algae and epiphytic assemblage of the *R. cirrhosa* leaves was carried out. Epiphytes were checked on all leaves of the three replicates and listed separately from the other bottom algae. All the algal taxa were identified at species level according to Irvine (1983), Fletcher (1987), Round *et al.* (1990), Burrows (1991), Maggs & Hommersand (1993), Irvine & Chamberlain (1994), Womersley (1984, 1987, 1994, 1996, 1998, Furnari *et al.* (2001) and Giaccone *et al.* (2003). The list of bottom algae and epiphytes (mean values for each pond) was reported, and the species richness ($R_i = N_i/N_t \times 100$) was also calculated for each pond.

### Statistical analyses

Statistical analyses were carried out to assess possible differences in suspended matter concentrations due to differences in plant coverage. As a first step, to solve the complexity of relationships among physical, trophic and biotic variables, a Principal Component Analysis (PCA) was performed on the correlation matrix obtained including all variables considered. Statistica 5.1 (StatSoft Inc., USA) was used to perform PCA. In a second phase, data were analysed using a three-way ANOVA (Underwood 1997) to test the null hypothesis that there was no difference in the structure at different levels of total coverage (<70% and >70%) in spring and summer. Periods (PER; spring and summer; two levels) and total vegetation coverage (COV; low < 70% and high > 70%; two levels) were treated as fixed factors and the two sampling dates of each season were treated as random factor and nested in PER. Four ponds were used as replicates. The heterogeneity of variances was checked using Cochran's C-test; by Student–Newman–Keuls test appropriate comparisons of means were made. GMAV rel. 5.0 (University of Sydney, personally licensed to G. Sará) was used to perform ANOVAs.

## Results

### Environmental factors

Depths of all ponds ranged between 0.3 and 0.7 m (on average 0.5 ± 0.2 m) and were quite constant throughout the study period (Table 2). Temperature and salinity (Tables 2 and 3) were significantly correlated (SAL = −37.2 + 3.1 * T; n = 8; r = 0.79; P < 0.01). TSM concentrations ranged between 239.2 ± 243.0 mg $l^{-1}$ in spring and 106.0 ± 75.4 mg $l^{-1}$ in summer. Organic fraction represented 66.4 ± 22.8% in spring and 57.2 ± 12.9% in summer. CHL *a* concentrations showed higher concentrations than Mediterranean coastal waters (*c.* 0.5 $\mu$g $l^{-1}$) above all in spring when concentrations were on average 5.5 ± 6.5 $\mu$g l-$^1$, while in summer were 1.5 ± 0.3 $\mu$g $l^{-1}$ (Tables 2 and 3).

Some strong correlations were recorded among variables: the highest between salinity and shoot density of *Ruppia cirrhosa* (r = 0.69), *R. cirrhosa* coverage and algal taxa (r = 0.70). Negative correlations were found between *R. cirrhosa* coverage and suspended organic matter and *R. cirrhosa* coverage and CHL a (r = −0.48 and −0.58, respectively) (PCA, Fig. 2). The two axes of the PCA model accounted for more than 70% of the variability and the eight ponds studied clustered into two different groups with different features. The group on the left of the ordination model was represented by high variable ponds with lower salinities and depths, while the group on the right of the model showed higher values of those variables; the temperature was not correlated with the first axis but most likely was the cause of higher variability along axis 2. These two groups are characterized by different biotic features as the left-sided group was characterized by high percentages of algal coverage, a lower number of algal taxa and higher concentration values of

**Table 2.** Mean values of chemical, physical and biological variables in the studied eight ponds.

| Season | Pond | T | SAL | D | TSM | ISM | OSM | CHL $a$ | TC | *Ruppia* C | Algal C | Algal T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spring | 1 | 24.9 | 36.2 | 0.4 | 97.8 | 13.3 | 84.5 | 1.6 | 90.8 | 85.8 | 14.2 | 11.5 |
| Summer | | 25.4 | 38.9 | 0.4 | 460.1 | 99.9 | 360.2 | 2.1 | 82.7 | 51.3 | 48.7 | 8.0 |
| Spring | 2 | 26.7 | 46.2 | 0.3 | 179.1 | 12.0 | 167.1 | 8.8 | 62.5 | 67.5 | 32.5 | 13.0 |
| Summer | | 27.6 | 47.3 | 0.3 | 72.3 | 22.7 | 49.6 | 3.1 | 76.3 | 50.4 | 49.7 | 8.5 |
| Spring | 3 | 24.4 | 33.3 | 0.3 | 596.5 | 92.0 | 504.5 | 22.6 | 60.8 | 95.8 | 4.2 | 10.2 |
| Summer | | 24 | 35.6 | 0.3 | 58.3 | 35.6 | 22.7 | 1.1 | 64.3 | 51.5 | 48.5 | 8.8 |
| Spring | 4 | 19.4 | 30.5 | 0.3 | 770.8 | 108.8 | 662 | 7.3 | 50.9 | 47.5 | 52.5 | 9.3 |
| Summer | | 27 | 30.7 | 0.4 | 46.6 | 15.9 | 30.7 | 0.3 | 65 | 50.2 | 49.9 | 7.5 |
| Spring | 5 | 19.8 | 38.4 | 0.6 | 98.7 | 7.8 | 90.9 | 0.4 | 77.7 | 78.2 | 21.8 | 22.3 |
| Summer | | 28.9 | 29.3 | 0.6 | 84.6 | 25.6 | 59 | 0.5 | 85.5 | 84.5 | 16.3 | 13.3 |
| Spring | 6 | 20.4 | 44.5 | 0.7 | 83.1 | 21.6 | 61.5 | 1.6 | 77.3 | 76.8 | 23.2 | 25.3 |
| Summer | | 27.6 | 33.7 | 0.7 | 60.6 | 17.9 | 42.7 | 3.8 | 76.2 | 77.2 | 22.8 | 14.3 |
| Spring | 7 | 19.6 | 39.2 | 0.5 | 18 | 11.9 | 6.1 | 0.9 | 85.8 | 76.3 | 23.7 | 13.5 |
| Summer | | 27.1 | 34.8 | 0.5 | 10.4 | 7.6 | 2.8 | 0.5 | 82.7 | 53.8 | 46.2 | 11.0 |
| Spring | 8 | 22.4 | 38.1 | 0.4 | 69.3 | 44.7 | 24.6 | 0.9 | 59.2 | 77 | 23 | 16.3 |
| Summer | | 27.5 | 31.5 | 0.4 | 55.1 | 16.4 | 38.7 | 0.3 | 90.7 | 92.9 | 7.2 | 11.8 |

T (°C), temperature; SAL, salinity; D (m), depth; TSM (mg l$^{-1}$), total suspended matter; ISM (mg l$^{-1}$), total inorganic suspended matter; OSM (mg l$^{-1}$), total organic suspended matter; CHL $a$ ($\mu$g l$^{-1}$), suspended chlorophyll $a$; TC (%), total coverage; *Ruppia* C (%), *R. cirrhosa* coverage; Algal C (%), algal coverage; Algal T (n), algal taxa.

**Table 3.** Mean values of chemical, physical and biological variables (±SE).

| Variable | Spring | Summer |
|---|---|---|
| Temperature (°C) | 22.15 ± 2.33 | 26.85 ± 1.20 |
| Salinity | 38.25 ± 2.47 | 35.20 ± 4.10 |
| TSM (mg l$^{-1}$) | 239.15 ± 243.03 | 106.00 ± 75.38 |
| ISM (mg l$^{-1}$) | 39.00 ± 24.75 | 30.20 ± 18.81 |
| OSM (mg l$^{-1}$) | 200.15 ± 218.28 | 75.80 ± 56.57 |
| CHL $a$ ($\mu$g l$^{-1}$) | 5.50 ± 6.51 | 1.50 ± 0.28 |
| Total algal coverage (%) | 24.35 ± 2.05 | 36.15 ± 18.46 |
| Total algal taxa (n) | 15.20 ± 5.94 | 10.40 ± 3.11 |
| Shoot density (n m$^{-2}$) | 3705.25 ± 461.10 | 2927.55 ± 1473.68 |
| Leaf number shoot$^{-1}$ | 2.25 ± 0.21 | 3.75 ± 0.07 |

TSM, total suspended matter; ISM, total inorganic suspended matter; OSM, total organic suspended matter; CHL $a$, suspended chlorophyll $a$.

suspended matter. In contrast, the right-sided group of ponds had high levels of *R. cirrhosa* coverage and lower suspended matter concentrations, but higher numbers of algal taxa. Differences in suspended matter in ponds were associated with different coverage (ANOVA, Tables 4 and 5). In particular, the lower the coverage, the higher the suspended matter in the water column. Indeed, the suspended organic matter (Fig. 3a) and CHL $a$ (Fig. 3b) were higher corresponding to the low value of total coverage, reaching the highest values in springtime.

### Plant's features

In the study area the dominant plant was *R. cirrhosa* representing about 75% and 65% of total coverage, in spring and in summer respectively, whereas macroalgal component represented respectively about 24% and 36% of total coverage (Tables 2 and 3). Small patches of *Cymodocea nodosa* were also observed in the ponds 5 and 8.

A total number of 46 taxa were found (algae *plus* epiphytes of *R. cirrhosa* leaves). Algal community was mainly formed by pleustophytic taxa (close to the bottom or forming floating clumps), with the dominance of opportunistic sheet-like and filamentous taxa, such as *Chaetomorpha*, *Cladophora* and *Ulva* genera. Species richness, calculated for each pond, resulted higher in the ponds 5, 6, 7 and 8 than in the other ones. The epiphytic flora was essentially formed by diatoms and red algae, among them *Chondria capillaris* (Hudson) M.J. Wynne was the most frequent taxon (Table 6).

Almost all variables (*Ruppia* coverage, algal coverage, total number of taxa, shoot density) varied significantly as a function of sampling period and total coverage (Table 5). Significant higher species richness was found at high levels of coverage (ANOVA, $P < 0.05$; Table 5; Fig. 4) and both variables were significantly correlated [taxa number = 3.5 (±3.2) + 0.14 (±0.04) *COV ($r$ = 0.54; $n$ = 32; $P < 0.05$)]. In addition, shoot density showed significant differences and was affected by the coverage levels (ANOVA, $P < 0.05$; Table 5; Fig. 5).

### Discussion

#### Effect of environmental variability on *Ruppia cirrhosa* features

In shallow environments, the occurrence and abundance of macrophytes is strictly related to physical variables
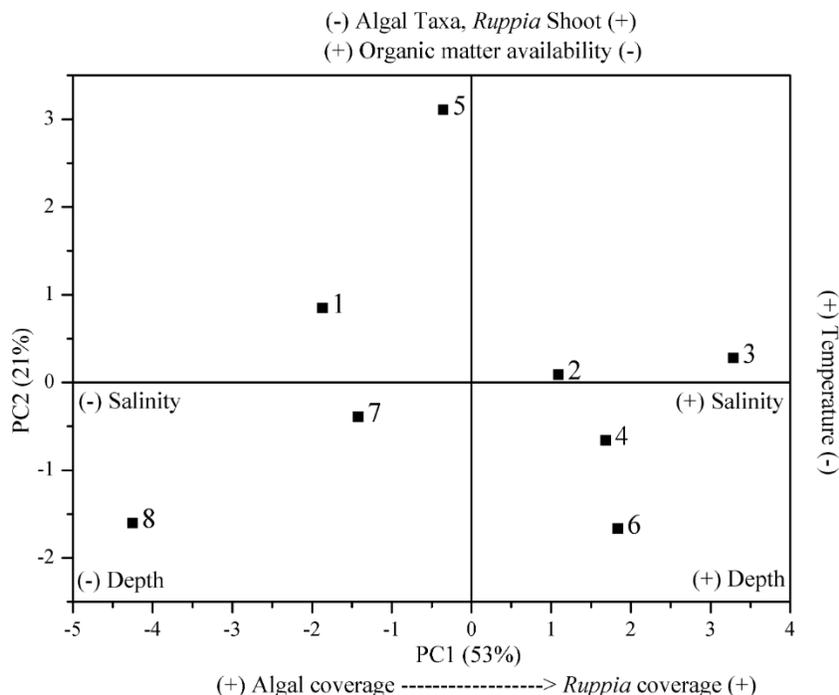
(-) Algal Taxa, *Ruppia* Shoot (+)
(+) Organic matter availability (-)



**Fig. 2.** Principal component analysis carried out on the correlation matrix obtained including all physical and biotic variables measured in the eight studied ponds (PC1, principal component 1; PC2, principal component 2; +, a positive correlation of variable with PC's; −, a negative correlation of variable with PC's).

**Table 4.** Analysis of variance.

| Source | df | TSM | | | ISM | | | OSM | | | CHL-a | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P | MS | F | P | MS | F | P |
| Period (PER) | 1 | 1.0 | 0.0 | n.s. | 623.0 | 36.8 | * | 123703.4 | 94.4 | *** | 3.1 | 136.2 | *** |
| Coverage (COV) | 1 | 3.0 | 0.1 | n.s. | 7595.3 | 4154.7 | *** | 302136.5 | 313.2 | *** | 5.9 | 173.3 | *** |
| Date (PER) | 2 | 48.7 | 109.4 | *** | 16.9 | 0.0 | n.s. | 1309.9 | 0.1 | n.s. | 0.0 | 0.1 | n.s. |
| PER × COV | 1 | 0.4 | 0.0 | n.s. | 141.1 | 77.2 | ** | 104653.1 | 108.5 | *** | 2.9 | 84.8 | ** |
| COV × date (PER) | 2 | 36.7 | 82.4 | *** | 1.8 | 0.0 | n.s. | 964.6 | 0.0 | n.s. | 0.0 | 0.1 | n.s. |
| Residuals | 24 | 0.4 | | | 1111.7 | | | 26205.1 | | | 0.4 | | |
| Cochran's Test | | | | n.s. | | | n.s. | | | n.s. | | | n.s. |

TSM (mg $l^{-1}$), total suspended matter; ISM (mg $l^{-1}$), total inorganic suspended matter; OSM (mg $l^{-1}$), total organic suspended matter; CHL *a* ($\mu g\ l^{-1}$), suspended chlorophyll *a*; n.s., not significant.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

**Table 5.** Analysis of variance.

| Source | df | Algal coverage (%) | | | Algal taxa (n) | | | Shoot density (n m$^{-2}$) | | | Leaf number shoot$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | F | P | MS | F | P | MS | F | P | MS | F | P |
| Period (PER) | 1 | 1110.4 | 12294.9 | *** | 0.8 | 5687.8 | *** | 0.6 | 284.4 | ** | 1.2 | 27494.6 | *** |
| Coverage (COV) | 1 | 1674.8 | 18544.0 | *** | 1.6 | 76624.2 | *** | 0.9 | 2990.6 | ** | 0.0 | 500.8 | * |
| Date (PER) | 2 | 0.1 | 0.0 | n.s. | 0.0 | 0.0 | n.s. | 0.0 | 0.0 | n.s. | 0.0 | 0.0 | n.s. |
| PER × COV | 1 | 1070.7 | 11855.4 | *** | 0.0 | 1379.7 | *** | 1.4 | 4449.4 | *** | 0.0 | 1651.0 | *** |
| COV × date (PER) | 2 | 0.1 | 0.0 | n.s. | 0.0 | 0.0 | n.s. | 0.0 | 0.0 | n.s. | 0.0 | 0.0 | n.s. |
| Residuals | 24 | 183.9 | | | 0.0 | | | 0.2 | | | 0.0 | | |
| Cochran's Test | | | | n.s. | | | n.s. | | | n.s. | | | n.s. |

n.s., not significant.
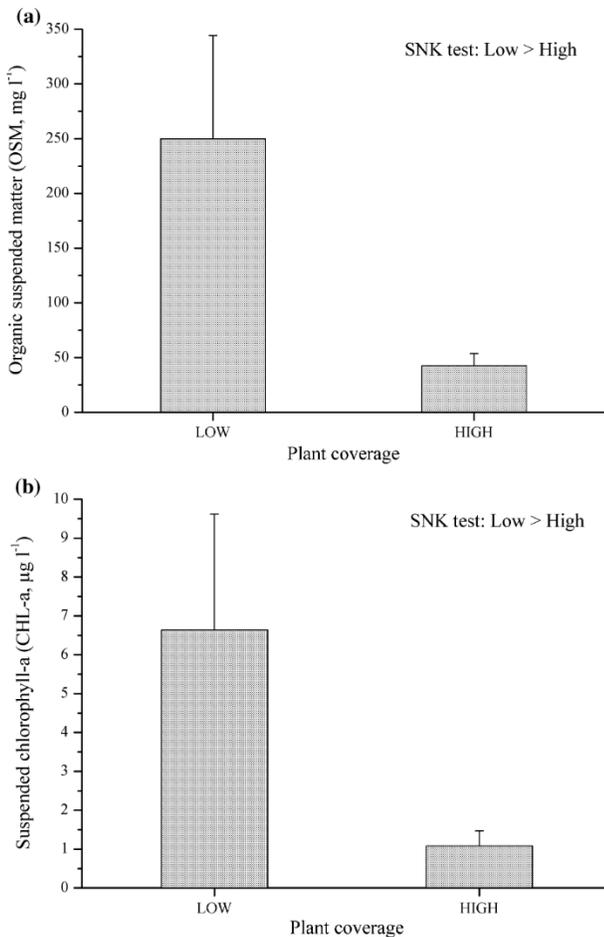*$P < 0.05$; ** $P < 0.01$; ***$P < 0.001$.

**Fig. 3.** Concentration of total organic matter (OSM, mg l⁻¹) (a) and concentration of total chlorophyll *a* (CHL *a*, μg l⁻¹) (b) as a function of low and high coverage (Student–Newman–Keuls test is also reported).

(Sanders 1968; Madsen 1991; Scheiner 1993; Carruthers *et al.* 1999). Also in the present study, physical factors (temperature, salinity and depth) are the determinants in structuring the plant system. The wide tolerance limits to salt variations, to osmotic stress and to air exposure allow *Ruppia cirrhosa* to colonize habitats from oligo- to hyperhaline (Verhoeven 1975, 1979; Brock 1982a; Adams & Bate 1994; Murphy *et al.* 2003). In contrast, *Posidonia oceanica* and *Cymodocea nodosa* have been observed to be vulnerable to salinity and air exposure variability. *Posidonia oceanica* is able to colonize only marine habitats while *C. nodosa* and *Zostera marina* inhabit more variable environments (Den Hartog 1967; Buia & Mazzella 1991), but always strictly within the marine limits.

Although there were no significant differences in salinity as a function of coverage, present data indicated that the growth of *R. cirrhosa* was the highest at marine salinity (about 37–40‰). In our study area *R. cirrhosa* mead-

ows reached the highest values of density (on average *c.* 3320 ± 1700 shoots m⁻²) recorded worldwide with respect to other seagrass systems (Anderson 1966; McMahan 1969). Its density was also higher than *P. oceanica*, *C. nodosa* and *Z. marina* meadows which have been observed to range from 154.0 ± 8.0 to 3.377.0 ± 285.0 shoots m⁻² (Sfriso & Ghetti 1998; Cancemi *et al.* 2002; Marbà *et al.* 2005).

The response of *R. cirrhosa* in the complete absence of water during the dry season is well-known and consists of the annual strategy leaving seeds able to germinate after the dry conditions (Verhoeven 1979; Brock 1982a,b; Malea *et al.* 2004). In contrast, when small quantities of water remain, *R. cirrhosa* adopts a perennial strategy (Richardson 1980; Calado & Duarte 2000). In the Sicilian area, due to man-management, water level in cold ponds is kept substantially constant throughout the year, and this favours the perennial strategy. As a main consequence, *R. cirrhosa* maintained vegetative structures throughout the period of quiescence with expansion peaks observed in spring and early summer. Instead, in the late summer, the decay of stem bases was observed due to decomposition, macroalgae and epiphyte growth, or grazing by consumers. Similar findings are consistent with the current literature reported on other seagrasses from different geographical areas (Verhoeven 1979; Cancemi *et al.* 2002; Malea *et al.* 2004).

### *Ruppia cirrhosa* as main regulator of suspended matter availability in Sicilian saltworks

In the Sicilian saltworks studied, *R. cirrhosa* appeared to control the suspended matter availability. It represented the main source of organic matter supporting a complex food web by the main transfer route of *R. cirrhosa* organic matter into the benthic food web through the bacterial decomposition of detritus. Due to intense wind-driven re-suspension (Sarà *et al.* 1999; Sarà in press), *R. cirrhosa* detritus is supposed to be daily-rearranged making food constantly available for secondary consumers. However, our data showed that suspended organic matter and its fresh fraction concentrations were inversely correlated to *R. cirrhosa* coverage. Such a result suggests that in the time-unit, organic matter quantities were higher in lower vegetated sediments than at higher levels of *R. cirrhosa* coverage. This difference in suspended matter concentration between low and high levels of plant coverage suggested that *R. cirrhosa* could have a role of steadying the effect of sediments, functioning as a trap system for organic matter due to its plant architectural structures. Thus, in low vegetated systems, in the absence of the sedimentary steadying effect exerted by *R. cirrhosa*, the sedimentary organic matter was more easily re-suspended

**Table 6.** List of the bottom and epiphyte plants recorded in the studied area.

| Pond | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S |
| **Seagrasses** | | | | | | | | | | | | | | | | |
| *Ruppia cirrhosa* (Petagna) Grande | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| *Cymodocea nodosa* (Ucria) Ascherson | | | | | | | | | + | + | | | | | + | + |
| **Algae** | | | | | | | | | | | | | | | | |
| **Cyanophyta** | | | | | | | | | | | | | | | | |
| *Anacystis aeruginosa* (Zanardini) F.E. Drouet et W.A. Daily | + | + | | | | | | | + | | + | + | | | | |
| *Calothrix crustacea* Thuret | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + | + |
| *Coccochloris aeruginosa* (Näegeli) F.E. Drouet et W.A. Daily | | | | | | | | | | | | | | | + | + |
| *Microcoleus lyngbyaceus* (Kützing) P. *et* H. Crouan | | + | | | + | | | | + | + | + | + | + | | | |
| **Rhodophyta** | | | | | | | | | | | | | | | | |
| *Acanthophora nayadiformis* (Delile) Papenfuss | | | | | | | | | + | | + | | | | | |
| *Boergeseniella fruticulosa* (Wulfen) Kylin | | | | | | | | | | | + | | | | | |
| *Chroodactylon ornatum* (C. Agardh) Basson | + | | + | | + | + | + | + | + | + | + | + | + | + | + | + |
| *Dasya baillouviana* (S.G. Gmelin) Montagne | | | | | | | | | + | | + | | | | | |
| *Jania rubens* (Linnaeus) J.V. Lamouroux v. *rubens* | | | | | | | | | | | + | | | | | |
| *Laurencia obtusa* (Hudson) J.V. Lamouroux | | | | | | | | | + | + | + | | + | + | | |
| *Spyridia filamentosa* (Wulfen) Harvey | | | | | | | | | + | + | | | + | + | | |
| *Stylonema alsidii* (Zanardini) K.M. Drew | | | | | | | | | | | + | + | | | + | + |
| **Chromophyta** | | | | | | | | | | | | | | | | |
| **Phaeophyceae** | | | | | | | | | | | | | | | | |
| *Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *dichotoma* | | | | | | | | | + | | + | + | + | | | |
| *Dictyota dichotoma* (Hudson) J.V. Lamouroux v. *intricata* (C. Agardh) Greville | | | | | | | | | + | | + | | + | | | |
| *Feldmannia paradoxa* (Montagne) Hamel | | | | | | | | | + | | + | | + | | | |
| *Sphacelaria fusca* (Hudson) S.F. Gray | | | | | | | | | | | + | | | | | |
| **Bacillariophyceae** | | | | | | | | | | | | | | | | |
| *Cocconeis* sp. | + | + | + | + | + | + | + | + | | | + | + | + | | + | + |
| *Gyrosigma* sp. | | | | | | | | | + | + | | | | | | |
| *Licmophora* sp. | | | | | | | | | + | + | | | | | | |
| *Navicula* sp. | + | + | + | + | + | + | + | | | | + | + | + | + | + | + |
| **Chlorophyta** | | | | | | | | | | | | | | | | |
| *Acetabularia acetabulum* (Linnaeus) P.C. Silva | | | | | | | | | + | | + | | + | | | |
| *Caulerpa prolifera* (Forsskål) J.V. Lamouroux | | | | | | | | | + | | + | | | | | |
| *Chaetomorpha linum* (O.F. Müller) Kützing | | | + | + | | | + | + | + | + | + | + | + | + | + | + |
| *Chaetomorpha mediterranea* (Kützing) Kützing v. *mediterranea* | + | + | + | + | | | | | | | + | + | | | + | + |
| *Cladophora sericea* (Hudson) Kützing | + | + | + | + | | | | | | | | | | | + | + |
| *Cladophora socialis* Kützing | | | | | + | + | | | | | + | | | | + | |
| *Entocladia leptochaete* (Huber) Burrows | + | | | | | | | | + | + | + | + | + | + | + | + |
| *Entocladia viridis* Reinke | | | | | | | | | | | | | | | + | |
| *Gayralia oxysperma* (Kützing) K.L. Vinogradova ex Scagel *et al.* f. *oxysperma* | | | | | | | + | | | | | | | | | |
| *Phaeophila dendroides* (P. *et* H. Crouan) Batters | + | + | + | | + | | + | + | | | + | + | + | + | + | |
| *Pringsheimiella scutata* (Reinke) Marchewianka | | | + | | | | | | | | | | + | | | |
| *Rhizoclonium tortuosum* (Dillwyn) Kützing | | | + | + | | | | | | | | | | | | |
| *Ulvella lens* P. *et* H. Crouan | | | | | | | | | | | + | + | | | | |
| *Ulva intestinalis* Linnaeus | | | + | | + | + | | | | | | | + | + | | |
| *Ulva laetevirens* Areschoug | | | + | | + | + | + | | + | | + | + | | | | |
| *Ulva prolifera* O.F. Müller | | | | | | | | | + | | + | | | + | | |
| ***R. cirrhosa* epiphytes** | | | | | | | | | | | | | | | | |
| **Rhodophyta** | | | | | | | | | | | | | | | | |
| *Ceramium diaphanum* (Lightfoot) Roth | | | | | | | | | | | | | + | | | |
| *Chondria capillaris* (Hudson) M.J. Wynne | | | + | | | | + | + | + | + | + | | + | + | + | |
| *Lophosiphonia oscura* (C. Agardh) Falkenberg | | | | | | | + | + | | | | | | | | |
| *Polysiphonia elongata* (Hudson) Sprengel | | | | | | | | | + | + | | | | | | |
| *Polysiphonia sertularioides* (Grateloup) J. Agardh | | | | | | | | | + | + | + | | | | | |
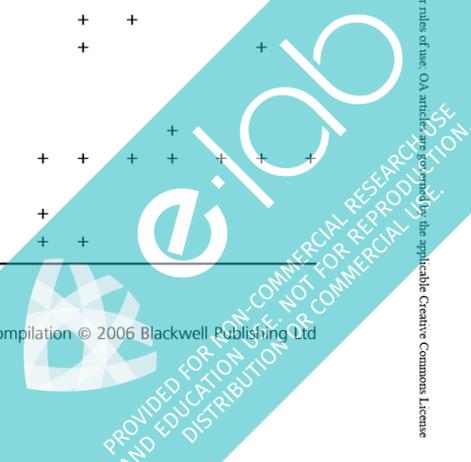
**Table 6.** Continued.

| Pond | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S | Sp | S |
| **Chromophyta** | | | | | | | | | | | | | | | | |
| ***Bacillariophyceae*** | | | | | | | | | | | | | | | | |
| *Fragilaria* sp. | + | | + | | + | + | + | | | | | | | | + | |
| *Nitzschia* sp. | + | | | + | + | | | | + | + | | | + | + | | |
| Total algal taxa (n) | 11 | 8 | 14 | 9 | 11 | 9 | 9 | 7 | 22 | 14 | 26 | 15 | 20 | 12 | 17 | 12 |
| Species richness (%) | 24 | 17 | 30 | 19 | 24 | 19 | 19 | 15 | 48 | 30 | 56 | 33 | 43 | 26 | 37 | 26 |

+, Presence; SP, spring; S, summer.
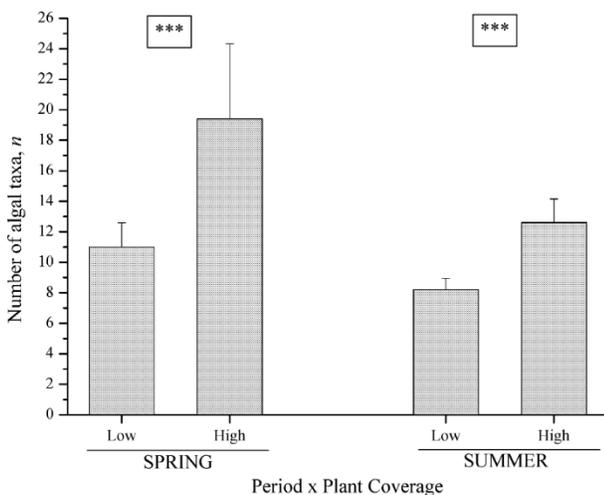


**Fig. 4.** Total number of algal taxa (n) as a function of low and high seagrass coverage both in spring and summer (Student–Newman–Keuls test is also reported).
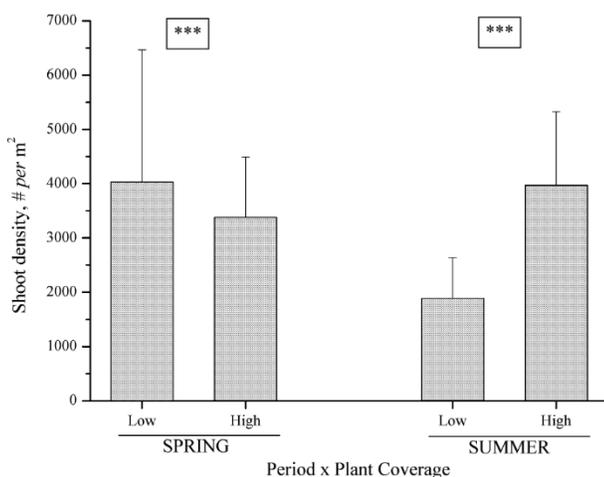


**Fig. 5.** *Ruppia* shoot density (no. m$^{-2}$) as a function of low and high coverage both in spring and summer (Student–Newman–Keuls test is also reported).

in the water column. Under similar enclosure and shallow conditions, but where dominant seagrass were *P. oceanica* or *C. nodosa*, the quantity of suspended organic matter was about 10 times lower (Sarà *et al.* 1999; Pusceddu *et al.* 2003; Sarà in press) than that measured in presence of *R. cirrhosa*. In other seagrass systems waters are generally oligotrophic. For example, in Western Sicily where *C. nodosa* dominates the macrophyte assemblage, and in a shallow sound dominated by *P. oceanica*, CHL *a* concentrations were very low (about 0.5 $\mu$g l$^{-1}$; Sarà *et al.* 1999; Sarà *et al.* 2000; Pusceddu *et al.* 2003). Instead, in the study area, CHL *a* concentration was on average about 3.0–4.0 $\mu$g l$^{-1}$, with peaks where *R. cirrhosa* reached its lower density. Such concentration levels were not common in habitats at southern Mediterranean latitudes, and were close to limits of eutrophication (*i.e.* an increase in the rate of supply of organic matter to an ecosystem; Nixon 1995). The constant production of organic matter by *R. cirrhosa*, although at lower density, enhanced nutrient inputs, resulting in increased growth rates both for benthic diatoms and macroalgae.

Forty-six algal taxa were found throughout the study period associated with *R. cirrhosa* in the study area. The number of algal taxa was positively correlated with *R. cirrhosa* coverage, it was higher at higher coverage values. Thus, *R. cirrhosa* provided not only organic matter directly to the cycle, but providing a physical support for the attachment of other macrophytes, would also amplify the production of the system and its diversity. The total diversity of the macroalgal component was lower than in other systems (Verhoeven 1980), but a similar array of organisms could contribute to the food web with nitrogen-rich organic matter more labile than organic matter produced by *R. cirrhosa* itself (Mann 1988). Nevertheless, macroalgae growth appeared to have a negative effect on *R. cirrhosa* coverage, thereby the higher the value of algal coverage, the lower the *R. cirrhosa* coverage. The higher levels of suspended matter at lower coverage would allow algal biomass to reach notably in summer higher values producing a shading effect by floating macroalgae limiting

R. cirrhosa growth and density (macroalgae shaded out the seagrass, weakened its stems, increasing their susceptibility to damage; Verhoeven 1980).

Under these conditions, the *R. cirrhosa* system would be (i) an endless system of production of organic matter produced by the seagrass itself not immediately available, but thanks to physical-driven events (wind + shallowness; *sensu* Sarà in press) would re-enter the water column from the sediments and (ii) an attachment support system for several producers of nitrogen-rich organic matter that instead would be immediately available to consumers.

Similar coupling mechanisms physically mediated, among seagrass and macroalgae have never been described before and further studies are needed for a better understanding of their roles in the dynamics of releasing nutrients and organic matter and the subsequent effect on secondary consumers.

## Summary

Relationships among chemical–physical features, total gross suspended matter and coverage of *Ruppia cirrhosa* in a saltworks system of western Sicily were investigated. Sampling was carried out in eight ponds during spring and summer 2004. TSM and its organic fraction concentrations varied both at different levels of coverage and between seasons. Dominant primary producer was the phanerogam *R. cirrhosa*, its epiphytic component and some macroalgal species. *Ruppia cirrhosa* represented 75% and 65% of total coverage, in spring and in summer respectively, whereas macroalgal component represented respectively about 24% and 36% of total coverage. A total number of 46 taxa (algae plus *R. cirrhosa* epiphytes) were found. Algal community was mainly formed by pleustophytic taxa. The complexity of the relationships inside the saltworks system was investigated by a multivariate approach allowing to separate two groups of ponds. A group of ponds characterized by lower values of *R. cirrhosa* coverage, higher levels of algal coverage, a lower number of algal taxa and higher concentration values of suspended matter and the other one with higher levels of *R. cirrhosa* coverage and lower suspended matter concentrations, but higher numbers of algal taxa.

## Acknowledgements

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