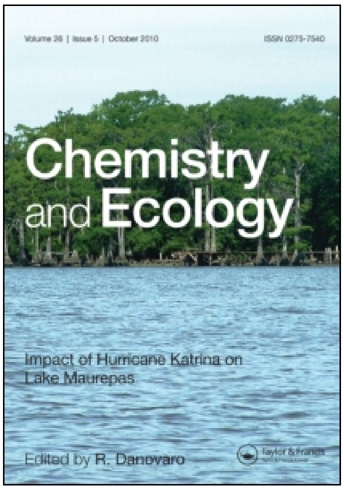

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Anchoring damage on *Posidonia oceanica* meadow cover: A case study in Prelo cove (Ligurian Sea, NW Mediterranean)

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Anchoring damage on *Posidonia oceanica* meadow cover: A case study in Prelo cove (Ligurian Sea, NW Mediterranean)

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Among the various types of human activities, the mechanical damages resulting from uncontrolled pleasure boats anchoring in shallow coastal waters would appear to be responsible for localized regressions of *Posidonia oceanica* meadows. This paper aims to describe and quantify the impacts of a large anchoring chains system on the structure of the *P. oceanica* meadow of Prelo cove (Ligurian Sea, NW Mediterranean). In this study, we provide evidence that this chains system had a negative effect on the meadow cover, generating dead 'matte' areas within the meadow. Meadow structure mapping, combined with the use of an environmental index (Conservation Index), which is linked to the proportional abundance of dead matte relative to living *P. oceanica*, underpins significant differences in the cover and in the conservation status of the meadow between areas characterized by the presence of the chains and areas without the chains. We also show that the chains affected the meadow in different ways according to *P. oceanica* cover. The approach proposed here, based on thematic mapping and a simple environmental index, provides relevant information for management actions on the conservation of *Posidonia oceanica* meadows.

Keywords: *Posidonia oceanica*; Anchoring; Ligurian Sea; Mediterranean Sea; Conservation Index; Cartography

1. Introduction

The endemic species *Posidonia oceanica* (L.) Delile is the dominant seagrass in the Mediterranean coastal waters [1] where it forms extensive and monospecific meadows on soft bottoms of the infralittoral zone, between the surface and the lower limit of about 40 m [2, 3]. *P. oceanica* meadows provide the most important and productive ecosystem in the entire Mediterranean Sea [4–6], playing a wide variety of roles in the ecological balance of coastal waters. In particular, the *P. oceanica* meadow contributes significantly to water oxygenation through photosynthetic activity, provides shelter and nursery to many marine animals, provides

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a major food resource for coastal and pelagic animals, produces a large quantity of biomass towards neighbouring ecosystems, helps to stabilize sandy shores and sea beds, and protects sandy beaches from erosion [7].

The terrace, constituted by live and dead intertwined rhizomes, together with the sediment that fills the interstices, is named 'matte' [8–10]. When *P. oceanica* dies, the matte when it is not eroded by currents may persist for a long time, and it is possible to assess the historical occurrence of *P. oceanica* in areas where it is currently absent [11].

Nowadays, *P. oceanica* meadows are experiencing a widespread decline throughout the Mediterranean Sea [8, 12–20]. Their location in shallower coastal waters makes them susceptible to environmental alterations resulting from human activities (e.g. coastal development, eutrophication and pollution, turbidity, anchoring, and trawling). Among these various types of human activities, the mechanical damage resulting from uncontrolled pleasure boats anchoring appears to be responsible for localized regressions of *P. oceanica* seagrass beds [21–23]. Many studies have qualitatively described the negative impacts of these activities on the seagrass [24–28], but few have analysed quantitatively the changes on the meadow structure [29, 30].

An alternative to direct anchoring is the deployment of anchoring chains-system to which buoys – and subsequently boats – are moored. This system is commonly used in several *P. oceanica* meadows located in coves of Liguria, an administrative region of NW Italy. In this paper, we investigated the impact of one such system on the *P. oceanica* meadow of Prelo cove (Eastern Ligurian Riviera, Mediterranean Sea). We used scuba surveys to produce the basic information on the distribution of the chains and on the cover of the meadow. This information, combined with previous data on the morphology of the meadow, is then used to compute the Conservation Index [31], which describes the conservation state of the meadow. We will show that the combined use of the Conservation Index, together with a detailed map, may constitute a validated method to evaluate and quantify the effects of the chains-system on the *P. oceanica* meadow.

2. Materials and methods

2.1 *Study area*

This study was carried out in Prelo cove, a small bay (about 80 000 m^2) along the Ligurian coast between Rapallo and Santa Margherita Ligure (Ligurian Sea, NW Mediterranean) (figure 1). In this cove, a *P. oceanica* meadow occurs, ranging from 1 to 14 m depth and covering an average surface area of about 48 000 m^2 [32]. The meadow is rather heterogeneous in terms of cover and shoots density but as a whole still exhibits a good state of health [33]. Recently, this meadow has been declared 'Site of Community Interest' (SCI).

Since the early 1970s, a large bottom chains system has been laid down from the surface by the local administration at the beginning of June and retrieved at the beginning of October. This anchoring chains system is characterized by several primary large chains (with an average length of about 130 m and with chain links about 10 cm long), crossing the cove from north to south and from west to east. These primary chains, ending with anchors, are not fixed at the sediment but are simply laid on the bottom, free from shifting. The system also has several secondary chains (with an average length of about 20 m and with chain links about 5 cm long) connected perpendicularly at the primary chains. Several surface buoys, departing from either the primary or the secondary chains, allow for the mooring of pleasure boats. No further anchoring is allowed within the cove.

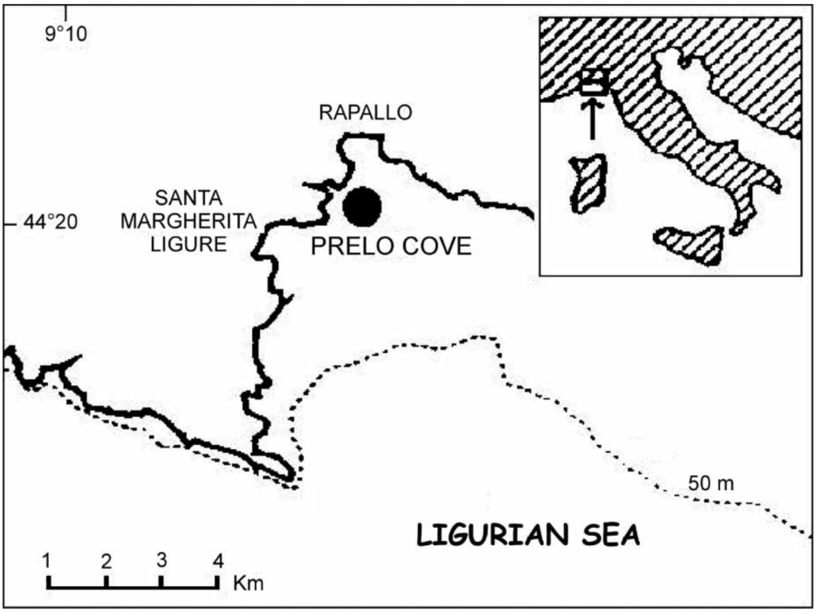

Figure 1. Geographic location of the study area.

2.2 *Field activities*

The investigations were conducted at the beginning of October 2004, a few days before the anchoring chains system of the Prelo cove had been retrieved. The area was inspected by scuba divers. A total of 30 spot dives were conducted at random points to cover the whole portion of the cove along which the presence of the chains was examined (figure 2). The exact position of the spot dives and each chain encountered was recorded using a GPS with a nominal precision of 10 m. During each dive, we followed the chain encountered, and we reported the key attributes on a PVC slate, namely: depth, and nature of the substrate (matte or dead matte) and the features of the chains (total length, length of the links of the chain, direction using a compass).

As recommended by Buia *et al.* [34], the percentage cover by living *P. oceanica* and by dead matte was estimated by eye by two divers independently every 5 m along the chain and swimming at about 1 m upon the bottom. A total of 212 cover data were recorded corresponding with the whole anchoring chains system. We also reported the occurrence and percentage cover of the green alga *Caulerpa prolifera* (Forsskal) Lamouroux, when encountered.

2.3 *Data treatment*

In this study, we used a previous thematic map, representing the morphology of the *P. oceanica* meadow in Prelo cove [32], where we reported the localization of the anchoring chains system using data recorded during spot dives. The resulting map (figure 3) was then divided into subareas, each with a surface area of 25 m^2. Two different portions of the cove were analysed: the shallow portion (3–6 m depth) and the deep portion (6–11 m depth). In the former, 100 shallow areas with chains and 100 shallow areas without chains were analysed. In the latter, 112 deep areas with chains and 112 deep areas without chains were also analysed (figure 4).

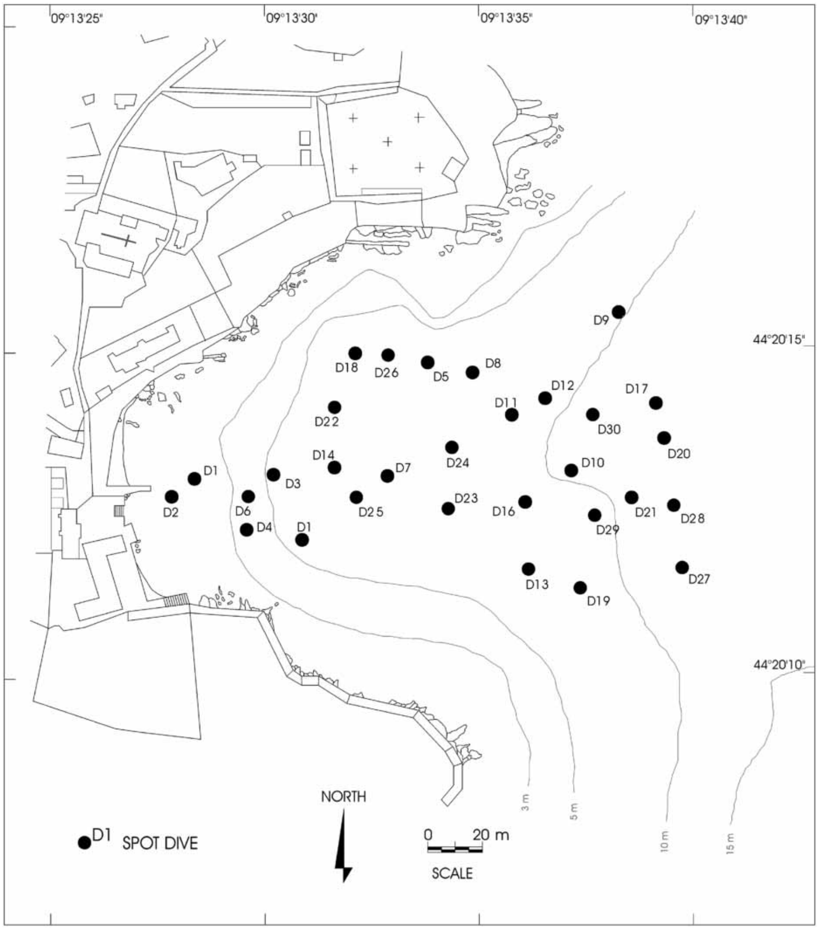

Figure 2. Map representing the field activities. The positions of 30 spot dives (D1–D30) are indicated.

In order to assess the differences between areas with or without chains, we used the cover data recorded along the chains during spot dives, combined with a set of cover data obtained in a previous study conducted on this meadow short before the deployment of the chains system [32], where the percentage cover of both *P. oceanica* and dead matte was recorded every 5 m along 12 scuba transects, each 200 m long, perpendicular to the shoreline and homogenously distributed within the whole meadow. Only 4 months of difference make this set of cover data [32] comparable with those measured during this study.

Based on the cover data, we computed the Conservation Index [31, 35] within each subarea. The index (CI) is expressed by the formula:

$$\mathrm{CI} = \frac{L}{L + D}$$

where L is the percentage cover of live *P. oceanica*, and D is the percentage cover of dead matte. The index ranges between 0 (minimum state of conservation with only dead matte present) and 1 (maximum state of conservation, a healthy meadow with no dead matte).

Student's t-test was used to assess the differences between the CI values obtained in the areas with chains and the areas without chains (both in the shallow and deep portions). The resulting values of CI for each subarea were then assigned to four intervals according to the procedure

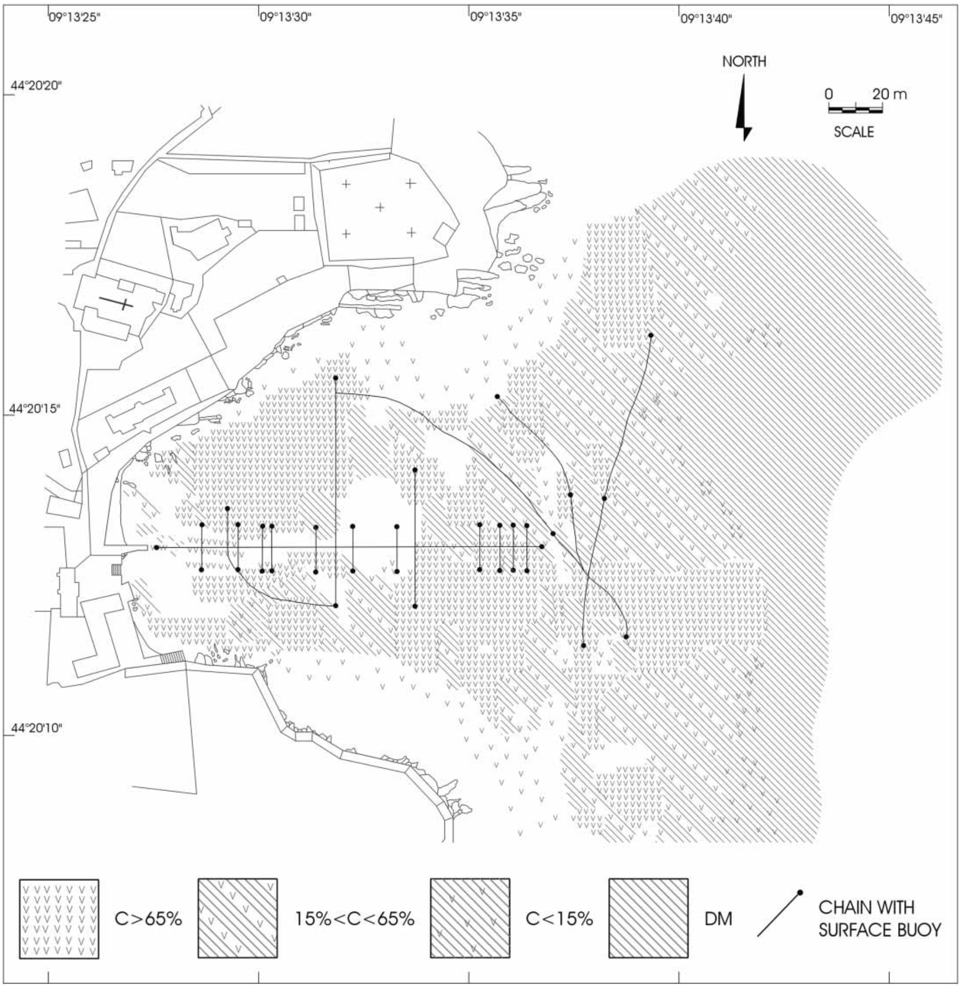

Figure 3. Map representing the positioning pattern of the anchoring chains-system in the Prelo cove (background thematic map from Lasagna [32]). C: percentage cover by living *Posidonia oceanica*; DM: dead matte.

proposed by Moreno *et al.* [31] and emended by Montefalcone *et al.* [35]:

(1) CI values $< (\bar{x} - (1/2)s)$;
(2) CI values from $< (\bar{x} - (1/2)s)$ to $\bar{x}$ excluded;
(3) CI values from $\bar{x}$ included to $< (\bar{x} + (1/2)s)$;
(4) CI values $> (\bar{x} + (1/2)s)$;

where $\bar{x}$ is the mean and s the standard deviation of the index calculated all over the 424 subareas as originally chosen by [31]. The frequencies of the four states of conservation obtained for each portion of the study area (shallow and deep) were compared between areas with chains and areas without chains. Statistical differences were assessed using the Chi-square test.

Finally, the frequencies of the subareas showing the occurrence of *C. prolifera* in correspondence of dead matte substrate were compared for areas with and without chains.

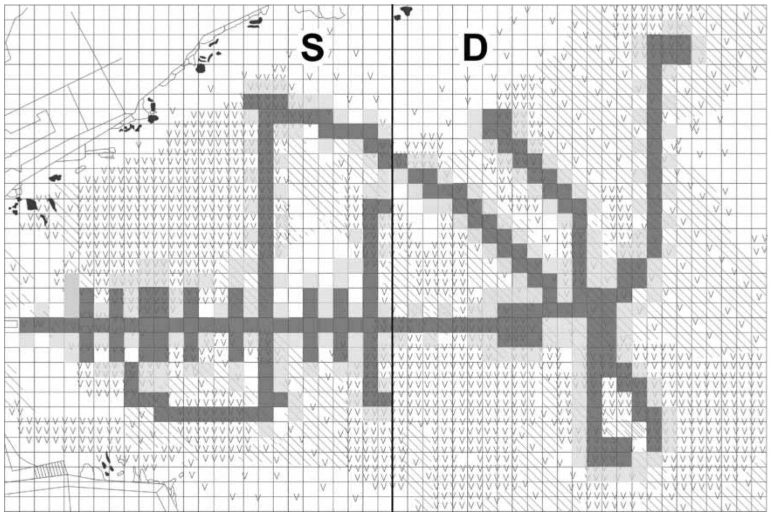

Figure 4. Frame of the study area divided into subareas. Dark grey indicates the areas with chains, and light grey indicates the areas without chains. The two different portions of the cove analysed, shallow (S) and deep (D), were also reported.

3. Results and discussion

3.1 *Distribution of the anchoring chains system*

We mapped a total of seven primary large chains, six of them crossing the cove from north to south and one crossing the centre of the cove and directed toward the coast, from about 12 m depth to the shoreline (see figure 3). A total of 11 secondary chains, each departing from the latter primary chain, were also reported. We estimated that each primary chain covered an average surface of about 13 m^2, while the secondary chain covered an average surface of about 1 m^2; the whole system of chains in Prelo cove covered a total surface area of about 103 m^2, that is about 0.2% of the meadow.

3.2 *Impact of the chains on the conservation state of the meadow*

In the 100 shallow areas with chains, CI varied from 0 to 1, with a mean value of 0.54 ± 0.34 (figure 5a). In the respective 100 shallow areas without chains, CI values varied from 0.13 to 1, with a mean value of 0.77 ± 0.21 (figure 5a). The differences between the two situations was found to be highly significant ($t_{198} = 5.84$, $p < 0.001$). In the 112 deep areas with chains, CI varied from 0 to 0.84, with a mean value of 0.41 ± 0.22 (figure 5b). In the respective 112 deep areas without chains, CI values varied from 0.29 to 1, with a mean value of 0.80 ± 0.12 (figure 5b). The differences between two situations was found to be highly significant ($t_{222} = 16.46$, $p < 0.001$). The average lowest values of CI obtained in correspondence of the subareas with chains are reflected by the high amount of substrate characterized by dead matte, thus confirming a negative effect of the chains on the meadow cover.

All the CI values obtained for each subareas were divided into four intervals [31, 35], thus allowing the recognition of four distinct states of conservation of *P. oceanica* meadow:

(1) advanced degree of regression (CI < 0.49);
(2) impacted meadow (CI between 0.49 and 0.63 excluded);

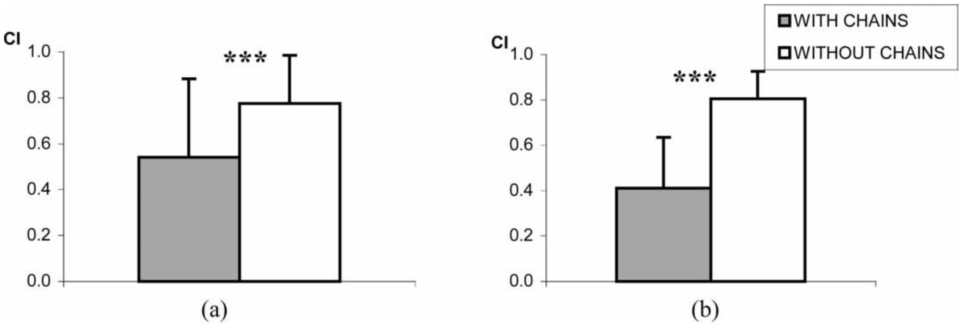

Figure 5. CI values in subareas with chains and in subareas without chains, respectively in the shallow portion (a) and in the deep portion (b) (mean + S.D.). ***Highly significant differences (Student's *t*-test).

(3) low to moderate conservation status (CI between 0.63 and 0.78);
(4) high state of conservation (CI $>$ 0.78).

The frequencies of the four states of conservation obtained for each portion of the study area (shallow and deep) were compared between areas with chains and areas without chains (figure 6). In the shallow portion of the meadow (figure 6a), state 1 (advanced degree of regression) mostly characterized the areas with chains, while state 4 (high state of conservation) prevailed in the areas without chains. A similar result was obtained in the deep portion (figure 6b).

In the shallow portion, the differences between subareas with chains and subareas without chains, characterized by state 1, was found to be highly significant ($\chi^2 = 21.4$, $p < 0.001$). In comparison, the differences between subareas with and without chains, characterized by state 4, was found to be significant ($\chi^2 = 5.7$, $p < 0.05$). No significant differences were observed for either of the other two conservation states (state 2, $\chi^2 = 0.71$; state 3, $\chi^2 = 0.3$). In the deep portion, the differences between subareas with and without chains, characterized by state 1 and state 4, was found to be highly significant (state 1, $\chi^2 = 55.5$, $p < 0.001$; state 4, $\chi^2 = 54.4$, $p < 0.001$). Also, the differences in the frequencies of state 2 (impacted meadow) and of state 3 (low to moderate conservation status) were found to be high and very significant among subareas with and without chains (state 2, $\chi^2 = 22.5$, $p < 0.001$; state 3,

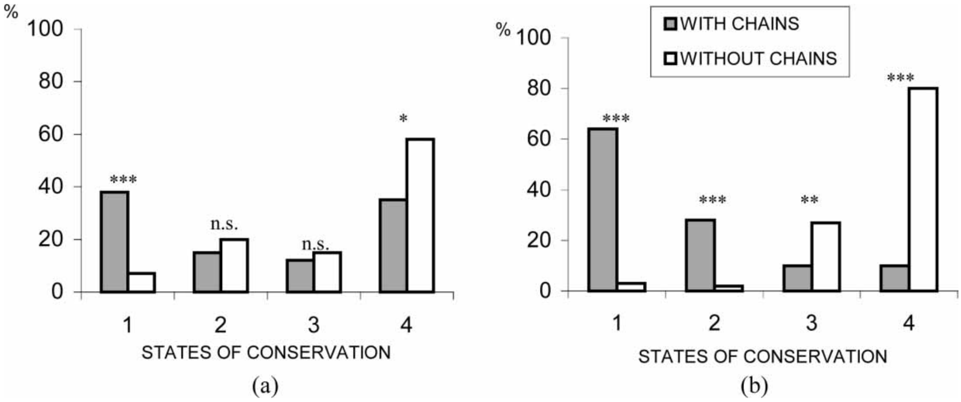

Figure 6. Frequencies of the four states of conservation obtained in the subareas with chains and subareas without chains for each portion of the study area, shallow (a) and deep (b). ***Highly significant differences; **very significant differences; *significant differences; n.s.: nonsignificant differences (Chi-square test).

$\chi^2 = 7.8$, $p < 0.01$). The frequency distribution in areas with chains symmetrically mirrored that in areas without chains, so that all differences were found to be significant.

In the deep portion of the meadow, the differences in frequencies for each conservation state were found to be stronger than in the shallow portion. Additionally, in the areas with chains, the frequency of the high conservation status (state 4) was very much lower than the advanced degree of regression (state 1) (10% and 64%, respectively). In contrast, in the shallow portion of the meadow, the areas with chains showing state 4 and state 1 were found to have a comparable frequency (35% and 38%, respectively). We presume that the shallow portion of the meadow, when subjected to mechanical damage, is more prone to recovery; in comparison, the deep portion of the meadow appeared to suffer greatly from the damage and to recover slowly in its cover. The two portions of the meadow reacted differently to the chains, and this could be related to meadow morphology, which appeared to be more homogeneous and more highly covered in the shallow portion than in the deep portion of the cove [32].

Once it had been demonstrated that the chains were largely responsible for impacting on the meadow structure, in terms of shifting its conservation status from 'high conservation status' to 'advanced degree of regression', we also evidenced how the chains impacted differently on the meadow according to *P. oceanica* cover. Based on the *P. oceanica* percentage cover, four major situations can be distinguished: (1) meadow exhibiting a high cover by *P. oceanica* ($C > 85\%$); (2) meadow with a medium cover ($65\% < C < 85\%$); (3) meadow showing a low cover ($C < 65\%$); and (4) dead matte.

In correspondence with these four situations, the chains were likely to have the follow impacts:

(1) in a high-cover meadow, the chains abruptly bend the *P. oceanica* leaves, thus inhibiting any further growth and reproduction process (figure 7a);

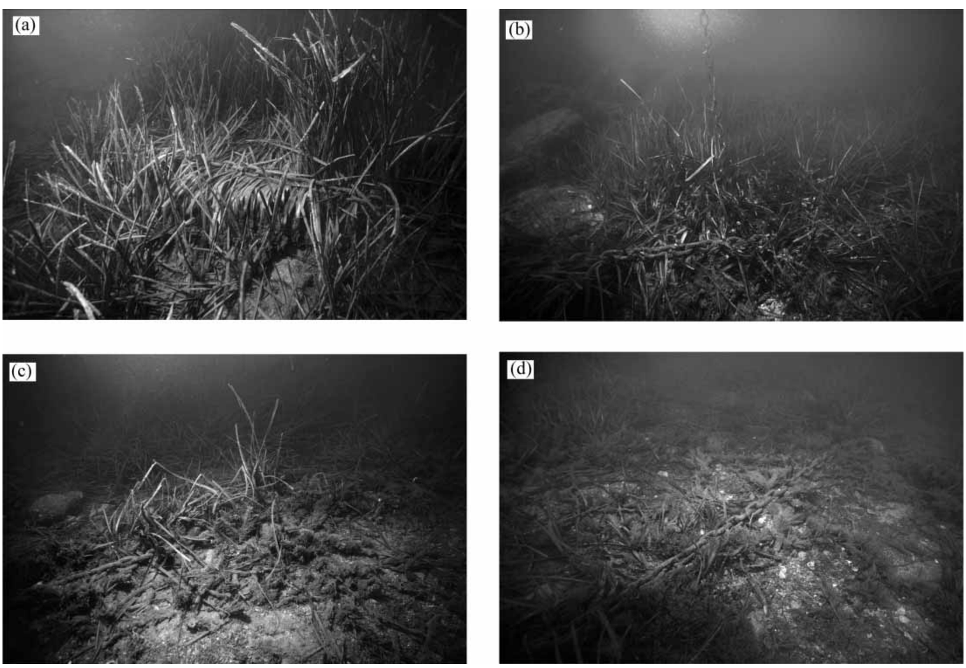

Figure 7. Effects of the chain in correspondence of four different *Posidonia oceanica* meadow situations: (a) high cover; (b) medium cover; (c) low cover; and (d) dead matte. Photos by C. N. Bianchi.

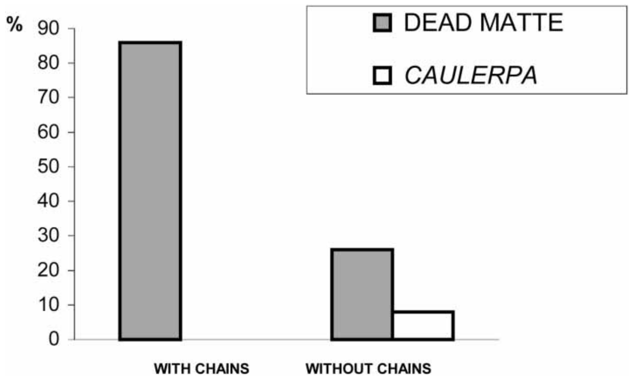

Figure 8. Frequencies of the subareas (both shallow and deep) characterized by the presence of dead matte and *Caulerpa prolifera* on dead matte, in the subareas with and without chains.

(2) in a medium-cover meadow, the chains were able to fall among the leaves reaching the base of the shoots, thus starting to undermine the rhizomes (figure 7b);
(3) in a low-cover meadow, the chains aggravated the rhizome baring (figure 7c);
(4) on dead matte, the chains directly abraded the matte (figure 7d).

3.3 *Impact of the chains on* **Caulerpa prolifera** *recolonization*

Based on the assumption described in the fourth situation, we focused on the occurrence of the green alga, *Caulerpa prolifera*, in Prelo cove, which used to develop on dead matte areas in both shallow and deep portions of the meadow. Analysing the frequencies of the subareas (both shallow and deep) characterized by the combined presence of dead matte and *C. prolifera* (figure 8), we observed that, in correspondence with the areas with chains, dead matte was always abundant, but *C. prolifera* was never found on these dead matte areas. In contrast, in the case of areas without chains, where dead matte was comparatively less abundant, the alga was observed. This result provided evidence that the chains also continued their abrasive action on dead matte areas, thus preventing any further recolonization.

4. Conclusion

Doumenge [36] considered the mechanical damage caused by pleasure-boat anchoring on *P. oceanica* meadows to be one of the most important causes of degradation of the coastal sea bed. Our study provided quantitative data on the damage caused by an anchoring chains system and showed that even a localized and short-term impact (due to seasonal deployment) can lead to a permanent and heavy mark on the *P. oceanica* meadow structure. The long-established practice of deploying the anchoring chains-system in Prelo during summer had, in the long run, a negative effect on the meadow in terms of baring the rizhomes, abrading the matte and generating large dead matte areas within the meadow. In addition, seagrass loss may also be enhanced by subsequent sediment erosion. As a consequence, the fragmentation of the meadow may represent a significant reduction in habitat, a potential loss of species diversity, a decrease in ecosystem functioning, and even possibly net erosion of the beach.

The poor conservation status of the areas in terms of the presence of the chains was clearly reflected by the low values of the Conservation Index found by Moreno *et al.* [31]. Combining the detailed mapping of the anchoring chains system with the evaluation of the proportion of dead matte, it is estimated that more than 2800 m^2 of meadow has been destroyed over the last few decades. This value corresponds to 5.8% of the total surface area occupied by *P. oceanica* in the cove and should be compared with the 0.2% occupied by the chains themselves. Considering that the chains system totals 1130 m in length, it can be reckoned that every linear metre of chain deployed led to a loss of 2.5–3 m^2 of meadow.

According to Kirkman [37], seagrass beds do not regrow or recolonize areas where rhizomes have been removed. Compared with the slow clonal growth of *P. oceanica*, estimated at about 1–7 cm yr^{-1} [38], recovery may take centuries. Any large-scale loss must therefore be considered to be almost irreversible on human-life timescales [39].

This aspect seems peculiar to *P. oceanica*, which contrasts with other seagrass species (e.g. *Posidonia sinuosa*, *Posidonia australis*, *Amphibolis antarctica*, and *Amphibolis griffithii*) capable of recovering from mooring damage at relatively faster rates [29, 30]; even with these species, however, recovery rates depend on the scale of mechanical damage, with only mooring holes <20 m in diameter being recolonized [30].

Further investigations are needed to explore the consequences of this kind of mechanical damage on other aspects of plant vitality, such as growth and phenology. To reduce the damage to seagrass by moorings, a new, environmentally friendly mooring design is required.

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