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Effects of boat anchoring in Posidonia oceanica *seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea)*

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ABSTRACT

1. A study was set up in the Port-Cros National Park in order to determine the effects of boat anchoring on *Posidonia oceanica* seagrass beds.
2. Experiments on the effects of anchors on the seagrass meadows revealed that, on average, 34 shoots were destroyed during an anchoring cycle (lock-in and retrieval), especially when the seagrass mat compactness is weak and the extent of rhizome baring is high.
3. Five parameters of the *Posidonia oceanica* beds (meadow cover, shoot density, extent of rhizome baring, proportion of plagiotropic rhizomes, degree of meadow fragmentation) were considered and it was shown that the extent of rhizome baring was not correlated with anchoring pressure. Meadow cover and mean shoot density were positively correlated with high anchoring pressure.
4. The proportion of plagiotropic (i.e. horizontally growing) rhizomes and the degree of meadow fragmentation were positively correlated with moderate anchoring pressure.
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KEY WORDS: anchoring; *Posidonia oceanica*; seagrass beds; Port-Cros

INTRODUCTION

Posidonia oceanica (Linnaeus) Delile, a protected species in France since 1988, is a marine phanerogam endemic to the Mediterranean Sea. This species forms extensive seagrass meadows from the surface to 30–40 m depth (Hartog, 1970). As with forests in the terrestrial environment, *P. oceanica* meadows are the climax community and their presence attests to a relatively stable environment. In numerous Mediterranean coastal water ecosystems, *P. oceanica* plays an important role in a number of key geomorphological and ecological processes such as nutrient recycling (reducing the degree of water movement, thus improving sediment stability), provision of food for herbivorous fauna, shelter and nursery areas for many organisms (e.g. fishes, crustaceans).

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Declines in seagrass communities can be linked to both natural processes (geological, meteorological, biological) and human activities (mechanical damage, sewage discharge and discharge of industrial effluents containing toxic compounds) (Péres and Picard, 1975; Short and Wyllie-Echeverria, 1996). The most common anthropogenic factor in the decline of seagrass habitats in near-shore coastal areas is eutrophication as a result of nutrient loading and a subsequent reduction in water quality (Short *et al.*, 1996). However, mechanical damage due to dredge-fill operations can also both directly (by smothering) and indirectly (through increased turbidity) alter the density and distribution of seagrass meadows. Shadowing due to the presence of boat docks often involves a regression of adjacent seagrass beds and the shadowed area is nearly always devoid of vegetation (Loflin, 1995). Propeller damage can also alter shallow-water seagrass communities (Zieman, 1976; Dawes *et al.*, 1997). Boat anchoring was also found to have a destructive impact on seagrass meadows (Walker *et al.*, 1989; Hastings *et al.*, 1995) as it does on the bottom fauna of coral reefs (e.g. Smith, 1988; Oehman *et al.*, 1993). For many years, scientists have been warning management authorities of the potential problem of anchoring in *P. oceanica* beds (e.g. Meinesz and Lefèvre, 1978; Robert, 1983; Porcher, 1984), however, very few quantitative studies of the effects of anchoring on seagrass meadows have yet been carried out (Walker *et al.*, 1989; Garcia-Charton *et al.*, 1993; Francour, 1994; Boudouresque *et al.*, 1995).

In the coming years, the increasing number of pleasure boats in the north-western Mediterranean Sea (National Seminar on the Effects of Marinas, Saint Raphaël, June 1996) will greatly increase the incidence of anchoring and consequent risk of damage in sensitive seagrass communities. In order to ensure the optimal organization of anchoring areas, it is now important to estimate and to quantify more precisely the effects of this activity on *P. oceanica* beds. Thus, a programme of evaluation was set up in the Port-Cros National Park. This study comprised: (1) *in situ* experiments involving replication of anchoring cycles, in different kinds of *P. oceanica* meadows in order to quantify the direct effects of anchoring on seagrass beds; and (2) a comparison of seagrass meadow characteristics between areas where anchoring is either restricted or allowed, in order to assess the large-scale effects of anchoring.

MATERIAL AND METHODS

The direct effect of anchoring

Several parameters which might significantly affect the number of uprooted shoots were studied: the density of the root mat (i.e. mat compactness), the seagrass meadow density (number of shoots m^{-2}, which is generally negatively correlated with depth) and the extent of rhizome baring (length of rhizome above the sediment, see below for a precise definition).

The characteristics of the boat used to perform these experiments were similar to those of many of the boats that operate in the Port-Cros National Park: 9 m length (250 tonne) with a Brittany type anchor (12 kg), 10 m of chain (10 mm diameter) and an electric windlass (Moreteau, 1981; Maxime Poulain, pers. comm.).

Experiments were carried out at seven sites (FM5, SP9, BS9, PC5, PC7, FM9, PC11: Figure 1) in order to determine the effect of anchoring on mat compactness, shoot density and extent of rhizome baring. In some places, the extent of rhizome baring is irregular within the same meadow (rhizome baring ranging from > 10 to 0 cm). For each anchoring cycle, the rhizome baring was noted in the area where the anchor fell, or where it 'locked-in' after the boat had pulled it across the substrate. Two levels of rhizome baring were defined: strong (> 10 cm) and weak (< 10 cm).

A penetrameter was used to measure the compactness of the rhizome mat. A 2 m long, 8 mm diameter rod was placed perpendicular to the bottom, and a 5 kg weight was dropped 50 cm on to a stop in the middle of the rod. The impact of the weight hitting the stop provided a constant force to drive the rod

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into the rhizome mat. This measurement was repeated 30 times at randomly selected sites at each sampling location. Compactness was defined as: strong (penetration < 50 cm), medium (50 cm < penetration < 100 cm) and weak (penetration > 100 cm).

Two phases of the anchoring operation were tested: (i) the retrieval of the anchor using an electric windlass (601 Leroy Somer®, 350 kg traction); and (ii) the locking-in of the anchor into the bottom, with

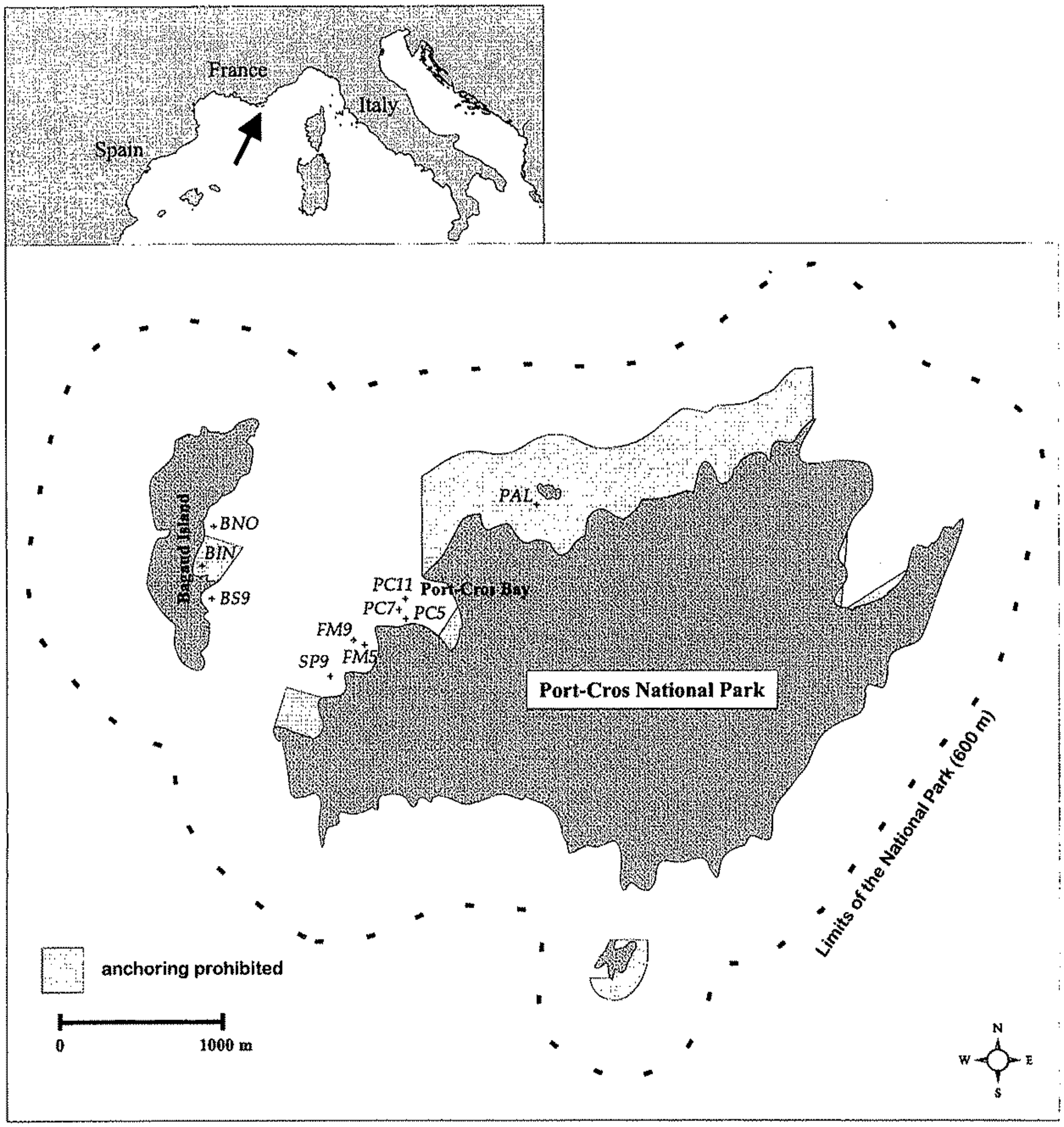

Figure 1. Locations of the stations studied in the Port-Cros National Park (Var, north-western Mediterranean Sea, France).

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the boat going astern (i.e. the normal way that yachtsmen bed their anchors). The anchor was then retrieved using the winch with the boat pulling up on to it. The number of uprooted or broken shoots due to the action of the anchor was recorded separately for the lock-in phase (the anchor being pulled by the boat), and the retrieval phase. The distance which the anchor was dragged across the bottom was also recorded.

Anchor retrieval was tested at all of the seven sites, but anchors were pulled by the boat to lock-in, at only three of the sites: (i) PC5, 5 m depth compact mat, shallow meadow; (ii) FM9, 9 m depth compact mat, deep meadow and (iii) PC11, 11 m depth slightly compact mat, deep meadow. A minimum of 10 replications were made for each phase of anchoring (lock-in and retrieval) at each site. When two kinds of rhizome baring occurred in the same meadow, 10 replications were made for each kind of rhizome baring. Thus, the results for a total of 100 anchoring cycles were recorded.

Field comparisons

Five parameters were measured (30 replications) at five sites with different anchoring histories (Figure 1), at similar depths (7–9 m: yachtsmen's average anchoring depth in the Port-Cros National Park): PAL (no anchoring for 15 years); BS9 (anchoring allowed for 3 years); BIN (anchoring prohibited for 3 years); and PC7 and BNO (high anchoring pressure).

Meadow cover

This is the percentage of substrate covered by the seagrass leaves. These cover values vary according to the meadow's vitality, decreasing with increasing depth and in the vicinity of disturbed areas (i.e. of construction or dumping). Cover also varies naturally according to the season (leaf length variation) or, for example, in the areas where strong hydrodynamism or hypersedimentation occurs. Cover was measured using a transparent PVC plate (40 cm × 40 cm divided in nine squares), held 2 m above the bottom.

Shoot density

This is the number of shoots per unit surface area. This density decreases naturally with increasing depth (Roméro-Martinengo, 1985). Seagrass meadow density was measured at approximately 30 locations at each site using a quadrat of 0.04 m^2 (ie. 20 cm × 20cm), (minimum surface for a statistical significant measurement). The spatial repartition of the shoots within a meadow displays a high variability, because of the meadow's natural heterogeneity (the 'patchiness' phenomenon of Panayotidis *et al.*, 1981).

Extent of rhizome baring

For plagiotropic rhizomes (i.e. horizontally growing rhizomes), this is the distance between the bottom part of the rhizome and the sediment; for orthotropic rhizomes (i.e. vertically growing rhizomes), it is the distance between the sediment and the base of the leaves, minus 2 cm (Boudouresque *et al.*, 1980). A high degree of rhizome baring generally indicates a sedimentary loss in the meadow but it does not imply a decrease of shoot survival; its occurrence, however, is an indication of the degree of water movement in an area.

Proportion of plagiotropic rhizomes

This is the number of plagiotropic (horizontal) rhizomes as a proportion of the total number of rhizomes within a given area. It was measured using a quadrat of 0.04 m^2, in the middle of the bed. At the edge of the meadow, a large proportion of running plagiotropic rhizomes is an indication of an expanding

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Table 1. Mean number ($\pm$ standard error) of uprooted and broken *Posidonia oceanica* shoots observed during an anchoring cycle (locking-in and retrieving)

Number of shoots	Locking-in ($n = 30$)	Retrieving ($n = 100$)	Anchoring cycle
Uprooted	15.6 (3.7)	12.0 (1.4)	27.6
Broken	4.3 (0.8)	1.6 (0.2)	5.9
Total	19.9 (4.3)	13.6 (1.5)	33.5

meadow. Within a dense meadow, this proportion is normally low and a high proportion of plagiotropic rhizomes may indicate a positive response to stress due, for example, to repeated anchoring.

Degree of meadow fragmentation

This is the frequency and extent of intermats (i.e. the patches of seabed without living shoots or devoid of vegetation) as measured along a randomly laid, 10 m length transect. The proportion of intermats was compared at the three sites around Bagaud Island (BS9, BIN, BNO: Figure 1). With the stress of anchoring pressure, the upper edge of the *Posidonia oceanica* bed might be thus divided, or the number of intermats within the seagrass meadow may increase (Porcher, 1984).

Data analysis

Non-parametric average comparisons and non-parametric variance analyses were performed on the data (Mann–Whitney test and Kruskal–Wallis test; Statistica Software). In the case of the non-parametric variance analyses, if the null hypothesis of average equality was rejected, the Student–Newman–Keuls test was performed to examine differences between the data (Zar, 1984). The non-parametric Wilcoxon test was carried out to compare two averages for which the samples are not independent (Statistica Software).

RESULTS

The direct effect of anchoring

The anchor used in the experiments damaged on average 34 *P. oceanica* shoots during each anchoring cycle (Table 1). The number of uprooted shoots was significantly greater than the number of broken shoots as a result of both the anchor 'locking-in' and the anchor retrieval (Wilcoxon test: $Z = 3.55$, $n = 30$, $p < 0.001$; $Z = 7.04$, $n = 100$, $p < 0.001$). The mean distance over which the anchor was dragged before 'locking-in' was not significantly different between sites (Kruskall–Wallis test: $H = 0.159$, $n = 30$, $p = 0.924$). This distance was on average, 2.2 ± 0.3 m. The number of uprooted or broken shoots observed during the lock-in phase was not significantly different between the three sites (Kruskal–Wallis test: $H = 3.041$, $n = 30$, $p = 0.219$). The total number of uprooted or broken shoots when the anchor was retrieved was significantly different between the seven sites (Kruskal–Wallis test: $p < 0.001$; Table 2). Assuming that the shoots were broken or uprooted on a 2.2 m length by 0.3 m width (i.e. the typical anchor scar), this represents a decrease of approximately 50 shoots m^{-2}.

In order to determine the most sensitive factors to boat anchoring, each parameter was tested independently.

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Mat compactness

Paired comparisons were made between sites differing by only this parameter as follows: sites FM9 (medium compactness) and SP9 (strong compactness), then the sites FM5 (strong compactness) and PC5 (medium compactness). In both comparisons, the extent of rhizome baring was similar. Mat compactness had a significant effect on the number of uprooted or broken *P. oceanica* shoots in the shallow zone but not in the 9 m depth zone (Mann–Whitney test: respectively $Z = -3.414$, $p < 0.001$, $Z = -0.122$, $p = 0.90$).

Shoot density

Sites FM5 and BS9 were similar with respect to mat compactness (high) and mean rhizome baring (6–7 cm). They differed only in relation to the depth (5 and 9 m) and the mean shoot density (500 and 430 shoots m^{-2}). The mean number of uprooted or broken shoots during anchor retrieval did not differ significantly between the two sites (Mann–Whitney test: $Z = -1.445$, $p = 0.15$).

Rhizome baring

Lock-in and retrieval of the anchor were each considered. When the boat locked-in the anchor, the rhizomes baring was systematically measured, first where the anchor fell, and then where it locked-in (three sites). The mean value of these two rhizome barings was taken into account for each test (10 replications per site). There was no significant correlation between the number of uprooted shoots and rhizome baring ($r = 0.209$, $n = 30$, $p = 0.268$), between the number of broken shoots and rhizome baring ($r = 0.326$, $n = 30$, $p = 0.078$) or between the total number of uprooted and broken shoots and rhizome baring ($r = 0.276$, $n = 30$, $p = 0.139$). Although the relationship between the number of broken shoots and rhizome baring is not significant ($p = 0.078$), the correlation suggests a positive relationship. This tentatively indicates that the higher the rhizome baring, the larger the number of broken shoots.

During the retrieval of the anchor, there is a positive correlation between the rhizome baring (where the anchor locks in) and the total number of uprooted and broken shoots ($r = 0.323$, $n = 90$, $p = 0.002$). The correlation between the number of broken shoots and rhizome baring was also significant ($r = 0.261$, $n = 90$, $p = 0.012$) but not between the number of uprooted shoots and rhizome baring ($r = 0.174$, $n = 90$, $p = 0.099$).

Table 2. Mean number ($\pm$ standard error) of uprooted or broken *Posidonia oceanica* shoots during anchor retrieval at various sites (name, depth and code)

Stations	Code	Number of shoots	n
Strong compactness			
Fausse Monnaie 5 m	FM5	7.9 (2.6)	20
Saint-Pierre 9 m	SP9	9.8 (1.8)	20
South Bagaud 9 m	BS9	19.4 (7.9)	10
Medium compactness			
Port-Cros Bay 5 m	PC5	28.6 (5.3)	10
Port-Cros Bay 7 m	PC7	25.2 (3.9)	10
Fausse Monnaie 9 m	FM9	10.8 (2.5)	20
Weak compactness			
Port-Cros Bay 11 m	PC11	21.4 (3.5)	10
Kruskal–Wallis test; $H = 31.0$; $n = 100$; $p < 0.001$			

$n = 10$ when there is one kind of rhizome baring, and $n = 20$ when there are two kinds of rhizome baring.

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Table 3. Estimation of seagrass bed vitality parameters: meadow cover, mean shoot density, rhizome baring, proportion of plagiotropic rhizomes and degree of meadow fragmentation

	PC7	BNO	BS9	BIN	PAL	K–W test
Boat number (day^{-1} 2500 m^{-2})	3.1	1.2	0.9	0	0	
Meadow cover						
Mean (%)	49.5	95.0	90.0	88.2	95.8	119.15
(S.E.) *n*	(2.4) 53	(1.2) 30	(2.4) 61	(1.8) 46	(1.5) 32	$p<0.001$
Shoot density						
Mean (shoots m^{-2})	280.5	433.0	431.1	495.1	449.5	76.5
(S.E.) *n*	(15.6) 73	(29.9) 30	(13.1) 61	(16.2) 61	(19.3) 46	$p<0.001$
Rhizome baring						
Mean (cm)	8.6	4.0	6.7	5.5	6.6	34.8
(S.E.) *n*	(0.5) 31	(0.5) 30	(0.6) 38	(0.5) 47	(0.8) 30	$p<0.001$
Proportion of plagiotropic rhizomes						
Mean (%)	15.8	17.0	15.0	10.6	7.4	13.34
(S.E.) *n*	(2.9) 60	(3.0) 45	(2.4) 36	(1.6) 36	(1.7) 50	$p<0.001$
Proportion of intermats						
Intermat number	–	2.1 (0.2)	1.1 (0.2)	2.1 (0.2)	–	17.78
Intermat width (cm)	–	53 (5)	28 (4)	48 (4)	–	14.65
Rate of division	–	11.8 (1.5)	4.7 (0.8)	11.6 (1.5)	–	20.46
n		30	40	40		All $p<0.001$

See station code in Table 2; S.E., standard error; *n*, number of experiments; K–W test, Kruskal–Wallis test; *p*, significance level; –, not measured.

Field comparisons

Meadow cover

Table 3 presents the cover measurements taken at five study sites. Just one site, the non-restricted anchoring area (PC7), is found to be different from the other sites (Student–Newman–Keuls test, $p < 0.05$). This site, where the mean cover is around 50%, is also the busiest anchoring site. The mean cover at all of the other sites, with an allowed or restricted anchoring, is greater than 90% (88–96%, Table 3).

Shoot density

The shoot density at site PC7 is significantly different from the other four sites studied (SNK test, $p < 0.05$; Table 3), however, the *P. oceanica* meadow at this site is particularly sparse with a density of only 280.5 shoots m^{-2} which is ranked as lower sub-normal according to Pergent-Martini (1994). At the four other sites, the density of the seagrass meadows are of normal density (>400 m^{-2}) for the depth where they occur (Pergent-Martini, 1994).

Extent of rhizome baring

The extent of rhizome baring at the different sites ranged from 4.0 cm at Bagaud Island (BNO) to 8.6 cm at Port-Cros Island (PC7). The two sites are both in non-restricted anchoring areas and the difference in extent of rhizome baring is significant (SNK test: $p < 0.05$; Table 3). However, there is no significant

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difference between anchoring and non-anchoring sites (e.g. PAL versus BS9; SNK test: $p > 0.05$). Consequently, the extent of rhizome baring, contrary to the other parameters measured (cover and density), does not seem to be linked to the effects of boating and anchoring. This parameter is mainly related to the sedimentary processes (i.e. sedimentary loss or supply within the seagrass meadow). Along a north–south axis, on the eastern coast of Bagaud Island at the three sites sampled there is a steady increase in the mean rhizome baring values. The prevailing current in the channel of Port-Cros is also oriented north–south. The rhizome baring increase is thus probably due to a decrease of the particulate load, resulting in a decrease in the rate of sedimentation in the seagrass meadow along this axis.

Proportion of plagiotropic rhizomes

The mean proportion of plagiotropic rhizomes within the *P. oceanica* bed clearly differs between the site in the restricted anchoring area (PAL: 7.4%; no anchoring; Table 3) and sites in areas of non-restricted anchoring (15–17%). Locations with intensive anchoring (PC7, BS9, BNO) showed a high proportion of plagiotropic rhizomes within the seagrass meadow. The site (BIN), where anchoring has been banned for 3 years (Table 3) does not show any significant difference to site in restricted area (PAL) where it has been, at least, banned for more than 15 years. The proportion of plagiotropic rhizomes within the meadow may thus be a good indicator of anchoring pressure and, moreover, it seems to react quickly (in 3 years or less) to modification of the intensity of anchoring.

Degree of meadow fragmentation

This parameter was only measured at three sites, along the eastern coast of Bagaud Island (BS9, BIN, BNO). The site BNO, where anchoring has always been allowed, showed a high degree of meadow fragmentation (around 12%; Table 3), as in BIN, the area where anchoring has been forbidden for 3 years (11.6%). In contrast, site BS9, where anchoring has only been allowed for the past 3 years, showed the lowest degree of meadow fragmentation (less than 5%; SNK test, $p < 0.05$). This is due to a significantly lower mean number of intermats and mean intermat widths at this site. The degree of meadow fragmentation is positively correlated with anchoring pressure, but the effects of changes in anchoring pressure on the structure of the meadow takes longer (i.e. > 3 years) to manifest than the proportion of plagiotropic rhizomes.

DISCUSSION

The direct effect of anchoring is clear as experienced *in situ*: 20 shoots on average are broken or uprooted when the anchor locks into the bottom and a further 14 shoots on average when it is retrieved with an electrical windlass. This average total of 34 broken or uprooted shoots represent a loss of about 50 shoots m^{-2}. The effect increases with weak mat compactness and high rhizome baring but not with shoot density. Moreover, the extent of rhizome baring influences the number of broken or uprooted shoots during the anchor lock-in and retrieval cycle.

Comparisons of seagrass meadows between sites with different historical anchoring usage indicate that the proportion of plagiotropic (horizontal) rhizomes and the degree of meadow fragmentation are positively correlated with moderate anchoring pressure. Furthermore, the cover of the meadow and the mean shoot density are negatively correlated with high anchoring pressure. The extent of rhizome baring does not depend on anchoring pressure, although it has a significant influence on the direct damage due to anchoring.

The results suggest that when anchoring is prohibited, the proportion of plagiotropic rhizomes within the *P. oceanica* meadow increase in a relatively short period of time (< 3 years), and if the prohibition

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is continued for longer there is evidence to suggest a decrease in the degree of meadow fragmentation. On the contrary, when anchoring is frequent, *P. oceanica* beds show a decrease in both shoot density and meadow cover. Field comparisons undertaken at Port-Cros of restricted and non-restricted anchoring sites suggest that the direct effect of anchors may lead to a decline in the health of the meadow. However, to quantify the long-term net effect of anchoring on *P. oceanica* meadows, direct loss of shoots (loss by a single anchor × number of annual anchoring) will have to be balanced against the bed extension by the multiplication of rhizomes.

The large areas without vegetation observed in the middle of small embayments are not directly related to anchoring but to bottom-currents flowing in and out of the bay, and resulting in the formation of compensation channels (Clairefond and Jeudy de Grissac, 1979). In a small bay, both the formation of compensation channels and direct loss of seagrass due to anchoring may impact on a seagrass bed over a large area, and result in broad-scale changes in the structure of seagrass meadows in these waters. Lenihan *et al.* (1990) described a similar change in hard-bottom communities in relation to boat mooring in San Diego Bay (CA, USA).

The management of anchoring in a busy boating area like the Port-Cros National Park should therefore involve three basic measures. (1) Restriction of anchoring, as much as possible, particularly in vulnerable areas where mat compactness is weak and rhizome baring high. (2) The development and implementation of a moratorium on anchoring in order to restore the *P. oceanica* beds in damaged areas. For the moratorium to be successful the period would need to last for more than 5 years to allow a decrease of the degree in meadow fragmentation. The recovery of *P. oceanica* beds can only occur if the damage is not too great and as such a rotation period shorter than 5 years will not allow such a recovery. (3) The public must be informed of the negative effects of anchorings on *Posidonia oceanica* beds by active promotion of a Code of Conduct for Anchoring on the Seagrass Meadows (CASE), an equivalent of the Code for Anchoring on the Reef (CARE) proposed by Hunnam (1987) for the Great Barrier Reef Marine Park in Australia.

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