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Effectiveness of Moorings Constructed from Rope in Reducing Impacts to Seagrass

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Abstract: Seagrass meadows commonly reside in shallow sheltered coastal environments which are typically safe havens for mooring boats. There is evidence from around the globe that the use of common swinging chain moorings leads to halos of bare sediment in otherwise productive seagrass. These halos reduce animal abundance and diversity and lead to a loss of the carbon stored within sediments. To protect and enhance seagrass ecosystem services, low-cost simple solutions are required that can solve the problems of boating-based disturbance. In the present novel study, we provide evidence that the simple replacement of mooring chains with rope can significantly reduce damage to sensitive benthic habitats such as seagrass. At three locations across a range of environmental conditions, we provide evidence that well-established moorings constructed from rope do not damage seagrass. Overall, there was a significant effect ($F_{1,756}$ = 299.46, $p < 0.001$) of the mooring type and distance from the mooring base. This equates to a 44% increase in seagrass cover within areas around a rope mooring relative to a chain one. Most small boat mooring activity happens within the summer months, therefore large heavy-duty winter mooring systems are not required in many situations, opening opportunities for adapted systems that have a reduced environmental impact. The present study suggests that there is a ready-made, low-technology, low-cost solution already in existence for halting the widespread loss of seagrass from small boat mooring damage and allowing recovery and opportunity for restoration.

Keywords: boats; anchors; moorings; seagrass; sustainability; conservation

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1. Introduction

Ideal coastal environments for seagrass meadows overlap those required for safe mooring locations suitable for recreational boating [1,2]. With a growing global nautical tourism that encompasses yachting, boating, cruises, and water sports industries [3], there is increasing demand for secure moorings where boat owners can leave a vessel for long periods without the need for anchoring. The growing demand for moorings places more pressure on seagrass meadows as mooring sites, creating a potential conflict between seagrass and boaters. Construction of moorings varies widely but the above-seabed segment is often dominated by heavy chains as the link between the base and the water surface [4]. The chain (or alternative) either connects to a base block comprised of concrete or metal or alternatively to a helical anchor embedded in the sediment. Chain-type boat moorings are also referred to as swinging chain moorings and create a source of small-scale, long-term, repeated physical disturbance.

The disturbance created by the swinging chain damages associated sensitive habitats such as seagrass, erodes the seabed, and remobilises the sediment [5]. Instances of chain mooring damage to seagrass have been documented globally, including a recent estimate of the long-term loss of 122 ± 126 m^2 of seagrass per mooring in the UK [5]. Given the large scale loss of seagrass globally [6], the current high levels of threat to these systems [7] and their value in supporting carbon storage and coastal livelihoods [8], it is crucial we provide solutions to prevent this damage.

Advanced mooring systems are an alternative to traditional swinging chain moorings, but their high cost remains prohibitive to the wide-scale roll-out of their use [9]. This has led to the search for other lower-cost methods, including a recent proposal to utilise subsea floats to reduce chain impacts [10]. Chain moorings create disturbance as their weight is part of the mooring mechanism, which results in the chain dragging on the sediment [11]. This dragging action and the chain links disturb the seabed, tearing away any biota and, in the context of seagrass, tearing the leaves and ripping up the rhizomes. Such heavyweight moorings are unnecessary for most smaller vessels (e.g., <10 m) that utilise moorings for short summer periods. Other lighter weight designs using readily available (and low-cost) materials provide a range of opportunities to reduce the impacts of moorings. Synthetic fibre rope moorings are sometimes used as an alternative to chain [12], but these are less common and the impact of these moorings on shallow marine ecosystems has not previously been quantified.

The present study aims to assess the impact that rope moorings have on seagrass by quantifying seagrass density in the area surrounding these moorings over a range of different environmental conditions. We hypothesise that due to the reduced drag of rope on the seabed, as a result of both its natural buoyancy and lack of abrasion created by metal chain links, the rope will have a reduced impact on seagrass across all environments.

2. Materials and Methods

Seagrass density was assessed around rope moorings across a range of environmental conditions in temperate and tropical meadows to understand the impact of rope moorings on seagrass. Sampling was dependent upon the presence of these types of moorings within seagrass areas. Rope is a less commonly used material relative to more popular swinging chain moorings and, therefore, less abundant to sample. This reduced presence is reflected by the unbalanced design of our study. Data were obtained from moorings in three areas; these were Puerto Rico (4 moorings), southern England (3 moorings), and north Wales (4 moorings). The sites in Puerto Rico were subject to very little tidal movement (mean 0.5 m), whereas the sites in England and Wales had over 4 m of tidal range. The moorings in Puerto Rico and southern England were all rope; however, the moorings in Wales had a small section of chain (1 to 2 m) at their base but were mostly rope.

Once suitable moorings were selected, the depth and construction of the mooring was described (whether the mooring line was chain, rope, or a combination of both) and assessments of the surrounding benthic habitat were then undertaken. The habitat within the surrounding area was measured in four directions from the mooring: north, south, east, and west following the methods described by [5]. A 0.25 m^2 quadrat was used to assess seagrass density (% cover) and canopy at points in each of those directions. The studies in north Wales (Porthdinllaen) and Puerto Rico (La Parguera bay) assessed seagrass every metre, however, due to the slightly deeper depth of the sites in southern England and the longer mooring ropes a more extensive area was evaluated and quadrats were placed every 2 m.

Additional data on seagrass cover and canopy height using the same method was collected around swinging chain boat moorings and was published in a previous study (conducted alongside this one) [5]. These data, which were collected on swinging chain moorings present in seagrass across the southeast of England and in Porthdinllaen, have been included in the present study as a comparison to rope moorings.

Data Analysis

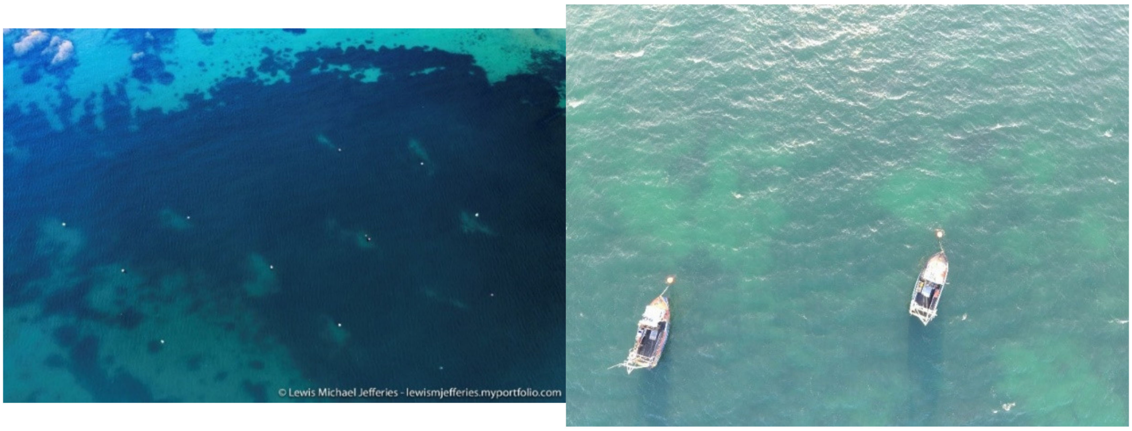
Data are presented as means ± SD. The experimental design of examining seagrass metrics with respect to different locations across a covariate (distance) necessitated the use of Analysis of Covariance. Kolmogorov–Smirnov and Bartlett tests were carried out to test for heteroscedasticity and normality of the data. All datasets failed these assumptions; however, it was decided that this analysis remained appropriate given the relative robustness of such analysis [13]. To minimise the risk of Type I error due to failures of statistical test assumptions, significance was only accepted based on *p*-values of <0.01 [14]. Further post hoc pairwise comparisons were conducted using Tukey's test.

3. Results

3.1. Seagrass Cover

Seagrass cover in the surveyed areas ranged from values of zero at Porthdinllaen (and some quadrats in Puerto Rico) to values of 100% in Puerto Rico. Within the first 0 to 5 m around the moorings, this averaged 56 ± 32%, and from 6 to 10 m this was a similar value of 53.1%, but with a smaller standard deviation at 18%. Cover was on average higher in Puerto Rico (68 ± 29%) than in southeast England (54 ± 17%) and Porthdinllaen (43 ± 33%).

Seagrass coverage was found to be abundant within the initial radius area of the bottom of the rope moorings in Puerto Rico (referred to on the graphs as 0 m). In Porthdinllaen, the seagrass cover at 0 m was very limited. These areas (see Scheme 1) correspond to the radius of the moorings influenced by a small section of chain. At Porthdinllaen, this initial density was 0.625 ± 1.9% rising slightly at 0.5 m away from the mooring to 7.25 ± 15.1%. By a 1 m distance from the mooring at Porthdinllaen, seagrass cover was similar to background at 59 ± 13%. Such close-up data are not available from around the rope moorings on the south coast of England as the first measurement was taken at a 2 m distance.



Scheme 1. Seagrass meadows containing swinging chain moorings have been documented to have bare sediment halos where the moorings drag on the seabed (left is Helford River, right is Porthdinllaen, both in *Zostera marina* in the UK). (Images: Jefferies (**left**) and Esteban (**right**)).

The seagrass cover was found overall to significantly change with respect to distance from mooring base ($F_{1,311}$ = 57.62, $p < 0.001$) and site ($F_{1,311}$ = 63.2, $p < 0.001$); however, there was also a significant interaction between distance and site. In Porthdinllaen, the seagrass was found to increase further away from all rope moorings (Figure 1) with a significant correlation between cover and distance (Pearsons, $r = 0.842$, $n = 24$, $p < 0.001$), but in Puerto Rico and southeast England this correlation was not observed.

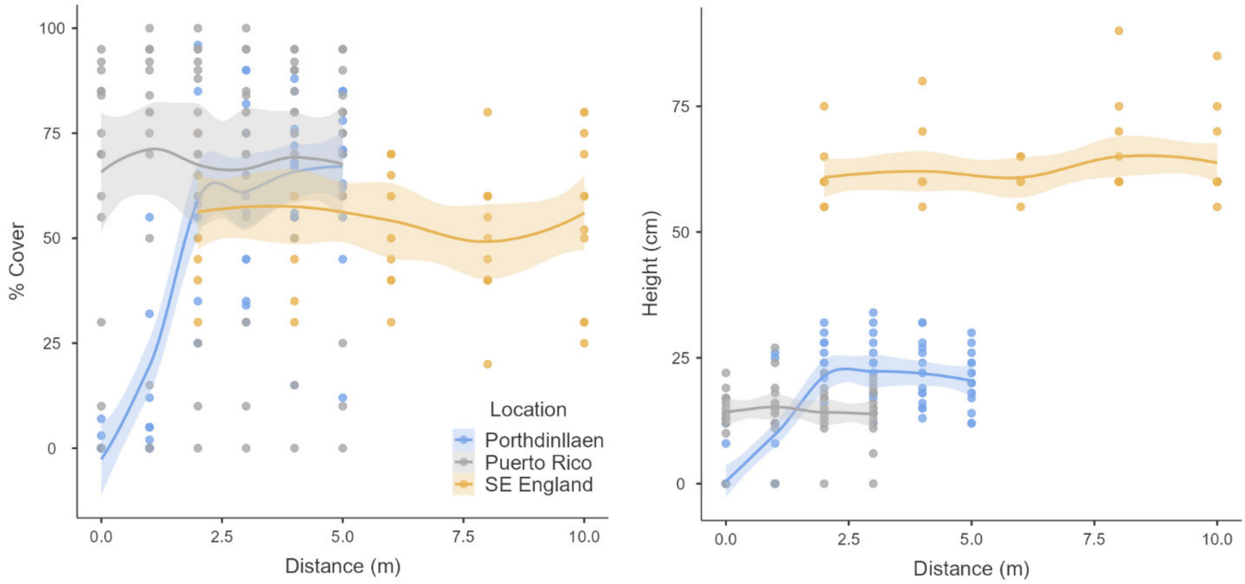


Figure 1. Seagrass % cover (left) and canopy height (right) with increasing distance from the base point of established boat moorings made from synthetic fibre rope in three locations (Porthdinllaen, north Wales, Puerto Rico, south England coast). A quadratic smoothed regression line is shown ± its standard error. Data were collected at the four cardinal points of the compass around the moorings.

3.2. Seagrass Canopy Height

The height of the seagrass that remained at Porthdinllaen around the initial base of the mooring was much shorter than that observed further away, with the height of the seagrass at the base of the mooring only reaching an average height of 1.25 ± 2.5 cm and only being able to reach a height of 6.83 ± 3.9 cm at 0.5 m, but at 1 m, this was found to be similar to the background at 21.4 ± 5.9 (cm). In Puerto Rico and in the southeast of England, no change was recorded with respect to distance from the mooring (Figure 1).

Seagrass height was also found to be significantly influenced by both distance ($F_{1,279}$ = 18.73, $p < 0.001$) and site ($F_{1,279}$ = 460.59, $p < 0.001$); however, there was also a significant interaction between site and distance due to the positive correlation between distance and canopy height observed at Porthdinllaen (Pearsons, $r = 0.739$, $n = 24$, $p < 0.001$).

3.3. Rope versus Chain

A direct comparison was also conducted between comparable seagrass data surrounding rope and chain moorings at Porthdinllaen and in southeast England (Figure 2-left). This showed that in the area corresponding to 10 m distance from the mooring, seagrass coverage was on average 12 ± 16% surrounding a chain mooring; however, in seagrass areas with a rope moorings, this was 56 ± 30%. Overall, this was a significant effect ($F_{1,756}$ = 299.46, $p < 0.001$) of the mooring type and distance from the mooring base point on seagrass cover (with no interaction). Canopy height, however, was not significantly affected ($F_{1,724}$ = 1.06, $p = 0.302$) by the mooring type, even though the mean height recorded around the rope moorings was higher than around the chain moorings (Figure 2-right). Canopy height was significantly affected by distance from the mooring base ($F_{1,756}$ = 299.46, $p < 0.001$).

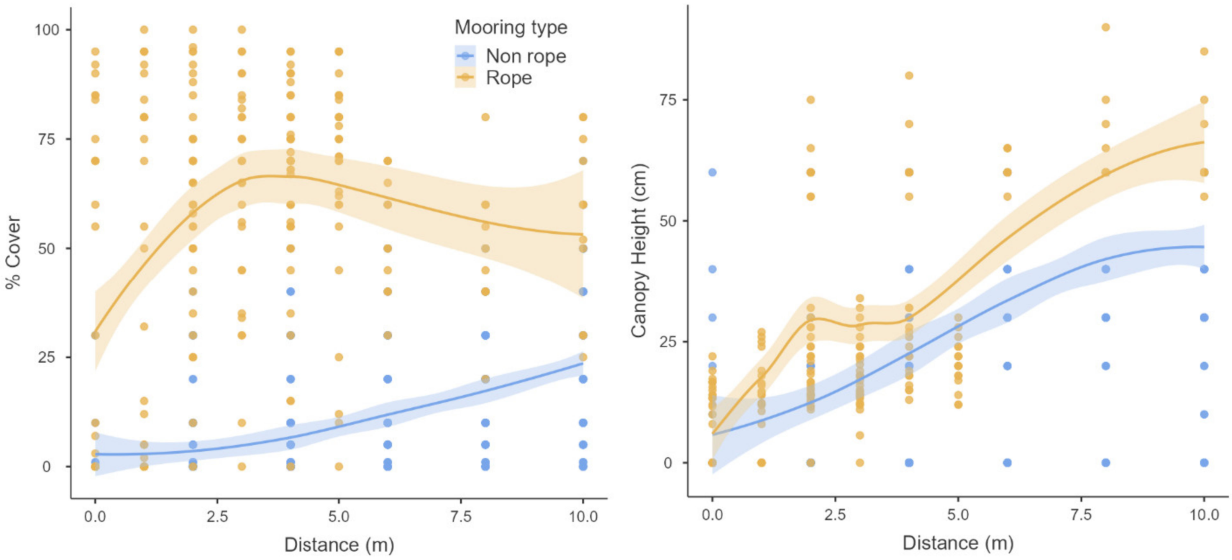


Figure 2. Seagrass % cover (**left**) and canopy height (**right**) with increasing distance from the base point of established boat moorings made from chain or rope (data combined across moorings in Porthdinllaen, north Wales, and southeast England, all sites are *Zostera marina*). The data exclude those from Puerto Rico as there are no comparable chain mooring data. A quadratic smoothed regression line is shown ± its standard error. Data were collected at the four cardinal points of the compass around the moorings.

4. Discussion

Achieving effective management of boating activities that overlap sensitive marine habitats remains a difficult challenge, with the use of moorings a particularly problematic issue [9]. When mooring activities damage seagrass and other soft sediment habitats, not only does it result in the remobilisation of carbon stored in the seabed but may also result in the release of other greenhouse gases (GHG) such as methane [2]. These small scale disturbances and fragmentation of the habitat may also influence the value of the seabed in supporting biodiversity [15]. In some locations, concern is also raised about impacts of mooring disturbances on charismatic fauna such as seahorses [16].

To aid the use of seagrass in mitigating climate emissions, low-cost, low-technology solutions are required to solve the problems of boating-related disturbance. In the present study, we provide novel evidence that demonstrates how the simple replacement of mooring chains with rope can significantly reduce damage to sensitive habitats such as seagrass.

Where rope moorings are used, there is strong evidence across all locations that no damage to seagrass could be attributed to the rope section of the mooring in terms of both seagrass density and canopy. The 11 moorings assessed in this study ranged from subtidal to intertidal locations under differing ranges of tidal movement with capacity to place considerable mooring drag on the seabed. Regardless, the seagrass remained abundant below the mooring ropes.

The rope mooring design used across the three sites varied from place to place, and at Porthdinllaen in north Wales a small section of chain (≈1 m) was present below the rope section (see Scheme 1), resulting in a significant decrease in both the height and coverage of seagrass. A significant correlation between the height and coverage of seagrass against the distance from the mooring was also observed. The data and the observation of this indicate that the point at which the seagrass returns is the point at which the rope commences (see Scheme 2). This pattern occurs across all four moorings observed at that site. Comparison of moorings made from chain at sites surveyed for rope moorings also reveal a significant increase in seagrass density from chain to rope.

Scheme 2. Rope moorings in seagrass meadows in Porthdinllaen (**top left and right**) and Puerto Rico (**bottom left and right**). The moorings in Porthdinllaen show a marked low density halo up to the point at which the mooring changes from chain to rope. The moorings in Puerto Rico that are 100% rope show no such halo.

We hypothesise that due to the lighter weight and more buoyant nature of the rope relative to the chain, even if the rope does pull close to the seabed, it does not scour in the way that a chain does. The absence of links within the rope also minimises tearing as the mooring moves. The larger areas studied around the rope moorings on the South England coast also indicated that rope moorings are not creating the large scars observed in previous studies [17,18] with data highlighting a healthy meadow.

This study does not consider the impact of the central anchor point to which either a chain or rope mooring can be attached. Typically, this is a weight of some description, such as a concrete block, that can also damage seagrass; however, the use of helical anchors appears to be becoming more common. Given that in some cases, the chain from swinging moorings dragging on the seabed actually contributes to the strength of the mooring, if a chain is to be replaced with a rope, due consideration for total mooring strength must be considered. Helical anchors can be sufficient to provide enough strength with appropriate rope [19]. If rope moorings are used in tandem with helical anchors, evidence from the present study indicates that a relatively low-cost alternative does exist for mooring small boats in both subtidal and intertidal environments. The site in Porthdinllaen now contains an abundance of rope moorings linked to helical anchors that provide suitable moorings for a range of vessels.

Although the present study shows how rope can be a very good, environmentally sensitive, alternative for mooring smaller boats, for larger vessels needing to be secured in deeper and more exposed locations, simple rope moorings may not be sufficient. In these cases, other alternative strategies (such as Advanced Mooring Systems or stranded wire rope) may be required to help reduce the impact on sensitive habitats such as seagrass [12]. The current widespread use of swinging chain moorings for smaller vessels in shallow sheltered environments is largely the result of precedent; data presented here provide an evidence-based alterative to this precedent.

Given that most boats mooring in the shallows within seagrass are recreational small vessels, it is unlikely that the use of large heavy chain moorings can be justified, especially in the context of their known impacts to seagrass. In addition, many well used mooring areas that exist within seagrass meadows are almost completely void of boats throughout the winter months when harsher conditions prevail which limit the capacity of these safe havens. It is often only during the summer months in many locations when seagrass moorings are commonly used by recreational vessels, highlighting the reduced requirements of most vessels for heavy duty swinging chain moorings. This study presents evidence of the need to expand the use of rope moorings as a low-cost alternative to swinging chain moorings in sensitive habitats such as seagrass.

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