Effects of organic matter input from a fish farming facility on a Posidonia oceanica meadow

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Abstract

In the Mediterranean, the development of aquaculture along the coasts appears as a source of disturbance to the littoral ecosystems, and in particular to Posidonia oceanica seagrass meadows. Although the impact of fish farms in Northern Europe has been studied over the last few years, the data are more scarce in the Mediterranean. Thus, a number of physico-chemical and biological parameters have been examined here in order to evaluate the impact of a fish farm in a littoral bay of Corsica. The following values that were recorded in the vicinity of the fish farm are much higher than those at the reference station: organic content of the sediment (24–21 versus 2%), nitrogen concentrations (ammonium: 19.5–8.4 versus 1.8 $\mu$M) and phosphorous levels in the pore water (orthophosphates: 5.2–1.3 versus 1.7 $\mu$M). The seagrass meadow vitality also seems to be affected in the vicinity of cages, with densities that drop from 466 (reference station) to 108 shoots m$^{-2}$ (20 m from cages). Total primary production also varies from 1070.6 to 87.9 g m$^{-2}$ year$^{-1}$. The main impact factors seem to be the input of organic matter originating from the cages and the high epiphyte biomass caused by the nutrient enrichment. The high level of organic matter and the presence of mud seem to alter the physico-chemical characteristics of the bottom sediment; moreover, the plant/epiphyte competition seems to lead to a leaf fragility and, more importantly, to a decrease in available light.

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1. Introduction

Over the last decade, nearly 90,000 ha of marine phanerogams has disappeared throughout the world, mainly due to the destruction of their natural habitats (Short & Wyllie-Echeverria, 1996). This regression can have dire consequences, both from an ecological and economical point of view. Indeed, it can mainly lead to (i) a qualitative and quantitative impoverishment of the floral and faunal species, including commercially exploited species (Mazzella et al., 1993; Ogden, 1980), and (ii) a modification of sedimentary budget and shoreline position (De Falco, Ferrari, Cancemi, & Baroli, 2000; Jeudy De Grissac, 1984; Moriarty & Boon, 1990, Chap. 15). Although it is true that natural phenomena may be behind certain regressions, the development of human activity appears to be the main cause of marine phanerogam destruction (Lapointe, Tomasko, & Matzie, 1994; Shepherd et al., 1990, Chap. 12; Short & Wyllie-Echeverria, 1996).

Among the various types of human activities, the development of aquaculture along littoral coasts would appear to be responsible for localized regressions of phanerogam seagrass beds (Delgado et al., 1997; Handy & Poxton, 1993). Indeed, the organic wastes that are released into the water column by the aquaculture facilities, due to either uneaten feed or fish excretion, are suggested to be mainly responsible for the observed regressions (Kibria, Nugegoda, Fairclough, & Lam, 1997; Wu, 1995). Most of the studies to have focussed on the impact of aquaculture facilities involve salmon fish farms.
in Northern Europe (Gowen & Bradbury, 1987; Handy & Foxton, 1993; Wu, 1995). Although most of the effects are concentrated in the immediate vicinity of the cages (Gowen & Bradbury, 1987), much broader repercussions can be felt, such as a decrease in benthic diversity (Wu, 1995) and a modification of the sedimentary characteristics (Wu, Lam, Mackay, Lau, & Yam, 1994).

In the Mediterranean, development of aquaculture along the coasts (e.g. Dicentrarchus labrax and Sparus aurata; Vicente, 1985) would appear to be one of the impact factors on littoral ecosystems. A number of authors (Cancemi, Villedieu, & Pergent-Martini, 1998; Delgado et al., 1997; Pergent, Mendez, & Pergent-Martini, 1999) have reported regressions of phanerogam seagrass beds of Posidonia oceanica located in proximity to aquaculture facilities (floating cages), despite these legislative measures taken to protect this phanerogam species in many countries of the Mediterranean (France, Spain, in Boudouresque et al., 1995). The accumulation of organic wastes on the bottom in the vicinity of fish farms generally leads to an increase in dissolved pore water nutrients (Hall, Holby, Kollberg, & Samuelsson, 1992), which can be rapidly utilized by Posidonia oceanica. Indeed, it has been demonstrated that high concentrations in nitrogen and/or phosphorous can affect the growth of this phanerogam (Harlin & Thorne-Miller, 1981; Hemmingsa, 1998; Short, Burdick, & Kaldy, 1995).

Although the impact of aquaculture farms in Northern Europe has been studied over the last few years (Gowen & Bradbury, 1987; Wu, 1995), the impact of such facilities in the Mediterranean, in particular the impact on Posidonia oceanica seagrass beds, has received less attention. The objectives of the present study are, thus, to evaluate the impact of an aquaculture facility that is present over a Posidonia oceanica meadow on the island of Corsica, and particularly to determine if within oligotrophic waters (Bethoux & Copin-Montegut, 1988), such as those of the Corsican coast, the nutrient enrichment of the environment represents a source of direct disturbance to the growth of the plant. Indeed, nitrogen and phosphorous are often considered to be limiting factors in the growth of benthic plants and algae, and in particular that of phanerogams (Harlin & Thorne-Miller, 1981; Orth, 1977). To this end, a number of parameters allowing the vitality of the seagrass meadow to be assessed were compared to the physical and chemical characteristics of the sediment, notably the level of dissolved reactive nutrients in pore water.

2. Materials and methods

The fish farm ‘A Dorada’, set up in 1985 within the bay of Figari (9°4′0″E, 41°28′13″N), located at the south-western extremity of Corsica (France), is made up of 30 floating cages measuring 25 m², with an individual volume of 60 m³, grouped into six groups of five cages, the groups being separated by about 20 m (Fig. 1). These cages are situated at approximately 200 m from the shore over a bottom depth of −10 m. Approximately 40–45 tons of fish have been produced by the fish farm between 1995 and 1999, tonnage constituted by two species: Dicentrarchus labrax (Sea Bass) and Sparus aurata (Sea Bream).

The bottom substrate is occupied by a Posidonia oceanica bed that has been exhibiting signs of regression (Pergent et al., 1999).

Three sampling stations were selected, all at the same depth (−10 m): Figari 0, directly beneath the cages where the seagrass is no longer present; Figari 20 and Figari 100, located 20 and 100 m from the cages in the direction of the bay opening, respectively. Posidonia oceanica is still present at these last two stations.

Another station, situated outside of the bay in open sea (2 km from the coast) was selected as a reference station, as it is present within a marine protected site set up in 1992 (les îlots des Moines; 8°54′32″E, 41°27′25″N) (Fig. 1). This reference station, located at a depth of 11 m, is also characterized by the presence of a Posidonia oceanica seagrass bed.

Measurements and samples were taken by SCUBA divers. Within the bay of Figari, the station Figari 20 was monitored monthly in 1995, whereas the stations Figari 0 and 100, as well as the reference station ‘Les Moines’, were monitored on a seasonal basis.

Water was taken from the sediment (pore water) using 60 ml syringes (sipping samples from a sediment depth of 5–6 cm) and from the water column (just above the seagrass canopy).

Each sample (three replicates) was subsequently filtered on a Whatmann filter (GF/C, 47 mm in diameter), refrigerated (4 °C maximum) and analyzed within 48 h. The concentrations in phosphate (ortho), nitrate, nitrite and ammonium were measured using colorimetric methods (absorbance measurements). The apparatus used was a HACH DR/2000 type spectrophotometer (Ormaza-Gonzales & Villalba-Flor, 1994).

Granulometry and organic matter levels were also assessed from sediment samples (three replicates) obtained using a PVC sediment corer (5 cm in diameter and 10 cm in length). Grain size analysis was performed using a laser system (Galai Cis I) (De Falco et al., 2000) on preserved sediment samples (63 μm). Sedimentary organic matter was determined by loss on ignition (6 h at 550 °C).

The analysis of phosphorous within the Figari sediments was performed following acid extraction (HCl 1 M) of dry and burned sediment. The phosphates extracted from the dry sediment are considered to be equivalent to the inorganic phosphorous, whereas those extracted from the burnt sediment represent total phosphorous. By subtracting, we obtain the levels of...
phosphorous associated with the organic fraction (Aspilia, Agemian, & Chau et al., 1976; Giordani & Astorri, 1986). Dissolved inorganic phosphorous was determined colorimetrically in a 1-cm cuvet with a spectrophotometer, as molybdate reactive phosphorous (Valderrama, 1981).

The density of the seagrass bed (number of shoots per square meter) was estimated at each site using a 40-cm² quadrat, with 8–10 replicates per station. At each station, 15 orthotropic shoots were sampled for pheno-logic and lepidochronologic analyses.

Shoot composition and leaf biometry were subsequently determined according to the technique described by Giraud (1979); the weights of the rank 1 adult leaf (the oldest) were obtained following desiccation in a drying oven (48 h at 80 °C). The leaf area index (LAI), which corresponds to the leaf surface area (Drew, 1971), and the coefficient A, which represents the percentage of leaves having lost their apices (broken leaves) according to Giraud (1979), were calculated. The epiphytes present on both adult and intermediate leaves were sampled by scraping with a razor blade and the total dry weight of these epiphytes was determined following desiccation in a dry oven (48 h at 80 °C).

Lepidochronology was performed on the first three annual scale thickness cycles (the most recent) and on the corresponding rhizome segments (Pergent, 1990).

Leaf production and that portion of production allotted to the elongation of the rhizomes were calculated according to the lepidochronologic method (Pergent-Martini, 1994).

Data were processed by one-way analysis of variance (one-way ANOVA) followed by Tukey’s honestly significant difference test. The statistica (v. 5, 97) for Windows software was used.

3. Results

The mud fraction (<63 µm) and organic matter levels were very high in the vicinity of the cages as compared to those levels recorded at the reference station of Les Moines (Table 1). At the three Figari stations, the mud fraction was 90–92% of the sediment and the organic matter ranged between 21 and 24%, with the highest values beneath the cages.

Nutrient concentrations measured within the water column, at all the stations examined, were substantially

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sediment characteristics at the four stations examined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Figari 0</td>
</tr>
<tr>
<td>Mud fraction (%)</td>
<td>92.0</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>24</td>
</tr>
</tbody>
</table>
low, with the exception of nitrate that exhibited a high mean concentration ($\text{NO}_3^-$/$\text{NO}_2^-$ = 4.0 ± 0.8 μM; $\text{NH}_4^+$ = 0.3 ± 0.5 μM; $\text{PO}_4^{3-}$ = 0.2 ± 0.2 μM; mean and confidence interval, 95%). The nutrient levels measured in the pore water of the sediment were clearly higher and failed to exhibit a clearly identifiable seasonal pattern for the stations examined (Table 2).

Mean nitrate levels in the sediment of the Figari seagrass bed are relatively constant, ranging from 2.3 to 3.7 μM (Table 2). The values recorded directly beneath the cages (Figari 0: 2.5 ± 0.7 μM) do not significantly differ from the other stations (Tables 3 and 4). At the Les Moines reference station, the mean nitrate concentration was in the order of 3.1 (±0.8) μM.

Ammonium concentrations in the pore water of the sediment varied as a function of the distance from the aquaculture facilities (Table 2), with a significant reduction observed at a distance of 100 m from the cages (Figari 100). The concentration values inside the bay (Figari 0, 20 and 100) were significantly higher with respect to the reference site (Les Moines) (Tables 3 and 4). At Figari 0 particularly these values were very high, (19.5 ± 8.7 μM, Table 2).

A similar spatial evolution was also observed for the phosphate concentrations, significantly higher beneath the cages with respect to the other stations (Tables 3 and 4). Nitrites exhibited very low concentrations at both the Figari and Les Moines stations.

Inorganic phosphorous and total phosphorous levels in the sediment, at the three Figari sites, presented very high values while, at the same time, exhibiting the same spatial gradient as a function of the distance from the fish cages (Table 5).

The density of Posidonia oceanica beds was very low within the Bay of Figari, in particular in the vicinity of the fish cages (Figari 20: 108 ± 16 shoots m$^{-2}$). Conversely, those values recorded at the reference station (Les Moines) were much higher (466 ± 35 shoots m$^{-2}$) (Table 6).

The mean number of leaves (adult + intermediate) per shoot was approximately five leaves for the Figari stations. A value of approximately 6 was recorded for the reference station (Table 6). The LAI, which is determined based on the number of leaves and their length and width, revealed much higher index values at

### Table 2
Seasonal variations in nutrient levels in the pore water of the sediment at the different stations examined (expressed in μM)

<table>
<thead>
<tr>
<th>Station</th>
<th>NO$_3^-$</th>
<th>NH$_4^+$</th>
<th>PO$_4^{3-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figari 0</td>
<td>2.9</td>
<td>15.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Figari 20</td>
<td>3.2</td>
<td>7.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Figari 100</td>
<td>2.9</td>
<td>11.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Les Moines</td>
<td>4.3</td>
<td>1.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

January 2.9 15.0 4.8 February 6.7 13.6 1.6 April 2.5 7.5 4.8 May 4.5 10.0 1.0 June 1.5 July 3.5 12.2 2.7 August 2.1 12.2 1.2 September 2.6 18.2 2.9 October 2.9 8.9 1.2 November 2.9 14.5 1.2 Mean 2.5 19.5 5.2 CI 0.7 8.7 0.6

Mean value and confidence interval (95%).

### Table 3
Summary of one-way ANOVA results: variability among and within stations, F-test and alpha level ($p$) values

<table>
<thead>
<tr>
<th>Variable</th>
<th>% Variability</th>
<th>Among stations</th>
<th>Within stations</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3^-$</td>
<td>64.44</td>
<td>35.56</td>
<td>1.8</td>
<td>0.18106</td>
<td></td>
</tr>
<tr>
<td>NH$_4^+$</td>
<td>93.95</td>
<td>6.05</td>
<td>15.5</td>
<td>0.00003</td>
<td></td>
</tr>
<tr>
<td>PO$_4^{3-}$</td>
<td>90.87</td>
<td>9.13</td>
<td>9.9</td>
<td>0.00043</td>
<td></td>
</tr>
</tbody>
</table>

The Figari 0, 20 and 100 stations and the Moines station were considered.

### Table 4
Results of the Tukey HSD test

<table>
<thead>
<tr>
<th>Variable</th>
<th>F0</th>
<th>F20</th>
<th>F100</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_3^-$</td>
<td>0.623</td>
<td>0.154</td>
<td>0.686</td>
</tr>
<tr>
<td>NH$_4^+$</td>
<td>0.933</td>
<td>0.884</td>
<td>0.913</td>
</tr>
<tr>
<td>PO$_4^{3-}$</td>
<td>0.000</td>
<td>0.000</td>
<td>0.031</td>
</tr>
</tbody>
</table>

Labels F0, F20 and F100 refer to Figari 0, 20 and 100 stations, M to Moines station. Significant differences ($p < 0.05$) are italicized.
Table 5
Inorganic phosphorous and total phosphorous per kilogram of sediment at the different stations examined

<table>
<thead>
<tr>
<th></th>
<th>Figari 0</th>
<th>Figari 20</th>
<th>Figari 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic phosphorous (mg kg⁻¹)</td>
<td>1876 ± 426</td>
<td>448 ± 180</td>
<td>252 ± 55</td>
</tr>
<tr>
<td>Total phosphorous (mg kg⁻¹)</td>
<td>2206 ± 429</td>
<td>786 ± 229</td>
<td>568 ± 33</td>
</tr>
</tbody>
</table>

Mean values ± confidence interval (95%).

the Les Moines station as compared to the two Figari stations (Table 6).

The overall coefficient A (adult + intermediate leaves) in the Figari seagrass bed ranged from 27 to 42% (Table 6). At the Les Moines station, the coefficient A was in the order of 53.0%. At the station closest to the cages (Figari 20), the intermediate leaves showed a very high percentage of broken leaf apices (30.5%) (Table 6).

Epiphytes biomass in the vicinity of the aquaculture cages (Figari 20) exhibited very high values with a mean annual biomass of 93.5 mg shoot⁻¹ (Table 6); at 100 m from the cages the values were still rather high (51.5 mg shoot⁻¹). At the Les Moines station the mean annual value of epiphyte biomass was 37.8 mg shoot⁻¹ (Table 6).

The mean number of leaves annually produced in the examined stations was 7.6 ± 0.1 for Figari 20 and 7.6 ± 0.2 for Figari 100; the annual rhizome growth rate was 5.0 ± 0.5 and 2.8 ± 0.8 mm, respectively (Table 7). At the reference station, annual leaf production was estimated as 8.6 ± 0.3, whereas annual rhizome growth was 10.7 ± 1.3 mm (Table 7).

Primary production estimates within the Bay of Figari exhibited very low values for the leaf tissues and rhizomes, notably for the station in proximity to the fish cages (Figari 20: 82.9 and 5.0 g dry wt m⁻², respectively) (Table 7 and Fig. 2). At 100 m from the cages the values were still rather low (123.0 and 6.2 g dry wt m⁻², respectively). Conversely, very high values were calculated for the Les Moines reference station (1 022.5 and 48.1 g dry wt m⁻², for the leaf tissues and rhizomes, respectively) (Table 7 and Fig. 2).

Table 6
Leaf area index coefficient A and epiphytes biomass at the three stations examined (mean annual values)

<table>
<thead>
<tr>
<th></th>
<th>Figari 20</th>
<th>Figari 100</th>
<th>Les Moines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoots density</td>
<td>108 ± 16</td>
<td>178 ± 55</td>
<td>466 ± 35</td>
</tr>
<tr>
<td>Number of leaves per shoot (adult + intermediate)</td>
<td>5.5 ± 0.6</td>
<td>4.9 ± 0.6</td>
<td>5.8 ± 0.7</td>
</tr>
<tr>
<td>Global LAI (m² m⁻²)</td>
<td>1.6 ± 0.3</td>
<td>2.0 ± 0.7</td>
<td>14.7 ± 4.0</td>
</tr>
<tr>
<td>Coefficient A (%)</td>
<td>42.2 ± 13.4</td>
<td>26.9 ± 16.1</td>
<td>53.0 ± 11.3</td>
</tr>
<tr>
<td>Global</td>
<td>48.4 ± 11.3</td>
<td>37.5 ± 16.3</td>
<td>71.4 ± 9.0</td>
</tr>
<tr>
<td>Adult leaves</td>
<td>30.5 ± 15.3</td>
<td>17.4 ± 19.5</td>
<td>18.9 ± 15.3</td>
</tr>
<tr>
<td>Intermediate leaves</td>
<td>93.5 ± 45.8</td>
<td>51.5 ± 55.3</td>
<td>37.8 ± 35.0</td>
</tr>
</tbody>
</table>

Mean value ± confidence interval.

4. Discussion and conclusions

The data presented here demonstrate the occurrence of substantial differences in both the sediment characteristics and morpho-structural parameters of a Posidonia oceanica seagrass bed among the various stations examined. The spatial gradient observed as a function of the distance from the aquaculture cages, and as compared to the reference station, confirms that there is indeed a considerable impact of these facilities on the environment.

The very high organic matter content in the sediment at the Figari station demonstrates that there is a significant accumulation of organic wastes on the bottom. The accumulation of the organic waste in the seabed is favored by the limited hydrodynamics within the bay, as confirmed by the muddy composition of the sediments. The observed gradient as a function of distance from the cages, in particular for interstitial NH₄⁺ and PO₄³⁻, would seem to suggest an intense mineralization of the organic matter present within the sediment, organic matter originating from the aquaculture facilities. This input in organic matter, which is linked to food surplus conditions and to fish physiology (excretion and secretion), has already been recorded for salmon aquaculture facilities (Wu, 1995).

Nitrogen, mainly in the form of ammonium, was at a maximum in the vicinity of the aquaculture cages. This is best explained by the fact that ammonium is the main excretion product in fish (Hall et al., 1992; Handy & Poxton, 1993). The nitrate concentrations recorded at the Figari stations were very low in the pore water, but very high in the water column as compared to published values for the Mediterranean (Ignatiades, Karydis, & Vounatsou, 1992). This distribution may be due to the environmental conditions that prevail in proximity to the aquaculture facilities, notably an oxygen deficiency in the sediment that would prevent the transformation of NH₄⁺ (the main input from the cages) to NO₃⁻ (Gowen & Bradbury, 1987; Handy & Poxton, 1993; Hemminga, 1998).

The low concentrations of dissolved phosphorous (orthophosphates) recorded in the water column and, to a lesser extent, within the pore water are compensated by very high concentrations of total and inorganic phosphorus which are linked in a stable manner to the sediment. Figari sediment showed very high values of total and inorganic sedimentary phosphorous with respect to other Mediterranean sites: 600 mg kg⁻¹ of total phosphorous in sediments from the Adriatic sea (Giordani, Asioli, Borsetti, Frignani, & Lucchini, 1990); 175 mg kg⁻¹ of total phosphorous and 121 mg kg⁻¹ of inorganic phosphorous in Posidonia oceanica sediments from the Gulf of Oristano, in Sardinia (De Falco, unpublished data). This inorganic phosphorus can be mobilized under certain conditions (anoxic conditions,
low pH; Kibria et al., 1997; Moriarty & Boon, 1990, Chap. 15) and thus utilized by the plant.

Examination of the main phenologic parameters reveals that the Figari meadow exhibits a very low vitality. Indeed, seagrass bed density values are markedly beneath that which is usually recorded at 10 m depths. At the station closest to the cages this density is in fact "abnormal", based on the classification scale established by Pergent, Pergent-Martini, Boudouresque (1995).

Epiphyte biomass is very high in proximity to the cages (e.g. Figari 20). This is most probably due to the nutrient enrichment of the environment (especially in NH₄⁺) (Harlin & Thorne-Miller, 1981; Pergent et al., 1999). The extensive development of epiphytic organisms on the leaves of seagrasses represents a source of disturbance to the plant (Cancemi et al., 1998; Tomasko & Lapointe, 1991) as it limits the quantity of light available to the plant for photosynthesis (Caye & Rossignol, 1983; Hemminga, 1998; Sand Jensen, 1997). This abundant epiphytic cover may also help explain the greater percentage of broken and/or grazed leaves in proximity to the fish cages, including the intermediate leaves (grazing by herbivores and increased fragility of the leaves due to the added weight of the epiphytes) (Wittman, Mazzella, & Fresi, 1981).

Primary production of the seagrass bed similarly follows a spatial gradient as a function of the distance from the fish cages. The values recorded for Figari 20 (leaf production, rhizome growth) correspond to abnormally low values (Buia, Zupo, & Mazzella, 1992; Pergent-Martini et al., 1994) and are approximately 10 times lower than those observed for the reference site. Conversely, the values recorded for the Les Moines station are very high compared to other sites of the Mediterranean (Buia et al., 1992; Pergent-Martini et al., 1994).

Thus, all of the parameters used to assess seagrass bed vitality and disappearance in proximity to the aquaculture cages suggest that the Posidonia oceanica seagrass bed in the bay of Figari is regressing. The main factor behind this regression would appear to be the input of organic detritus originating from the cages, as has been demonstrated by Delgado, Ruiz, Pérez, Romero, & Ballesteros (1999). In addition, the limited circulation of the water mass within the bay does not allow a good dispersal and/or dilution of the wastes associated with the aquaculture activities. This mostly leads to modifications in the physico-chemical characteristics of the sediment.

The occurrence of mechanical problems in plant anchoring to the substratum can be proposed at the Figari stations. Due to the high organic matter content and the very fine grain size, Figari sediments probably have mechanical properties (Hain, 1991) that greatly differ from that which is normally found in Posidonia oceanica beds (Colantoni, Gallignani, Fresi, & Cinelli, 1982). This may play a role in altering the stability of the plant with respect to its substratum (Chassefiere & Monaco, 1982). This is supported by the fact that, in
proximity to the cages, an extensive root system is present whereas, under normal conditions, root production and biomass of the orthotropic rhizomes of *Posidonia oceanica* are generally quite low (Ott, 1980). The biomass for the roots at the Figari 20 station was very high, being 35.1 ± 8.3% of the below-ground biomass. This value is twice that of recorded for the Figari 100 station (18.0 ± 5.3%) or in the literature (15.6% in Mazzella et al., 1998).

In addition, important mineralization of the organic matter (oxidation processes) can lead to anoxic conditions in the sediment (Delgado et al., 1999), a situation that can affect ion absorption through the roots (Hemminga, 1998). Also, the lack of oxygen can favor the activity of anaerobic bacteria and thus the production of toxic substances to the plant (sulfide compounds). Carlson, Yabro, Barber (1994) demonstrated that hydrogen sulfide, within the pore water of the sediment, was one of the main causes of the regressions of the seagrass *Thalassia testudinum*.

Insofar as the nutrient enrichment of the environment as the result of organic matter mineralization is concerned, the high level of dissolved nutrients does not necessarily represent a source of direct disturbance to the growth of phanerogams. Conversely, high environmental nutrient concentrations cause negative indirect effects, such as the massive development of algae and an aggravated plant/epiphyte competition, which can lead to an increased leaf fragility and, more importantly, to a decrease in available light.

In conclusion, the data gathered would seem to suggest that a generalized disequilibrium of the physiology processes exists within the seagrass bed of the bay of Figari. Indeed, the efforts made by the plant to adapt to the very poor living conditions within the sediment, namely extensive root development, would lead to a high respiratory demand by the below-ground plant compartment. Conversely, the decrease in leaf photosynthetic activity (very low LAI and high epiphyte competition) leads to a decrease in oxygen production and, as a result, may affect oxygen transport towards the below-ground parts.

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**References**


