The detrimental consequences for seagrass of ineffective marine park management related to boat anchoring

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ABSTRACT

Posidonia oceanica (L.) Delile meadows are recognized as priority habitat for conservation by the EU Habitats Directive. The La Maddalena Archipelago National Park (Mediterranean Sea) *P. oceanica* meadow, the dominant coastal habitat of the area, is mostly threatened by boat anchoring. 12 years after the establishment of mooring fields and anchoring restrictions, a study was conducted to measure their effectiveness on the conservation of seagrass and the mitigation of anchoring damage. We found that: (i) the condition of *P. oceanica* was disturbed, both in the mooring fields and in control locations; (ii) mooring fields and anchoring restrictions did not show to be an efficient system for the protection of seagrass, in fact anchor scars increased after the tourist season; (iii) the mooring systems had an impact on the surrounding area of the meadow, probably due to their misuse. On the basis of these results, management recommendations for marine parks are proposed.

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1. Introduction

Seagrass meadows are considered a pivotal marine habitat and provide important ecosystem services (Costanza et al., 1997), including raw materials and food, coastal protection, erosion control, water purification, maintenance of fisheries, carbon sequestration, and tourism, recreation, and education (Barbier et al., 2011). Despite the importance of seagrass, its presence has shown to be in significant decline worldwide, and this decline appears to have accelerated over recent decades (Short and Wyllie-Echeverria, 1996; Waycott et al., 2009). One-third of the world's seagrass species are in decline with 10 species having a high risk of extinction (Short et al., 2011).

Seagrass loss has been attributed to a broad spectrum of anthropogenic and natural disturbances (Duarte, 2002; Airoldi and Beck, 2007). However, various human activities are responsible for seagrass regression, including direct mechanical damage from fishing activities (e.g. trawling, gillnetting) and anchoring and dredging (Short and Wyllie-Echeverria, 1996; Duarte, 2002; Ardizzone et al., 2006; Ceccherelli et al., 2007; Montefalcone et al., 2008).

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These activities can cause the physical removal of seagrass rhizomes and shoots, reducing habitat complexity and creating bare patches (gaps) of different size. Removal of seagrass biomass due to disturbance has consequences on species diversity, both on stocks of important commercial and recreational fish, mollusks and crustaceans (Bell and Pollard, 1989; Butler and Jernakoff, 1999; McArthur and Boland, 2006), and on a large number of rare and threatened species, many of which rely on seagrass habitat for survival (Short et al., 2011). Furthermore, habitat loss can favor the establishment of non-indigenous species by reducing competition from native species and/or by enhancing resource availability (Mack et al., 2000; Shea and Chesson, 2002). Particularly, introduced species have often been implicated in seagrass declines, even if the evidence for negative effects on seagrasses is largely correlative (Glasby, 2013 for a review). Nevertheless, in general, invasions by macro algae occur in seagrass meadows already exposed to human perturbations (Stafford and Bell, 2006; Montefalcone et al., 2007; Bulleri et al., 2011; Ceccherelli et al., 2014). Thus, as the gaps in seagrass created by mechanical disturbance can take a long time to be re-colonized, the occurrence of introduced algae may thus be useful in diagnosing the quality of seagrass restoration and damage (Creed and Filho, 1999).

Green and Short (2003) reported that only some of the 247 MPAs worldwide are known to include seagrasses, spread over

72 countries and territories, and questions remain regarding their effectiveness in protecting seagrass ecosystems (e.g. Eklöf et al., 2009; Marbà et al., 2002; Montefalcone et al., 2009). In Europe, numerous initiatives arising from the Rio Convention, Barcelona Convention, Bern Convention and the Habitats Directive have led to seagrass meadows being specifically targeted for conservation and restoration. Seagrasses have also been named as a component of the EU Habitats Directive and EU Water Framework Directive.

P. oceanica (L.) Delile is endemic of the Mediterranean Sea, with a wide distribution throughout the whole basin. Some authors have proposed that the ongoing decline of *P. oceanica* is the result of global processes (Jordà et al., 2012), while other studies have shown that it is due to an accumulation of local impact factors (González-Correa et al., 2007). Meadows of *P. oceanica* are very vulnerable to direct mechanical damage (Francour et al., 1999; Milazzo et al., 2004; Ceccherelli et al., 2007; Montefalcone et al., 2008) particularly because of the slow growth of plant recovery (Ceccherelli et al., 2007). In the last three decades, to reduce the local mechanical impact on *P. oceanica* meadows many conservation actions have been undertaken, based primarily on (i) installation of moorings (both traditional and seagrass-friendly) and protective artificial reefs to minimize the damage of boat anchoring and the impact of trawler fishery, respectively; (ii) restrictive regulations about anchoring and moorings (Díaz-Almela and Duarte, 2008). These actions were realized extensively in MPAs, with the support and funding of local, national and European authorities (e.g. Life Nature Project in Italy, Spain and Greece). Despite such extensive efforts, to our knowledge, very few studies have been conducted to measure the effectiveness of such mitigating action and regulations (but see Marbà et al., 2002).

At the La Maddalena Archipelago National Park (PNALM, Sardinia – Italy) the major cause of shallow seagrass degradation is mechanical damage due to boats anchoring (Cossu et al., 2006). In order to reduce the physical impact of boat anchoring, since 1998 the PNALM regulations have forbidden boat anchoring on seagrass beds and since 2001 a series of mooring fields have been established in some of the areas most frequented by boaters. Traditional mooring systems were employed: dump weight (usually a concrete block) deployed on the seabed, linked to a heavy chain, ropes and floats to hold vessels in position. Despite recommendations from the scientific community (Hastings et al., 1995; Walker et al., 1989; Demers et al., 2013) and both international and national authorities, in which mechanical disturbance of seagrasses (mainly patch formation and fragmentation) due to these kinds of mooring systems was emphasized, for more than 10 years, the mooring systems have not been replaced, nor have their effects on seagrass been monitored.

In this study the objective was to evaluate the effectiveness of traditional mooring systems and anchoring park regulations as a tool for the maintenance of seagrass conditions and for the mitigation of mechanical damages caused by boat anchoring. This was done using three experimental designs to test the hypothesis that: (1) if traditional mooring systems have been an effective tool for seagrass conservation, the condition of *P. oceanica* inside the mooring fields should be better preserved than in areas outside; (2) if restrictions on anchoring have been observed, at the end of the summer the number of anchor scars on *P. oceanica* meadows should be similar to estimates made before summer, both inside and outside the mooring fields, and (3) if dump weights do not directly affect *P. oceanica*, no differences should be found comparing seagrass shoot density at different distances around it. Further, to verify if *Caulerpa racemosa*, the most widely introduced rhizophytic macro-algae at the PNALM, is colonizing the seagrass gaps taking advantage of the disturbance, the occurrence of this algae was also quantified.

2. Material and methods

2.1. Study area

The PNALM is a geo-marine protected area consisting of islands situated along the North-East coast of Sardinia (Italy, Mediterranean Sea), in the Bonifacio Strait between Sardinia and Corsica. At PNALM, the *P. oceanica* meadow is the dominant subtidal habitat, occupying an area of about 5000 ha, widely distributed along the coast and around all the islands (Cossu et al., 2006). The meadows are mainly found on sandy substrates, although they can also be found on rocky bottom or matte. The area, despite the fact it lies within a National Park and a SIC, is subject to strong pressure from tourism and pleasure boats traffic, mainly during the summer.

The study was done during summer 2013 in two locations (Cala Portese = CP and Porto Madonna = PM) inside the Mb zone (partial protection) of the PNALM (Fig. 1). These locations are among the most frequented by boaters and have been equipped with mooring fields since 2001; in 2013 they contained 16 and 12 buoys, respectively. Within mooring fields, anchoring is only permitted at the buoys, while outside the fields anchoring is not permitted on the seagrass and allowed only on sandy bottom. To anchor at the buoys, boats must be pre-authorized by park authorities, are required to pay a park entrance ticket, and are allowed to moor at specific buoys depending on the size of the boat (>50 m cannot use moors); also, for all boats, to use buoys wind force must be less than 15 knots. Park guardians can conduct surveillance, although they cannot require the payment of a fine if restrictions on anchoring are not observed.

2.2. Mooring field effectiveness on P. oceanica meadow conservation

P. oceanica meadow structure within the location PM and CP was estimated at a depth between 3 and 16 m, the depth range at which boaters usually anchor in the area. At each location two zones were considered: one inside the mooring field and one outside (control zone), at a distance of about 300–500 m from the edge of the mooring field. Particularly, at each zone 5 areas of approximately 400 m² were chosen and in each of them (i) the seagrass density (number of shoots m^{-2}) was measured using a 40×40 cm quadrat (10 replicates) and (ii) the average cover of *P. oceanica* (percentage of substrate covered by seagrass leaves) was visually estimated by scuba divers. Also, within each area the occurrence of *C. racemosa* was recorded.

2.3. Boat anchoring damage on P. oceanica meadows

The impact of boat anchoring on *P. oceanica* was estimated by two surveys, one before (June-July 2013) and one after (late September–October 2013) the peak of the tourist season. At the locations PM and CP, in the mooring field and in the control zone, underwater videos by scuba divers along ten 100 m long transects (randomly located) were realized, five before and five after the tourist season. Transects were recorded by means of a GPS (Geographical Positioning System, nominal precision 40 cm). The underwater videos were obtained by a Sony camcorder and a Go-Pro action camera and were subsequently analyzed with video analysis software (IMovie on Mac) to obtain several pieces of information: type of sea floor substrate (sand, rock, sand and rock), qualitative description of the meadow (presence of seedling, matte or dead matte), fragmentation (number of inter-mats, i.e. the patches of seabed without living shoots or vegetation – Francour et al., 1999-, per 100 m), and anchor damage (number of anchor scars, such as areas were shoots were broken or uprooted, per 100 m).
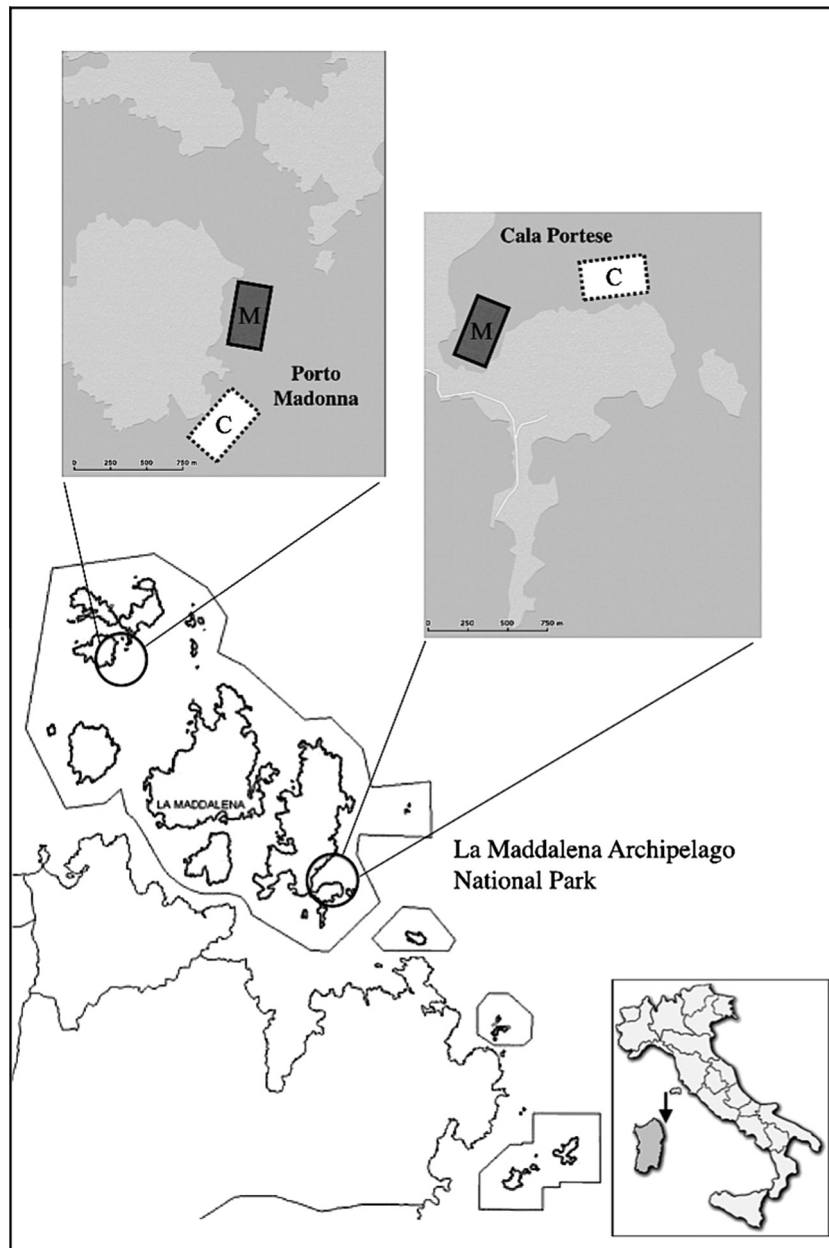
Fig. 1. Study area. Mooring (M) and control (C) areas in Cala Portese and Porto Madonna locations at the La Maddalena Archipelago National Park (Sardinia, Italy).

2.4. Impact of traditional mooring systems on P. oceanica

Finally, to estimate whether the traditional mooring systems (dump weights) have changed the condition of seagrass since their placement, seagrass shoot density and *Caulerpa racemosa* occurrence were measured at two distances from five different moorings (0–3 m and 6–9 m from the center of the mooring system, referred as close and far, respectively). At each distance, measurements were taken on four 40×40 cm quadrat (placed haphazardly around the moor). As controls, the same number of observations was taken at five sites with similar depths.

2.5. Analysis of data

To estimate the mooring field effectiveness on the seagrass meadow, variability in shoot density and meadow cover was analyzed by two and three-way ANOVAs where mooring (fixed factor,

two levels: mooring and control) and location (random factor, two levels: CP and PM) were considered orthogonal and area (random factor, five levels) was nested within their interaction.

To estimate the anchoring effect on the *P. oceanica* meadow, variability of anchor damage and fragmentation was analyzed by two and three-way ANOVAs where period (fixed factor, two levels: Before and After), mooring (fixed factor, two levels: mooring and control) and location (random factor, two levels: CP and PM) were treated as orthogonal. However, for the variable 'fragmentation' only mooring and location were considered, due to the fact that fragmentation is assumed not to vary within the summer. This measurement was therefore taken only once.

To measure the traditional mooring systems' effect on *P. oceanica*, variability in shoot density was analyzed by a two way ANOVA where mooring (fixed factor, two levels: mooring and control) and distance (fixed factor, two levels: close and far) were treated as orthogonal.

To test for normality and homogeneity of variances, the Shapiro Wilk test and Levene's test were run, respectively, and data were converted by Box Cox transformation, when necessary. All descriptive statistics and analyses were done using R for Mac.

3. Results

P. oceanica condition was extremely different depending on the presence of the mooring field (Fig. 2). Particularly, the analysis showed that both shoot density and cover of the meadow was significantly affected by the presence of the mooring. Also, the effect of the mooring changed depending on the location and the area considered (Table 1, Fig. 2). In each area, shoot density falls under the classification "very disturbed" (abnormal density, Pergent et al., 1995), in spite of the significant difference among all of them. Cover was statistically lower in mooring fields compared to controls, while it was consistent between locations (Table 1, Fig. 2). The occurrence of *C. racemosa* was not statistically different between the two locations, while it was larger in mooring fields compared to controls (chi-square test, $p < 0.001$).

The number of anchor scars was significantly higher after the tourist season both inside the mooring fields and in controls, with differences in magnitude depending on the location, as highlighted by the interactive effect of period x mooring x location (Table 2, Fig. 3). The damage after the tourist season was serious in all locations, but was particularly dense in the Porto Madonna mooring and in the Cala Portese control (Table 2). Fragmentation differed only as a function of mooring: the meadow appeared more fragmented in moorings than in controls (Table 2, Fig. 4). Furthermore, in the presence of traditional mooring systems (dump weights), *P. oceanica* fragmentation was significantly higher compared to controls.

P. oceanica shoot density also differed as a function of distance from the mooring, being lower at the close compared to the far position (Table 3, Fig. 5). Finally, the occurrence of *C. racemosa*

Table 1

Outcomes of three-way ANOVA run on the effect of mooring (mooring and control), location (PM and CP) and area (nested in the interaction M × L) on the shoot density of *P. oceanica* and two way ANOVA run on the effect of mooring and location on the cover of *P. oceanica*. Significant values are given in bold.

Source	df	MS	F value	P
Density				
Mooring = M	1	89,846	46.335	**<0.0001**
Location = L	1	16,580	8.551	**0.0039**
M × L	1	51,553	26.587	**<0.0001**
Area (M × L)	16	13,068	6.740	**<0.0001**
Residual	180	1939		
Cover				
Mooring = M	1	0.14645	11.633	**0.0036**
Location = L	1	0.00002	0.001	0.9710
M × L	1	0.00067	0.054	0.8199
Residual	16	0.01259		

was not different depending on the presence of mooring systems or distance (Chi square test, $p > 0.05$).

4. Discussion

This study found disturbed or very disturbed seagrass conditions in all the areas investigated. Overall, density of the meadow appeared lower in Cala Portese than in Porto Madonna and inside the mooring fields compared to controls. The percentage cover of the meadow was also lower, with values inside the mooring fields ranging between 50% and 60% on average, compared to 80–90% in the control areas. The seagrass meadows at mooring fields also appeared more fragmented.

Thus, the mooring fields and anchoring restrictions at the PNALM do not seem to have been an effective tool for seagrass protection over this 12 years period. However, one could argue that this result may only be due to, or be confused by, the lack of
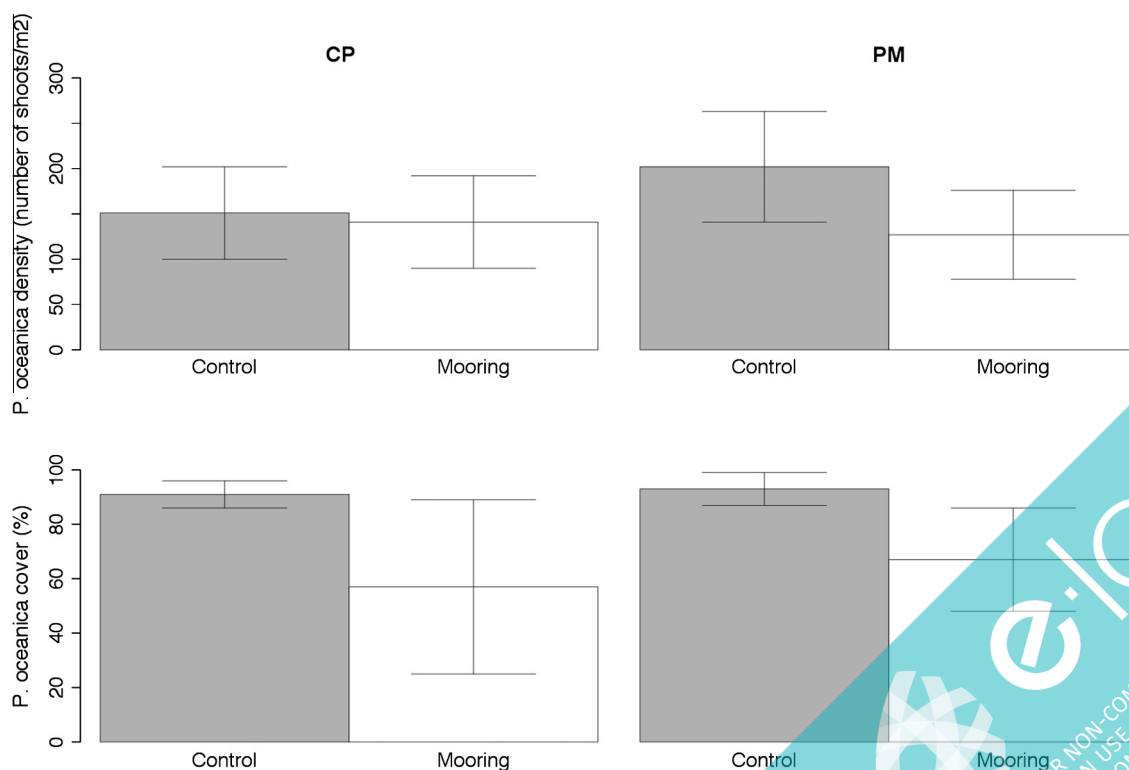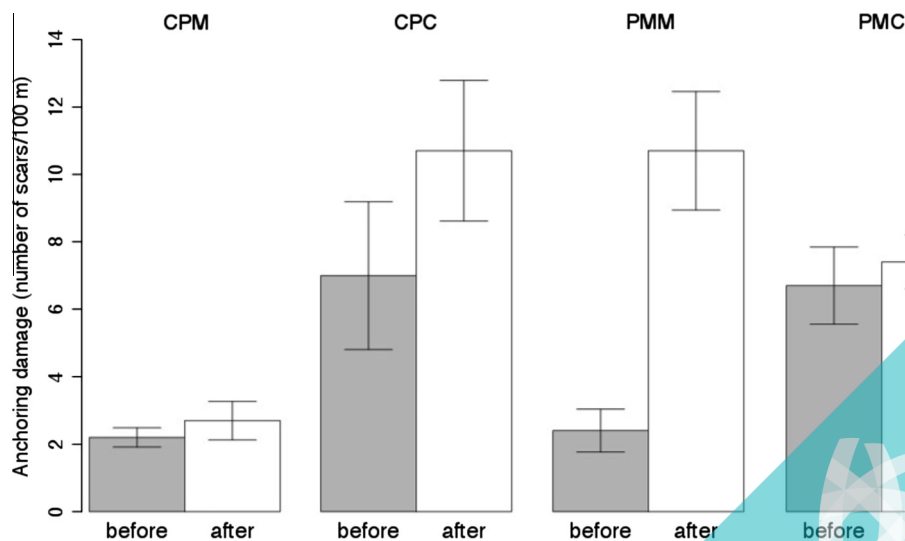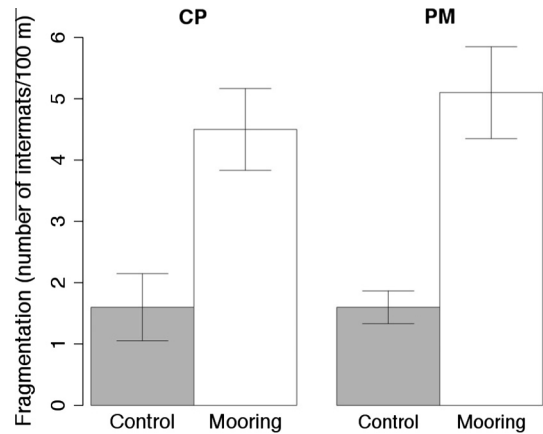

Fig. 2. Mean (±SE) *P. oceanica* shoot density and cover as function of mooring and location PM and CM.

Table 2

Outcomes of three-way ANOVA run on the effect of mooring (mooring and control), location (PM and CP) and period (before and after) on the number of anchor damages and of two-way ANOVA run on the effect of mooring and location on the fragmentation of *P. oceanica* meadow. Significant values are in bold.

Source	df	MS	F value	P
Anchor damage				
Mooring = M	1	31.078	38.432	**<0.0001**
Location = L	1	0.060	0.074	0.7879
Period = P	1	15.319	18.943	**0.0001**
M × L	1	10.320	12.762	**0.0011**
M × P	1	0.001	0.001	0.9771
L × P	1	0.128	0.158	0.6934
M × L × P	1	7.068	8.740	**0.0058**
Residual	32	0.809		
Fragmentation				
Mooring = M	1	15.997	9.238	**0.0044**
Location = L	1	3.825	2.209	0.146
M × L	1	1.068	0.617	0.4375
Residual	36	1.732		

Fig. 4. Mean number (±SE) of intermats of *P. oceanica* as a function of mooring and location (PM and CM).

Table 3

Outcomes of two-way ANOVA run on the effect of mooring (mooring and control) and distance from mooring and control (close = 0–3 m and far = 6–9 m) on the shoot density of *P. oceanica* meadow. Significant values are in bold.

Density				
Source	df	MS	F value	P
Mooring = M	1	36,358,446	18.288	**<0.0001**
Distance = D	1	12,322,795	6.198	**0.015**
D × M	1	2,007,794	1.010	0.318
Residual	76	1,988,091		

the seagrass recovery, as accurate estimates of seagrass density and cover at the same locations before mooring field establishment are not available and the comparison of *P. oceanica* condition before-after mooring establishment cannot be done retrospectively. In fact, seagrass habitat at PNALM in the early 2000s (Cossu et al., 2006) had been classified and only the general condition of the meadow around the whole archipelago, according to Pergent et al. (1995), was given: 33% of the meadow was very disturbed (abnormal density), 20% was disturbed (low density) and 47% meadow was in equilibrium (normal density). Consequently, differences between mooring fields and controls can only be drawn by an ACI (after-control-impact) design (Underwood, 1997) and the eventual recovery of the plant would remain unevaluated. However, our estimates of boat anchoring damage and impact of the dump weights corroborate the hypothesis that mooring fields and the present anchor restrictions were ineffective in protecting *P. oceanica*. In fact, at each sampled area an increase (up to 34%) in anchoring damage was observed just after the tourist season, indicating that the current restriction, which forbids anchoring outside the mooring fields on the meadows, remains an unattended measure of protection, as anchor damage substantially increased even in the areas considered as controls (18% and 70% at Cala Portese and Porto Madonna, respectively). Also, our results

showed a direct impact on *P. oceanica* of traditional mooring systems as seagrass density was lower in the presence of dump weights respect to control and gaps were larger at decreased distance from it. This strongly suggests that in the presence of either strong wave action or the misuse of moorings, dump weights can become dislodged and moved along the bottom, affecting surrounding areas of the meadow (Fig. 6) similar to the deleterious effects of the traditional mooring system evidenced by Demers et al. (2013) for *Posidonia australis*. In our study it is also evidenced that the overall occurrence of *C. racemosa* was higher in damaged areas of *P. oceanica*, as its successful establishment and spread
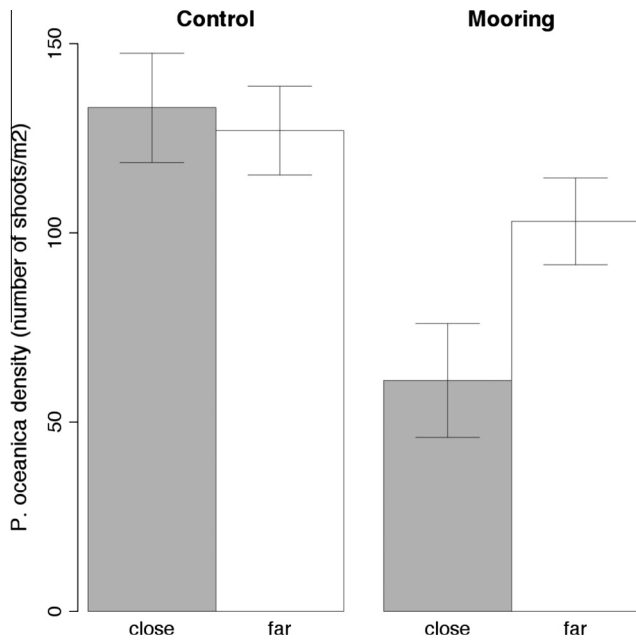

Fig. 3. Mean number (±SE) of anchor damages on *P. oceanica* as a function of mooring and location (PM and CM) before and after the tourist season.

Fig. 5. Mean (±SE) *P. oceanica* shoot density as function of dump weight (mooring and control) and distance (close and far).
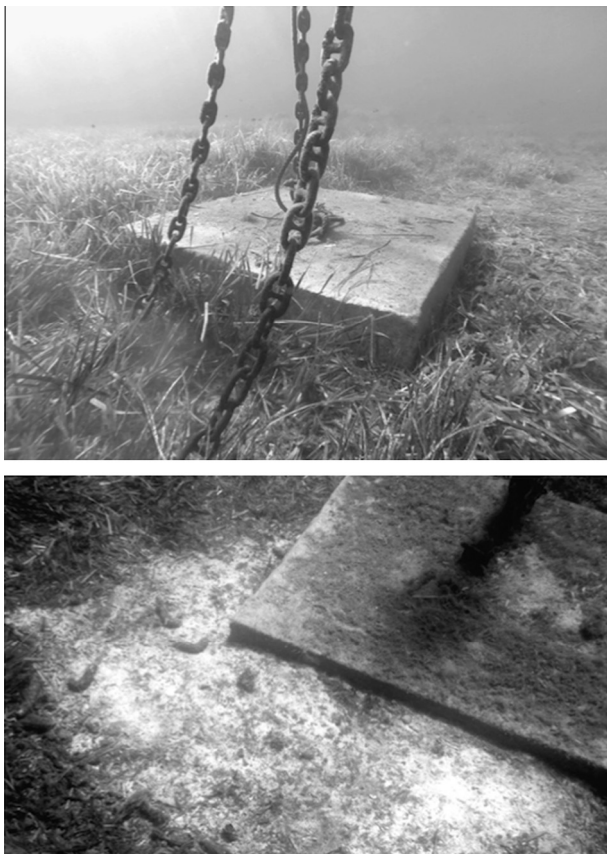

Fig. 6. Mooring impact on *P. oceanica* meadow.

depends on the physical attributes of the seagrass habitat (Ceccherelli et al., 2014).

Hence, at PNALM, anchoring damage represents a current threat to the seagrass: the present results suggest that actual anchor damage not only date back to past periods when anchoring

regulations were lacking or different, but they increase year by year. Therefore, if anchoring has a negative impact on the meadow because it bares the rhizomes, abrades the matte, generates large dead matte areas and facilitates the colonization of alien species, our results show that some management of anchoring can be either useless or detrimental, as the disturbance provoked by weight dislodgment has further heavy impacts on the meadows. The magnitude of the impact on *P. oceanica* seagrass is likely to depend on the size of the gap created but, in any case, it is particularly detrimental because the species cannot promptly recolonize areas where rhizomes have been removed, and recovery may take centuries due to the slow clonal growth (estimated from about 1–7 cm yr^{-1} Montefalcone et al., 2006). As a consequence, the edges of a newly formed gap are likely to be temporarily unstable and more susceptible to disturbance than other areas of the bed. Thus, inside the anchoring scars the unprotected sediment is mostly subjected to storm wave action, which progressively reduces its cohesion, leaving a depression in the seabed; further storms and the actions of sea animals, such as crabs, continue to undermine the edge of the surviving seagrass (Collins et al., 2010), leading to a progressive fragmentation of the meadow and bringing the meadow into a state of regression from which it can no longer recover.

The volume of information on seagrass conservation practices has increased enormously over the last 10–20 years (Pullin et al., 2004). Although clear evidence for some seagrass conservation actions exists, general conservation actions lack in quantitative estimates thorough time and they are often still based on anecdote, personal experience and the interpretation of traditional management practices (Pullin et al., 2004). Despite the fact that the legal protection of seagrass is easily possible where disturbance derives from proximal causes (such as boat anchoring), the paucity of sufficient data on seagrass distribution and quality status hinders the effective implementation of management policies (Duarte, 2002). The results of this study evidence the failure of the PNALM management approach, which was implemented many years ago on the basis of incomplete scientific evidence available at that time, and was not subjected to scientific controls, nor it has been reviewed and updated. Indeed, effective management goes beyond implementation and conservation actions, and it is integrally linked to well-designed monitoring and evaluation systems (Margoluis and Salafsky, 1998). The present study highlighted that benefits of adequate management were missed. This could be mainly attributed to the lack of a periodical and long-term monitoring program to evaluate management strategy (mooring systems and regulation) effectiveness and the lack of identification of discriminant conditions (e.g. boat tourism development, need for surveillance, appropriate use of the mooring fields, and education of boaters).

In conclusions, from lessons learnt from PNALM, we suggest a number of management, legislative, monitoring, and educational actions that marine parks should put into practice to make the protection of *P. oceanica* from anchoring effective: (1) in cases of high boat traffic, it would be advisable to establish free zones for anchoring, located in places where the seagrass is not present, reducing the boat pressure on the forbidden area and on the mooring fields; (2) although we recognize the importance of boat tourism for the economy of the surrounding communities, a maximum number of boats permitted to access the park should be established based on the number of mooring buoys available and the capacity of designated anchorage areas on sandy bottoms; (3) traditional mooring systems in seagrass meadows should be replaced by 'seagrass-friendly' systems in order to make plant recovery possible in the areas damaged by anchoring and mooring; inferred from the number of permits issued to enter the Park, the number, concentrations and localization of buoys should be

carefully determined; (4) considering the general inobservance of restrictions on anchoring, local surveillance should be implemented, also employing video technologies and closer co-operation with law enforcement; (5) the implementation of a proper and periodical educational program, containing awareness actions about the importance of marine habitats and campaigns in order to change boaters' attitudes and behaviors regarding anchoring in coastal areas, should be one of the main conservation goals of a marine park; (6) design of a long-term monitoring plan to measure the effects of any new management strategy should be established and considered as a priority.

Acknowledgements

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