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Impact of fish farming facilities on *Posidonia oceanica* meadows: a review

Christine Pergent-Martini[1], Charles-François Boudouresque[2], Vanina Pasqualini[1] & Gérard Pergent[1]

1 EqEL, Faculty of Sciences, University of Corsica, Corte, France
2 UMR CNRS DIMAR, Faculty of Luminy, Marseilles Cedex, France

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Correspondence
Gérard Pergent, EqEL, Faculty of Sciences, University of Corsica, BP 52, 20250 Corte, France.
E-mail: pergent@univ-corse.fr

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Abstract

The impact of fish farming facilities on *Posidonia oceanica* meadows was assessed from studies of intensive facilities carried out over the last few years. The disturbances caused by these fish farms were measured by means of both abiotic (light, sediment, interstitial water) and biotic variables (meadow density, leaf biometry, lepidochronology, primary production, epiphytes, reserve carbohydrates in the rhizomes), in function of increasing distance from cages and/or inside a geographically close reference site. The results showed significant degradation of these seagrass meadows in all the sectors investigated. When fish farming cages were placed above a *P. oceanica* bed, the meadow was severely degraded or disappeared and the sediment showed a strong increase in organic matter that could lead to anoxia phenomena. The irreversible impact of fish farming projects on *P. oceanica* meadows requires the application of the precautionary principle. Several recommendations (site selection, preliminary studies and monitoring over time) are suggested in order to enable piscicultural activities to be incorporated in a global process of Integrated Coastal Zone Management.

Problem

The term aquaculture covers all activities whose objective is the production and commercialization of aquatic species, whether (i) plants or animals, (ii) fresh, briny or salty water, (iii) a part of or all of the reproduction cycle (Barnabé 1989). In 1990, Mediterranean aquaculture produced 130,000 tons of fish, molluscs and crustaceans, *i.e.* 1.6% of world marine aquacultural production (De La Pomélie 1991). At present, the piscicultural production represented more than 654 million dollars, and the development of aquaculture is attracting numerous Mediterranean countries (*e.g.* three new countries started production in 1999; Belias & Dassenakis 2002; FAO 2006). In 2003, Italy, Greece and Spain are the three countries with a major production in the Mediterranean Sea, with respectively 172,287, 138,713 and 82,273 tons of marine fish (FAO 2006).

In some cases the development of pisciculture seems to be a threat to the quality of coastal zones (Videau & Merceron 1992), and therefore to certain uses (coastal recreation and tourism in PNUE 1999). Because of (i) their specific geographical locations, often in sheltered bays where water circulation is limited, (ii) the large quantities of waste (unconsumed food, excretion), (iii) the frequent use of 'sanitary' substances (antibiotics, oligo-elements), aquacultural installations can have a negative impact on the natural environment (Handy & Poxton 1993; Hevia *et al.* 1996; Miner & Kempf 1999; Boyra *et al.* 2004; Machias *et al.* 2004).

While the impact of intensive marine pisciculture (cages) has been the subject of numerous studies in Northern Europe (*e.g.* development of salmon farming; Gowen & Bradbury 1987; Munday *et al.* 1994; Merceron & Kempf 1995; Wu 1995), there is less data concerning its impact in the Mediterranean Sea, where the activity is more recent (Mendez *et al.* 1997; Karakassis *et al.* 1999, 2000, 2002; Pergent *et al.* 1999; Cancemi *et al.* 2000, 2003; Dimech *et al.* 2000a,b; Mazzola *et al.* 2000; Ruiz 2000; Ruiz *et al.* 2001; Machias *et al.* 2004). Recently, the European programs 'Medveg' and 'Meramed' were realized in the Mediterranean Sea (Medveg 2006; Meramed 2006). The projects are focused particularly to provide information on the loss of dissolved and particulate effluents at fish farms, on the nutrient regeneration in fish farm sediments and on effects on population dynamics of seagrasses in fish farm surroundings (Marbà *et al.* 2006).

Posidonia oceanica (L.) Delile, a marine magnoliophyte endemic to the Mediterranean Sea, plays a major ecological, sedimentary and economic role in coastal ecosystems (Bellan-Santini *et al.* 1994; Costanza *et al.* 1997). *P. oceanica* is formed by a rhizome, horizontal or erect, with sheaths attached to it and a foliar shoot at the apex. Posidonia shoots make up dense meadows between the surface and at 40 m depth (Proccacini *et al.* 2003). Rhizome growth rate is very low, between 1.0 and 7.0 cm·year^{-1} on average (Caye 1982). These seagrass meadows produce enormous quantities of organic matter (leaves, epiphytes), which constitute the basis of the food web both within and outside the ecosystem. This production is also exported to other ecosystems, where it is the main source of food (Pergent *et al.* 1994; Walker *et al.* 2001). *P. oceanica* is legally protected in many Mediterranean countries (Platini 2000). Despite these protection measures, significant regression of these meadows has been shown in several sectors of the Mediterranean coastal zone, in particular around conurbations and large industrial port centres (Ardizzone & Pelusi 1984; Boudouresque 2003). In 1999, the United Nations Environment Programme (UNEP) adopted an action plan for the conservation of marine vegetation in the Mediterranean Sea, in which *P. oceanica* meadows featured as a priority habitat (Anonymous 2000).

In this context, a first review of the impact of these fish farming facilities, established on the basis of the studies carried out over the last few years, is required. The ever increasing demands of fish-farming professionals, often together with stakeholders, for the setting up of new facilities requires a true assessment of the impact of these activities on the natural environment, particularly *P. oceanica* meadows, the cornerstone of Mediterranean coastal ecosystems. In addition to simply protecting *P. oceanica* meadows, the definition of potential sites appropriate for the development of fish farming facilities, reconciling the preservation of the natural environment with economic development, is a decision-making aid for many local authorities with a view to Integrated Coastal Zone Management (ICZM).

Case Studies

Several studies, carried out since the 1990s (Table 1), concern intensive fish farming facilities, using cages, for sea bass *Dicentrarchus labrax* (Corsica – Verneau *et al.* 1995; Pergent *et al.* 1999; Cancemi *et al.* 2000, 2003; Sardinia – Pergent *et al.* 1999), sea bream *Sparus aurata* (Balearic Islands – Delgado *et al.* 1997, 1999; Malta – Dimech *et al.* 2000a,b), amberjack *Seriola dumerilii* (Spain – Ruiz 2000), or several of these species (Ruiz 2000; Ruiz *et al.* 2001). The production of these farms varies from a few tons (Sant'Amanza Gulf, Corsica, 15 t·year^{-1}; Figari Bay, Corsica, 18 t·year^{-1}) to several hundred tons (Aranci Gulf, Sardinia, 200 t·year^{-1}, El Hornillo Bay, Spain, 700–800 t·year^{-1}). The disturbance caused by the fish farming

Table 1. Location and main characteristics of studied sites. Opening date corresponds to the date of the first exploitation; Surface and production correspond to the values recorded during the studied period.

site	location	depth (m)	opening date	surface and production	habitats	references
Ajaccio Bay (Corsica)	N41°54′06″, E08°38′12″	18–25	1989		*P. oceanica*	Verneau *et al.* (1995)
Figari Bay (Corsica)	N41°28′11″, E09°03′54″	9–10	1985	700 m^2, 18 tons	*P. oceanica*	Pergent *et al.* (1999), Cancemi *et al.* (2000)
Sant'Amanza (Corsisa)	N41°24°26″, E09°13′25″	5–7	1988	320 m^2, 15 tons	*P. oceanica*	Pergent *et al.* (1999), Cancemi *et al.* (2000)
Aranci Gulf (Sardinia)	N40°58′59″, E09°38′05″	23	1991	8000 m^2, 200 tons	*P. oceanica*	Pergent *et al.* (1999), Cancemi *et al.* (2000)
Fornells Bay (Minorca)	N40°03′12″, E04°08′17″	5–6	1986	1500 m^2, 22–77 tons	*P. oceanica*, *C. nodosa*	Delgado *et al.* (1997, 1999)
Hornillo Bay (Spain)	N37°24′30″, E01°33′30″	5–20	1989	70000 m^2, 800 tons	*P. oceanica*, *C. nodosa*	Ruiz (2000), Ruiz *et al.* (2001)
Saint Paul Bay (Malta)	N35°57′05″, E14°23′43″	12–16	1991	3600 m^2	*P. oceanica*	Dimech *et al.* (2000a)

facilities is usually assessed using a variety of factors (light, sediment, interstitial water) and biotic variables (meadow density, leaf biometry, lepidochronology, primary production, epiphytes, reserve carbohydrates in the rhizomes) in function of increasing distance from the cages and/or inside a geographically close reference site.

The increase in turbidity recorded near the cages leads to a significant reduction in light intensity. This reduction is estimated to be more than 30%, on average, under the cages in Figari Bay (Corsica; −10 m; Pergent *et al.* 1999) and 23% at 40 m from the El Hornillo cages (Spain; −8 m; Ruiz *et al.* 2001). When the cages are situated in shallow zones, irradiance at seabed level remains much higher than that measured at the lower limit (maximum extension depth due to light availability) for *P. oceanica* meadows. Nevertheless, this factor needs to be taken into consideration for fish farming facilities situated over deeper meadows (Verneau *et al.* 1995). In addition, the shade cast by the cages (independently of turbidity) significantly reduces the density of the *P. oceanica* shoots (Ruiz 2000; Ruiz & Romero 2001).

Furthermore, there is an increase in the levels of organic matter and silt close to the cages (Delgado *et al.* 1999; Pergent *et al.* 1999; Dimech *et al.* 2000a). This enrichment in organic matter is best observed at the level of the deepest layer of sediment (Fig. 1; layer 10–15 cm). Beneath the cages, the sediment is black and anoxic, giving off methane CH_4 and hydrogen sulphide H_2S (Karakassis *et al.* 2002). Close to the cages, the fauna is dominated by the polychaete *Capitella capitata*, a species indicative of very heavy pollution (Bellan *et al.* 1975; Karakassis *et al.* 2000).

Other factors such as concentrations of nutritive salts (Table 2) and levels of chlorophyll and pheopigments are also strongly influenced by the presence of the cages (Pergent *et al.* 1999).

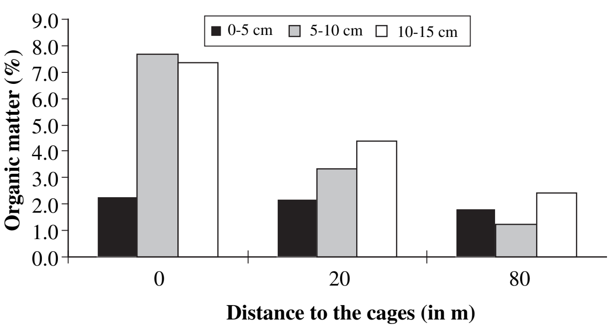

Fig. 1. Variations of organic matter levels in the sediment, in function of the distance from the cages and the layer of sediment concerned (0–5, 5–10 and 10–15 cm), Sant'Amanza, April 1994 (Pergent *et al.* 1999).

Table 2. Concentrations of nutrients (mean ± 95% confidence level) in the interstitial water of the sediment (μm) at three stations in Figari Bay and in the Moines Islands reference site (Cancemi *et al.* 2003).

	0 m	20 m	100 m	Les Moines
total phosphorus ($mg \cdot kg^{-1}$)	2206 (±429)	786 (±229)	568 (±33)	ND
NO_3^-	2.5 (±0.7)	3.7 (±0.8)	2.3 (±0.9)	3.1 (±0.8)
NH_4^+	19.5 (±8.7)	12.4 (±2.3)	8.4 (±1.6)	1.8 (±1.1)
PO_4^{3-}	5.2 (±0.6)	1.8 (±0.6)	1.3 (±0.6)	1.7 (±0.6)

ND, no data.

Numerous changes were observed in the *P. oceanica* meadows: in particular, the density (number of shoots per m^2) showed a significant decrease in the vicinity of the cages (Table 3). Even at a distance of 300 m, the mean density measured at the Figari (Corsica) and St Paul (Malta) sites was still low compared with density values regarded as 'normal' for this depth (Pergent-Martini *et al.* 1999). In El Hornillo Bay (Spain), the impact on *P. oceanica* is detectable up to several hundred metres from the cages; 11 ha of meadow were destroyed and 10 ha significantly degraded (decrease in shoot density), which represents a total of 53% of the initial surface area of meadow in the bay; the surface area of meadow destroyed or degraded is seven times larger than that of the zone occupied by the cages (Ruiz 2000; Ruiz *et al.* 2001). Contrary to what has been observed with other benthic populations, for which certain authors note no impact beyond 25–30 m from the cages (Karakassis *et al.* 2000, 2002; Machias *et al.* 2004), the impact on *P. oceanica* meadows is thus perceptible over large distances.

In the Balearic Islands, monitoring of *P. oceanica* and *Cymodocea nodosa* meadows over time shows a significant regression of these formations after the setting up of fish farming facilities (Delgado *et al.* 1997). This regression takes the form of a reduction in the density of the meadows, or even their disappearance (Fig. 2). In addition, Delgado *et al.* (1999) showed that the regression continues 3 years after the end of fish farming activities.

While the average number of leaves per shoot does not seem to be influenced by the presence of a fish farming facility, in spring the average length of adult and intermediate leaves increases significantly close to fish farming facilities (Fig. 3), as does the surface area (Leaf Area Index) and leaf biomass (expressed per m^2; Pergent *et al.* 1999). However, in summer, the average length of these leaves is reduced close to the cages (Delgado *et al.* 1999; Dimech *et al.* 2000b); this phenomenon could be the result of higher grazing pressure during a period of the year when leaf growth is reduced, and when the development of epiphytic algae could lead to competition with respect to *P. oceanica*. This hypothesis is corroborated

Table 3. Density of the *Posidonia oceanica* meadow (number of shoots per m^2).

sites	distance to cages					
	beneath cages	1 m	20 m	80 m	300 m	'normal values'
Figari (−10 m) Corsica[a]	0	63 ± 11	108 ± 16	250 ± 28	313 ± 41	349–573
St Paul (−12 m) Malta[b]	0			225 ± 20	310 ± 30	303–527
Aranci (−23 m) Sardinia	0	110 ± 16		175 ± 29	200 ± 32	137–361

Average values + confidence interval (95%). The 'normal values' according to Pergent-Martini *et al.* (1999) are given in the last column.
[a]Pergent *et al.* (1999).
[b]Dimech *et al.* (2000b).

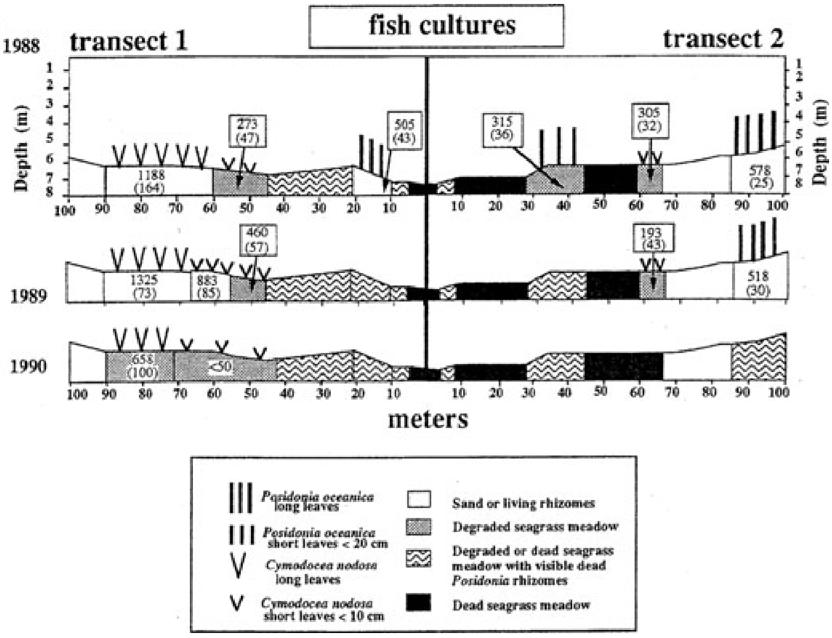

Fig. 2. Variations of *Posidonia oceanica* and *Cymodocea nodosa* meadows from 1988 to 1990, in the Balearic Islands after the setting up of fish farming facilities (Delgado *et al.* 1997). The figures correspond to the mean (standard deviation in brackets) of the density of the leaf shoots.

(i) by an increase in coefficient A (percentage of broken leaves – without apex), which indicates the impact of herbivores close to the cages (Pergent *et al.* 1999) and (ii) by the values obtained during the course of an annual cycle (Cancemi *et al.* 2003). In El Hornillo Bay (Spain), Ruiz (2000) and Ruiz *et al.* (2001) attribute the bulk of the regression of the *P. oceanica* meadow, both direct and indirect, to the increase in grazing by herbivores; the initial cause of this would be that the leaves are richer in nitrogen closer to the cages, and that the herbivores choose grazing sites in function of the nitrogen content of the grazed plants (Ruiz 2000); this overgrazing reduces the photosynthetic potential of the *P. oceanica*, and consequently the storage of reserve carbohydrates in the rhizomes; the annual growth cycle of the plant, whose carbon balance is negative for much of the year, depends on these reserves (Alcoverro *et al.* 2001).

The biomass of the epiphytes of *P. oceanica* leaves increases sharply close to fish farming facilities (Fig. 4; Ruiz *et al.* 2001); on average epiphyte biomass varies over the year between 93.5 ± 45.8 mg per shoot (Figari, Corsica, 20 m), 51.5 ± 55.3 mg per shoot (Figari, Corsica, 100 m), and 37.8 ± 35.0 mg per shoot (Moines Islands reference zone, Corsica; Cancemi *et al.* 2003). Nevertheless, the maximum values are not observed at the closest station to the cages (where nutrient levels are highest), but at a distance between 20 and 40 m (Pergent *et al.* 1999; Dimech *et al.* 2000a). This result could be explained by the copper added to the fish food (estimated at between 450 and 500 g·year^{-1} for the Figari fish farm; Pergent *et al.* 1999) and to the nets of the cages (antifouling action) acting as an algicide in the immediate proximity of the cages.

Neither the number of leaves produced annually nor the growth rate of the rhizomes seems to be influenced

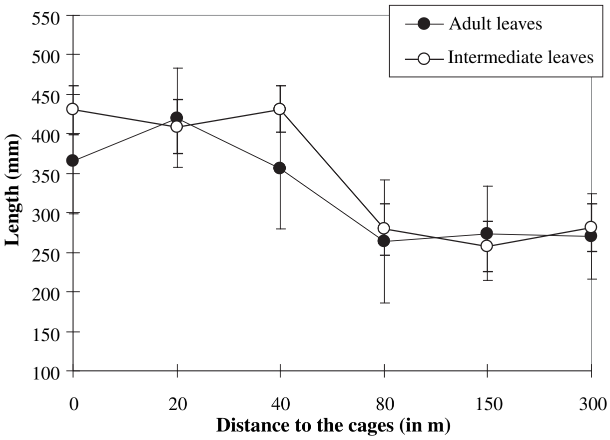

Fig. 3. Variation of the length of adult (n = 21 to 41) and intermediate (n = 22 to 40) leaves, in function of the distance from the cages in Figari Bay, May 1994. The confidence interval (95%) is indicated (Pergent *et al.* 1999).

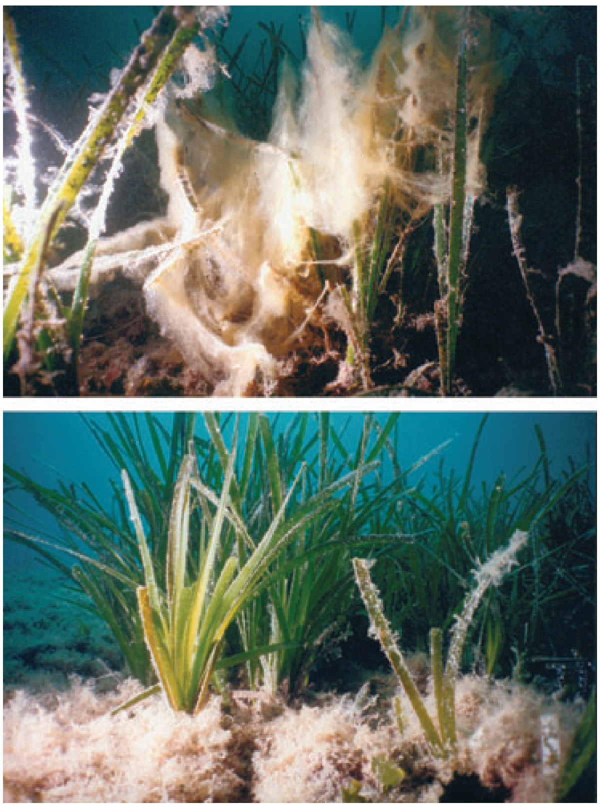

Fig. 4. Appearance of the *Posidonia oceanica* meadow, at 80 m (A) and 300 m (B) from the Figari cages (April 1994).

by the starting up of fish farming facilities or the distance from the cages. However, the *P. oceanica* near the facilities has a particularly highly developed root system which seems to result from an adaptation to silting (allowing a better resistance to water movement, Pergent *et al.* 1999).

Table 4. Production of *Posidonia oceanica* with increasing distance from a fish farm in Figari Bay (Corsica) compared with a reference site: Les Moines (Cancemi *et al.* 2003).

	20 m	100 m	Les Moines
Leaf production (g PS m^{-2})	82.9	123.0	1022.5
Rhizome production (g PS m^{-2})	5.0	6.2	48.1

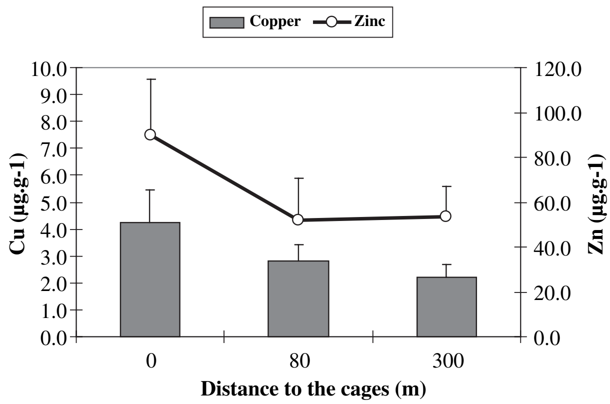

Fig. 5. Average concentrations of Copper and Zinc ($\mu g{\cdot}g^{-1}$ PS) in rhizomes of *Posidonia oceanica*, in function of the distance from the Figari cages (Pergent *et al.* 1999).

Primary production, measured by lepidochronology over the course of an annual cycle, gives much higher values for the reference station (Moines Islands) than close to the fish farming cages (Table 4; Cancemi *et al.* 2003).

The levels of Copper and Zinc recorded in the rhizomes of *P. oceanica* are higher close to the cages (Fig. 5). In addition, Zinc levels in particular seem to increase after fish farming facilities are started up (Fig. 6). Similar

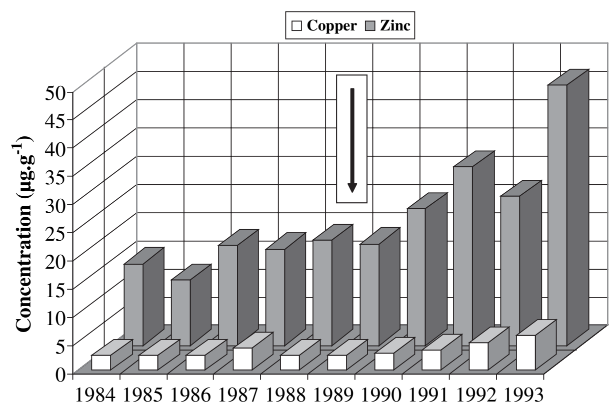

Fig. 6. Average concentrations of Copper and Zinc ($\mu g{\cdot}g^{-1}$ PS) in rhizomes of *Posidonia oceanica*, in function of time at Sant'Amanza (Pergent *et al.* 1999). The arrow indicates the year when the fish farming facility started up.

phenomena have been highlighted for the impact of salmonid faeces on sediment (Uotila 1991; Merceron & Kempf 1995). It seems that the source of this enrichment is linked to the addition of these two oligo-elements as a dietary supplement. The respective measured levels are 9.9 and 118 $\mu g \cdot g^{-1}$ in the food used (Mendez *et al.* 1997).

The benthic macrofauna in the matte of *P. oceanica* shows greater biodiversity in a reference meadow compared with a meadow situated close to a fish farming facility. Preliminary measurements carried out in October 2002 on 0.01 m^3 of matte in Calvi Bay (Corsica) show that on average the number of species goes from 45.3 ± 4.4 to 31.3 ± 5.3. In Malta, the greatest species density and abundance are recorded at a distance between 50 and 170 m from the cages (Dimech *et al.* 2000b). In addition, a study of the distribution of several species of this macrofauna (echinoderms, decapods and molluscs) shows zonation in function of the distance from the cages (Dimech *et al.* 2000b). This zonation is similar to that observed for a salmonid farming facility in Scotland (Brown *et al.* 1987):

- an azoic zone (=without macrofauna) under the cages,
- a much enriched zone,
- a transition zone,
- a 'clean' zone (similar to the reference zone).

Although lesser in amplitude (surface area affected), this distribution, perhaps linked to the addition of large quantities of organic matter, on a smaller scale bears some similarities to that observed near sewage outlets. Ruiz *et al.* (2001) estimate that the fish farming in Hornillo Bay annually supplies about 24 kg of phosphorus, 162 kg of nitrogen and 330 kg of carbon per ton of fish produced. The magnitude of these loads has been compared with sewage sludge and is likely to cause significant local changes in water and sediment quality (Pillay 1991; Wu *et al.* 1994).

Discussion

Studies concerning the impact of fish farms on *P. oceanica* meadows are still recent and few in number. Nevertheless, the results show significant degradation of these seagrass meadows in all the sectors studied (Table 5). In general, when fish farming cages are set up above a *P. oceanica* meadow it results in a degradation or disappearance of this habitat (Delgado *et al.* 1997; Pergent *et al.* 1999; Ruiz *et al.* 2001; Marbà *et al.* 2006). It is important to underline that this impact is irreversible on the human scale (once the meadow has been destroyed). The studies that show relatively rapid reversibility of the impact (after fish farming facilities are closed down) do not concern *P. oceanica* meadows (Mazzola *et al.* 2000). On the contrary in the case of a *P. oceanica* meadow, the impact can even

Table 5. Variations in *Posidonia oceanica* characteristics between a reference site and beneath fish farming site.

sites	references	meadow surface	shoot density	meadow cover	epiphyte biomass	shoot size	leaf size	leaf growth	Nb leaf/shoot	rhizome growth	sucrose concentration	photosynthetic capacity
Ajaccio Bay (Corsica)	Verneau *et al.* (1995)	↘	↘	↘	↗	↘						
Figari Bay, Sant'Amanza (Corsica)	Pergent *et al.* (1999), Cancemi *et al.* (2000)	↘	↘	↘	↗	↘	↗	↘	↔	↘		
Aranci Gulf (Sardinia)	Pergent et *al.* (1999)	↘	↘	↘	↗		↗		↘			
Fornells Bay (Minorca)	Delgado *et al.* (1997, 1999)	↘	↘	↘	↗	↘				↘	↘	↘
Hornillo Bay (Sain)	Ruiz *et al.* (2001)	↘	↘	↘	↘	↘		↘	↘		↘	↘
Saint Paul Bay (Malta)	Dimech *et al.* (2000a)		↘		↗		↗		↔			

↘: the values decrease near the cages; ↗: the values increase near the cages; ↔: the values do not vary significantly.

continue to worsen after closure, especially due to the very low colonization rate by rhizomes (Caye 1982; Delgado *et al.* 1999).

With regards to the effect of fish farming on the environment, particularly in areas characterized by *P. oceanica* meadows (a protected species and habitat in several countries; Platini 2000), the setting up of new facilities should take into account:

- the characteristics of the site (physico-chemical and biological factors, in particular the study of currents, conflicts of usage),
- the planned exploitation practices (species raised, type of food, method of distribution, management of daily rations, waste management, sanitary products),
- the planned production (tonnage) with respect to the characteristics of the site (carrying capacity),
- legal constraints, in particular the presence of *P. oceanica* meadows.

Only the implementation of a global policy – like the one initiated by the Corsica Region through the initiative of professionals of the Corsican Economic Development Agency, in collaboration with scientists – will be able to respond to these requirements. To this end, an environmental approach has been developed in order to put in place a system to aid decision-making, concerning the setting up of new fish farming facilities along the Corsican coast (Pasqualini *et al.* 2003).

This work is based on data concerning the ecological heritage of the marine coastal zone (protected, threatened and heritage species), in particular the distribution of *P. oceanica* meadows. By means of Geographical Information Systems, a map has been plotted to show the suitability of coastal areas for the setting up of new fish farming facilities with regards to ecological sensitivity. Three categories of ecological sensitivity have been identified: maximum, variable and low. Sites classed as being of maximum ecological sensitivity can be considered to be potentially excluded from the setting up of new facilities, whereas those categorized as being of low ecological sensitivity can be considered to be potentially favourable. Sites considered to be of variable ecological sensitivity require complementary analysis so as to produce a real ecological diagnosis with regards to the setting up of new fish farming facilities.

The summary of these observations shows that sites whose environmental sensitivity is considered as low or variable represent more than 50% of seabeds between 0 and −50 m (Table 6). Combining our results with those concerning legislative aspects (*e.g.* temporal forbidden fishing areas, natural reserves, sea-landing zones for specialized forest fire fighting aircraft), provides a suitability map for the setting up of fish farming facilities along the whole of the Corsican coast.

Table 6. Environmental sensitivity of the Corsican coast with respect to the setting up of fish farming facilities.

bathymetric layer (m)	low	variable	maximum
0–10	0.6 (159.5)	70.1 (17897.1)	29.2 (7462.4)
10–30	5.2 (2685.5)	17.5 (9012.0)	77.3 (39796.5)
30–50	56.4 (32170.6)	26.5 (15083.4)	17.1 (9747.1)
0–50	26 (35015.5)	31 (41992.4)	43 (57006.0)

Values represent % (ha).

The Liguria Region (Italy), in the framework of environmental impact assessment (VIA), has produced a document (adopted 28 March 2001) that establishes a series of technical standards with regards to fish farming facility projects. The criteria for positioning fish farming facilities in exposed sites, together with a fish farming suitability map, are a useful tool for project leaders because they provide useful indications for identifying favourable sites and performing impact studies. The elements that need to be taken into account for positioning a fish farming facility are as follows:

- Sites of Community Importance (SCIs – Habitat Directive). A suggested safe distance in function of environmental characteristics (currents, seabed typology, *etc.*) and the characteristics of the fish farming facility (number of cages, quantity of fish, *etc.*)
- Marine Protected Areas (existing or planned). A safe distance should be respected, in function of environmental characteristics and the characteristics of the fish farming facility.
- Protected Land Areas. For landscaping reasons, fish farming facilities should not have a negative visual impact from the land (distance, angles of view, size, *etc.*)
- *Posidonia oceanica* and *C. nodosa* meadows. A safe distance should be respected in function of environmental characteristics and the characteristics of the fish farming facility.
- Bathymetry. A depth of at least 30 m is required, which will generally position the fish farming facility away from the most sensitive populations and ensure better dilution of the effluents produced by the fish farm.
- Distance from the shore: at least 1000 m.
- River mouths. Care should be taken with these outlets for several reasons: introduction of fresh water, interaction with currents, introduction of pollutants, *etc.*
- Wastewater outlets. A sufficient distance should be used to avoid contamination of the fish in the farming facility.
- Zones regulated by harbour authorities (anchorage of commercial shipping, *etc.*)
- Submarine power lines. A safe distance should be respected with regards to submarine water pipes and telephone or electrical cables.

- Archaeological sites (for example wrecks). A safe distance should be respected.

The impact study procedure of the Liguria Region also plans for the setting up of a surveillance programme in order to assess the environmental situation of the zone where the fish farming facility is located (Giovanni Diviacco, personal communication, Regione Liguria, Italy).

French Law regulates the authorization to use the Domaine Public Maritime for fish farming by means of the 'authorization for the exploitation of marine cultivation' instructed by the Maritime Affairs body. An impact study is required. In addition, for a production of more than 20 $t{\cdot}year^{-1}$, or in case of the extension of a fish farm causing it to exceed that production, the fish farmers must make a request to the veterinary services classified for the protection of the environment.

To date, while some predictive models concerning benthic eutrophication by intensive fish farming are available (Cromey *et al.* 2002), the impacts on a *P. oceanica* meadow, in function of its location (depth, distance from the shore, water circulation, *etc.*) and characteristics (species produced, planned tonnage, planned load in the cages in kg of fish m^{-3}, fish farming techniques, type of food used) are poorly understood. Furthermore, given the irreversible nature of the damage that may occur, the precautionary principle should be applied.

In particular, concerning sectors where seagrass meadows are present, we therefore propose the following recommendations:

- No fish farming facility should be set up directly above *P. oceanica* and *C. nodosa* meadows.
- If there is a meadow nearby, a minimum distance of 200 m from the cages should be respected. This generally corresponds to the effective area of impact on the benthos (Doglioli *et al.* 2004). This distance should be increased near the meadow's lower limit (more sensitive to turbidity than shallow-water meadows) and varied in function of currents and the size of the fish farm.
- Generally speaking, facilities should be set up over 45–50 m depth whenever possible.
- An impact study should be carried out for every request to set up a fish farming facility, before implementation.
- The authorization to set up a fish farming facility should be re-examined every 4 years with a view to possible extension, on the condition that the *P. oceanica* meadows situated nearby have not regressed (in terms of size or vitality). This requirement, which involves the setting up of a meadow monitoring system, should lead fish farmers to move as far as possible away from seagrass meadows.

This approach will enable piscicultural activities to be incorporated into a global process of ICZM so as to maximize the benefits provided by the coastal zone and to minimize conflicts and the harmful effects of activities upon each other.

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