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Evaluating microplastic trapping efficiency in seagrass meadows using hydraulic flume simulations

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ABSTRACT

Microplastic (MP) pollution poses a significant environmental threat, with projections indicating a 50-fold increase in pollution levels by 2100. Seagrass meadows, important for carbon storage and sediment stabilisation, may also serve as a Nature-based Solution for MP pollution. Despite the well-documented presence of MPs in seagrass sediments, the efficiencies of MP capture by these habitats remain largely unexplored. In this study, hydraulic flume simulations were conducted to assess how different seagrass planting configurations influence MP trapping. The results indicate that meadows with random spatial distribution are 6 % more effective at trapping MPs under high concentrations compared to grid-patterned meadows, while lower planting densities enhance trapping efficiency by 14 %. These findings offer insights into optimising seagrass restoration efforts for mitigating MP pollution, and this highlights the need for further needed to understand the broader ecological implications of MP retention in these critical ecosystems.

1. Introduction

Microplastic (MP) pollution (plastics <5 mm) has emerged as a critical environmental stressor, with projections indicating a potential fifty-fold increase in pollution levels by the year 2100 (Choudhury et al., 2018; Everaert et al., 2018; Gerstenbacher et al., 2022; Unsworth et al., 2021). This rising concern is compounded by the ongoing degradation of plastic materials already present in the environment, which are expected to fragment into smaller MPs due to mechanical processes and climatic factors (Alimba and Faggio, 2019). This ongoing fragmentation process is likely to contribute to an exponential rise in MP pollution within aquatic environments. MP particles are pervasive and pose significant hazards for the functioning and health of marine ecosystems (Fan et al., 2023). These recalcitrant pollutants can adsorb chemical toxins and bioaccumulate throughout the food web, leading to negative effects on organisms across trophic levels (Boshoff et al., 2023; Huang et al., 2020; Paduani, 2020). The response by organisms to MPs varies greatly, with effects including reduced photosynthesis and an increase in oxidative stress being observed (Fan et al., 2023). This underscores the urgent need for comprehensive research and intervention strategies to address this escalating issue.

Due to the ability of MP pollution to be easily transported, the distribution of MP pollution is now ubiquitous and persistent (Ivar Do Sul and Costa, 2014; Macleod et al., 2021; Meizoso-Regueira et al., 2024; Prata et al., 2019; Thompson et al., 2009). MPs have been identified in aquatic environments globally, from the deep-sea to coastal sediments (Shen et al., 2020). However, the fluxes of MPs in transitional coastal ecosystems, such as intertidal wetlands are currently understudied (N. ying Li et al., 2024; Malli et al., 2022; Mancini et al., 2023a; Mancini et al., 2023b; Paduani, 2020).

Seagrass meadows are already recognised as a Nature-based Solution (NbS) to climate change (Duarte et al., 2013; Liu et al., 2021; Taillardat et al., 2020; Were et al., 2019; Zou et al., 2021), contributing up to 25 % of carbon storage in marine systems while covering <2 % of coastal waters (Duarte et al., 2013; Zou et al., 2021). In addition to their role in carbon sequestration, these ecosystems promote sediment deposition and retention (De Boer, 2007; do Amaral Camara Lima et al., 2023; Tang, 2024), positioning them as potential tools for trapping MPs and removing them from aquatic environments. It is estimated that in some systems where seagrass meadows are well established, they receive approximately 11.6 % of the plastic pollution transported by rivers (Harris et al., 2021; Li et al., 2023). By reducing the interaction between

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Fig. 1. Seagrass sampling site in SSSI Porthdinllaen, Wales, UK (52.942554, -4.566012)

MPs and primary producers, seagrass meadows could help mitigate the negative impacts of MPs on higher trophic levels and, ultimately, human health (Winder and Sommer, 2012).

Recent evidence has suggested that seagrass meadows can act as filters for MP pollution, trapping and retaining a variety of MP particles. Studies comparing the sediments within seagrass beads to adjacent unvegetated areas have found significantly higher volumes of MPs in seagrass associated sediments (Huang et al., 2020; Jones et al., 2020; Paduani, 2020). Jones et al. (2020) observed significantly higher volumes of MP particles within sediments of *Z. marina* beds compared to adjacent bare sandy sediments, highlighting the ability of seagrass meadows to sediment and store MP particles.

Few studies are available on the efficiency of MP particle trapping in seagrass meadows and the most efficient way for seagrass restoration to be carried out to optimise this potential ecosystem service. A study by de los Santos et al. (2021) highlighted the ability of seagrass meadows to retain MP particles under varying meadow canopy densities (0–200 shoots per m^2). They found the meadow with 200 shoots per m^2 to be the most efficient at trapping MP particles. They revealed that marine canopies may act as sinks for MP particles.

Despite their ecological importance, seagrass meadows have experienced a significant global decline, disappearing at a significant rate of 110 km^2 yr^{-1}. In the last 40 years, it is estimated that 29 % of seagrass meadows have been lost (Gerstenbacher et al., 2022; Green et al., 2021; Waycott et al., 2009). This widespread degradation threatens both biodiversity and the critical ecosystem services seagrass meadows provide to the surrounding environment and ultimately, the human population (Gerstenbacher et al., 2022; Nordlund et al., 2018).

Given their dual role in combating climate change and MP pollution, understanding the role of seagrass meadows in mitigating plastic pollution is crucial for assessing their ecological significance. There are noticeable gaps within the knowledge on MPs within seagrass ecosystems (C. Li et al., 2023). While the presence of MPs in seagrass meadows is well documented, the efficiency with which different meadows capture these particles remains relatively unexplored. Given the ongoing conservation efforts and active restoration of seagrass meadows across the UK (Gamble et al., 2021), it is crucial to understand how to optimise planting strategies to enhance the role of these ecosystems as a NbS for mitigating the effects of environmental pollution, in addition to climate change.

The aim of this study was to evaluate how effectively these different formations of seagrass meadows trap microplastics. In addition, we aimed to explore how to potentially restore and expand seagrass meadows to maximise the ecological benefits these ecosystems provide. To achieve this, controlled comparative experiments were conducted in a hydraulic flume to analyse the mechanisms and locations where MP particles were trapped within the test area. By introducing varying volumes of MP particles, the study evaluated the capacity of different meadow configurations to capture and retain MPs, providing insights into the potential role of seagrass meadows in mitigating MP pollution.

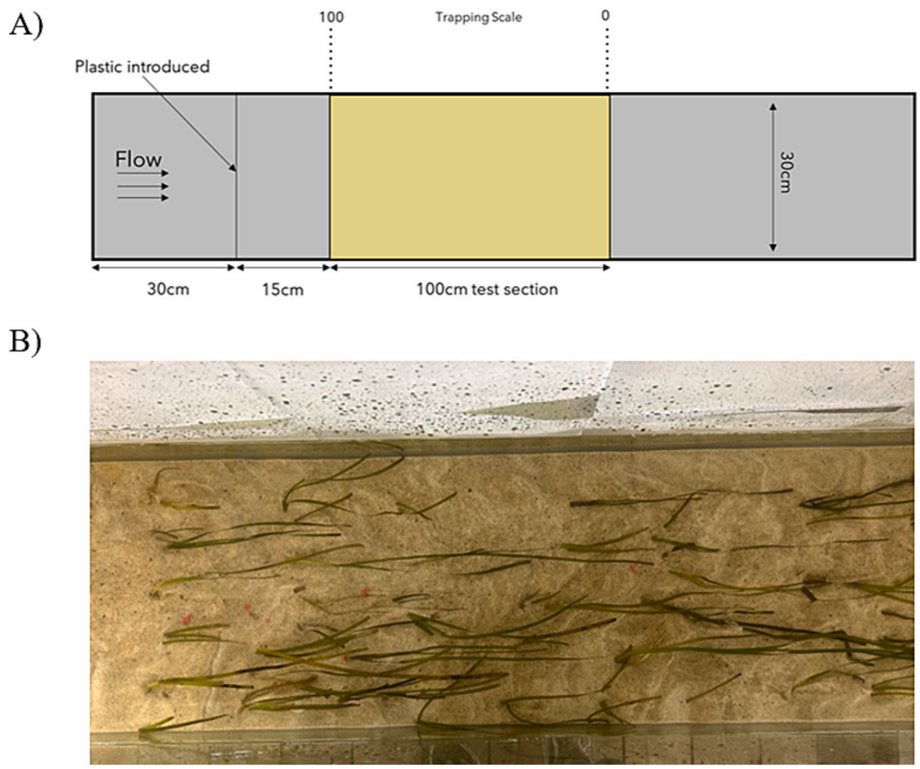

Fig. 2. Flume set up A) Diagram (not to scale) showing an aerial view of the hydraulic flume with the point of the MP particle introduction and direction of flow. Shown with 100cm length test area. Hydraulic flume is 8 m long, 0.3 m wide and 0.5 m deep. the water level was consistently set to 0.15 m. the MP particles wre simultaneously released 15 cm from the start of the test section. B) Birds-eye view of the hydraulic flume set up. Seagrass planted in the 100 cm text section in white sand to allow for standardistaion of the experiments. Flow initiated causing the seagrass to bend with the flow of water.

Table 1
Details of different artificial seagrass meadows constructed in the hydraulic flume for MP trapping simulation.

Treatment	Treatment detail	Number of plants	Plant density (plants per m^2)	Test area (cm)
1	Random planting in groups of 10	100	1111	30 × 30
2	Plants randomly planted in pairs in 10 lines of 4.	80	266	100 × 30
3	Mimic the edge of a meadow. Randomly placed in half of the flume laterally	80	266	100 × 30
4	Singly planted randomly	18	200	30 × 30
5	Singly planted randomly in 10 lines of 6	60	200	100 × 30
6	Single seagrass plants over a length of 23 cm planted randomly	18	200	30 × 30
7	Single seagrass plants under 23 cm in length planted randomly	33	366	30 × 30
8	Single seagrass plants under 23 cm in length planted randomly	18	200	30 × 30
9	Single plants planted in 10 rows of 6, in a grid formation	60	200	100 × 30
10	Single plants planted in 10 rows of 6, in a grid formation	60	200	100 × 30
11	Singly planted randomly in 10 lines of 6	60	200	100 × 30

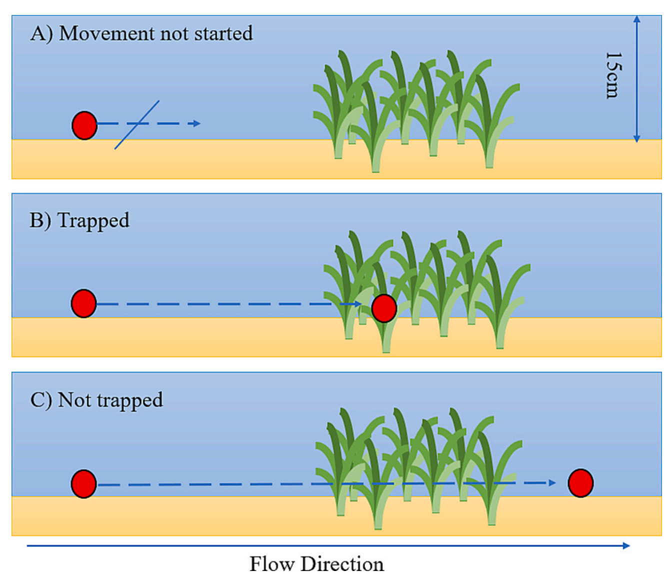

Fig. 3. Diagram (not to scale) detailing three behavioural categories of MP particles defined for the MP trapping simulation trials. A) movement not started (when the flow velocity was not high enough to initiate movement of the MP particle), B) trapped (when the MP particles was observed to be trapped by the seagrass shoots or sediment in the test section for more than 2 minutes after the initial movement), C) not trapped (when the MP particle moved through the test section after the initial movement had started).

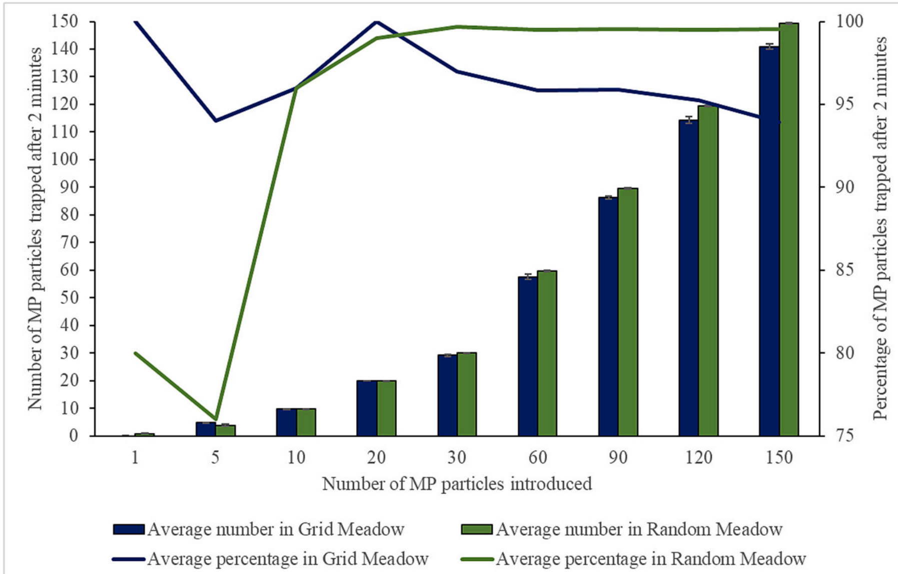

Fig. 4. Mean number and percentage of MP particles trapped and retained by the grid and random formation seagrass meadows after 2 minutes. Error bars represent standard error. Error bars were not inlcuded for percentage data as their size would have compromised clarity and interpretability.

2. Methods and materials

2.1. Microplastic particles and plant material

Microplastic particles were obtained by cutting sections of a coil of polylactic acid (PLA), with a thickness of 2.5 mm. This was chosen due to its density (1.25 g/cm^3) and its environmental significance as an MP in the environment (Ainali et al., 2022; Barrasa et al., 2021). The maximum length (mm) of each individual plastic piece was determined using a digital calliper (±0.4 mm). The average length was 3.38 mm ± 0.03 mm. They were weighed in a precision balance (± 0.01 mg) with the average weight being 0.42 g ± 0.004 g. These parameters give a settling speed of around 14 cm/s from Eq. (13) in Francalanci et al. (2021), using a seawater density of 1.025 g/cm^3.

Eelgrass (*Zostera marina*) shoots were collected from the SSSI Porthdinllaen National Trust site, North Wales (Fig. 1), during a spring tide in May 2023. Permission to harvest seagrass shoots was obtained before collection from the National Trust. The shoots were transported directly back to Bangor University, where they were kept in outdoor tanks with flowthrough sea water (34.12 PSU, 14.32 °C) from the Menai Strait, North Wales. The *Z. marina* plants had an average shoot length of 23 mm ± 1.1 mm, shoot width of 0.3 mm ± 0.005 mm and average shoot total area of 13.61 mm^2 ± 0.8 mm^2 (shoot length and width refer to the maximum length and width of the individual leaves within a shoot; data is given as mean ± standard error, $n = 80$).

2.2. Hydraulic flume set-up and trapping simulation trails

Microplastic retention in *Z. marina* canopies was simulated using a hydraulic flume, located in the School of Ocean Sciences, Bangor University. The flume is 8 m long, 0.3 m wide and 0.5 m deep. Two 4 cm ramps were placed in the flume to create a test area for sediment to be placed and stored at a 5 cm depth; this is where the seagrass was planted (Fig. 2). White sand was used to allow for easier detection of microplastics and to establish standardised experimental conditions throughout the trails.

The water level was maintained at 15 cm with seawater from the Menai Strait, using the same source as the storage tanks, to simulate a high velocity flow of 15.6 cm/s for all simulations. In concurrence with Meysick et al. (2019), the velocity and flow of the water through the flume was deemed a more important factor than the total water depth as this study focussed on transport and sedimentation of microplastics.

The flow velocity was measured with an acoustic Doppler velocimeter (Nortek, Vectrino) at a sampling rate of 30 Hz. The horizontal flow velocity was used for characterizing the flow conditions in the flume and was measured at 5 cm above sediment surface and at 3 different points (0 m, 1 m and 2 m along the test section). This was repeated 3 times for each simulation and the average was taken. Flow was initialised for 2 min before the start of each trial to establish laminar flow conditions in the flume outside of the test section.

To initially assess the capacity of differing seagrass meadows to trap microplastics, 9 treatments were investigated (Table 1). This was carried out by manipulating the configuration of seagrass shoots within the test section, as well as manipulating the density of plants and length of artificial meadow planted (Test area, Fig. 2). The MP retention capacity of the different canopies was determined under five different total particles of plastic (1, 5, 10, 20 and 30 particles). Each test was run 5 times, accounting for 225 trials in total.

The most efficient canopies at trapping and retaining 30 MP particles were then tested a further 5 times to ensure robustness of the data, accounting for another 50 trials. These canopies were then tested under an overloading treatment, adding 150 MP particles to the canopies in increments of 30. Each simulation was run 10 times, accounting for 100 trials in total. A total of 375 simulated trials were carried out to obtain our dataset. The coordinate locations for the seagrass plants in the random meadow configurations were generated using an online random number generator.

Each artificial meadow was created by individually hand planting the seagrass plants, to ensure firm placement in the sediment. Before each setup, the surface of the sediment was smoothened to standardize initial sediment conditions experienced by the microplastic in the flume. It was then allowed to be naturally modified by the unidirectional flow of water and turbulence created by the seagrass.

To account for shoot morphology (linked to life history and adaptation to environmental conditions), we used a varying selection of shoots. These were randomly selected unless the treatment required a specific length of shoots. Due to bending of shoots with water movement, the seagrass canopy was constantly below the surface of the water during the experimental test runs. This was true even for shoots with a length that exceeded the water depth (15 cm).

After the flow was initialised, the microplastic particles were simultaneously released by hand 15 cm upstream from the start of the

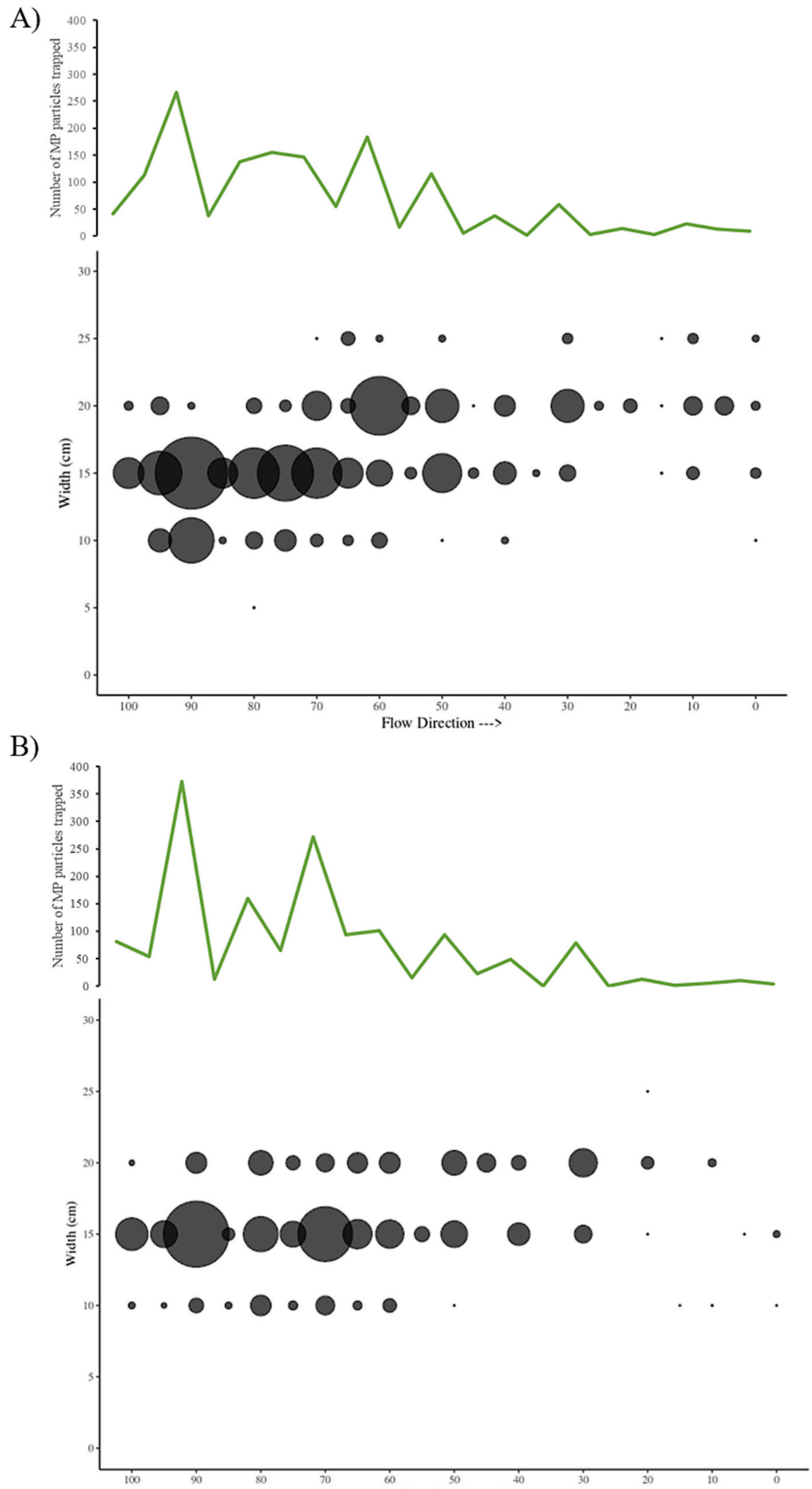

Fig. 5. Distribution of average number of trapped MP particles (150 pieces) within the random distribution of seagrass plants and the grid formation seagrass canopy. Test area set at 100 x 30 cm. The larger the bubble, the greater the volume of MP particles captured at that coordinate in the hydraulic flume test area. A) Seagrass planted in 10 rows of 6 (grid formation), B) seagrass planted randomly.

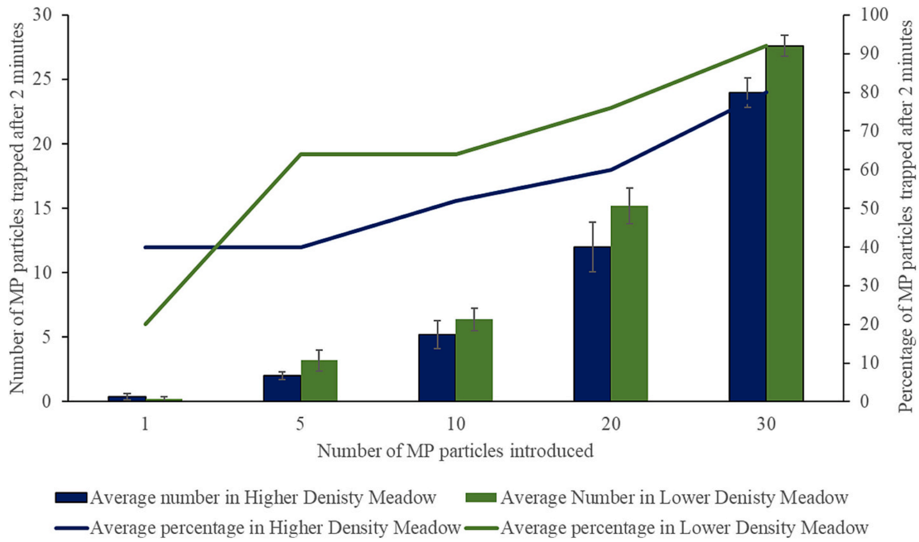

Fig. 6. Mean number and percentage of MP particles trapped and retained by the dense (366 plants per m^2) and less dense (200 plants per m^2) seagrass meadows after 2 minutes. Error bars represent standard error. Error bars were not included for percentage data as their size wouldhave compromised clarity and interpretability.

test section at a depth of 0 cm. Each simulation was run for 2 min and subsequently the number of microplastic particles trapped within the test section were counted by visual inspection and the trapping location of each particle was recorded.

If the microplastic particle moved, it was allowed to pass through the section being tested, or until it got trapped in the meadow or substrate for at least 2 min. The 2-min condition for the classification of the trapping was based on preliminary trials in which we observed that this period did not normally imply a resuspension of the MP particles. If the particle was classified as trapped in the test section, the distance from the start of the test section that the particle was trapped was measured using a metric tape measure and rounded to the nearest 5 cm. In concurrence with the recording of MP trapping by de los Santos et al. (2021), the data was recorded in two ways. The location was recorded on a 100–0 linear scale based on the distance at which it was trapped, with a value of 100 being trapped at the beginning of the section and 0 being trapped at the very end of the test section. The location was also recorded as a categorical variable with three different categories; trapped, not trapped and movement not started (Fig. 3).

2.3. Data analysis

All analyses were conducted in RStudio (version 4.3). Data was assessed for normality using Shapiro Wilks tests. Homogeneity of variance was evaluated using Levene's tests. Any outliers were identified using a Grubbs test.

To assess the difference in MP trapped at each volume of plastic for each meadow comparison, *t*-tests were carried out on data sets with a normal distribution and Wilcoxon Signed-rank tests were carried out data with a non-normal distribution.

To assess the spatial similarity between the capturing points of the compared meadow formations, Bray Curtis analyses and PERMANOVAs were conducted.

3. Results

3.1. Comparing random and grid meadow planting techniques for MP capture

Seagrass meadows with a random spatial arrangement of plants exhibit higher MP capture efficiency than those with a grid-like formation, particularly under conditions of high MP load.

When 150 pieces of MP were introduced into the grid and randomly planted meadows, the random meadow had a higher trapping efficiency, capturing and storing an average of 149.3 ± 0.3 MP particles for 2 min. The grid planted meadow stored an average of 140.9 ± 3.1 MP particles within the meadow after 2 min (Fig. 4). We found that there was a significant difference between the number of particles trapped ($W = 18.5$, $p = 0.016$).

The higher the number of MP particles introduced into the random meadow, the higher the trapping efficiency of the meadow up to 60 pieces of plastic (Fig. 4). After this point there was a plateau in trapping efficiency at approximately 100 % efficiency. To contrast this, in the grid formation meadow, as a higher number of MP particles were introduced into the meadow, there was a decline in the efficiency of trapping. A trend was observed where, as the volume of MP introduced into the meadows increased, the difference in trapping efficiency between the two meadows became increasingly significant (Fig. 4).

When a total of 30 MP particles were introduced into the grid and randomly planted meadows, the random meadow had a higher trapping efficiency, capturing an average of 29.6 ± 0.2 MP particles for 2 min. The grid planted meadow trapped an average of 29.2 ± 0.5 MP particles within the meadow after 2 min (Fig. 4). It was found that there was no significant difference found between the number of particles trapped in the two meadows ($W = 52.5$, $p = 0.85$).

All MP pieces successfully initiated movement, and no data points were excluded from the analysis due to missing values.

A greater volume of MP particles was trapped earlier in the random meadow compared to the grid formation meadow (Fig. 5). The trapping locations of the MP particles in these two meadows was found to have a Bray-Curtis dissimilarity value of 0.33, indicating that 33 % of the trapping locations were dissimilar, highlighting a significant moderate level of dissimilarity, which was found to be statistically significant ($F_2 = 7.37$, $p = 0.001$). It can also be observed that the trapping locations of the MP particles were more centralised within the random meadow compared to the grid meadow.

3.1.1. Evaluating seagrass density and length for its efficiency in microplastic trapping

Lower-density seagrass meadows demonstrate greater efficiency in trapping MP particles, highlighting the influence of plant density on retention capacity.

When a total of 30 MP particles were introduced into the meadows with different plant densities (366 and 200 plants per m^2), the less dense

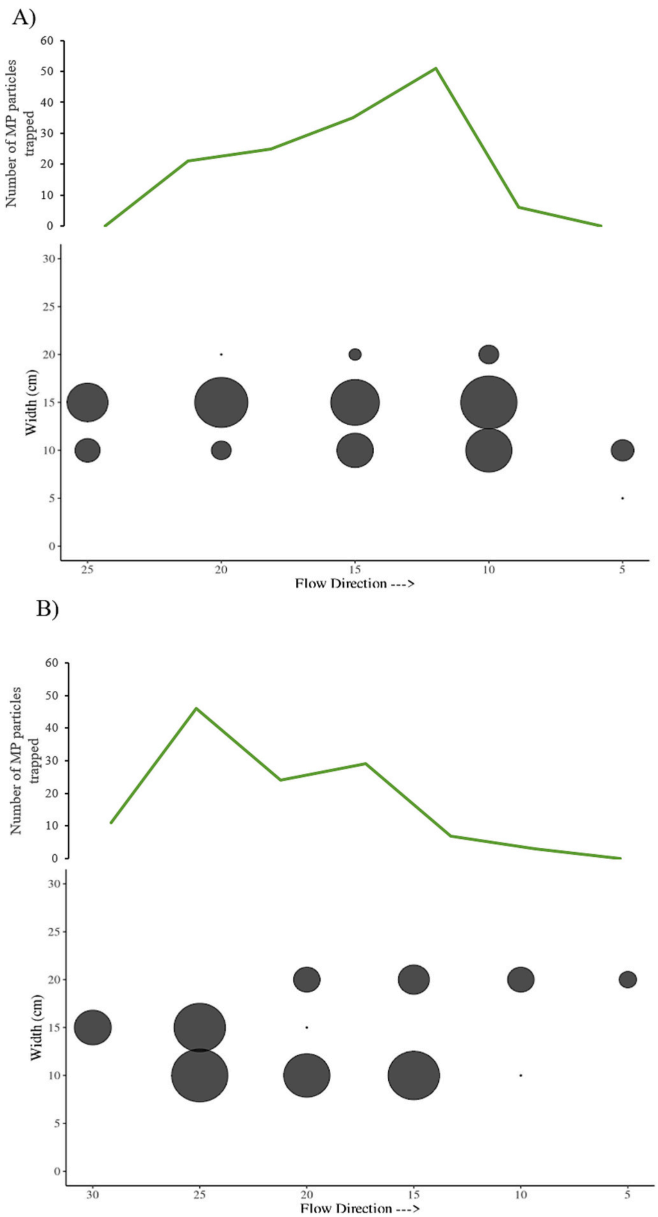

Fig. 7. Distribution of average number of trapped MP particles (30 pieces) at each coordinate within the flume traials testing for efficiency of density of seagrass meadows. Test area set at 30 x 30 cm. The larger the bubble, the greater the volume of MP particles captured at that coordinate in the hydraulic flume test area. A) Lower density of seagrass plants (200 plants per m^2), B) Higher density of seagrass plants (366 plants per m^2).

meadow was more efficient at trapping MP particles, trapping an average of 27.6 particles (Fig. 6). The denser meadow trapped an average of 24 particles. It was found that the difference in the trapping efficiency was found to be significant ($t(8) = -2.57$, $p = 0.033$).

There is little difference in the trapping locations of MP particles between the two meadows (Fig. 7). The trapping locations of the MP particles in these two meadows were found to have 21 % dissimilarity (Bray Curtis, $F_2 = 12.27$, $p = 0.001$). It can also be observed that the trapping locations of the MP particles were more centralised within the lower density meadow (200 seagrass plants per m^2) compared to the higher density meadow (366 seagrass plants per m^2).

Shorter seagrass meadows enhance MP trapping, suggesting that canopy height plays a key role in determining the effectiveness of MP capture in seagrass ecosystems.

When a total of 30 MP particles were introduced into the meadows comprised of long or short seagrass plants, the shorter meadow had a higher capture efficiency, capturing an average of 27.6 ± 0.8 MP particles for 2 min. The long grass meadow captured an average of 23.4 ± 1.6 MP particles after 2 min (Fig. 8). No significance was found between the efficiency of MP capture between these two meadows ($t(8) = -2.31$, $p = 0.0501$).

There is little difference in the trapping locations of MP particles between the two meadows (Fig. 9). The trapping locations of the MP particles in these two meadows was found to have 22 % dissimilarity (Bray Curtis, $F_2 = 12.27$, $p = 0.001$).

All MP pieces successfully initiated movement, and no data points were excluded from the analysis due to missing values.

4. Discussion

Our results indicate that a seagrass meadow with randomly distributed plants is more effective in trapping MP particles at higher levels of MP exposure compared to a meadow with a grid-like plant arrangement. The random spatial distribution of seagrass in this study may have increased the irregularity and complexity of water flow patterns, potentially simulating habitat fragmentation and amplifying the edge effects commonly associated with patchy seagrass meadows. At the transitional zones between seagrass patches and open water, flow structures were disrupted, resulting in turbulence and the formation of eddies (González-Ortiz et al., 2014; Lara et al., 2012). The shift from faster-moving water outside the patches to slower, more sheltered conditions within the patches led to increased flow complexity, driven by the spatial heterogeneity of seagrass distribution observed in this experiment.

This irregular spacing of seagrass patches is likely to have further disrupted water currents, generating localised turbulence and small-scale eddies around individual plants, as is also observed by González-Ortiz et al. (2014) and Peterson et al. (2004). As a result, the overall kinetic energy of the water likely reduced (Peterson et al., 2004), which enhanced the retention of MP particles by limiting their resuspension and preventing their transport out of the system.

From a flume study, Weitzman et al. (2015) suggested that density might be the most important factor for influence over wave attenuation by seagrass canopies. To build on the work of de los Santos et al. (2021), we investigated the effect of seagrass meadow density on the efficiency of MP particle trapping. We examined meadows with densities of 200 and 366 plants per m^2 and found that the lower-density meadow was significantly more effective in capturing MP particles under high exposure conditions. This finding aligns with de los Santos et al. (2021), who reported that a density of 200 shoots m^{-2} was optimal for MP capture. As well as González-Ortiz et al. (2014), who found lower density patches of seagrass meadow to provide greater protection from hydrodynamic forces, this would therefore cause attenuation of flow velocity and allow for settling of MP particles.

The enhanced trapping efficiency observed in lower-density meadows can be attributed to hydrodynamic behaviour, where horizontal water flow is redirected around individual seagrass blades, as described by Bouma et al. (2009). This flow diversion results in sediment scouring around individual shoots, creating sheltered pockets at the base of the plants that are protected from the flow velocity. These areas, characterised by reduced hydrodynamic energy (Fonseca et al., 1982; Risandi et al., 2023), provide favourable conditions for the deposition and retention of MP particles.

The more open canopy structure of lower-density meadows permits greater water flow through the meadow, which facilitates the transport and eventual trapping of MP particles within the scouring zones at the base of the seagrass shoots (González-Ortiz et al., 2014; Navarrete-Fernández et al., 2022). These findings suggest that seagrass density plays a critical role in determining the efficiency of MP retention, with lower-density meadows offering a hydrodynamically favourable environment for particle entrapment.

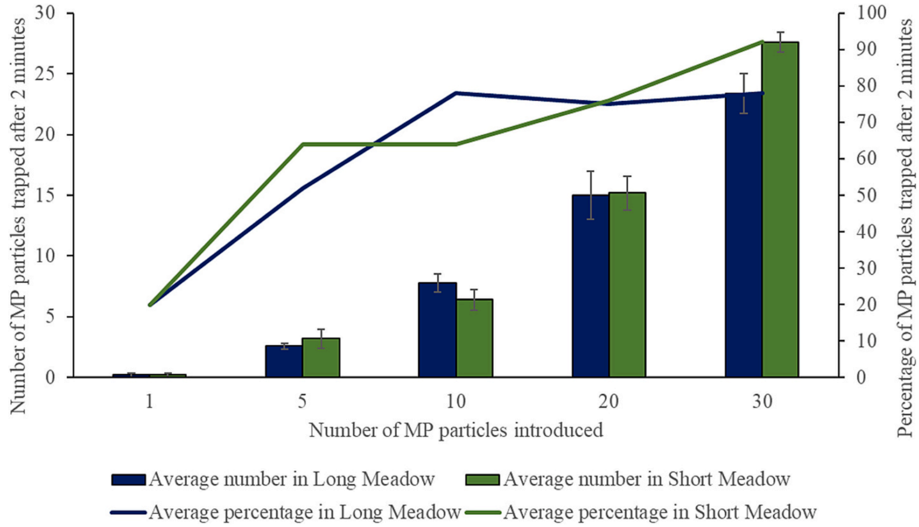

Fig. 8. Mean number and percentage of MP particles trapped and retained by the long seagrass plants and short segrass plants meadows after 2 minutes. Error bars represent standard error. Error bars were not inlcuded for percentage data as their size would have compromised clarity and interpretability.

Additionally, the phenomenon in fluid dynamics known as the 'wall effect' may be applied here (Cummins et al., 2018). In dense seagrass meadows, the boundary layers of individual plants merge, forming a larger boundary layer. This reduces the flow's cross-sectional area, increasing velocity and causing more sediment erosion. The smaller stagnation zones behind individual plants result in fewer areas for MP particles to become trapped. In contrast, in less dense meadows, the boundary layers are less converged, so flow velocity remains lower, creating larger stagnation zones where MP particles are more likely to be trapped due to reduced kinetic energy.

These findings underscore the critical role that the spatial arrangement and density of seagrass plays in shaping the hydrodynamic environment and, by extension, its influence on the efficiency of particle retention within aquatic ecosystems.

We show that meadows with shorter seagrass plants are more efficient at trapping MP particles, when exposed to higher volumes of pollution. The shorter plants create a denser canopy closer to the sediment surface. Seagrass blades are readily bent by flow velocity, which lowers the distal portion of the shoots, which has the greatest percentage of the shoots surface area. These are lowered into the lower zones of the water column where baffling by neighbouring shoots and other protuberances causes a decrease in the current velocity (Peterson et al., 2004). The dense MP particles become trapped in these areas of low velocity as they are dragged along the sediment of the meadow. This near-bottom vegetation effectively slows down the water flow at the sediment-water interface (Christianen et al., 2013; Risandi et al., 2023), hereby reducing the capacity of the water to carry the MP particles. As a result, the MP particles are more likely to settle within the seagrass meadow becoming trapped.

The meadow with taller plants, extended higher into the water column, this would lead to a stronger flow velocity near the sediment surface, as when the seagrass blades are bent over, they intermesh to form a dense layer that redirects the water flow over and under the layer. The water can move more freely beneath the taller canopy (Fonseca et al., 1982; Risandi et al., 2023), decreasing the efficiency of the canopy to trap MP particles. This can be partly explained by the 'wall effect.' The longer seagrass blades act like a solid surface, creating an 'umbrella' effect. This causes the boundary layers to converge, reducing water flow over the blades while increasing flow underneath them.

As the MP particles used in this experimental study were dense particles (0.125 g mm^{-3}), they sank and were dragged along the sediment by the flow velocity before being trapped within the meadow or not. As shown in Fig. 3, it is likely that these particles were trapped in the areas around the seagrass shoots that were subjected to scouring, caused by the near-bed kinetic energy of the current flow. As the flume used in this study had a high flow velocity (up to 15.6 cm/s) to cause the MP particles to move through the meadow, it is likely that this led to scouring around the base of the seagrass plants.

In this study, we focused on a single type of microplastic (polylactic acid) and one seagrass species (*Zostera marina*). However, a wide variety of microplastics exist in the environment (Hale et al., 2020) and approximately 70 seagrass species found globally (Daru and Rock, 2023; Mtwana Nordlund et al., 2016). Different microplastic types may interact with various seagrass species in diverse and potentially complex ways. We suggest the need for further research to explore the interactions between different microplastic types and seagrass species, which could provide a more comprehensive understanding of these dynamics.

To advance future research and determine the most effective seagrass planting methods for microplastic capture, it is crucial to examine the combined effects of planting regimes, seagrass density, and plant length. Gaining a deeper understanding of how these factors interact could offer valuable insights for optimising seagrass restoration efforts and enhancing the efficiency of microplastic capture in these ecosystems.

When extrapolated to the natural environment it cannot yet be concluded whether the capturing of MPs by seagrass meadows can be categorised as a true Nature-based Solution (NbS) to anthropogenic pollution as MPs can directly affect seagrasses and the wider habitat. This is done through blocking light, affecting the turnover of leaves and shoots, degenerating the root structure, and causing oxidative stress (Li et al., 2023; Tang, 2024). Once the MP particles trapped within the seagrass meadows, they can then be incorporated into the marine sediments by processes of sedimentation (De Boer, 2007; Unsworth et al., 2021). The MP particles can then influence microbial communities, leading to negative changes in biogeochemical cycling of nutrients, as well as increasing the concentration of pollutants, such as heavy metals (Seeley et al., 2020; Tang, 2024).

In addition to the impacts on the prokaryotic biome, MPs can become incorporated into the epiphytic communities, comprised of cyanobacteria, diatoms, and other algae, adhering to the blades of the seagrass. Despite there being no peer reviewed publications exploring the impacts of this accumulation directly, from research shown in previous study by our group and other publications (Gerstenbacher et al., 2022; Li et al., 2023; Molin et al., 2023; Tang, 2024), it can be assumed that there will be negative consequences to this aggregation, such as a decline in

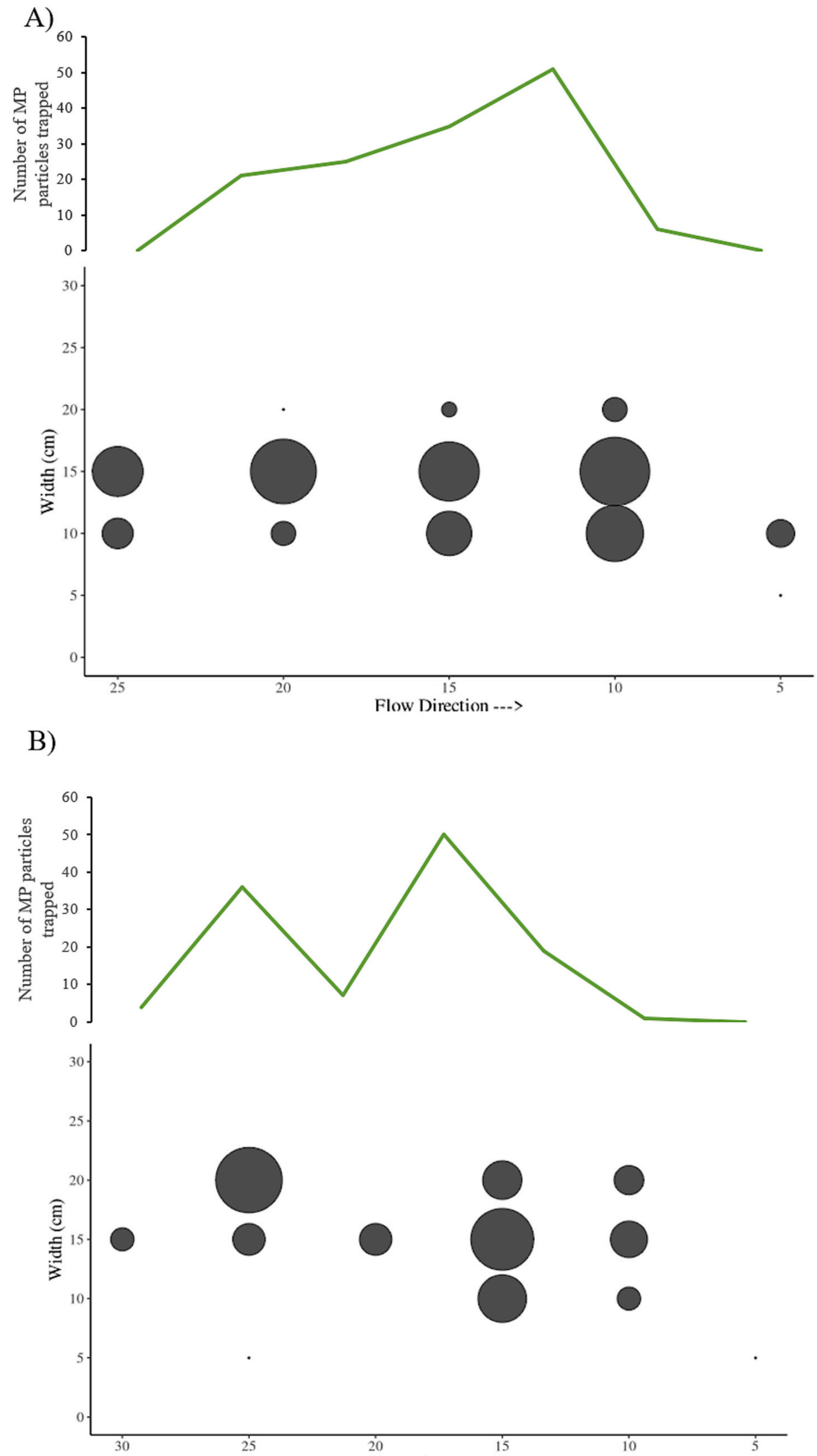

Fig. 9. Distribution of average number of Mp particles (30 pieces) at each coordinate within the flume trials testing for the efficiency of length of seagrass. Test area set at 30 x 30 cm. The larger the bubble, the greater the volume of MP particles captured at that coordinate in the hydraulic flume test area. A) Long seagrass plants (over 23 cm), B) Short seagrass plants (under 23 cm)

phytoplankton abundance and biodiversity (Besseling et al., 2014; Long et al., 2017; Sjollema et al., 2016), increased toxins in the environment (Elizalde-Velázquez and Gómez-Oliván, 2021) and a change to the biogeochemical cycling of elements (Ma et al., 2020).

Therefore, further research into the wider implications of MP trapping in seagrass meadows is needed to determine whether the trapping of MP particles can be classed as a NbS to anthropogenic pollution and an ecosystem service provided by these coastal wetland habitats.

The novel nature of this study means that there are few previous studies directly relevant to our work. This underscores the significance of our research and highlights the need for further investigations into the interactions between seagrass meadows and microplastics.

5. Conclusions

We investigated the efficiency of MP capture by shallow subtidal canopies under experimental conditions, using eelgrass (*Z. marina*). The efficiency of MP capture was overall higher in the meadow in which the seagrass plants were randomly planted, in the meadow with shorter seagrass plants and in the meadow that was less densely planted. Our findings further the body of research dedicated to understanding the patterns of MP accumulation in shallow subtidal ecosystems and aid in the research regarding NbS to anthropogenic pollution and climate change.

Our study demonstrates that seagrass meadows with a random spatial arrangement capture a greater volume of MP particles compared to those arranged in a grid-like pattern, though the spatial distribution of trapped MPs showed only moderate variability. This suggests the need for further investigation into the impact of different random planting configurations on MP trapping efficiency. To support conservation and restoration that enhance MP capture in seagrass meadows, we recommend adopting a planting strategy with lower density (around 200 plants per m^2) in a random arrangement. This approach would not only increase MP capture, reducing their presence in the water column and their potential interaction with higher trophic levels, but may also foster beneficial interactions with epiphytic communities, offering additional ecological advantages.

Alternatively, if the intention is to minimise MP accumulation within seagrass meadows and underlying sediments, a denser, grid-like planting configuration should be considered. This arrangement would reduce the meadow's effectiveness as an MP sink, potentially mitigating the impact of MPs on sediment environments. Further research is necessary to explore the long-term ecological implications of MP trapping in seagrass ecosystems and to assess whether this mechanism can be effectively integrated as an NbS for mitigating anthropogenic pollution in coastal areas.

CRediT authorship contribution statement

Abigail Cousins: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christian Dunn:** Writing – review & editing, Supervision, Conceptualization. **Dan Aberg:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Abigail J. Smyth:** Investigation. **Max Williams:** Investigation. **J.A. Mattias Green:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Martyn Kurr:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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