UPSCALING SEAGRASS RESTORATION WITH INSIGHTS FROM SEED-SEDIMENT DYNAMICS

Seagrass restoration is increasingly recognised for its potential to enhance biodiversity and contribute to carbon sequestration. However, planting methods are largely based on manual techniques, posing challenges for upscaling and implementation as nature-based solutions (NbS) within the dredging industry. To address this, techniques to combine sediment nourishments with seed-based seagrass restoration are explored. Seed settlement behaviour is investigated via laboratory experiments, analysing seed settling velocities and distribution in various sediment concentrations, revealing the importance of grain size and sediment dynamics. These findings lay the groundwork for innovative, large-scale restoration techniques leveraging traditional dredging methods, with pilot projects planned for 2025.

Seagrass restoration

Seagrasses are marine flowering plants that contribute significantly to coastal ecosystems by sequestering carbon in their rhizome root systems, stabilising sediments and providing critical habitat for marine biodiversity (Duarte and Krause-Jensen, 2017; Hansen and Reidenbach, 2012; Infantes et al., 2022; Mtwana Nordlund et al., 2016) These plants thrive in shallow coastal waters across various climates, from temperate to tropical regions. Among the many species, *Zostera marina*, is a species known to produce large amounts of seeds that can be harvested easily (Kilminster et al., 2015; Marion and Orth, 2008). It is prevalent in the Northern Hemisphere and serves as the focus of this research on scalable restoration methods (Short et al., 2007).

Over recent decades, seagrass habitats have experienced substantial declines (Waycott et al., 2009). This degradation disrupts the positive feedback loop that seagrass ecosystems depend on for their survival (van der Heide et al., 2011). Seagrasses stabilise sediments with their root systems, reducing turbidity and resuspension while creating clearer waters that foster further growth. When this loop is disturbed, previously

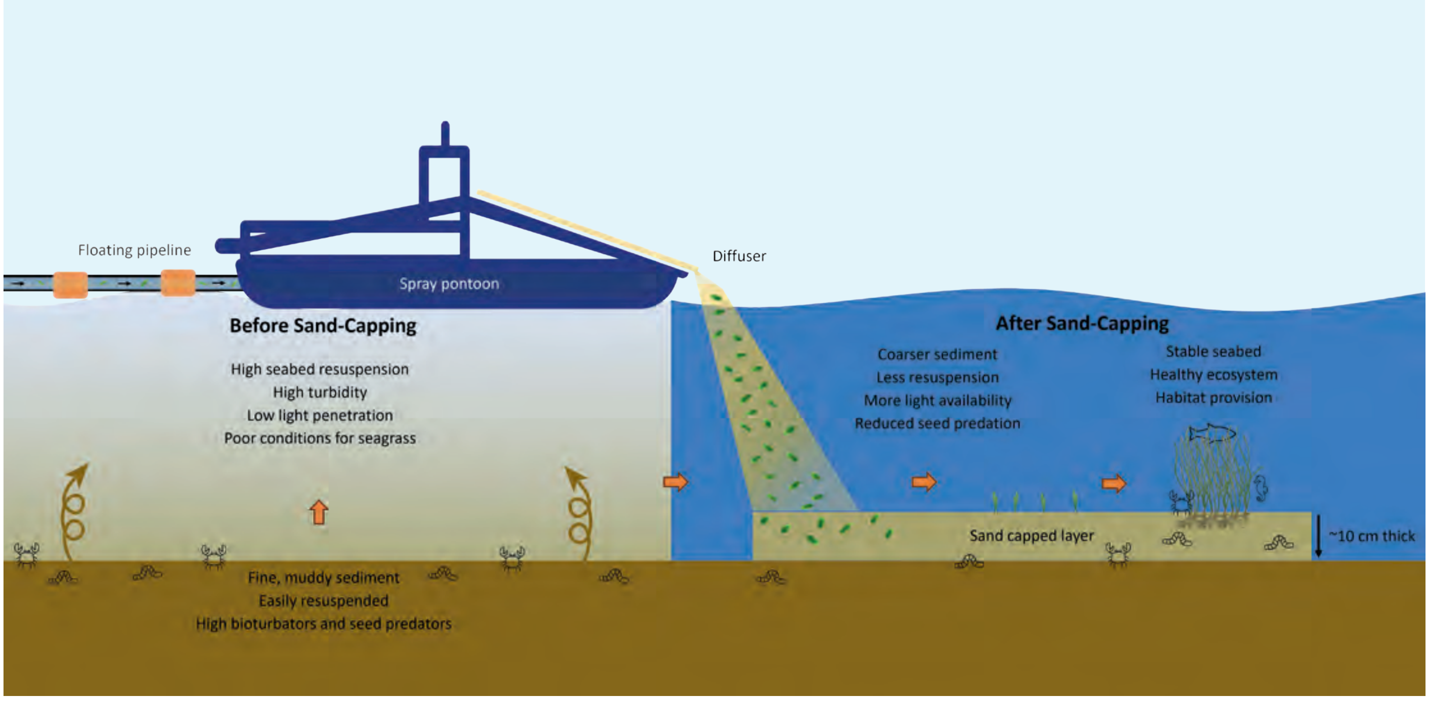


FIGURE 1

Visualisation of the effects of sand-capping technique.

thriving seagrass areas become unsuitable for natural regeneration. To address this, restoration strategies should focus on restoring the physical and ecological conditions that enable seagrasses to regenerate and sustain themselves.

Sand-capping technique

Sand-capping, a method of placing a thin-layer of coarser sand on top of the existing bed, has emerged as a promising technique to enhance seagrass restoration by reducing sediment resuspension and improving light conditions. Flindt et al. (2022) conducted laboratory experiments demonstrating that a 10 cm layer of sand can significantly reduce resuspension compared to uncapped beds and improve conditions for seagrass growth. This method also increases erosion thresholds, enhancing the anchoring capacity for root vegetation. Oncken et al. (2022) extended this research with large-scale field tests in Denmark, applying a 10 cm sand cap in two locations. The decades of eutrophication had led to impoverished benthic fauna and organic-rich muddy sediments quickly resuspended. The sand-cap stabilised the mud without mixing the sand-mud interface after one year. The associated lower resuspension of fine particle improved light conditions in the overlying water. These findings highlight the potential benefits of thin-layer capping in environments where seagrass meadows previously existed but cannot naturally regrow due to current turbidity conditions and resuspension.

Despite advancements in manual restoration methods such as hand broadcasting seeds in large-scale projects like those in Chesapeake Bay, these techniques remain highly labour-intensive and limited by low seed germination rates, typically below 4%. Alternative methods, including Bags of Seagrass Seeds (BoSS)-line, Buoy Deployed Seeding (BuDS), and Dispenser Injection Seeding (DIS), have improved germination rates to as high as 11.4% (Govers et al., 2022; Gräfnings et al., 2023; Unsworth et al., 2019), but still depend heavily on manual effort. Similarly, shoot-based transplantation, which can achieve survival rates of 30-40% (Bayraktarov et al., 2016; van Katwijk et al., 2016), usually requires divers to manually plant shoots and seedlings on the seabed. A process that is both time-consuming, resource intensive and undesirable due to safety standards.

Challenges of seed-based seagrass restoration

A major challenge lies in the current unavailability of large-scale seed cultivation in nurseries. Wild seagrass beds remain the primary source of seeds, necessitating careful collection practices to ensure the health and sustainability of donor beds. Harvesting seeds from wild beds is labour-intensive, has legal restrictions and the limited availability of healthy donor sites further constrains restoration efforts. To address this, various initiatives are exploring innovative solutions, such as mechanical seed harvesting and the establishment of seed nurseries, which could provide a more sustainable supply in the future. The scarcity of seeds underscores the critical importance of maximising seed protection and germination rates when developing new restoration techniques.

A recent study explored the synergistic effects of combining shoot-based restoration with sand-capping. Infantes (2021) conducted a field study capping a one-hectare area at 1.3-1.9 m depth to test its potential to reduce resuspension and promote eelgrass growth. Using an excavator with high-precision global positioning system (GPS), a sand cap with an average thickness of 9.3±1.3 cm was placed on site. The following summer, divers successfully planted 80,000 eelgrass shoots on top of the sand-capped area. Observations indicated that the 80,000 planted shoots grew to approximately 860,000 shoots within one year.

Additional research has highlighted the potential benefits of covering seeds with a thin sand layer to improve germination rates. Infantes et al. (2016) found that seedling establishment rates increased by 2 to 6 times when seeds were covered with a 2 cm layer of sand, likely due to reduced predation and erosion as well as improved light availability. However, the burial depth of seeds remains critical, as studies have shown that germination success decreases significantly at depths beyond 5.5 cm (Greve et al., 2005; Jarvis and Moore, 2015). Optimal burial depths for seed establishment range from 2-4 cm, as noted in studies by Granger (2000), Jørgensen et al. (2019) and Marion and Orth (2010).

Combining insights from these studies, future restoration efforts should aim to optimise seed placement within the ideal depth range of 1-5.5 cm. By leveraging the dredging industry's expertise in hydraulic placement and sediment management, this integrated technique has the potential to enhance the scalability and success of seagrass restoration, ultimately contributing to the recovery and resilience of these vital marine ecosystems.

Settling behaviour of particles

In fluid dynamics, the settling velocity of particles is influenced by several factors, including grain size, shape, specific density and the properties of the surrounding fluid. For discrete particles of constant size, shape and weight, settling under gravity occurs until the drag force counterbalances the gravitational force, achieving a terminal settling velocity. In laminar flow conditions, characterised by a particle Reynolds number below 1, this velocity can be determined using Stokes' equation. Beyond this regime for higher velocities, empirical formulas, such as those proposed by Budryk (1936) and Ferguson and Church (2004), offer more accurate predictions, especially for irregularly shaped particles such as sand grains that deviate from perfect spheres.

While some research exists on the settling behaviour of high-density particles such as stones (e.g. Dietrich, 1982; Francalanci et al., 2021; Komar and Reimers, 1978), limited studies have explored the dynamics of ellipsoidal particles. This knowledge gap necessitated practical experiments to verify the settling behaviour of seagrass seeds, which differ significantly from the particles typically studied with a larger size, lower density and more natural variation.

In mixtures containing multiple particles, additional phenomena, such as hindered settling and density currents, influence particle behaviour. Stokes' formula for terminal settling applies to individual particles in stagnant fluid; however, in practice, particles interact dynamically. For a particle to descend, fluid upstream must move downward, creating space, which generates a small upward force affecting nearby particles. At higher concentrations, particles within close proximity (less than one particle diameter apart) enter each other's sphere of influence, leading to hindered settling. Consequently, when particle concentration surpasses a threshold, the mixture's settling velocity diminishes compared to the terminal velocity of individual particles.

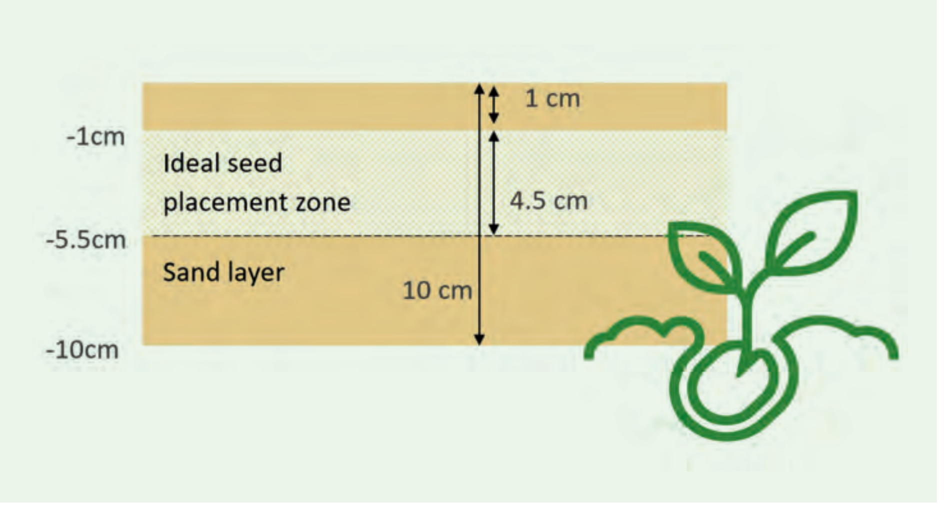


FIGURE 2

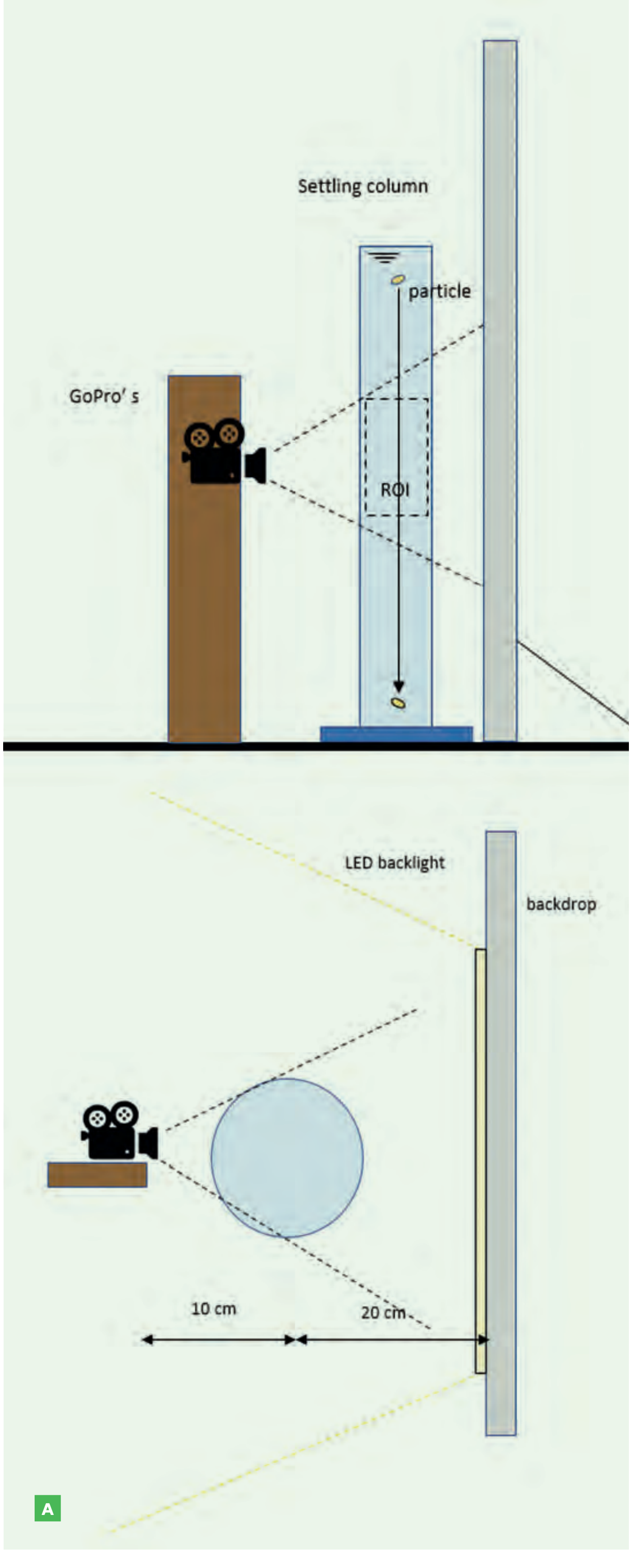
Diagram of ideal sediment cap with seagrass seeds.

A major challenge lies in the current unavailability of large-scale seed cultivation in nurseries.

From settling column experiments, Richardson and Zaki (1954) found a retardation factor applicable to Stokes settling equation for single-sized particle systems. In mixtures with varying particle types, such as seagrass seeds and sand grains, further adaptations are required. A common approach incorporates the volume fraction or concentration of each particle type to account for differences in density and size. In non-cohesive particle mixtures, settling velocities at low concentrations align with the terminal settling velocities of individual fractions. However, as volumetric concentration increases, hindered settling effects intensify, reducing the settling velocities of both fractions. The degree of reduction varies based on particle size, density and mixture concentration. Based on the formula from Mizra and Richardson (1979), larger particles such as seeds generate return currents that disproportionately affect the settling of smaller particles such as sands. The relative decrease in settling velocity of sand is expected to be higher than for seeds due to the return current of the larger particles influencing the finer particles more.

At sufficiently high densities, sediment mixtures may form a density current. Upon introduction into the water column, the mixture behaves as a denser collective body, settling as a unit before dispersing into individual particles. Additional factors, such as turbulent mixing introduce further complexity, which is challenging to quantify empirically with limited data.

To address these knowledge gaps, initial laboratory experiments investigated the settling behaviour of seagrass seeds by



tracking their trajectories under controlled conditions. These experiments provide critical insights into the hydrodynamic interactions between seeds and sediment, laying the groundwork for optimising large-scale restoration techniques.

Experiments

Terminal settling velocity

The first experiment was set up to find the terminal settling velocity of the seeds and their variation based on size by releasing the particles into a graduated cylinder filled with saline water up to the 400 mm mark, maintaining a salinity of 32 parts per thousand (ppt) to prevent seed germination. A disk with a central gap was used to drop particles from the column's centre and then released by hand at the water surface. A LED screen provided an evenly distributed light source, enhancing the visibility of particle trajectories that was captured with a GoPro camera and later analysed.

Each seed was weighed and measured along three axes to investigate potential correlations with shape, size and density. Large natural variations in seed size and density were observed both within and between populations from Varna (Bulgaria), Voerså (Denmark) and Hamburger-Hallig (Germany). While no clear correlation between shape, density or settling velocity was established, these variations align with patterns reported in the literature. However, the accuracy of density measurements of individual seeds was limited by the precision of the scale, adding some uncertainty to the results.

The analysis of settling behaviour required not only determining terminal velocities but also tracking seed trajectories to assess horizontal movement and settling dynamics. A multi-step video analysis process was employed, including cropping, grayscale conversion and distortion correction. The trackpy package (Kim et al., 2018) was used to identify and follow individual seed trajectories, enabling precise calculations of average velocities. *Zostera marina*

FIGURE 3

Schematic overview of setup for particle tracking (A) and photo of actual setup (B).

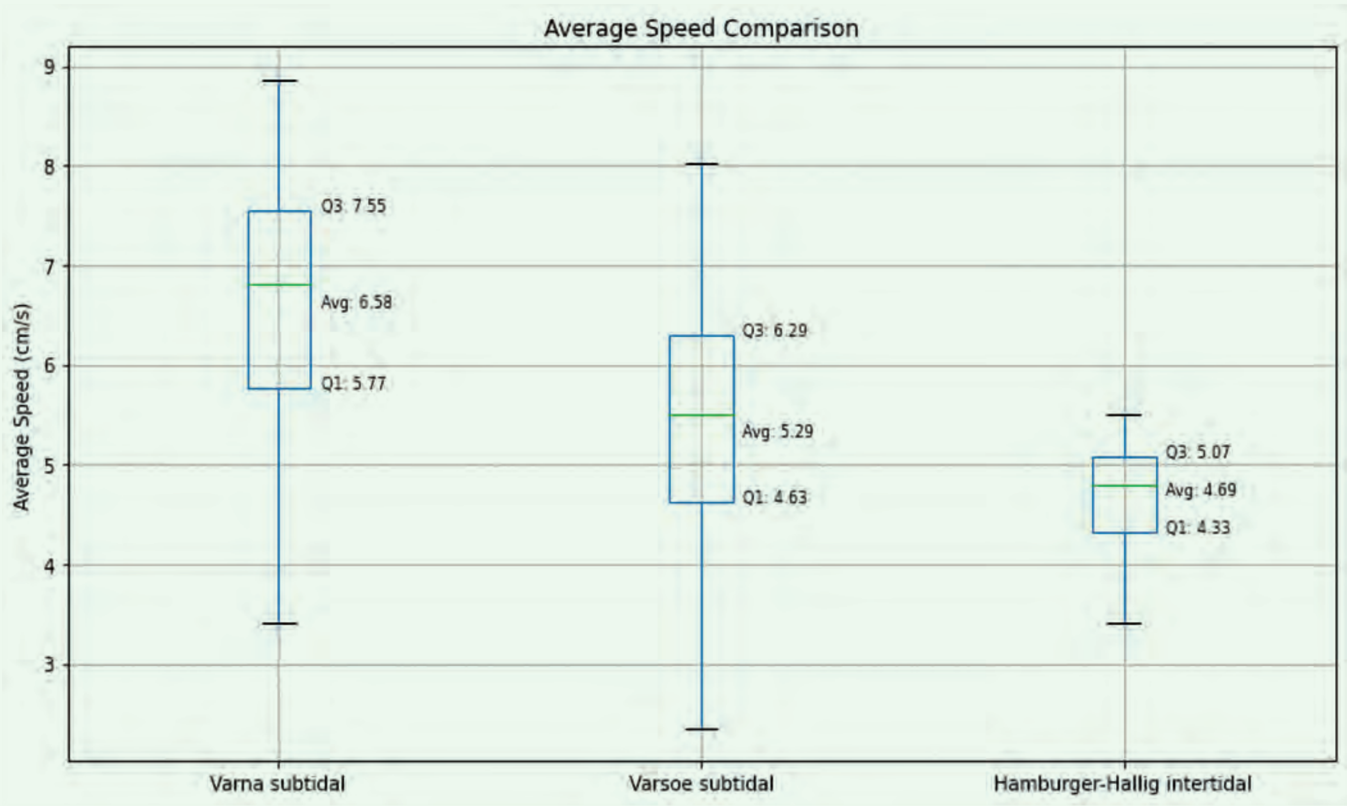


FIGURE 4

Spread in velocities of *Zostera marina* seeds from different locations.

seeds demonstrated an average settling velocity of 5.97 cm/s, with a standard deviation of 1.51 cm/s and a coefficient of variation (CV) of 0.252, reflecting substantial variability in the dataset.

Further analysis compared subtidal and intertidal *Zostera marina* seeds with seed mimics to explore their settling behaviour. Due to limited availability of *Zostera marina* seeds for experiments, several more commonly available seeds, i.e. clover, millet, alfalfa, cress have been studied for their shape and settling behaviour. Clover seeds, which shared a similar elliptical shape and most comparable mean settling velocity of 6.21 cm/s, were identified as the most suitable mimic for subtidal *Zostera marina* seeds, despite being slightly smaller in size. Using natural seeds also mimicked the natural variation of seeds found in seagrass seeds opposed to using nylon thread or 3D-printed particles that were also tested.

Subtidal seeds generally settled faster than their intertidal counterparts, with variations linked to differences in biotope conditions across the studied populations. This significant natural variability resulted in a broad distribution of settling velocities, highlighting the complexity of predicting seed behaviour in restoration efforts even with modification to formulas used for ellipsoidal particles.

Seed distribution

Various sediment concentrations (0.05, 0.1, 0.15, 0.2, 0.3) were used in the experiments. Initial tests utilised sieved mono-sized sand mixtures, including coarse, medium-coarse and fine sand. Based on the terminal settling velocity of the seed, the sediment mixture that has a similar velocity for medium-coarse sand (d=0.35mm), smaller velocity for fine sand (d=0.2mm) and larger settling velocity for coarser sand (d=0.43mm) were tested. The mixture tests were conducted using a transparent acrylate pipe, 120 cm in height and 10.5 cm in diameter, to observe the settling behaviour of seeds and sand in a confined space. The setup included a custom-designed 3D-printed plug for controlled sediment layer removal and a gate valve to maintain a vacuum and prevent air pockets. The entire assembly was placed on an elevated wooden table with a drainage system connected to a plastic tube and a ball valve for controlled water flow. It was possible to extend the setup with an additional piece of pipe and create a still water column below the ball valve in the second experiment. The two set ups are shown in Figure 5.

During every test approximately 100 seed mimics were used in each run to ensure consistency and control. In the first phase, the sediment was added in the pipe to achieve different concentration, then saline water with a salinity of 32 ppt was added and finally the mimics were introduced into the mixture. The column was manually mixed to achieve homogeneity and then allowed to

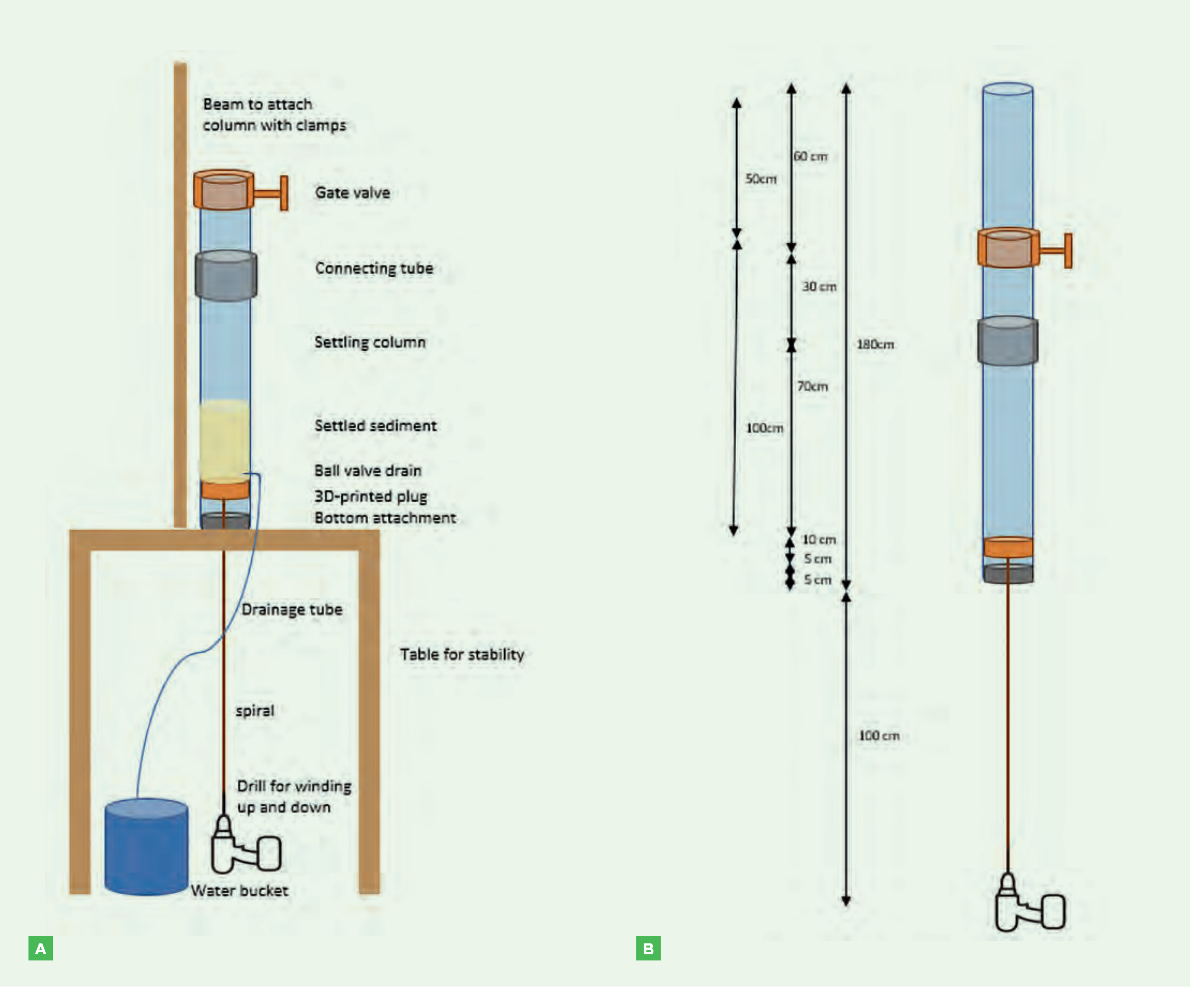


FIGURE 5

Experimental setup mixture test phase I (A) and phase II (B).

settle. The settled layer was pushed upward using a power tool and 1 cm slices were carefully sieved to count the number of seeds per layer.

In the second phase, a secondary pipe was added to introduce a mixture into the still water column, simulating a slurry being pumped into the water. The sediment-seed mixture was created on top of the water column and mixed using a paddle attached to a power tool. The suspended mixture was then released into the water column below by opening the valve with a raster printed beneath to prevent horizontal flows from the power tool as much as possible. The settled layer was analysed using the same methodology as in phase I.

Results

The initial hypothesis suggested that seeds and sand with similar settling velocities, particularly medium-coarse sand, would result in a more or less homogeneous distribution, with a slight segregation of the seeds to the bottom based on the hindered settling effect observed by Mirza and Richardson (1979). However, the results demonstrated a clear segregation effect, with seeds tending to accumulate in the upper layers of the sand mixture, especially at higher concentrations.

In phase I of the experiment, all seeds segregated to the top of the mixture, with the effect becoming more pronounced as seed concentration increased (see Figure 6). For medium-coarse and finer sand, seeds were distributed into lower layers, however a clear segregation effect persisted. This outcome contradicted the initial hypothesis. Due to the turbulence introduced by hand mixing the column, it was decided to test in phase II whether the same effect would occur under more realistic conditions by releasing the mixture into a still water column.

For medium-coarse sand (d_{50}=0.34 mm) at concentrations of 0.05 and 0.1, a significant portion of seeds settled in the ideal layer. However, at higher concentrations, most seeds accumulated above the ideal layer. Fine sand (d_50= 0.17 mm) similarly exhibited more seeds settling in the ideal and lower layers at lower concentrations, but segregation remained prominent at higher concentrations (above 0.2), with a substantial number of seeds ending at the top.

During phase II of the experiment, releasing a mixture by opening a gate valve for coarse sand (d_50=0.52 mm), the seeds segregated to the upper layer in the lower concentrations. In medium-coarse sand (d_50=0.34 mm), the seeds had similar settling velocities to the sand and resulted in a more homogeneous distribution as expected, however segregation still occurred, particularly at higher concentrations. For concentrations of 0.05 and 0.1 most of the seeds ended in the ideal layer. Fine sand (d_50= 0.17 mm) showed seeds distributed slightly lower in the layer, but segregation was still present at higher concentrations. These tests aligned better with the hypothesis yet still show the effect of hindered settling at higher concentrations, which was even more visible in phase I.

The study concluded that too coarse sand is unsuitable for seed distribution as it would not provide any benefit compared to hand-broadcasting to increase survival rate, as the seeds all end up in the top layer. While medium-coarse and fine sand showed better results at lower concentrations. Medium-

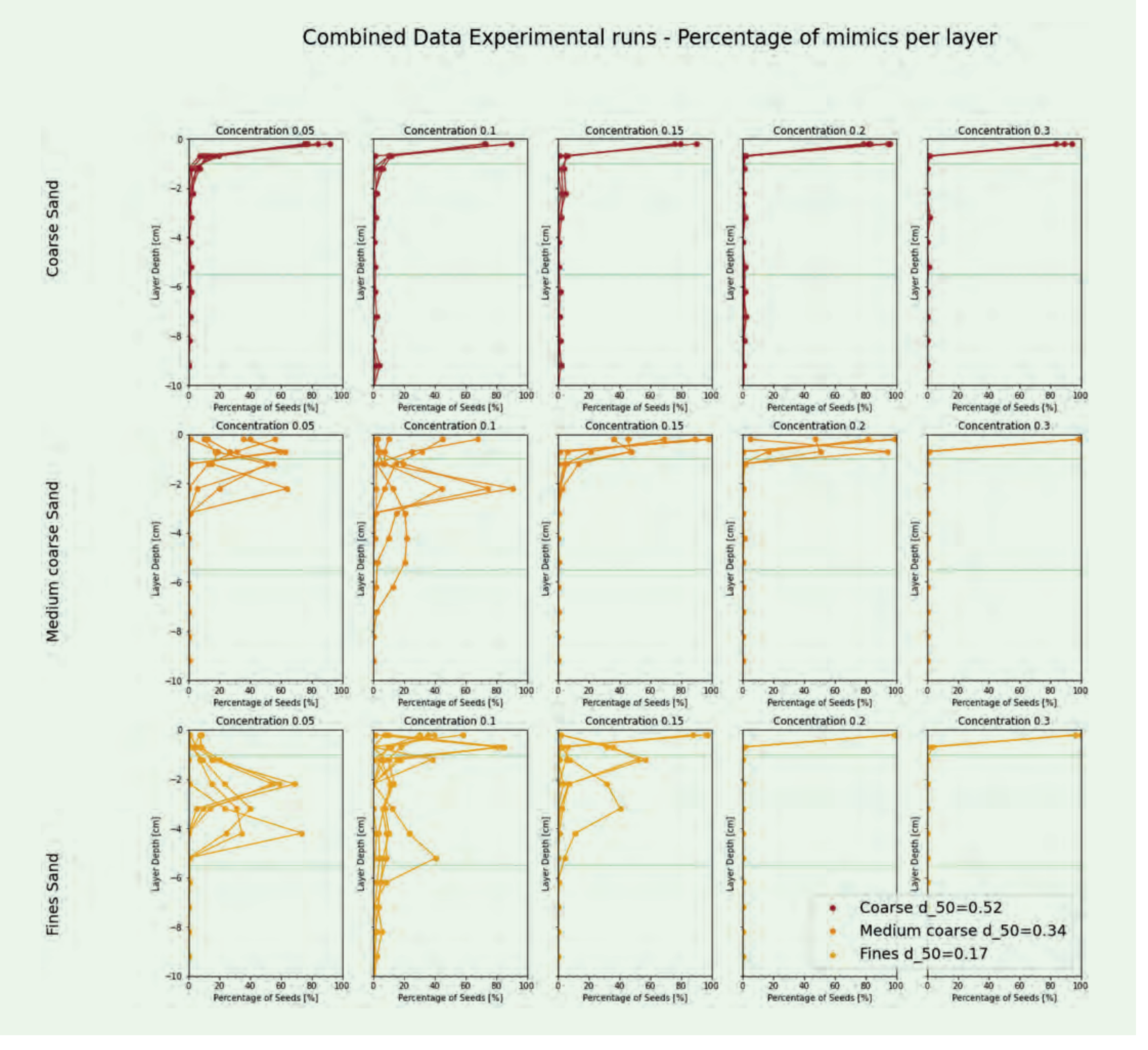


FIGURE 6

Results of where seed mimics end up in the settled layer for different types of sediment and concentration in mixture test phase I.

coarse sand would likely provide the most protection for the seeds and thus is the starting condition for further investigation of this new technique.

During the experiments, video analysis revealed a key observation: the dynamic behaviour of seeds differed significantly from that of the sand particles. While sand particles moved downward collectively, seeds exhibited rotational and hovering motions influenced by turbulence and return currents. This dynamic interaction contributed to the observed segregation effect, with seeds appearing to "hover" in place under certain conditions. Figure 8 provides a visual representation of these particle behaviours, highlighting the contrast between the steady downward motion of the sand and the complex rotational and turbulent motions of the seeds.

The findings suggest that the hindered settling effect and the dynamic behaviours of seeds are critical factors in determining the final distribution. Coarse sand is unsuitable for large-scale seed dispersal, while medium-coarse and fine sand show promise, particularly at lower concentrations. These insights are vital for refining techniques to optimise seagrass seed distribution in restoration projects.

Discussion

Seagrass restoration is crucial for coastal ecosystem management and seed-based methods offer promising potential for

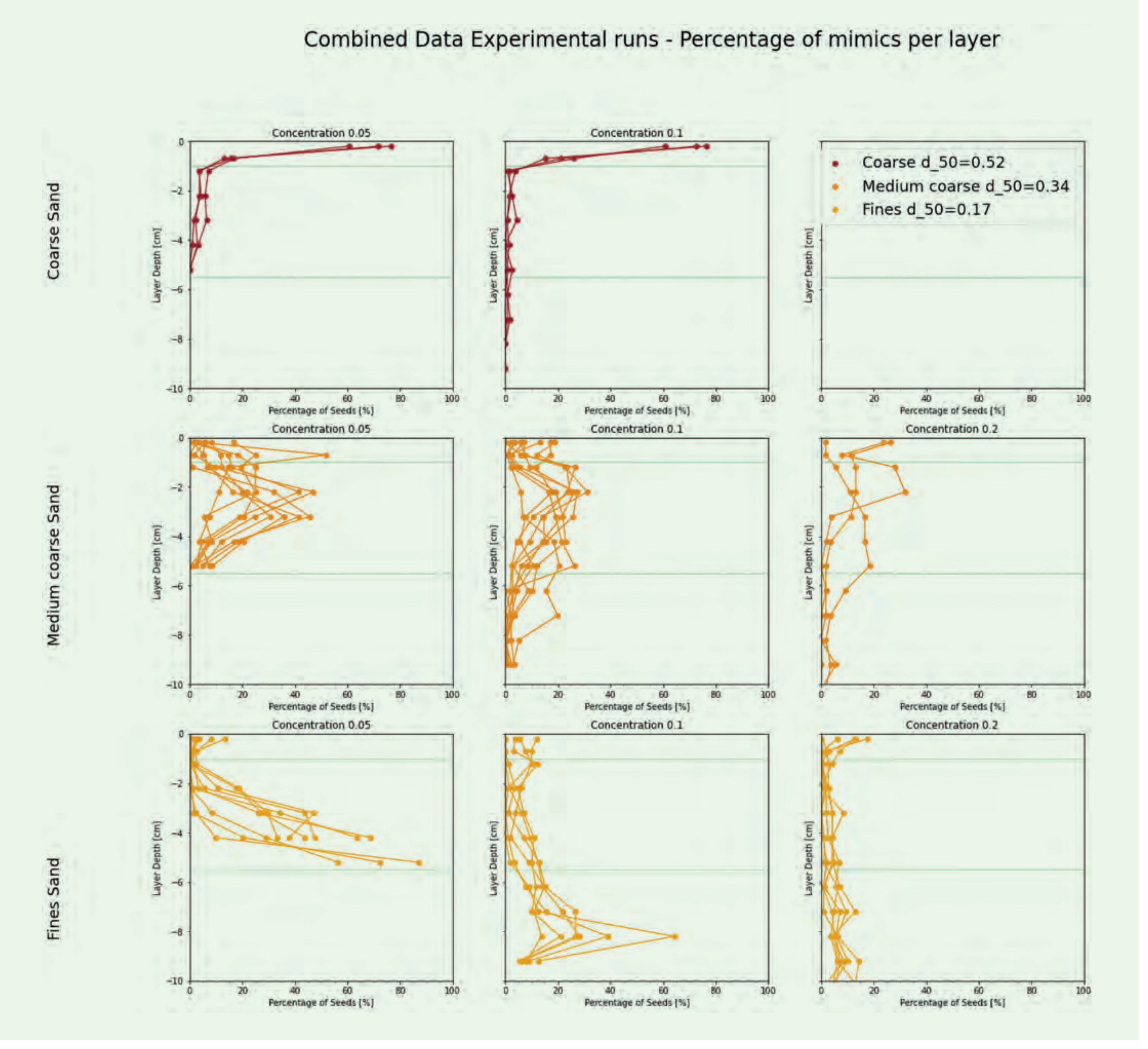


FIGURE 7

Overview of where seed mimics end up in the settled layer for different types of sediment and concentration in mixture test phase II.

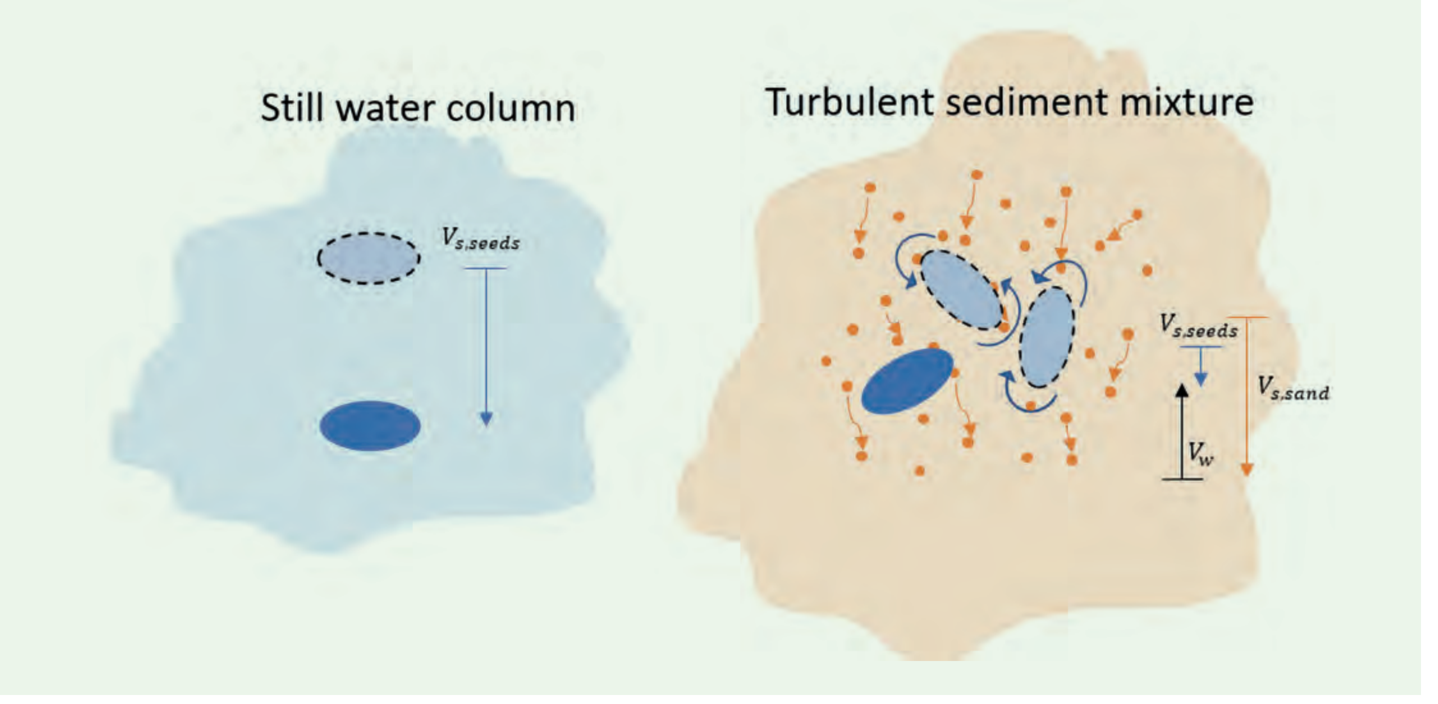


FIGURE 8

Visualisation difference in seed behaviour.

large-scale restoration efforts. An essential component of designing effective restoration techniques is understanding the settling behaviour of seagrass seeds, as this directly impacts their distribution and establishment. The study revealed significant variations in seed size and density, leading to a wide range of settling velocities. Seed mimics were used due to the scarcity of actual *Zostera marina* seeds, but this introduced complexities and differences, emphasising the need for cautious interpretation of results. While these seed mimics showed similarities in shape, size and settling velocities, minor differences in their settling paths were observed, such as increased horizontal movement and more drifting.

The initial hypothesis that seeds with similar settling velocities to sand particles would lead to a homogeneous distribution was not supported by the experimental results. Instead, seeds consistently segregated towards the upper layers, with this segregation effect becoming more pronounced at higher sand concentrations. This discrepancy suggests that the physical properties of the sediment mixture influence the settling behaviour of seagrass seeds differently from sand particles. The hindered settling effect, alongside the seeds' larger size and ellipsoidal shape, was identified as a likely cause for this behaviour. These factors resulted in seeds experiencing the sediment as a dynamic fluid medium with varying densities, which in turn led to significant rotational movement and less predictable settling dynamics compared to the sand particles. This highlights the need for further investigation into the complex interactions between seed morphology, sediment characteristics and settling behaviour in restoration settings.

In phase I of the experiment, which involved rotating a settling column, the hindered settling effect was effectively captured. However, this setup was also influenced by induced turbulence from the rotation and wall effects, which may have contributed to some inconsistencies in the data.
In contrast, phase II that simulated the pumping of a sediment mixture into still water produced different results due to additional factors, such as entrainment and initial seed velocities. These variations suggest that further refinement is needed to replicate real-world conditions more accurately. Additionally, material constraints such as the narrow grading of sand particles used in the experiments do not accurately reflect sediment mixtures available for large-scale execution. Future experiments should address these limitations and explore modifications that can enhance the accuracy and reliability of the method, including adjustments to sediment grading and experimental setups.

Further development

The ongoing research, which is part of a same programme with Van Oord, has shifted focus towards the practical application of these findings in the field. Moving away from fundamental behaviour analysis and concentrating on the methodology's rollout and implications for real-world seagrass restoration projects. In a laboratory, a scaled working model of a spreader pontoon was constructed to test the creation of thin sand

Coarse sand is unsuitable for large-scale seed dispersal, while medium-coarse and fine sand show promise.

FIGURE 9

Location of trial using seed mimics (Scotland, November 2024).

layers with medium coarse sand at the suggested concentration of 0.05 and 0.1 with seed mimics. By sampling at various points, the seed distribution in each layer was compared to fundamental behaviour results, while varying water column heights, pumping speeds, etc.

Additionally, biological trials were conducted with the University of Groningen in the Netherlands to assess the germination rate of seeds in a sand-capped layer under different abrasion conditions caused by hydraulic pumping. With the obtained knowledge, a trail was executed using seed mimics in the cold month of November in preparation for the pilot with actual seed (see Figure 9). Future pilot tests are planned for April 2025 with *Zostera marina* seeds, marking an important step in evaluating the effectiveness of this approach in real-world conditions. This pilot will provide valuable insights into the operational feasibility of using sediment mixtures in large-scale seagrass restoration efforts and biological success rates when using this new method.

Conclusion

The study explored the potential of using traditional dredging techniques for seagrass restoration, focusing on the settling velocities of *Zostera marina* seeds and their distribution in sand-seed mixtures. The use of seed mimics due to the scarcity of actual seeds introduced complexities but provided valuable insights for large-scale restoration applications. The experiments demonstrated that seeds using low concentrations and medium-coarse to find sand would lead to the best distributions in a settled layer, increasing the survival rate of the sand. This behaviour was attributed to the hindered settling effect and the shape factor of the seeds, which caused them to experience the mixture as a fluid medium with different densities. The study highlighted the need for further research to understand the phenomena influencing seed distribution in sediment mixtures as it was different to the hypothesis based on fluid mechanics. Further research is needed to refine technique and understand the impact of various factors not yet examined, such as initial velocity, use of diffusers, less narrowly graded sand and other practical questions still to be further explored.

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Summary

Seagrass restoration is crucial due to its benefits for coastal protection, carbon sequestration and biodiversity enhancement. Traditional planting methods, which involve manually planting seagrass shoots, are labour-intensive and challenging to scale. This research explored the initial steps to a seed-based restoration approach, which could be more scalable and cost-effective.

The study focuses on the fluid mechanics and behaviour of seagrass seeds (*Zostera marina*) in sand mixtures. Laboratory experiments were conducted to determine the best sediment concentration and grain sizes to achieve optimal depth for seed placement, which was found to be between 1-5.5 cm based on previous research. The experiments used seed mimics to simulate the behaviour of actual seagrass seeds, given their scarcity. The average terminal settling velocity of the seeds was measured at 5.97 cm/s, slightly higher, comparable and smaller than that of sand particles of the different mixtures.

Various sediment-water mixtures were tested, revealing that seeds tend to segregate to the top of the settled sand layer, especially in mixtures with larger grain sizes and higher sediment concentrations. The best results were obtained with low sediment concentrations of 0.05-0.1 and fine to medium coarse grain sizes, where the majority of seeds settled at the optimal depth.

The findings provide valuable insights into the dynamics of seed segregation in sediment mixtures, highlighting the potential for using seed-based methods in large-scale seagrass restoration projects using conventional dredging techniques.

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References

Bayraktarov E., Saunders M.I., Abdullah S., Mills M., Beher J., Possingham H.P., Mumby P. J. and Lovelock C.E. (2016)
The cost and feasibility of marine coastal restoration. *Ecological Applications, 26*(4), 1055-1074. https://doi.org/10.1890/15-1077

Budryk W. (1936)
Contribution à la théorie du lavage. *Revue de L'Industrie Minérale*, 374.

Dietrich W.E. (1982)
Settling velocity of natural particles. *Water Resources Research, 18* (6), 1615-1626. https://doi.org/10.1029/WR018i006p01615

Duarte C.M. and Krause-Jensen D. (2017)
Export from seagrass meadows contributes to marine carbon sequestration. *Frontiers in Marine Science, 4*(JAN), 217090. https://doi.org/10.3389/FMARS.2017.00013

Ferguson R.I. and Church M. (2004)
A Simple Universal Equation for Grain Settling Velocity. *Journal of Sedimentary Research, 74*(6), 933-937. https://doi.org/10.1306/051204740933

Flindt M.R., Oncken N.S., Kuusemäe K., Lange T., Aaskoven N., Winter S., Sousa A.I., Rasmussen E.K., Canal-Verges P., Connolly R.M. and Kristensen E. (2022)
Sand-capping stabilizes muddy sediment and improves benthic light conditions in eutrophic estuaries: Laboratory verification and the potential for recovery of eelgrass (*Zostera marina*). *Journal of Sea Research*, 181, 102177. https://doi.org/10.1016/J.SEARES.2022.102177

Francalanci S., Paris E. and Solari L. (2021)
On the prediction of settling velocity for plastic particles of different shapes. *Environmental Pollution, 290*, 118068. https://doi.org/10.1016/J.ENVPOL.2021.118068

Govers L.L., Heusinkveld J.H.T., Gräfnings M.L.E., Smeele Q. and van der Heide T. (2022)
Adaptive intertidal seed-based seagrass restoration in the Dutch Wadden Sea. *PLOS ONE, 17*(2), e0262845. https://doi.org/10.1371/JOURNAL.PONE.0262845

Gräfnings M.L.E., Heusinkveld J.H.T., Hoeijmakers D.J.J., Smeele Q., Wiersema H., Zwarts M., van der Heide T. and Govers L L. (2023)
Optimizing seed injection as a seagrass restoration method. *Restoration Ecology, 31*(3), e13851. https://doi.org/10.1111/REC.13851

Granger S., Traber M.S. and Nixon S.W. (2000)
The influence of planting depth and density on germination and development of *Zostera marina* L. seeds. *Biologia Marina Mediterranea, 7* (3), 55–58.

Greve T.M., Krause-Jensen D., Rasmussen M.B. and Christensen P.B. (2005)
Means of rapid eelgrass (*Zostera marina* L.) recolonisation in former dieback areas. *Aquatic Botany, 82*(2), 143-156. https://doi.org/10.1016/J.AQUABOT.2005.03.004

Hansen J. and Reidenbach M. (2012)
Wave and tidally driven flows in eelgrass beds and their effect on sediment suspension. *Marine Ecology Progress Series, 448*, 271-287. https://doi.org/10.3354/meps09225

Infantes E. (2021)
Sand capping to promote eelgrass restoration. https://www.eduardoinfantes.com/sand-capping-eelgrass-restoration/

Infantes E., Eriander L. and Moksnes P. (2016)
Eelgrass (*Zostera marina*) restoration on the west coast of Sweden using seeds. *Marine Ecology Progress Series, 546*, 31-45. https://doi.org/10.3354/meps11615

Infantes E., Hoeks S., Adams M.P., van der Heide T., van Katwijk M.M. and Bouma T.J. (2022)
Seagrass roots strongly reduce cliff erosion rates in sandy sediments. *Marine Ecology Progress Series, 700*, 1-12. https://doi.org/10.3354/MEPS14196

Jarvis J.C. and Moore K.A. (2015)
Effects of seed source, sediment type, and burial depth on mixed-annual and perennial *Zostera marina* L. seed germination and seedling establishment. *Estuaries and Coasts, 38*(3), 964-978.https://doi.org/10.1007/S12237-014-9869-3

Jørgensen M.S., Labouriau R. and Olesen B. (2019)
Seed size and burial depth influence *Zostera marina* L. (eelgrass) seed survival, seedling emergence and initial seedling biomass development. *PLOS ONE, 14*(4), e0215157. https://doi.org/10.1371/JOURNAL.PONE.0215157

Kilminster K., McMahon K., Waycott M., Kendrick G.A., Scanes P., McKenzie L., O'Brien K.R., Lyons M., Ferguson A., Maxwell P., Glasby T. and Udy J. (2015)
Unravelling complexity in seagrass systems for management: Australia as a microcosm. *Science of The Total Environment, 534*, 97-109. https://doi.org/10.1016/J.SCITOTENV.2015.04.061

Kim D., Son Y. and Park J. (2018)
Prediction of settling velocity of nonspherical soil particles using digital image processing. *Advances in Civil Engineering, 2018*(1), 4647675. https://doi.org/10.1155/2018/4647675

Komar P.D. and Reimers C.E. (1978)
Grain shape effects on settling rates. *The Journal of Geology, 86*(2), 193-209. https://doi.org/10.1086/649674

Marion, S.R. and Orth R.J. (2008)
Innovative techniques for large-scale seagrass restoration using *Zostera marina* (eelgrass) seeds. *Restoration Ecology, 18*(4), 514–526. https://doi.org/10.1111/j.1526-100X.2010.00692.x

Marion S.R. and Orth R.J. (2010)
Innovative techniques for large-scale seagrass restoration using Zostera marina (eelgrass) seeds. https://doi.org/10.1111/j.1526-100X.2010.00692.x

Mirza S. and Richardson J.F. (1979)
Sedimentation of suspensions of particles of two or more sizes. *Chemical Engineering Science, 34*(4), 447–454. https://doi.org/10.1016/0009-2509(79)85088-5

Mtwana Nordlund L., Koch E.W., Barbier E.B. and Creed J.C. (2016)
Seagrass ecosystem services and their variability across genera and geographical regions. *PLOS ONE, 11*(10), e0163091. https://doi.org/10.1371/JOURNAL.PONE.0163091

Oncken N.S., Lange T., Kristensen E., Quintana C.O., Steinfurth R.C. and Flindt M.R. (2022)
Sand-capping – A large-scale approach to restore organic-enriched estuarine sediments. *Marine Environmental Research, 173*, 105534. https://doi.org/10.1016/j.marenvres.2021.105534

Richardson J.F. and Zaki W.N. (1954)
The sedimentation of a suspension of uniform spheres under conditions of viscous flow. *Chemical Engineering Science, 3*(2), 65-73. https://doi.org/10.1016/0009-2509(54)85015-9

Richardson J.F. and Zaki W.N. (1954)
Sedimentation and fluidisation. *Trans. Inst. Chem. Eng., 32*(4).

Short F., Carruthers T., Dennison W. and Waycott M. (2007)
Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology, 350*(1-2), 3-20. https://doi.org/10.1016/j.jembe.2007.06.012

Unsworth R.K.F., Bertelli C.M., Cullen-Unsworth L.C., Esteban N., Jones B.L., Lilley R., Lowe C., Nuuttila H.K. and Rees S.C. (2019)
Sowing the seeds of seagrass recovery using hessian bags. *Frontiers in Ecology and Evolution, 7.* https://doi.org/10.3389/fevo.2019.00311

van der Heide T., van Nes E.H., van Katwijk M.M., Olff H. and Smolders A.J P. (2011)
Positive feedbacks in seagrass ecosystems – Evidence from large-scale empirical data. *PLOS ONE, 6*(1), e16504. https://doi.org/10.1371/JOURNAL.PONE.0016504

van Katwijk M.M., Thorhaug A., Marbà N., Orth R.J., Duarte C.M., Kendrick G.A., Althuizen I.H.J., Balestri E., Bernard G., Cambridge M.L., Cunha A., Durance C., Giesen W., Han Q., Hosokawa S., Kiswara W., Komatsu T., Lardicci C., Lee K., ... Verduin J.J. (2016)
Global analysis of seagrass restoration: the importance of largescale planting. *Journal of Applied Ecology, 53*(2), 567–578. https://doi.org/10.1111/1365-2664.12562

Waycott M., Duarte C.M., Carruthers T.J.B., Orth R.J., Dennison W.C., Olyarnik S., Calladine A., Fourqurean J.W., Heck K.L., Hughes A.R., Kendrick G.A., Kenworthy W.J., Short F.T. and Williams S.L. (2009)
Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences of the United States of America, 106*(30), 12377-12381. https://doi.org/10.1073/PNAS