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Boat anchoring on *Posidonia oceanica* beds in a marine protected area (Italy, western Mediterranean): effect of anchor types in different anchoring stages

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Abstract

Seagrasses worldwide are noted for suffering from mechanical damage caused by boat anchoring. This is particularly so in sites highly frequented by boaters (marine protected areas or coastal urbanised areas). In the last decades, different strategies have been put into practice to reduce such impacts on seagrasses (i.e. by anchoring bans or by deploying boat moorings). More recently, in consideration that few marine protected area (MPA) management bodies or local administrations have the resources to enforce their anchorage regulations, the self-regulatory approach based on education and information of boaters has been preferred in several cases. At present, however, very little is known on the correct anchoring practices to ensure the safeguarding of seagrasses. The aim of the present study was to experimentally quantify in the field the damage caused to *Posidonia oceanica* shoot density by anchoring. A multifactorial experiment was designed to test whether the damage is dependent on (1) different anchor types (Hall, Danforth and Folding grapnel), (2) the use of a chain vs. a rope, (3) the three anchoring stages (anchor fall, dragging/lock-in and weighing), and finally (4) whether the pattern is consistent among different locations of the meadow.

As expected, the three anchor types employed in the present study differed in the levels of damage inflicted on the *P. oceanica* meadows of the Ustica Island MPA. In particular, the use of the Hall type anchor seems to be preferable to minimise this impact in comparison with the other two anchor types. Moreover, the effect on the meadow of the three anchor types is greatly dependent on the anchoring stage. These results confirm that the weighing stage is the critical stage of the anchoring process. The number of damaged shoots of *P. oceanica* was not affected by the presence of the chain. These patterns were consistent between locations.

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In the long term, even anchoring on *P. oceanica* by small boats using low-impact anchors may potentially have detrimental consequences. For this reason, we suggest that in vulnerable sites, it is preferable to implement an educational program based on information of boaters on correct anchoring practices and anchor typology to use, rather than adopting strong restrictions to boat anchoring or deploying mooring buoys. Although the use of these management strategies is still recommended in the case of anchorage frequented by bigger vessels using heavier anchors and chains.

Keywords: Boat anchoring; Impact; Marine protected area; Mediterranean sea; *Posidonia oceanica*; Seagrass

1. Introduction

The marine phanerogam *Posidonia oceanica* (L.) Delile is the most widespread seagrass in the Mediterranean Sea (den Hartog, 1970). It plays an important role in ecosystems of shallow coastal waters in several ways by: (1) providing habitat for a highly diverse fauna and flora (Mazzella et al., 1989, 1991); (2) significantly reducing coastal erosion (Cavazza et al., 2000); and (3) offering a nursery area for many fish and invertebrate species (Macpherson et al., 1997; Guidetti, 2000).

However, *P. oceanica*, like other seagrasses worldwide (Shepherd et al., 1989), is sensitive to disturbance. Along most Mediterranean coasts, the perceived decline of *P. oceanica* has been attributed to both natural causes (see Marbà et al., 1996b for review) and anthropogenic disturbance (Pérès and Picard, 1975; Bourcier, 1989; Peirano and Bianchi, 1995). On a large spatial scale (i.e. from 10^3 to 10^4 m), the regression of Mediterranean phanerogams is attributed to human activities. They have either direct physical impact (e.g. illegal trawling) or cause alterations to hydrodynamic regimes and water quality (e.g. creation of coastal dumping areas, fish farming, construction of marinas, and sewage discharge) (Ardizzone and Pelusi, 1984; Meinesz et al., 1991; Sànchez-Jerez and Ramos-Esplà, 1996; Delgado et al., 1997; Martìn et al., 1997). By contrast, on a smaller spatial scale (from 10 to 10^2 m), seagrasses suffer from mechanical damage caused by boat anchoring (Porcher, 1984; Garcia-Charton et al., 1993; Francour et al., 1999) or moorings (Walker et al., 1989; Hastings et al., 1995). Particularly, this occurs in coastal areas subjected to intense recreational activity, both in the Mediterranean as well as other areas (Hunnam, 1987; Creed and Amado-Filho, 1999; Francour et al., 1999, but see Milazzo et al., 2002b for review).

Major damage to seagrasses seems to be caused by dragging anchors and scraping anchor chains along the bottom, as boats swing back and forth (Francour et al., 1999). Generally this may result in dislodgement of plant rhizomes or leaves (Milazzo, personal observation).

In the Mediterranean sea, several studies have assessed the impact of anchoring on *P. oceanica*, suggesting that there may be a direct adverse effect on meadow cover and shoot density (Porcher, 1984; Garcia-Charton et al., 1993; Francour et al., 1999).

For this reason, appropriate management and monitoring of this recreational activity is particularly important, as the loss of seagrass structural complexity resulting from intensive boat anchoring (Francour et al., 1999) may have also an indirect detrimental effect on associated faunal assemblages (Garcia-Charton et al., 1993).

Moreover, there have been very few attempts to estimate the recovery time for damaged seagrasses worldwide and little information is available concerning spreading rates, rhizome growth and seedling establishment (see Meehan and West, 2000). This makes it difficult to assess the magnitude of impacts on seagrasses and to predict if and when partial and full recovery will occur (Duarte, 2002).

In recent decades, especially within marine protected areas (MPAs) or in coastal urbanised areas, different strategies have been adopted to reduce impacts on seagrasses. For example, boat number and size have been limited, anchoring has been restricted in certain periods of the year and moorings of various shape and type have been deployed (Poulain, 1996; Milazzo et al., 2002b). More recently, since few MPA management bodies have the resources to enforce anchorage regulations, the self-regulatory approach, based on informing and educating boaters, has been favoured (Antonini and Sidman, 1994). However, more research is required to better identify correct anchoring practices that will ensure preservation of the seagrasses.

The aim of the present study was to experimentally quantify in the field the damage caused to *P. oceanica* shoot density by anchoring. A multifactorial experiment was designed to test whether the damage is dependent on (1) different anchor types (Hall, Danforth and Folding grapnel), (2) the use of a chain vs. a rope, (3) the three anchoring stages (anchor fall, dragging/lock-in and weighing), and finally (4) whether the pattern is consistent among different locations of the meadow. Specific hypotheses could be proposed a priori. In particular, one would expect larger damage using a more penetrating anchor type such as the Folding grapnel and using a chain that is heavier than the rope. Furthermore, more *P. oceanica* shoots were expected to be damaged during the anchor fall and weighing stages rather than during dragging/lock-in, when the anchor is expected to be at rest. Then, shoots that are damaged because of the anchor fall are expected to be broken because of the anchor weight, while those that are damaged because of the weighing stage are expected to be uprooted. In contrast, no a priori hypothesis on changes in spatial variance of *P. oceanica* shoots damaged was possible.

2. Materials and methods

The study site is located within the Ustica Island marine protected area (western Mediterranean, 10°43′43″E–38°42′20″N) that is popular with scuba divers, snorkelers and boaters. The MPA, destined for biodiversity conservation, educational and research activities, was established in 1986 but has been effectively running since 1991. It is divided into three zones with different levels of protection (Fig. 1). Each of these zones has different restrictions on the exploitation and human use of the marine environment. Zone A, in the western part of the island, is a no-take area (or integral reserve) where only scientific research is permitted. Local commercial fishing is permitted in zone B and zone C. There are no restrictions on recreational activities (i.e. scuba diving, boat anchoring, swimming and angling) in both these zones. Temporal data series indicating current levels

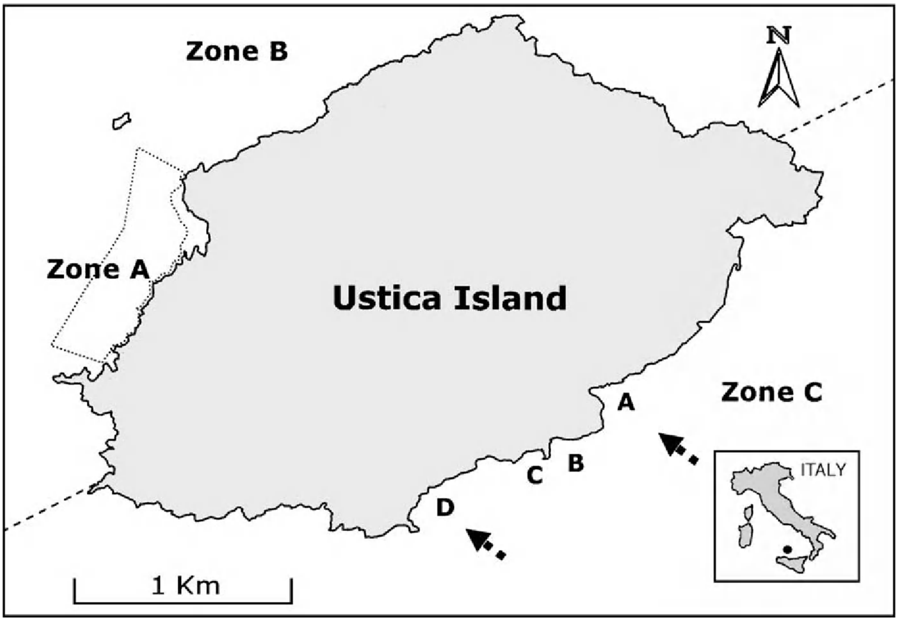

Fig. 1. The Ustica Island MPA and the four locations of the seagrass meadow in which shoot density was estimated: (A) Cala S. Paolo; (B) Punta Galera (eastern side); (C) Punta Galera (western side); (D) Grotta Verde. The experimental simulations were carried out in the two locations indicated by the arrows.

of recreational uses at the site are largely unavailable. The MPA management body is the Ustica Town Council.

Well-developed *P. oceanica* meadows growing on rocky bottoms occur mainly in the southern/southeastern side of the island from 4 to about 40 m depth (Andaloro et al., 1998). Difficult access from land, strong winds from north/northwest and the presence of diving sites in underwater or semi-submerged caves result in a high frequentation of nautical tourism.

Estimation of *P. oceanica* shoot density was done in early summer 2000 using a quadrat of 0.09 m^2 (30 × 30 cm) in four locations (Fig. 1). Shoot density was measured at 8–12 m deep, which is the depth range at which boaters most commonly anchor at this site (Milazzo et al., 2002a). Average (± SE) density values ranged between 504 (± 131.3) and 529 (± 85.3) shoots/m^2, which correspond to a high value of normal density meadow at this depth range (Pergent et al., 1995), and no significantly difference was found among the four sampling locations ($F_{3,36} = 0.23$, $p > 0.05$). The experiment was carried out in two randomly chosen locations (out of the four) along the southern/southeastern side of Ustica Island (Fig. 1).

The experimental anchoring simulations were all carried out in good weather conditions during summer (i.e. from late June to early September 2000), with calm waters and absence of strong winds. The boat used for simulations was less than 5.5 m in length, which is similar to the boats most frequently operating in the Ustica Island MPA (Milazzo et al., 2002a). Similarly, the three anchor types used for simulations (e.g. Hall, Danforth

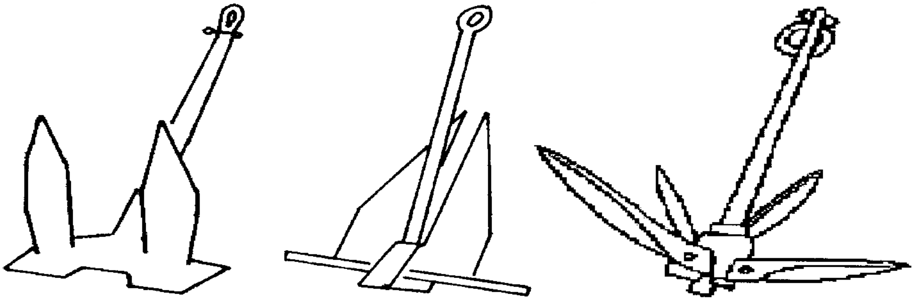

Fig. 2. The three anchor types used to quantify the damage caused to *P. oceanica*.

and Folding grapnel) (Fig. 2), each weighting 4 kg, were commonly employed by boaters at this site (Milazzo et al., 2002a). These anchors were either held by a rope or by an anchor chain 3 m long (10 mm diameter) tied to a rope.

As a response variable, the number of shoots dislodged either for rhizome break or shoot uprooting (i.e. both plagiotropic and orthotropic rhizomes) was quantified in the field during anchoring simulations. Underwater, the diver counted the broken/uprooted shoots independently at each combination of treatments. Damage was quantified for each anchor chain/rope combination of treatments during each of the three stages of anchoring (anchor fall, dragging/lock-in and weighing) separately. This means that during an anchoring process, data were gathered each time from only one of the three anchoring stages. While operating, a scuba diver: (a) waited for anchor fall at the bottom, lifted the anchor and accurately recorded the number of shoots affected by the physical impact; (b) followed the anchor during its dragging/lock-in stage for 10 min recording the number of uprooted shoots; (c) and counted the number of uprooted shoots as a result of the anchor retrieval.

To avoid different weighing anchor practices distorting our damage estimations the boat was moved by engine to the vertical point (i.e. anchor apeak) before the anchors were retrieved. Three independent observations were made for each combination of treatments.

Data were analysed by using a four-way ANOVA with ‘stage’ of anchoring (three levels), the presence of ‘chain’ (two levels), type of ‘anchor’ (three levels) and ‘location’ (two levels). All factors were treated as orthogonal, being stage, chain and anchor fixed while location random. Cochran’s test was used to check for the homogeneity of variances (Winer, 1971), with data transformed when necessary. When appropriate, Student–Newman–Keuls’ (SNK) test was employed to separate means (at $p=0.05$).

3. Results and discussions

The damage caused to *P. oceanica* by boat anchoring simulations ranged on average ($\pm$ SE) between 0 and 4.5 ($\pm$ 0.9) shoots in the presence of the anchor chain, and between

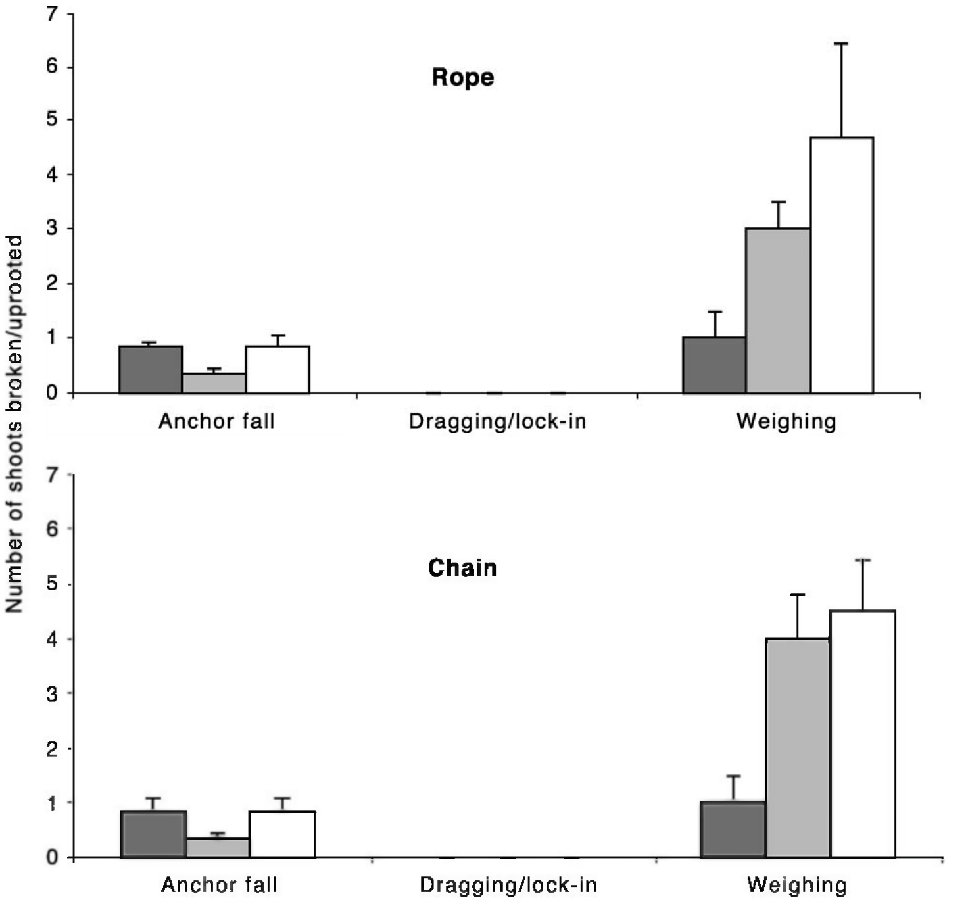

Fig. 3. Mean (± SE) number of shoots uprooted/broken by the three anchor types (Hall in black; Danforth in grey; Folding grapnel in white) used in the presence of the anchor chain or a rope during the three anchoring stages. Data from the two sampling locations were pooled ($n = 6$).

0 and 4.7 (± 1.7) shoots with the anchor tied to a rope (Fig. 3). As expected, the three anchor types employed in the present study differed in the levels of damage inflicted on the *P. oceanica* meadows of the Ustica Island MPA. Also, their impact is greatly dependent on the stage of anchoring ($F_{4,72} = 28.76$, $p < 0.01$, Table 1).

During anchor fall, the number of shoots uprooted was very limited and it was null during the dragging/lock-in stage. In both anchoring stages, the damage on *P. oceanica* did not differ significantly among the three types of anchor used (SNK test, Table 1 and Fig. 3). On the contrary during the weighing stage, which is the more impacting stage, the number of shoots broken/uprooted by the Folding grapnel anchor was significantly higher than that affected by the Danforth, which caused an intermediate impact. The Hall anchor was the least damaging type (SNK test, Table 1 and Fig. 3).

Table 1
Four-way analysis of variance on the number of shoots uprooted/broken by the three anchor types (Folding grapnel, Hall, Danforth) used with a chain or a rope during the three anchoring stages (anchor fall, dragging/lock-in, weighing), in two locations

ANOVA				
Source of Variation	*df*	No. of shoots		
		MS	*F*	F versus
Chain: Ch	1	0.0146	0.32^{ns}	Ch × Lo
Stage: St	2	8.344	453.63**	St × Lo
Anchor: An	2	0.9068	62.16*	An × Lo
Location: Lo	1	0.0696	1.06^{ns}	Res
Ch × St	2	0.0182	0.16^{ns}	Ch × St × Lo
Ch × An	2	0.0206	0.24^{ns}	Ch × An × Lo
Ch × Lo	1	0.0454	0.69^{ns}	Res
St×An	4	1.1216	28.76**	St × An × Lo
St × Lo	2	0.0184	0.28^{ns}	Res
An × Lo	2	0.0146	0.22^{ns}	Res
Ch × St × An	4	0.0188	0.18^{ns}	Ch × St × An × Lo
Ch × St × Lo	2	0.1135	1.74^{ns}	Res
Ch × An × Lo	2	0.0872	1.33^{ns}	Res
St × An × Lo	4	0.039	0.60^{ns}	Res
Ch × St × An × Lo	4	0.1032	1.58^{ns}	Res
Residuals	72	0.0654		
Transformation		Sqrt (x + 1)		
Cochran's test		C = 0.18, $p > 0.05$		
SNK tests				
St × An interaction				
(a) Anchor fall	no alternative			
Dragging/lock-in	no alternative			
Weighing	Folding grapnel > Danforth > Hall			
(b) Hall	weighing = anchor fall > dragging/lock-in			
Danforth	weighing > anchor fall = dragging/lock-in			
Folding grapnel	weighing > anchor fall > dragging/lock-in			

ns (not significant).
* ($p < 0.05$).
** ($p < 0.01$).

Moreover, the magnitude of impact of anchors is different through stages. The Folding grapnel anchor caused greater damage on *P. oceanica* shoot density during the weighing stage than during the anchor fall, while no impact at all was detected during dragging/lock-in stage (SNK test, Table 1 and Fig. 3). The Danforth anchor had a greater impact during the weighing stage than during the other anchoring stages. Conversely, the Hall anchor affected the seagrass more during anchor fall and weighing stages than during the dragging/lock-in (SNK test, Table 1). In all stages, the damage caused to the meadow by this anchor type was very limited (Fig. 3).

These results confirm our prediction that the weighing stage is the critical stage of the anchoring process. However, this did not agree with previous studies on the effect of anchoring on *P. oceanica* meadows within the Port-Cros National Park (southern France) (Francour et al., 1999). These authors recorded the greatest damage to the meadow when the anchor locks into the bottom rather than during weighing stage. This difference may be explained by the fact that Francour et al. (1999) used a larger boat with a heavier anchor (12 kg). Thus, the difference in damage to *P. oceanica* could be due to deeper anchor sunk into the seagrass matte during locking-in and, consequently, to greater friction from the larger boat. In particular, these authors caused a much greater impact on the seagrass. In fact, they found on average 33.5 ($\pm$ 5.8) shoots uprooted or broken during a complete anchoring cycle. Conversely, in this study, we found that the number of *P. oceanica* shoots dislodged during a complete anchoring process (i.e. sum of broken shoots through stages) ranged, on average, between 5.5 ($\pm$ 3.5) and 1.8 ($\pm$ 0.2) shoots using the Folding grapnel and the Hall anchor type, respectively.

Unexpectedly, the number of broken/uprooted shoots of *P. oceanica* was not affected by the presence of the chain. No differences in the factor 'chain' were detected (Table 1). This result may support the use of a chain attached to the anchor as a necessary and standard component of reliable anchoring gear in seagrass meadows also from an ecological point of view. If on the one hand the chain does not negatively affect the seagrass, on the other hand, it should enhance anchoring efficiency by giving further stability to the anchor. Patterns observed were consistent between locations as indicated by the analysis of data (Table 1).

In our study, anchoring damage was only recorded on orthotropic rhizomes (i.e. vertical shoots) of *P. oceanica*. Also, direct field observations revealed that the orthotropic rhizomes were uprooted because of a break in the branching point of the plant (i.e. the insertion point of the orthotropic rhizome in the plagiotropic one), which seems the most vulnerable part of the plant. In all cases, no plagiotropic (i.e. horizontal) rhizomes were uprooted. These results are in accordance with Francour et al. (1999) who found a larger mean proportion of plagiotropic rhizomes within the *P. oceanica* beds in sites where the anchoring pressure was high. Overall, evidence for a selection of the horizontal rhizomes by repeated boat anchoring through the years has been given.

It is very likely that the damage inflicted to the seagrass can be dependent on location: either matte compactness of the meadow (Francour et al., 1999) and shoot density are likely to greatly influence plant damage. In fact, the frequency of horizontal rhizomes (i.e. holding several vertical shoots) vulnerable to uprooting during the weighing stage of anchoring can be higher in meadows of weak matte compactness and low shoot density. However, no direct evidence for this is available, yet.

Notwithstanding, there is strong evidence that both direct and indirect consequences of boat anchoring on this seagrass may be long-term, as the slow-growing *P. oceanica* requires several years to recover from damage (Marbà and Duarte, 1997; Francour et al., 1999; Guidetti, 2001). In fact, for this species, successful recovery is accomplished by vegetative growth rather than seed production and seedling establishment (Marbà et al., 1996a). The vegetative growth is very slow and, according to Boudouresque and Jeudy de Grissac (1983), estimated rates of vertical rhizome elongation range between 0.4 and 1.1 cm year^{-1}, and of horizontal elongation between 0.4 and 7.4 cm year^{-1}. Francour et al. (1999), for example, suggested that *P. oceanica* can recover from low levels of anchor damage only if all sources of disturbance are removed for at least 5 years.

However, to properly forecast seagrass colonisation, quantitative data on the recovery rate are still strongly needed (but see Rasheed, 1999).

In general, response of seagrasses to anchoring damage is likely to be species-specific, due to a wide variety of growth strategies (Duarte et al., 1994): theory predicts that the small species would show the fastest rate of recovery due to the high growth rate (Vermaat et al., 1995).

Intense anchoring activity, which is the non-natural cause of shoot mortality, when not compensated by shoot recruitment (Duarte et al., 1994) may result in both a decreased shoot density and a change of the shoot size/age distribution in a particular area. In turn, this may lead to a decrease of seagrass structural complexity and a loss of species richness (Hemminga and Duarte, 2000; but see also Eckrich and Holmquist, 2000).

Furthermore, only some information is available about physiological integration between ramets of seagrasses (Marbà et al., 2002b) suggesting that resource translocation, although species-specific, can be essential in supporting seagrass clonal expansion. Further experimental studies are still needed to address questions about possible plant compensation to the damage.

In conclusion, this study suggests that the magnitude of damage inflicted on the *P. oceanica* meadows is dependent on the anchor type adopted during the anchoring process. In particular, the use of the Hall anchor seems to be preferable to minimise the impact on the meadow in comparison with the other two anchor types. Given the ecological importance of *P. oceanica* in the Mediterranean Sea, these conclusions are relevant for increasing the protection of the plant at local scale (see Marbà et al., 2002a). However, the generality of the results presented in this study should be tested in other locations where *P. oceanica* is found. More broadly, testing the effects of these types of anchors on other species of seagrasses, where there is intense recreational boating, would also increase our understanding about the ecological consequences of this activity.

In general, in sites mainly frequented by small boats using light anchors, such as in the Ustica Island MPA (Milazzo et al., 2002a), it could be important to implement a self-regulatory approach (Antonini and Sidman, 1994) based on educating and informing boaters on correct anchor types to use when anchoring on *P. oceanica*, rather than enforcing restrictions on anchoring or deploying mooring buoys. Nevertheless, the use of these management strategies is still recommended in the case of anchorage frequented by bigger vessels using heavier anchors and chains (Francour et al., 1999). But more experimental data are needed to elucidate this aspect.

This is a key (and complex) issue in environmental impact assessment and conservation activities, where a closer interaction between experimental research and management decisions is strongly required (Peterson, 1993; Underwood, 1995). Actually, there is a growing need for MPA managers to receive detailed information from ecological research to plan conservation strategies (Badalamenti et al., 2000). This is particularly true when MPAs have a recent history like in the Mediterranean Sea (Badalamenti et al., 2000), where managers have been enforcing regulations that belong to experience from far elsewhere. For this reason, field experimentation, like the one here proposed, may represent an important tool to influence the outcome of decision-making by MPA managers. In a later stage, when MPAs are on regime, the role of experimental ecology could be to test the consequences of the management activity (see Underwood, 1995 for further reading).

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