Wilder Humber

Turning the Tide & Wilder Oysters

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Annual Report 2025

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Introduction

The 2025 Annual Report for the Wilder Humber Programme details the progress that has been achieved over the past year towards achieving the goal of data-led restoration of lost intertidal ecosystems across the Humber Estuary - seagrass meadows, native oyster reefs, saltmarshes, and sand dunes. Notable developments in 2025 include the continued seagrass recovery and trial of new planting methodologies, implementing a pioneering intertidal oyster trial and the development of a purpose-built seed bank and plant nursery at Seaview Farm.

As Wilder Humber moves into 2026, we will focus on expanding methods of restoration that have proved successful to date, refine and continue our monitoring programme and strengthen partnerships to drive long term recovery. We will build understanding of why some restoration methods have not worked at certain locations including sharing experiences with the marine restoration sector and seek new locations for restoration. Specifically, we aim to:

- Scale up restoration based on successful seagrass and oyster trials;
- Initiate turf-cutting trials to assess the effectiveness of cutting in controlling the spread of sea couch grass within the saltmarsh, and to evaluate its impacts on plant communities and invertebrate biodiversity, as part of a wider Natural England evidence programme to inform national saltmarsh management policy;
- Begin seed collection and start the propagation process at Sea View Farm, working with Kew Millennium Seed Bank and the national network within the Wildlife Trust family, and;
- Begin saltmarsh restoration at new location and continue sand dune management at various sites.

The 2025 Annual Report reviews achievements, identifying key findings and lessons learned. This review has also allowed for informed decisions to be made regarding the next stage of large-scale ecological recovery and biodiversity enhancement in the Humber Estuary into 2026.

Key Highlights

Seagrass

- Completed seagrass planting trial comparing three planting methods – Direct injection seeding (DIS), hessian seed bags and transplant cores, the findings of which inform strategy to scale up seagrass restoration.
- Secured a lease to plant within more of the Spurn NNR.
- Achieved the highest number of volunteers hours to date dedicated to the project – 79 volunteers supported seagrass project in 2025 over 515 volunteer hours.
- Lesson around strategic opportunity mapping and practicalities of restoration on the ground.
- 2 hectares of seagrass planted in 2025, bringing the total planted area to 18 hectares since the project began.

Oysters

- First and largest intertidal oyster experiment in the UK, with 280,000 native oysters returned to the Humber.
- Oyster project presented at the international conference Native Oyster Restoration Alliance 6 in Spain.
- Achieved the highest number of volunteer hours to date dedicated to the project – 89 volunteers supported oyster project in 2025 over 617.5 volunteer hours.

Saltmarsh / Sand Dunes

- Enhanced dune habitats through adaptive grazing, improving botanical diversity and habitat structure.
- Reduced invasive species and strengthened breeding bird protection, with improved fencing and ongoing control work.
- Launched the Sea View Farm Nursery & Inducted 22 volunteers at Sea View Farm.
- Identified 1,400 m^2 of saltmarsh for sea couch cutting trials- planned for 2026.
- Seed bank and plant propagation work programme celebrated in the international publication, Samara, by Kew Millennium Seed Bank, as part of their 25th Anniversary with global media promotion.

Communications Highlights

- Raised national profile through BBC Countryfile and major TV news coverage, reaching between an estimated 8–10 million viewers.
- Generated sustained national and international media interest through a pioneering oyster restoration trial.
- Secured £2.36 million in AVE press coverage across 37 articles, reaching over 67 million readers.
- Achieved strong digital growth, with Facebook impressions increasing by 161% and Instagram monthly reach rising by 123% compared to last year.
- More than doubled website visits, driven by national coverage and digital storytelling.
- Delivered 19 engagement events reaching approximately 5,200 people, a 53% increase on 2024.

Seagrass

Background

Seagrass is an important ecosystem that has experienced significant habitat decline over the past century. This decline has also been observed locally on the north bank at Spurn Point, where the area of seagrass meadow has reduced from approximately 480 ha (Philips G., 1936) **(Fig.1)** to its estimated current extent of around 10 ha of seagrass (inclusive of established seagrass meadow and new developing areas of seagrass restored; **Fig.16**). This represents a higher rate of loss (98 %) than the national loss in seagrass cover, which is estimated at least 44% since 1936 (Green et al., 2021). A need to support the protection and enhancement of the remaining seagrass beds at Spurn point NNR was identified to both reinforce a habitat that has experienced serious decline, and to increase the ecosystem benefits of a complex intertidal habitat on this National Nature Reserve, including supporting elevated benthic biodiversity, stabilising sediments, enhancing nutrient cycling, and contributing to carbon storage.

Seagrass site locations

Spurn Point (Yorkshire) and Horseshoe Point (Lincolnshire) are two intertidal sites within the Humber Estuary SSSI, SAC and SPA, which were selected for *Zostera noltii* restoration **(Fig.2).**

Spurn point is a dynamic, curved peninsula on the north bank of the Humber at the mouth of the estuary and is owned by the Yorkshire Wildlife Trust (Fig.3). The peninsula offers protection to the mudflats of Spurn Bight where the natural meadow of seagrass used as a donor site is located. The substrate on the inner (Humber) side is gently sloping shallow sandy-muddy intertidal sediment, which historically supported extensive seagrass meadows. The donor meadow lies halfway down the peninsula and is interspersed with islands of saltmarsh made up of Spartina anglica. The intertidal mudflats, with their seagrass sub-feature, are a qualifying habitat of the SAC, and the SPA designation highlights the reliance of migratory and overwintering birds on benthic invertebrates associated with these flats (JNCC., 2024).

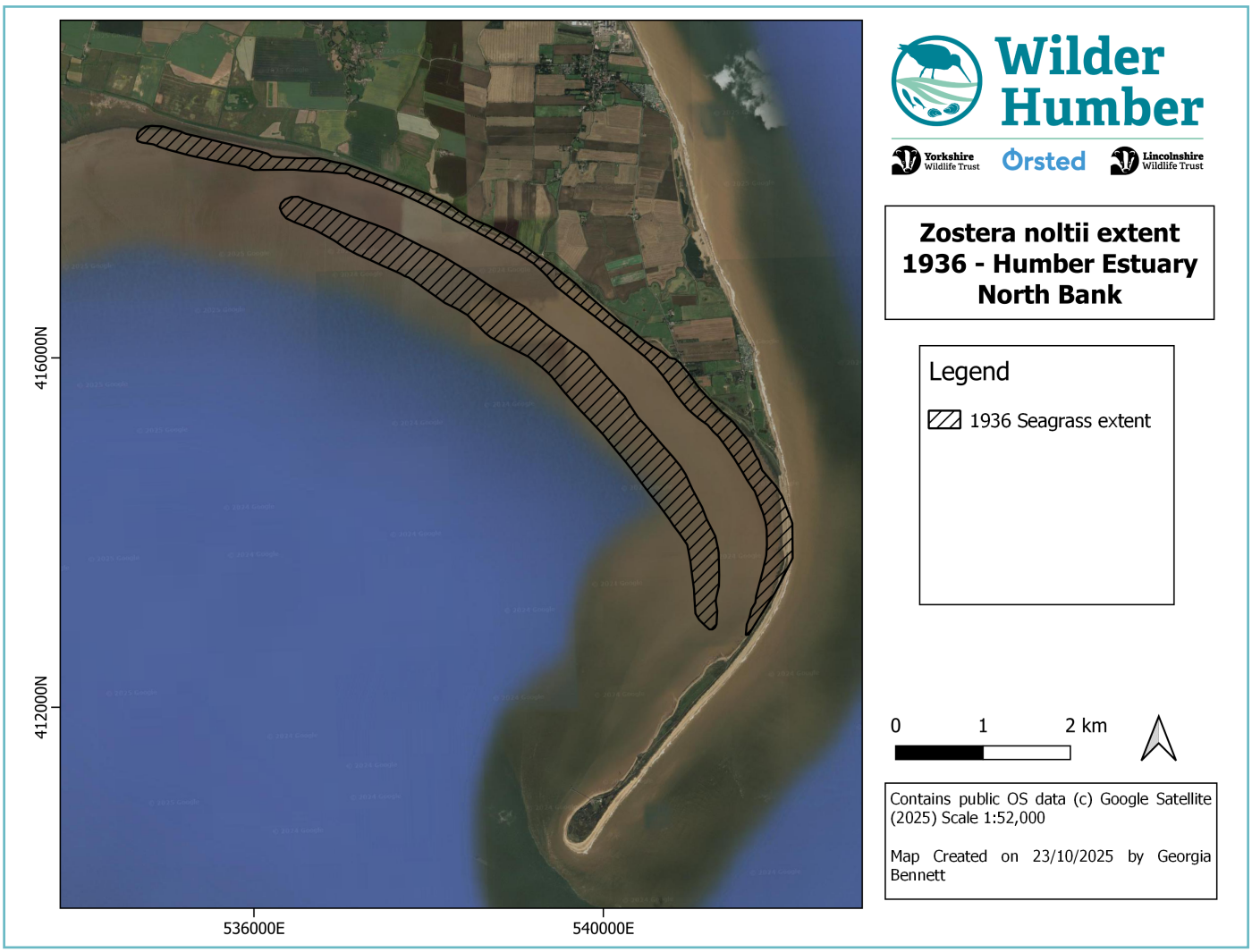


Figure 1 *Extent of seagrass with area of Spurn Bight (Philips, 1936).*

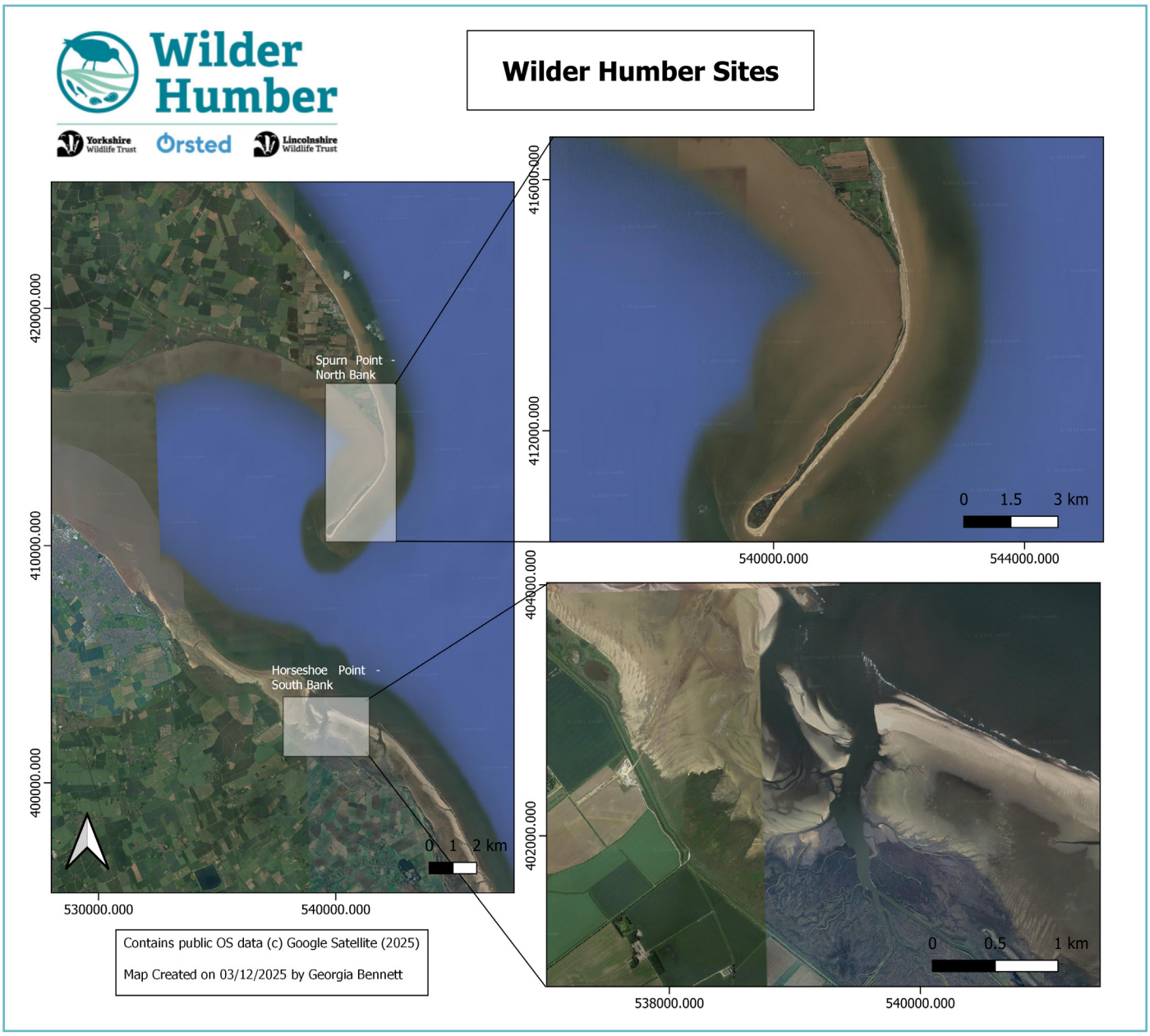


Figure 2 *Map of the Wilder Humber project sites in the Humber Estuary, showing Spurn Point (north bank) and Horseshoe Point (south bank)*



Figure 3 *View South-west into the estuary overlooking the mudflats at Spurn point that hold the donor meadow of seagrass.*

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Horseshoe Point lies on the Lincolnshire coast side of the Humber, featuring extensive mud- and sand-dominated intertidal flats. The outlook of this site is facing northeast out of the mouth of the estuary **(Fig.4)**. Historically, these flats supported *Z. noltii* beds, now largely degraded or lost, as confirmed by surveys (Eastern IFCA, 2017) but still protected within a bait digging bylaw box. Like Spurn Point, the seagrass is a sub-feature of the intertidal mudflat SAC habitat, and it should be providing essential ecosystem services, including stabilisation of sediments, nursery habitat for fish and invertebrates, and food resources for wading birds. Restoration trials at Horseshoe Point aim to re-establish *Z. noltii* meadows and enhance the ecological function of these intertidal flats, complementing broader Humber Estuary management objectives. The substrate at Horseshoe Point contains more sand than Spurn point, and is adjacent to a large expanse of saltmarsh , large number of tidal channels and more exposure to the North Sea.



Figure 4 *Mud and sand flat at Horseshoe Point, showing a characteristic channel running from the right side of the image. Seagrass persists close to these channels as a single remnant patch. isolated patch in the area.*

Seed Collection

Seeds of *Zostera noltii* **(Fig.5)** are collected annually by hand from the healthy meadow at Spurn Point NNR between August and September. In 2024, a total of 111,000 seeds were harvested for restoration trials in Spring 2025, the highest collection to date. The total count of seed in 2025 shows a notable decline in seed production- despite increase in volunteer effort and staff time, only 2500 seeds were collected (please refer to water quality chapter for further details).

Seagrass planting

Seagrass restoration in the Humber estuary commenced with a small-scale seed collection in August–September 2020 and has subsequently expanded to approximately 4 hectares per year following the launch of the Wilder Humber Programme in 2021. Majority of the restoration has been delivered using a grid-based, seed-led approach Ravioli bags, until last year when we began to shift towards new planting methods. Overview of 2025 restoration activities are outlined below:

Spring 2025

- **Spurn Point Seagrass Planting Trial** aiming to compare effectiveness of seagrass planting methods including Ravioli Bags, DIS & Transplants.
- **Core restoration at Spurn Point:** 1.5 ha of seagrass was planted through seed-based techniques.
- **Core restoration at Horseshoe Point (HSP):** 0.5 ha at Horseshoe Point of seagrass was planted through seed-based techniques and a limited number of transplant units.

Autumn 2025

- **Core restoration at Spurn Point:** only ~ 0.25 acres planted due to low seed numbers.
- **Core restoration at Horseshoe Point (HSP):** No planting due to failed germination of seeds in previous 18 months.

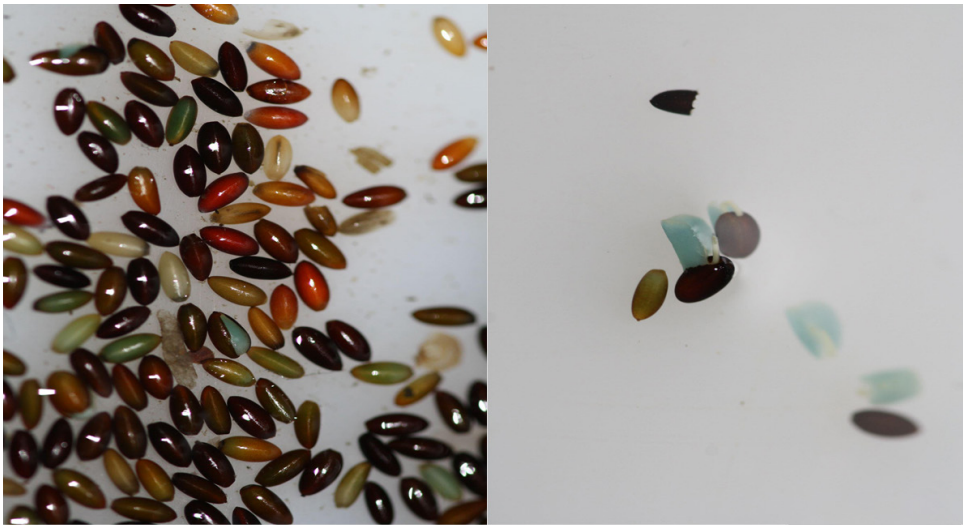


Figure 5 *Seeds of Zostera noltii, approximately 1.5–2 mm in length. The image on the right shows seeds undergoing germination after freshwater forcing.*

Planting at Horseshoe Point (HSP) in spring 2025 did not result in successful seagrass establishment. Field observations and follow-up monitoring indicate that the site is more physically dynamic than anticipated, with prolonged aerial exposure during neap tides, active sediment deposition and channel infilling, and limited freshwater input compared to Spurn Point **(Fig. 6).** These conditions are known to be unfavourable for *Zostera noltii* establishment, as desiccation and aerial exposure reduce survival and recruitment (Greve et al., 2004) and impair photosynthetic performance through physiological stress (Hemminga & Duarte, 2000).

Mobile sandy sediments can further limit establishment by burying seedlings and reducing rhizome anchorage, with restoration success typically higher in finer, more cohesive substrates (Fonseca et al., 2002; McKenzie, 2016). Although a small number of transplants initially persisted, survival was not sustained by the October follow-up. Seed germination and early seedling development in Zostera spp. are sensitive to salinity and temperature, with lower salinities generally enhancing germination and elevated salinity or thermal stress reducing seed viability (Hootsmans et al., 1987; Greve et al., 2004; van Katwijk et al., 2016; Jackson, 2024). Limited freshwater input and greater exposure to North Sea at HSP likely exacerbate these constraints. Overall, the combination of tidal exposure, sediment mobility, and poor germination conditions suggests that HSP is currently unsuitable for reliable seed-based establishment. As such no planting took place at HSP in Autumn 2025, and alternative restoration sites on the south side of the Humber are now being investigated.

It is critical that this experience at HSP is shared with the wider marine restoration sector, as the area has been mapped as potential area for such restoration in strategic reports. These opportunity maps can hopefully be refined based on this experience for pin-pointing sites in future.



Figure 6 *Evidence of channel infilling, extensive dry sand deposition, poor transplant growth, and saltmarsh desiccation within planted areas.*

Seagrass restoration success - methodology

To evaluate the effectiveness of seagrass restoration at Spurn Point, a coordinated monitoring and research framework has been implemented across structural, spatial, environmental, and biodiversity components. This framework integrates experimental trials, long-term ecological monitoring, and comparative habitat assessments to determine whether restored meadows establish successfully, develop structural complexity, and deliver functional ecosystem benefits comparable to natural seagrass habitats.

All monitoring components, variables measured, analytical approaches, and associated scientific objectives are summarised in Table 1. Results and interpretation for each monitoring component are presented in the subsequent Results and Discussion sections, respectively.

Table 1 *Overview of the monitoring and analytical framework used to assess seagrass restoration performance at Spurn Point, including structural, spatial, environmental, and biodiversity components (2021–2025). Statistical analysis was carried out in R version 4.5.2 and Minitab (Donor Recovery only).*

Theme	What we measure	How we measure it	Statistical approach (summary)	Scientific aim (condensed)
Seagrass Planting Trial (Method Comparison)	Total patch number; patch size classes (<11 cm, 11–30 cm, >30 cm); distance from donor meadow; plot location	Experimental grid; 4 treatments (Control, DIS, Ravioli, Transplant); 4 replicates/ treatment; patch classification & mapping	One-way ANOVA (total patch count) + Tukey HSD; GLMM (negative binomial) for patch size × method; AICc model selection; diagnostics via DHARMa	Identify most effective restoration method and determine which produces stable, structurally robust patches
Transplant Growth & Donor Recovery	Core survival; lateral expansion (cm); reproductive structures; donor meadow percentage cover (extraction vs control)	Monitoring 70 days post-planting; measurement beyond 11 cm core; paired photoquadrats (n=15)	Descriptive survival & growth metrics; two-sample t-test for donor recovery	Evaluate transplant resilience and confirm no lasting donor meadow impact
Spatial Seagrass Mapping (Ground-Based)	Seagrass extent; patch distribution; expansion over time	Walkover surveys; GIS mapping; annual comparison of parcel presence	Spatial change detection (descriptive comparison across years)	Track spatial recovery and patch consolidation
Structural Seagrass Development (Seed-Based Sites)	percentage cover; mean blade number; mean blade length; seed density treatment; time since restoration	Random quadrats (5/site); blade counts in sub-squares; 6 blade length measures per quadrat; surveys 2024–2025	Log-transformed one-way ANOVA (2025 data) for restoration age effects; pooled ANOVA (2024–2025) for seed density; Tukey HSD post-hoc tests	Assess meadow structural maturation and evaluate influence of restoration age and seed density
Bird Biodiversity & Community Structure	Total abundance; species richness; species composition; Shannon diversity; Pielou's evenness; species-specific abundance (Brent Goose, Oystercatcher, Red Knot, Redshank)	Monthly surveys (2022–2025); three fixed sectors (control/north, mid/late-restored, south/early-restored); outgoing tide counts	Negative binomial GLMs (abundance & richness); interaction tests (site × year); PERMANOVA (composition); NMDS ordination; Gaussian LM (diversity & evenness); Kruskal–Wallis + Wilcoxon (species-specific)	Assess whether restoration influences bird abundance, richness, community composition, dominance structure, and species-specific habitat use
Finfish Abundance, Structure & Functional Composition	Juvenile abundance; species richness; species composition; family-level trends; functional guild classification; feeding guild structure; age/life-stage structure	Microseine net (3 replicates/site); restored vs natural meadow; seasonal sampling (2024–2025); species ID; guild assignment; age categorisation	Negative binomial GLMs (abundance & richness); PERMANOVA (community composition); PCoA (feeding guild structure); statistical analysis of age structure; interaction tests (site × year)	Determine whether restored meadows provide equivalent nursery habitat, trophic structure, and functional fish community composition compared to natural meadow
Environmental DNA (eDNA) – Water & Sediment	Water: Fish (12S Tele), fish & vertebrates (16S MV3). Sediment: Bacteria (16S Bac), meiofauna (18S SSU), invertebrates (COI LB). Taxonomic presence/absence and haplotype diversity across restored, established and control sites.	Water (inDepth filters) and sediment samples collected and DNA extracted (QIAGEN kits); triplicate PCR per marker; Illumina MiSeq sequencing. ASVs generated using DADA2; taxonomic assignment via curated databases; negative controls included; read counts converted to presence/absence.	ASV-based community characterisation; multivariate community comparisons among habitats; credibility scoring to assess detection reliability	Establish a multi-trophic biodiversity baseline and compare pelagic and benthic communities among seagrass restored, established and control sites
Water Quality Monitoring	Temperature (air & water), depth, pH, dissolved oxygen, TDS, conductivity, salinity, turbidity, nitrates	AquaSonde & AquaProbe multiparameter sondes; repeated sampling; restored vs natural meadow vs sandy/mudflat control	Visual comparison of time-series patterns across habitats	Provide environmental baseline and explore habitat-level differences relevant to restoration performance

Seagrass Planting Trial including Transplant Growth and Donor Meadow Recovery

Seagrass restoration at Spurn since 2021 has primarily relied on seed-based methods, with most areas planted using Ravioli bags and some initial trials of Dispenser Injection Seeds (DIS). Ravioli bags enable rapid on-site deployment and reduce intertidal working time; however, they require substantial preparatory work and carry a risk of anoxia if the bags are over-wrapped. DIS has proved to be so far the most efficient in terms of preparation time, with seed mixtures prepared immediately before planting. DIS requires strong team coordination to ensure consistent coverage, however it provides resilience to tidal disturbance.

The main limitation of seed-based approaches is seed availability, influenced by variable harvest yields and high natural seed mortality. As part of our 2025 seagrass seed collection efforts, we observed a notable decline in seed production, likely due to extreme weather (further discussed in water quality chapter). Despite increased volunteer participation and staff hours, only 2,500 seeds were collected. Similar declines have also been reported by other seagrass restoration projects during group calls with *"The noltii network"*, suggesting this may reflect a broader unplannable event rather than a site-specific issue. Even under optimal conditions, seagrass seeds survival rates remain low, and effective restoration is generally more effective when seeds are sown at higher densities (Gräfnings et al, 2024) and scale is large (van Katwijk et al 2016, Gräfnings et al, 2023). This highlights one of the key challenges in scaling up seagrass restoration efforts.

An alternative to seed-based methods are transplants, which have been shown as a new evolving and reliable method of seagrass restoration even in less ideal environments such as contaminated sediments (Oliveira et al, 2025). There has been a UK industry shift toward transplants and away from seed-based methods, as discussed at the Seascape Symposium, ZSL, London, 2025 and the UK Seagrass Symposiums (2023 & 2025). A key benefit that is reported with transplants is the year one growth and movement of the biome alongside the transplants. Essentially moving the habitat and conditions needed by the plant to thrive, such as beneficial bacteria and nitrogen fixing symbionts, these bacterial partners facilitate nutrient acquisition and directly support plant growth and survival (Mohr, 2021; Sun et al. 2024).

In 2024 we carried out a pilot study in trialling seagrass transplantation. Cored donor sites were filled with local sediment and recovery was monitored by noting new shoot growth coming through the bare sediment of the cored site. Results from the 2024 pilot showed that donor sites recovered rapidly, showing initial colonisation of harvested cored sites in 25% of sites after

4 weeks and 77.7% after 7 weeks. 92 % sod survival within the first 6–7 weeks, supporting the rationale for the larger Stage 2 comparison. In 2025 we carried out a Seagrass Planting Trial to compare between two seed-based seagrass restoration methods- DIS and Ravioli Bags and Seagrass sod transplantation **(Fig.7)**.

Trial results will allow us to effectively shape the Humber Estuary Seagrass Restoration strategy, provide evidence to guide regional planning and share best practice across the restoration community.



Figure 7 *Three seagrass planting methods tested during 2025 planting trial.*

Experimental Overview

Seagrass restoration performance was evaluated under four experimental planting treatments: Control (no planting), Dispenser Injection Seeding (DIS), 'Ravioli' style seed bags, and transplants. Planting was conducted within a pre-defined grid established at the experimental location **(Fig.8)**. The grid was subdivided into randomly assigned treatment plots. Four replicates per treatment were implemented across the grid to provide balanced representation and allow statistical assessment of treatment effects. Within each plot, planting followed the method-specific protocols for each treatment. The control plots were left undisturbed.

Each transplant core consisted of a single 11 cm sediment plug containing established seagrass shoots. Planting units were formed from three such cores arranged in a triangular configuration. Patch development was monitored across all plots, and each newly observed patch was assigned to one of three size classes based on its spatial extent: small (< 11 cm), medium (11–30 cm), or large (> 30 cm). These categories were defined in relation to transplant sizes, as a primary objective of the trial was to compare seed-based establishment with transplant methods. Specifically, 11 cm corresponds to the size of a single transplant unit, while 30 cm represents the approximate combined size of three transplants planted together. Although no formal upper limit was set for the large size class, patch sizes in practice rarely exceeded 1 m.
In addition, the distance of each patch from the edge of the mother meadow (m) was recorded to evaluate potential edge effects on establishment success. Plot location was also documented to assess whether spatial position influenced outcomes.



Figure 8 *Map showing location of seagrass restoration trial in Spurn Point as well as scientific design of the trial area.*

Results

Key findings

- Seagrass Sod Transplantation produced the most stable outcomes, favouring medium and large patches that are more likely to persist and expand into continuous meadows **(Fig.9)**.
- DIS generated many small patches, indicating rapid colonisation but limited progression (within timeline of this experiment) into larger, resilient patches, but there is a risk of grazing and physical disturbance.
- Ravioli performed poorly, with establishment rates similar to Control plots, suggesting limited effectiveness under the energetic tidal and sediment conditions at Spurn Point.
- Distance and location had no significant effect.

Overall Patch Establishment

Total patch establishment differed significantly among restoration treatments **(Figure 10)**, with transplanting and DIS producing substantially higher numbers of patches than Ravioli and Control. A one-way ANOVA confirmed that the restoration method had a significant effect on total patch counts. Post-hoc Tukey HSD comparisons indicated that transplanting and DIS did not differ significantly from one another, but both produced significantly more patches than Ravioli and Control which did not differ significantly from one another Overall, transplanting and DIS produced approximately 250–275% more patches than the Control and 150–160% more than Ravioli, highlighting their superior establishment performance.

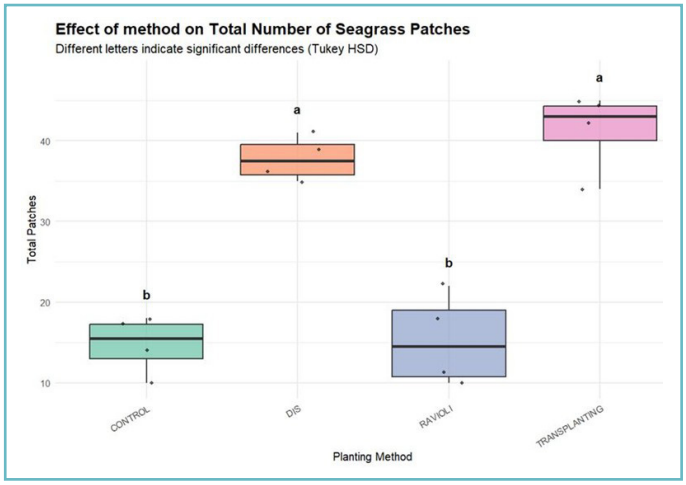


Figure 10 *Total patch establishment across restoration methods. Boxplots show total numbers of established seagrass patches under each restoration method (Control, DIS, Ravioli, and Transplanting). Each box represents the interquartile range (IQR), the horizontal lines denote the median, the points indicate individual plot values.*

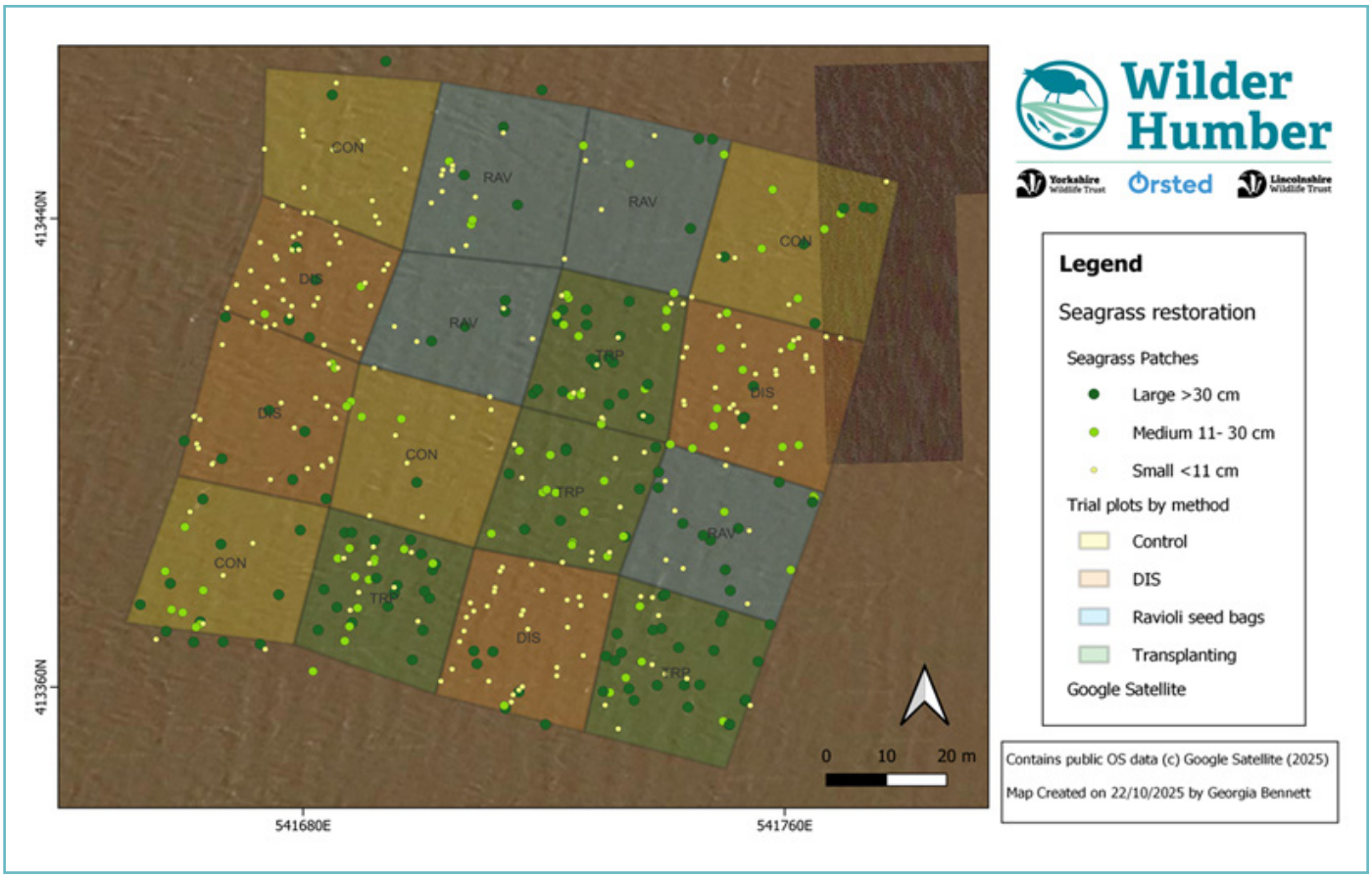


Figure 9 *Distribution of seagrass patches established during the restoration trial. Points represent individual patches, coloured by size class (small < 11 cm, medium 11–30 cm, large > 30 cm). Shaded plots indicate restoration treatments (Control, DIS, Ravoli seed bags, Transplanting).*

Patch Size Distributions

Patch size distributions varied strongly across restoration methods, as indicated by a significant interaction between restoration method and patch size class in the GLMM ($\chi^2_4 = 29.84$, $p < 0.001$). In the Control treatment, patch counts were low and relatively uniform across size classes reflecting minimal spontaneous establishment, with no significant differences among size classes. DIS produced disproportionately more small patches than medium, or large patches, with GLMM pairwise contrasts confirming that small patches were significantly more abundant than medium and large patches. Ravioli yielded slightly more small patches than medium while large patches remained rare and not significantly different from small patches. In contrast, transplanting plots exhibited a shift toward larger patches, with large patches averaging 22 ± 4, medium 15 ± 3, and small 8 ± 2 patches. Post-hoc contrasts showed that large patches were significantly more abundant than small patches, while medium patches were intermediate and did not differ significantly from either small or large patches.

Comparisons among restoration methods within each patch size class revealed clear patterns **(Fig.11)**. For small patches, DIS produced significantly higher counts than all other methods, representing approximately 2.5–3 times more small patches than Transplanting and 3.5 times more than Ravioli or Control. For medium patches, Transplanting outperformed DIS, Ravioli, and Control, producing 150–275% more medium-sized patches. Large patches were predominantly established through transplanting, which generated 5–10 times more large patches than any other treatment. Distance from the meadow edge did not significantly affect patch establishment in any model ($p > 0.1$), and the variance component for the random effect of site was near zero, indicating minimal influence of spatial heterogeneity on establishment outcomes.

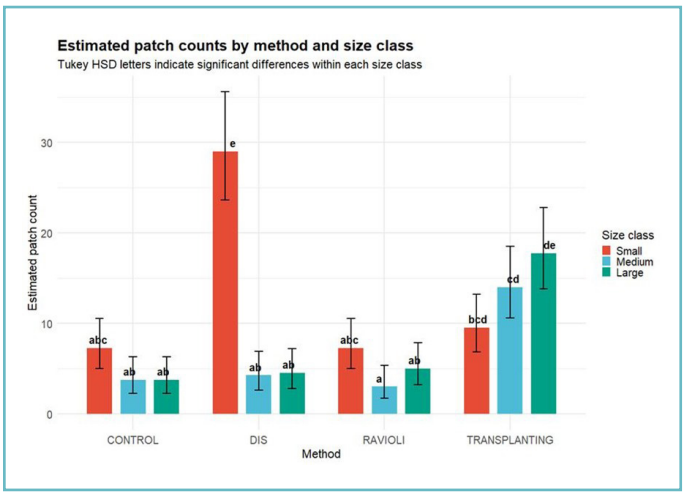


Figure 11 *Estimated patch counts by restoration method and size class. Mean (± SE) estimated patch counts for small (red), medium (blue), and large (green) seagrass patches across restoration methods (Control, DIS, Ravioli, and Transplanting).*

Transplant growth success in restoration area

In additional to patch development we also assessed survival of the transplants 70 days after planting. Out of the 192 individual cores planted, 178 survived, representing a 92.7% overall survivability rate after the initial monitoring period. This high survival demonstrates strong transplant resilience and effective site selection for restoration. Growth beyond the original core was evident across nearly all surviving units, with an average lateral expansion of 22.74 cm. The smallest recorded extension was 5 cm, while the greatest reached 40 cm, indicating robust vegetative growth under prevailing environmental conditions **(Fig.12)**. Reproductive structures were also observed early in the restoration process, with reproductive spathes recorded in 55 of 62 planting units. This suggests that many transplants not only survived but also reached a reproductive stage, an encouraging indicator of meadow establishment and long-term self-sustainability. This was not unexpected as colonising meadows tend to have good production of reproductive bodies (Alexandre et.al, 2006).



Figure 12 *Photo-quadrat divided into 10 cm grid squares showing the estimated initial extent of the 11 cm transplant cores (red circles) and subsequent expansion beyond the original planting area. The two lower cores demonstrate lateral growth of at least 20 cm from their origin points*

Natural Meadow recovery after transplants sods extraction

The donor meadow from which transplant sods were extracted was assessed three months post-harvest. The aim was to determine whether the extraction areas had recovered, based on whether their percentage cover differed significantly from adjacent unharvested control areas. Photo quadrats were taken from a subsample of extraction sites (n = 15), alongside corresponding control images from immediately adjacent undisturbed meadow.

Results

No significant difference in seagrass percentage cover was observed between the treatment site (where transplant sods were taken) and the control site ($p > 0.005$; **Fig. 13 &14)**. This effectively means the area from which transplants were taken was indistinguishable from the surrounding control area. Natural meadow has reached full recovery following transplants extraction.



Figure 13 *Example of a 50 cm² area from which a transplant core was removed (top) and an immediately adjacent, equivalently sized undisturbed patch (bottom). The images illustrate typical local variation in percentage cover and show no significant difference in cover between extraction and control sites.*

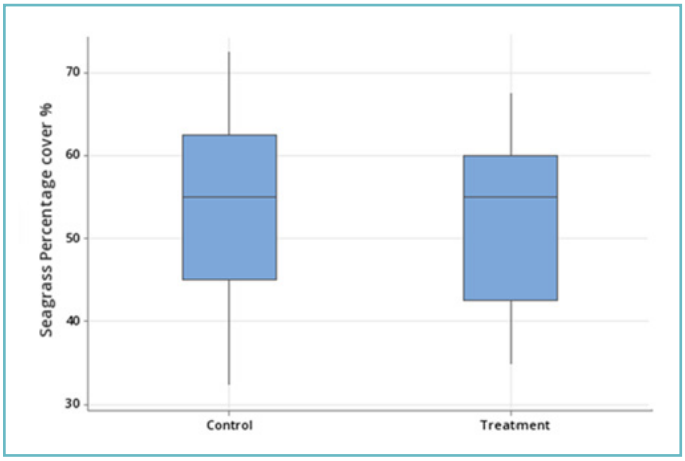


Figure 14 *Seagrass percentage cover in control and treatment areas (where transplant sods were removed). Boxes indicate the interquartile range, lines show medians, and whiskers represent data range.*

Discussion

This study demonstrates that restoration method was the primary determinant of early *Zostera noltii* establishment at Spurn Point. Transplanting and DIS were the most successful treatments, and their contrasting strengths provide clear guidance for future restoration strategy. Importantly, transplanted cores not only survived and expanded but also showed evidence of reproductive development, while the donor meadow exhibited recovery. This confirms that sediment core transplantation represents genuine ecological restoration rather than simply relocating seagrass between sites.

Transplanting consistently produced the most structurally robust outcomes. Medium and large patches occurred predominantly in transplant plots, with measurable lateral expansion beyond the original 11 cm core size and, in some cases, extending ≥20 cm from the origin point. Large patches were almost exclusive to transplant treatments, indicating enhanced stability and persistence relative to other methods. High survival and evidence of reproduction further demonstrate that sediment core transplantation can rapidly establish stable nuclei capable of sustained growth. These findings align with studies showing that high initial shoot density enhances sediment stability and resilience (Van Keulen et al., 2003; van Katwijk et al., 2016; O'Brien et al., 2018). For *Z. noltii,* dense shoots reinforce positive feedback between canopy structure and sediment cohesion (Widdows et al., 2008), strengthening resistance to hydrodynamic disturbance. Larger patches are also likely to enhance stability by reducing edge exposure and promoting sediment deposition (Widdows et al., 2008; Maxwell et al., 2017; Pazzaglia et al., 2021). More broadly, seagrass meadows function as ecosystem engineers: dense root and rhizome networks stabilise sediments, reduce turbidity and nutrient loads, and promote conditions favourable to plant establishment and growth (Unsworth et al., 2022). By transplanting intact cores with rhizomes attached, practitioners can leverage these feedbacks, sediment stabilisation, improved water clarity, and habitat provision, to enhance transplant survival and expansion (van Katwijk et al., 2016).

DIS also performed strongly, generating numerous new patches; however, these were predominantly small and more vulnerable to disturbance. Small, isolated patches are more prone to erosion and may fail to transition into persistent meadow (Marbà et al., 2014). Low-density patches develop more slowly and may be less resistant to physical stress before sediment–canopy feedback is fully established. In contrast, the Ravioli method performed poorly and resembled control plots. This likely reflects reduced seed retention and oxygen limitation within sediment bags (Pickerell et al., 2005; Marion & Orth, 2010), compounded by strong tidal flows and mobile sandy sediments at Spurn Point, which are known to limit seedling establishment (Infantes et al., 2016; Paulo et al., 2019; Orth et al., 2020). Similar failures of seed-bag approaches in energetic systems have been widely reported (Unsworth et al., 2019; Tan et al., 2020; Wegoro et al., 2022). Although distance from the donor meadow had no detectable effect, the energetic hydrodynamics and sandy substrate at Spurn Point likely favoured transplant-based approaches over seed-only techniques, consistent with known habitat constraints (O'Brien et al., 2018).

Crucially, assessment of the donor meadow demonstrated no significant difference in percentage cover between extraction sites and adjacent unharvested areas after three months. This indicates recovery of harvested patches and supports the conclusion that sediment core transplantation does not simply displace seagrass spatially but enables positive habitat net gain when implemented appropriately. Given the wider ecosystem services provided by seagrass, including biodiversity support, nursery habitat provision, blue carbon sequestration, and coastal protection (Borum, 2023), successful core-based restoration delivers benefits that extend well beyond plant replacement alone. However, long-term success depends on matching transplant material to suitable environmental conditions (Fonseca et al., 2002; McKenzie, 2016) and ensuring that broader biome-level processes and positive species interactions are re-established, as these underpin persistence beyond the transplant units themselves.

Taken together, these findings support a shift toward patch-based restoration strategies, which integrate the structural stability of transplanted cores with the scalability and cost-efficiency of seed-based methods. Given the contrasting strengths of transplanting and DIS observed here, integrating both approaches may be advantageous in heterogeneous systems such as Spurn Point. While early establishment patterns are clear, long-term persistence remains to be tested.

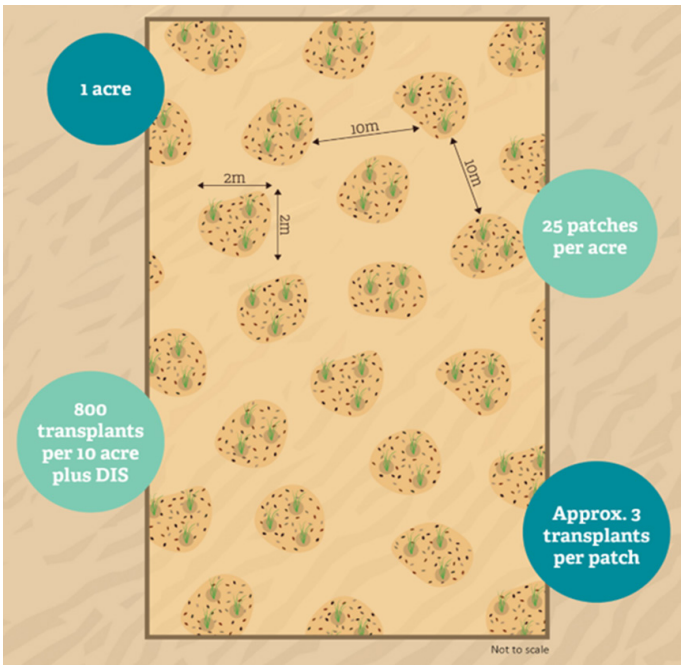


Figure 15 *Seed Sod Synergy infographic.*

Seed Sod Synergy: A Hybrid Patch-Based Restoration Strategy

Seagrass meadows function as biomes, interconnected systems of plants, sediment microbes, fauna, and physical processes that collectively generate ecosystem services such as sediment stabilisation, water quality improvement, carbon sequestration, and habitat provision (Hemminga & Duarte, 2000; Duarte, 2002; Orth et al., 2006; Waycott et al., 2009). These services emerge from interactions and feedback within the system, rather than from individual plants alone. Restoring a biome therefore requires re-establishing structural complexity and ecological processes, ensuring that ecosystem functions are rebuilt and maintained over time (Fonseca et al., 1998; Koch et al., 2009; van Katwijk et al., 2016). In energetic environments, transplantation may provide a more reliable pathway to meadow establishment because intact transplants introduce shoots, rhizomes, and associated biological communities simultaneously. This helps restore stabilising feedback and accelerates the transition toward a self-sustaining meadow state (Fonseca et al., 1998; van Katwijk et al., 2016).

Direct injection seeding (DIS) remains the most efficient method for dispersing seeds at scale, particularly in sheltered environments where hydrodynamic disturbance is lower and seed retention is higher. In such settings, DIS can facilitate broad spatial recruitment and promote genetic diversity, supporting longer-term meadow expansion. To maximise both efficiency and ecological impact, we propose a hybrid, patch-based restoration strategy – **Seed Sod Synergy** **(Fig.15)** - that integrates whole-plant transplants with DIS. Rather than planting in rigid grids, restoration would focus on patches of varying size and density. This approach will extend the effective reach of limited donor material, enabling a single donor meadow to support a larger restoration footprint. It will also leverage positive biome feedbacks, whereby transplants stabilise sediments, improve local environmental conditions, and create microsites favourable for seedling recruitment as well as promote structural heterogeneity, enhancing ecological function, biodiversity, sediment retention, and overall resilience. This strategy aligns with guidance from the OSPAR Commission, which indicates that *Zostera noltii* meadows should achieve at least 5% cover to be considered established (OSPAR, 2009). Patch-based planting more closely mimics the natural growth patterns of this species and allows comparatively small volumes of donor material to be distributed strategically across a wider area, rather than concentrating effort in uniformly planted grids.

By combining seed-based and transplant-based techniques, the project can adopt a flexible and adaptive restoration framework responsive to annual conditions. In years of low seed availability, effort can prioritise transplanting, while high-yield years can focus on broader-scale seeding through DIS. This mixed approach also facilitates the continued movement of reproductive material among meadows, supporting genetic exchange, an increasingly important consideration given the low genetic diversity currently documented at Spurn NNR (Natural England, 2024).

Spatial seagrass mapping

Monitoring undertaken by the Wilder Humber team demonstrates that restoration has been successful at SP **(Fig. 16)**. All sites restored in 2021–22 now support established seagrass, while more recently restored sites are showing early development. Site 8 (planting trial) stands out with particularly high seagrass presence despite being the newest planting site, likely reflecting the combined use of whole-plant transplant sods and DIS, which may accelerate establishment.

Structural Seagrass Development

While spatial monitoring demonstrates an expansion of seagrass across restored areas, understanding the drivers of early meadow development is critical for evaluating restoration performance and informing adaptive management. In particular, it is important to determine whether differences in meadow structure reflect time since restoration, seeding density, or an interaction between the two. This study therefore examined variation in key structural indicators of seagrass condition, percentage cover, mean blade number, and mean blade length, in relation to time since restoration and seeding density. Because seed density treatments partially overlapped with restoration year, potential confounding effects between meadow age and planting density were also considered.

Survey method

Surveys were carried out in two consecutive years – 2024 and 2025. At each restored site five quadrats were selected at random. Within each quadrat, the number of seagrass blades was counted in three randomly selected squares, with each quadrat divided into 12 squares. Six blades were randomly selected within each quadrat, and their lengths were recorded. The seeding density (seeds per acre) was recorded to assess its potential influence on seagrass development. Surveys were conducted in 2024 and 2025, and data from both years were pooled to evaluate overall patterns in seagrass structure in relation to seed density.

Seed density varied among restoration years due to contractual requirements, regulatory guidance, and surplus seed availability, resulting in partial overlap between seed density and time since restoration **(Table 2)**.



Figure 16 *Spurn Point seagrass restoration parcels (yellow) and recorded seagrass presence in summer 2025. Light green shows the 2025 seagrass bed extent; darker green indicates higher seagrass presence (20 m buffer). Red dashed line marks the IFCA Fishing Byelaw (2022) boundary.*

Table 2 Distribution of seed density treatments (seeds per acre) across years since restoration, showing the survey years in which each seed density was applied.

Seed density (seeds per acre)	1 year since restoration	2 years since restoration	3 years since restoration	4 years since restoration
2000	(2024)	(2025)	–	–
4000	(2024)	(2024, 2025)	(2024, 2025)	(2025)
8000	(2025)	–	–	–

Results

Key findings

- Sites restored four years ago showed higher blade density and longer blades than sites restored more recently.
- Seed number had some effect on blade length when data from 2024 and 2025 were pooled, but this was not significant, with the highest seeding rate (8000 seeds per acre) associated with shorter blades compared to the 4000-seed treatment.

Effects of time since restoration on seagrass metrics at the time of survey (2025).

There was no significant difference in percentage cover of seagrass between restored sites (p = 0.291), **(Fig.17)**.

There was a significant difference between mean number of blades differed against restoration ages (p = 0.0201). Pairwise comparisons showed that sites surveyed four years after restoration had higher blade numbers than sites surveyed three years and one year after restoration (both p<0.05). No other pairwise differences were detected **(Fig.18)**.

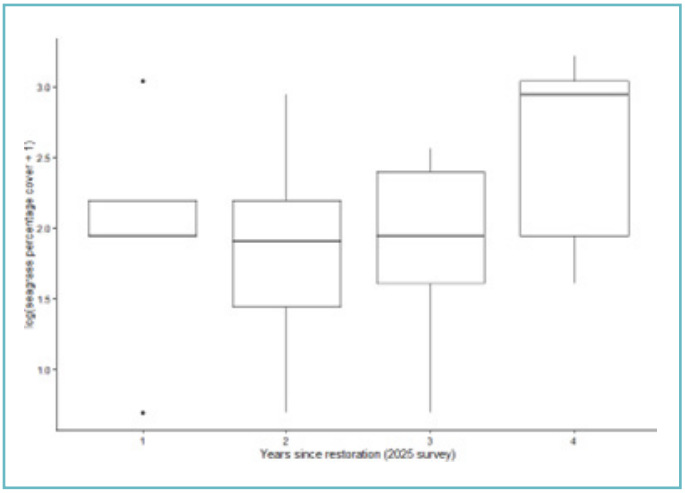


Figure 17 *Boxplots of log-transformed seagrass percentage cover (log[% cover + 1]) in 2025 across sites restored 1–4 years prior to the survey.*

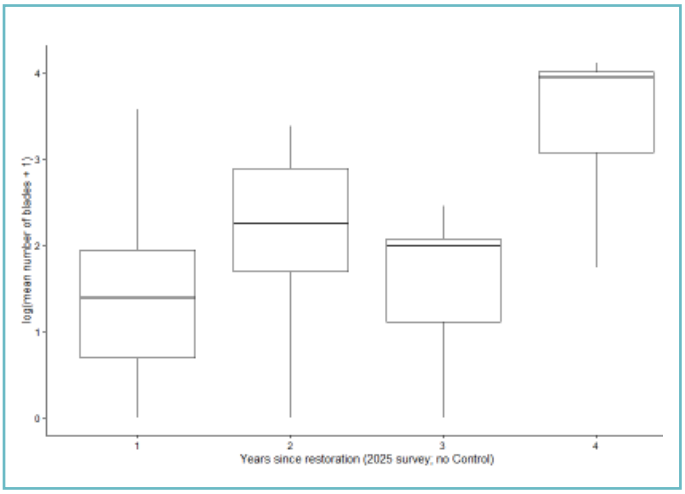


Figure 18 *Mean seagrass blade number on restored sites at different years since restoration (2025), shown on a log(x + 1) scale.*

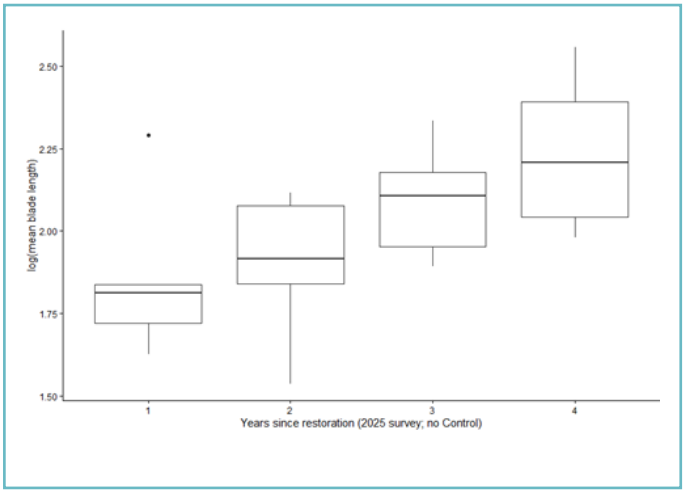


Figure 19 *Boxplots of mean seagrass mean blade length across restored sites surveyed at different times since restoration (2025). Blade number is presented on a log(x + 1) scale.*

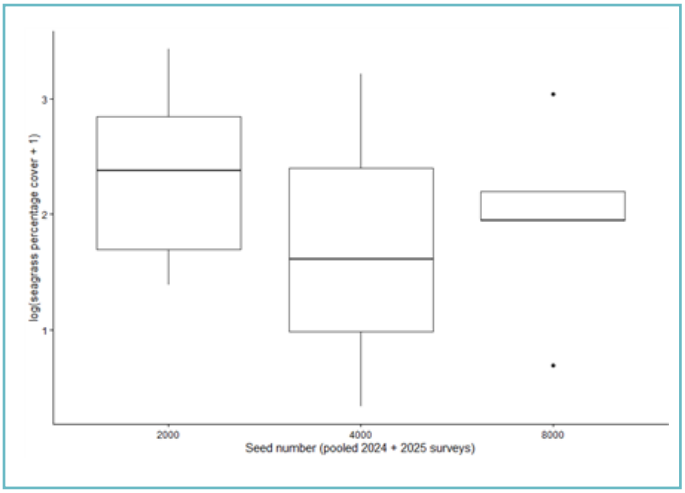


Figure 20 *Boxplots of log-transformed seagrass percentage cover by seed number, pooled across the 2024 and 2025 surveys.*

There was a significant difference between Mean blade length and restoration planting years (p = 0.0118). Sites surveyed four years after restoration had longer blades than sites surveyed one and two years after restoration (both p<0.05) **(Fig.19).**

Effects of seed number on seagrass metrics

Seagrass percentage cover did not differ significantly among seed number treatments (p= 0.0774), and no pairwise differences were detected **(Fig.20).**

Mean blade length showed a significant response to seed density treatment (p = 0.0566, **Fig.21**). Post hoc Tukey tests identified a significant difference between the 8000-seed and 4000-seed treatments (p = 0.0498), with blades generally shorter at the highest seed density, while no significant difference was detected between the 8000-seed and 2000-seed treatments (p = 0.0855). This pattern may partly reflect differences in time since restoration, as the highest seed density was applied only in 2024 and therefore represents sites one year after restoration, suggesting that blade length responses may be influenced by meadow age in addition to seed density.

Mean number of blades did not differed amongs seed density treatments (p = 0.133, **Fig.22**).

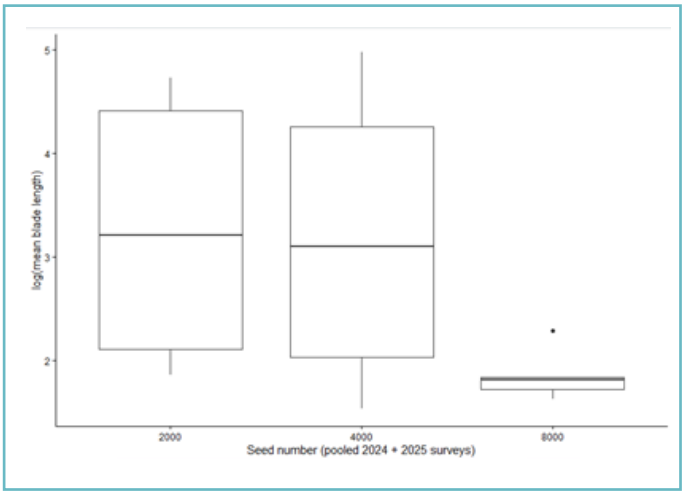


Figure 21 *Boxplots of log-transformed mean blade legth in plots established with different seed densities per acre, using data pooled from the 2024 and 2025 surveys.*

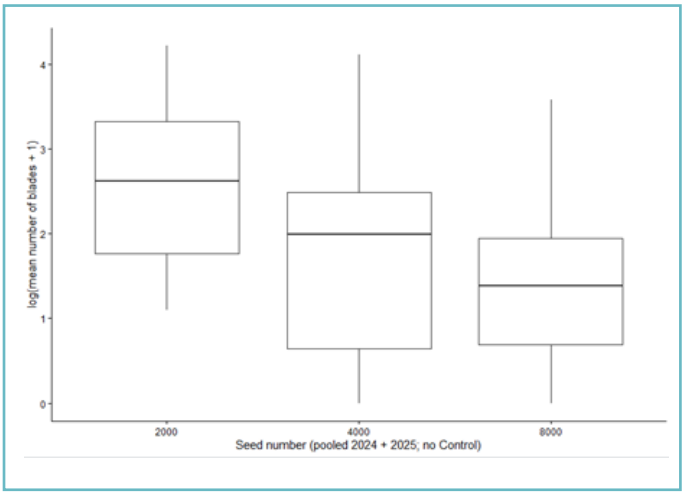


Figure 22 *Boxplots showing mean seagrass blade number in plots established with different seed densities per acre, using data pooled from the 2024 and 2025 surveys. Blade number is presented on a log(x + 1) scale.*

Discussion

Meadow development and structural maturation

The clearest pattern emerging from this study is that meadow structure strengthens with time since restoration. Older sites consistently exhibited more developed structural characteristics, indicating progressive maturation following initial establishment. This aligns with the expected trajectory of seagrass recovery, in which early recruitment is followed by gradual increases in shoot density, canopy height, and vegetative expansion as plants allocate resources to below-ground development and clonal growth (Orth et al., 2020).

In the first years following restoration, structural metrics are more variable and indicative of early-stage establishment. Over time, this variability reduces as meadows appeared to consolidate. Such patterns are consistent with broader restoration literature, where restored seagrass systems often transition from sparse, heterogeneous patches to more structurally complex assemblages as competitive and self-thinning processes regulate shoot density (Duarte et al., 2015; van Katwijk et al., 2016).

Collectively, these findings suggest that structural recovery at Spurn follows a gradual, multi-year trajectory, and that short-term assessments may underestimate long-term restoration success.

Structural development versus spatial extent

Although structural indicators show clear evidence of maturation, spatial cover did not exhibit the same age-related pattern. Seed-led approaches typically promote dispersed recruitment across broad areas rather than immediate formation of contiguous meadow (Orth et al., 2012; Statton et al., 2018). As a result, early development may occur internally within patches before translating into measurable increases in overall spatial extent.

This distinction between structural and spatial recovery has important monitoring implications. Quadrat-based assessments are well suited to detecting changes in plant morphology and density but may be less sensitive to patch expansion at larger spatial scales. As restoration progresses, and particularly as transplant techniques are incorporated, more rapid gains in contiguous cover may be expected (Fonseca et al., 1998; van Katwijk et al., 2016). Integrating broader-scale mapping approaches (e.g., drone or acoustic surveys) alongside simplified quadrat metrics could therefore strengthen future monitoring efficiency and interpretation.

Seed density and early establishment dynamics

The influence of seed density on meadow development remains uncertain. Interpretation is constrained by overlap between restoration age and planting density, preventing clear separation of density effects from temporal development. In practice, differences among treatments are difficult to attribute solely to seeding rate. While higher seeding densities may increase initial recruitment probability, they can also introduce density-dependent processes such as competition for light and nutrients during early development (Granger et al., 2002; Kendrick et al., 2012; Statton et al., 2020). Consequently, subsequent structural development and blade morphology are more strongly shaped by site-specific environmental conditions than by planting density alone (Orth et al., 2012; van Katwijk et al., 2016).

It is important to note that the seeding densities applied in this project are comparatively low relative to those reported in other studies, which have used substantially higher rates. Gräfnings et al. (2024) found that for *Zostera noltii*, 125 seeds m² (~506,000 seeds per acre) was most efficient when seed supply was limited, whereas 500 seeds m² (~2,023,000 seeds per acre) resulted in the greatest overall establishment when seed availability was not limiting. The relatively modest densities employed in our study here may limit the likelihood of detecting strong treatment effects. Future trials would benefit from experimentally structured, replicated density treatments within the same restoration year to isolate true density-dependent responses.

Study constraints and environmental context

Several factors constrain the strength of inference in this study. Restoration age and seed density are partially confounded because the monitoring framework was designed primarily to track planted areas rather than to provide balanced replication across treatments and years. As a result, replication is limited, reducing statistical power and the ability to disentangle treatment effects. In addition, important environmental drivers—including light availability, nutrient concentrations, sediment characteristics, and hydrodynamic exposure—were not explicitly incorporated as explanatory variables. These factors should be incorporated in future monitoring and analyses to better account for environmental variability and improve interpretation of restoration outcomes (Lee et al., 2007; Peralta et al., 2007; Smit et al., 2021). In this system, spatial variation in hydrodynamic exposure is likely particularly influential and may account for some of the variability observed among sites. Seasonal dynamics, including winter dieback and spring regrowth cycles (Duarte, 1989), further complicate interpretation depending on survey timing. Accordingly, the findings should be interpreted as indicative of developmental trajectories rather than as evidence of definitive causal relationships.

Implications for restoration practice

Despite these limitations, three important implications emerge:

- **Persistence and maturation** – Restored seagrass persist beyond initial establishment and demonstrates progressive structural development over multiple years.
- **Gradual recovery trajectory** – Early-stage sites should not be interpreted as unsuccessful based on low initial density or cover; structural recovery unfolds over extended timescales.
- **Structural recovery may precede spatial expansion** – Seed-based restoration can generate internal meadow development before substantial increases in overall spatial extent are detectable.

Overall, the restoration at Spurn appears to be working, with clear evidence of structural maturation over time. Achieving large-scale spatial consolidation will likely require longer-term monitoring, improved experimental design, and complementary restoration techniques. Integrating whole-plant transplantation alongside seed-based methods may accelerate both structural and spatial recovery.

Future monitoring could be improved with increased sample size, broader-scale spatial mapping, and deliberately replicated treatment designs within comparable environmental settings, enabling stronger inference regarding the drivers of restoration success and long-term meadow resilience.

Seagrass Biodiversity uplift – Birds

Intertidal estuarine mudflats support internationally important populations of waterfowl and waders in the UK (Frost et al, 2023), and many of these species are closely linked to eelgrass (Zostera spp.) habitats (Ganter, 2000). Eelgrass provides both a direct food source and indirect trophic support. Herbivorous species such as Brent Geese (Branta bernicla) and Wigeon (Anas penelope) feed directly on eelgrass leaves and rhizomes (Fox 1996; Ganter 2000), with eelgrass comprising up to 100% of the diet of Brent Geese in some studies (Nienhuis & Groenendijk 1986). Historical declines in Zostera during the 1930s were associated with major reductions in brent goose populations, demonstrating the strong ecological linkage between seagrass availability and bird distribution (Ganter, 2000). Grazing by geese and ducks may also play a role in meadow dynamics and persistence (Nacken & Reise 2000).

Beyond direct herbivory, seagrass meadows enhance benthic productivity and provide habitat for fish and invertebrates that form prey for wading birds. Although these indirect relationships are less well quantified, evidence suggests that the presence of seagrass can increase bird abundance at coastal sites (Unsworth & Butterworth 2021). Together, these trophic linkages indicate that changes in bird abundance, community composition and feeding behaviour can reflect underlying changes in seagrass extent and condition, making birds a valuable ecological indicator of restoration success.

Bird surveys method

Dedicated bird surveys were conducted monthly between January 2022 and December 2025 at three fixed monitoring sites (north, mid, and south) located within the IFCA byelaw box at Spurn Point. Surveys were undertaken during the outgoing tide, when intertidal mudflats were exposed, thereby maximising the detectability and abundance of birds using the site. As bird monitoring was carried out concurrently with seagrass restoration activities, the resulting dataset allows for the assessment of temporal and spatial variation in bird assemblages across the three survey sites. A description of the survey sites **(Fig. 23):**

North – No seagrass restoration, no areas of classified seagrass meadow, infrequent patches of seagrass. This site is the first to be exposed on the outgoing tide and is in close proximity to a saltmarsh roosting site. This site for the analysis was treated as control/ unplanted site.

Mid – Medium sized areas of classified seagrass meadow, frequent smaller seagrass patches. Restoration seed planting carried out in 2023 & 2024. This site for the analysis was treated as late restoration site.

South – Large areas of classified seagrass meadow, at the highest densities we observe on site, present prior to restoration work but has expanded since. Frequent smaller seagrass patches. Restoration seed planting carried out in 2021 & 2022. This site for the analysis was treated as early restoration site.

Spatial and Temporal analysis of bird species richness and abundance

Key findings

Overall, restored sites (south & mid) supported significantly lower total abundance than control site (north), whereas species richness did not differ among site categories. Species richness increased significantly over time across all sites, while total abundance showed no significant trend over time. Temporal trajectories of both abundance and species richness were similar among control, early-restored, and late-restored sites, indicating no evidence that restoration status or timing influenced rates of change through time.

Total abundance differed significantly between control and restored sites **(Fig. 24)**. Relative to control sites, abundance was lower at both restored sites, with significantly reduced abundance at late-restored sites ($p = 0.009$) and early-restored sites ($p < 0.001$). There was no significant overall temporal trend in total abundance ($p = 0.157$, **Fig. 25**). In addition, temporal trajectories of abundance did not differ among control, late-restored, and early-restored sites, with no evidence of an interaction between site category and time (all $p > 0.05$).



Figure 23 *Bird surveying sides over Spurn Point seagrass restoration areas.*

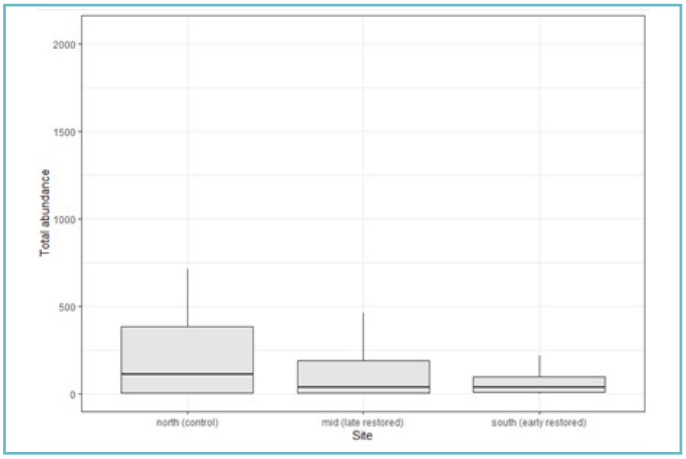


Figure 24 *Total abundance at north (control), mid (late restored), and south (early restored) sites. Boxplots show the median (central line), interquartile range (boxes), and 1.5× interquartile range (whiskers).*

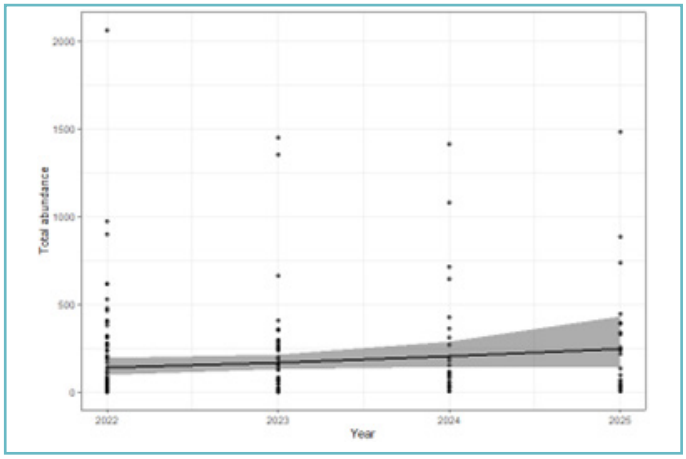


Figure 25 *Temporal trend in total abundance across the study period. Points represent observed total abundance values by year. The solid line shows the fitted mean from a negative binomial model, and the shaded ribbon indicates the 95% confidence interval around the model prediction.*

Species richness did not differ significantly between site categories. Neither late-restored site (p = 0.265) nor early-restored site (p = 0.734, **Fig. 26**) differed from control site in mean species richness. In contrast, species richness increased significantly over time across all sites (p < 0.001). Temporal trends in species richness were similar among site categories, with no evidence that rates of change differed between control, late-restored, and early-restored sites (all p> 0.05, **Fig. 27**).

Bird composition analysis on seagrass sites

Key findings

- Community composition differed across sites and years when considered together, but these factors explained only a small proportion of the overall variation.
- Communities did not change differently through time among sites, as no site × year interactions were detected.
- Species richness varied through time, while diversity and evenness differed among sites, indicating differences in species dominance rather than species number.
- NMDS ordinations supported these patterns, showing partial separation among sites with substantial overlap among years.

Differences in bird community composition among sites

The overall PERMANOVA model indicated significant differences in community composition when survey site and year were considered together ($F = 2.30$, $R^2 = 0.065$, $p = 0.001$). Although the overall model was significant, survey site and year together explained only a small proportion (6.55%) of the total variation in community composition, indicating that additional unmeasured factors likely contribute to community differences. The interaction between survey site and year was not significant ($F = 0.81$, $R^2 = 0.009$, $p = 0.77$), indicating no evidence that temporal patterns in community composition differed among survey sites.

Differences in within-group variability

Multivariate dispersion did not differ significantly among survey sites (p = 0.787), indicating that differences in community composition were not driven by unequal within-group variability.

Diversity, and evenness

Shannon diversity and evenness differed significantly among survey sites (p < 0.05), while neither metric was influenced by time (p > 0.05) and no significant survey site × year interactions were observed (p > 0.05). Together, the site-level differences in Shannon diversity and evenness indicate variation in species dominance patterns among survey sites, which is investigated further in the following section.

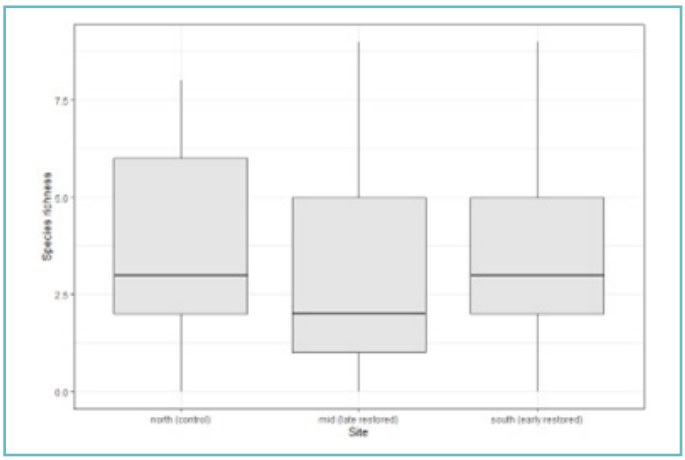


Figure 26 *Species richness at north (control), mid (late restored), and south (early restored) sites. Boxplots show the median (central line), interquartile range (boxes), and 1.5× interquartile range (whiskers).*

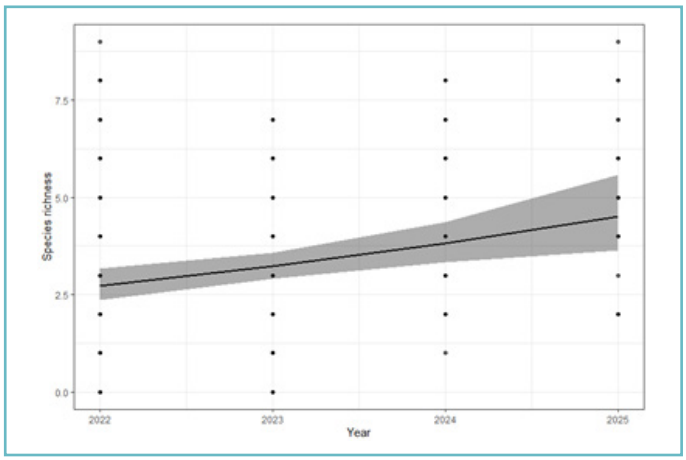


Figure 27 *Temporal trend in species richness over the study period. Points represent observed species richness values by year. The solid line shows the fitted mean from a negative binomial model, with the shaded ribbon indicating the 95% confidence interval.*

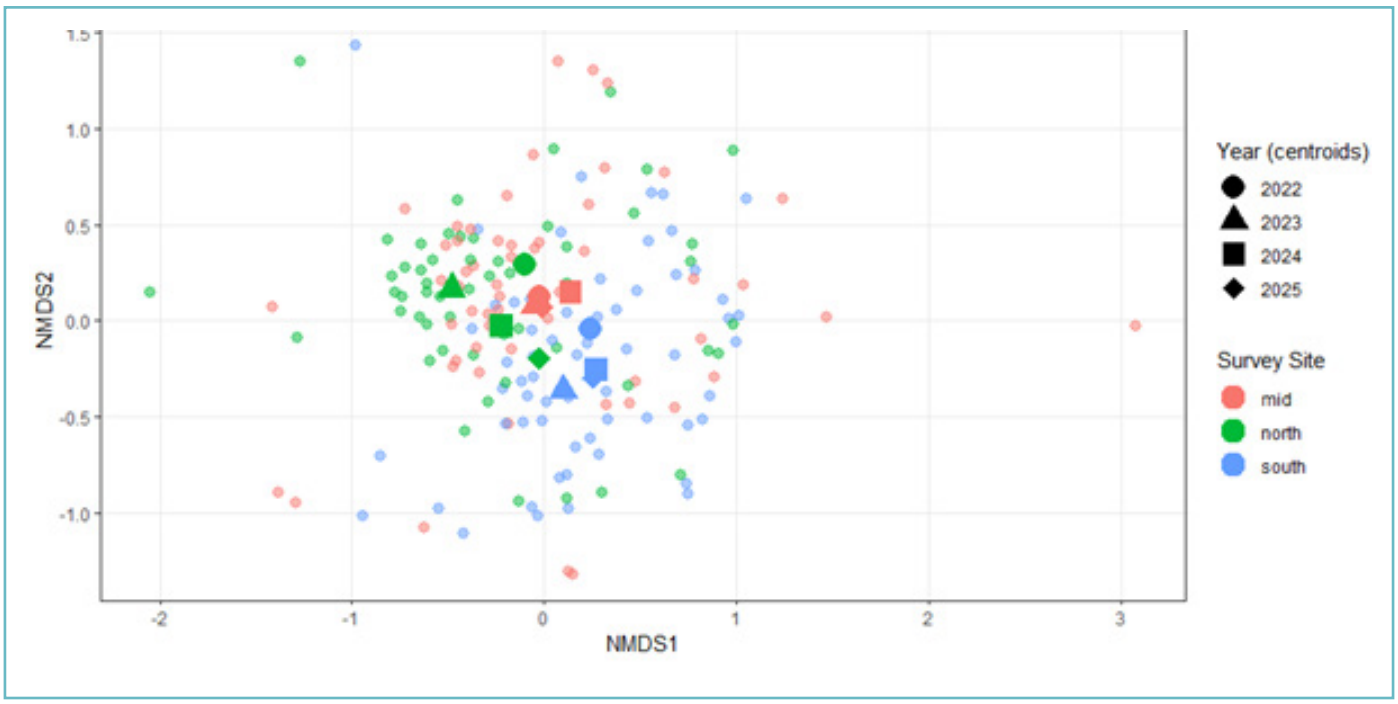


Figure 28 *NMDS ordination of bird community composition based on Bray–Curtis dissimilarities calculated from raw abundance data. Points represent individual samples, coloured by survey site (north, mid, and south), while symbols denote year. Centroids represent the mean position of each survey site × year combination. The stress value (0.199) indicates an acceptable representation of community dissimilarities.*

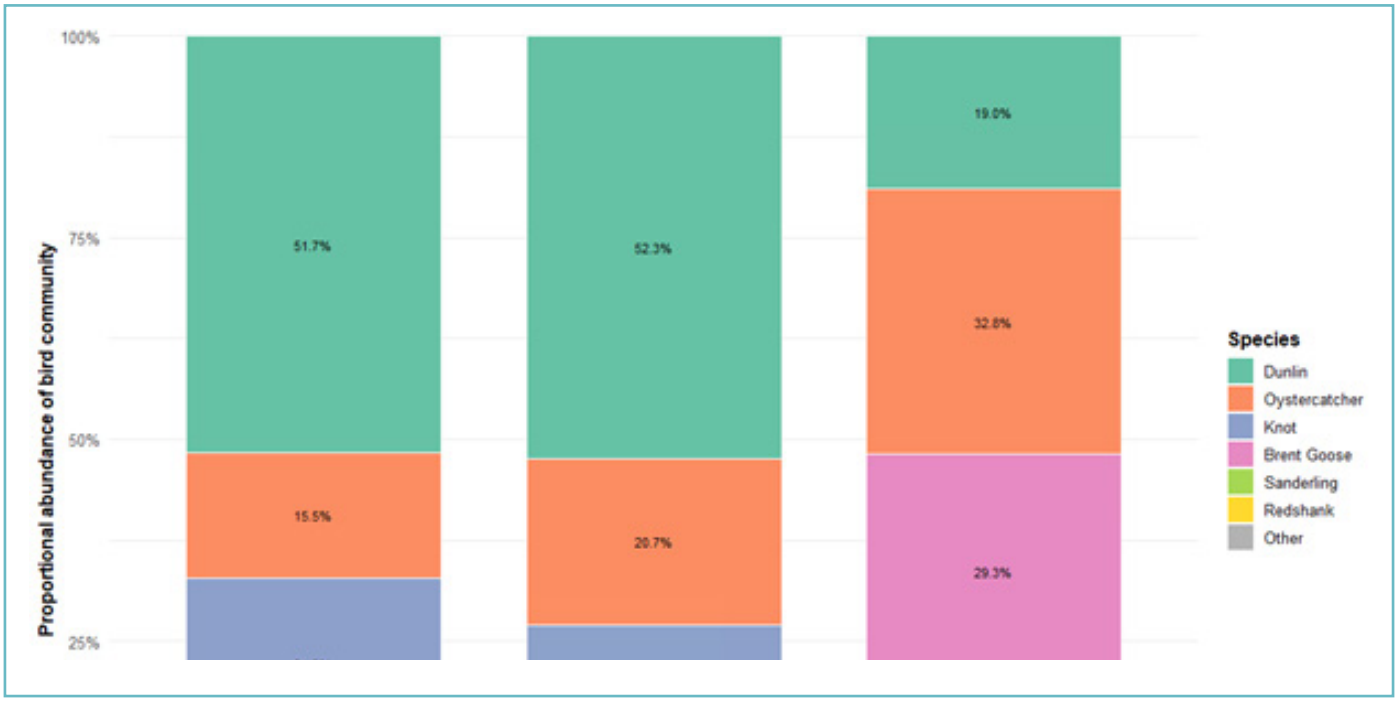


Figure 29 *Proportional abundance of the bird community recorded across the north, mid and south survey sectors between 2022 and 2025. Bars represent community composition standardised to 100% of all birds recorded per sector. The five most abundant species are shown individually, with all remaining species grouped as "Other".*

Ordination (NMDS)

The NMDS ordination provided an acceptable representation of community dissimilarities (stress = 0.199, **Fig.28**), showing partial separation among survey sites with substantial overlap among years, consistent with the PERMANOVA results.

Proportional abundance of bird community across seagrass sites

Bird community composition varied between survey sides over the 2022–2025 period **(Fig.29)**. The north and mid survey sides were strongly dominated by Dunlin, which accounted for just over half of all individuals recorded in both areas (approximately 52%). Knot and

Oystercatcher formed the next most important components, together contributing around 35–40% of the total community, while other species occurred only at low proportions. The pooled other category accounted for 6–7%, indicating that these assemblages were highly concentrated among a small number of species.

In contrast, the south survey side supported a more evenly distributed bird community dominated by Oystercatcher, which was the most abundant species (~33%). Brent Goose (~29%) and Dunlin (~19%) were also prominent components, and the other category was higher (~11%), suggesting greater diversity and a broader spread of less abundant species.

Overall, the results indicate a Dunlin-dominated assemblage in the north and mid survey sides, compared with a more heterogeneous community in the south, where no single species overwhelmingly dominated.

Differences in Abundance of Four Shorebird Species Between Survey Sites

Intertidal habitats support a wide range of waterbirds by providing feeding opportunities that vary spatially with sediment type, vegetation cover, and invertebrate communities. At Spurn, the presence of seagrass and adjacent mudflat habitats has the potential to influence the distribution and abundance of shorebirds through both direct and indirect ecological pathways. Understanding how different species use these sites is important for informing habitat management and assessing the potential benefits of seagrass restoration.

Brent Geese *(Branta bernicla)* are closely associated with vegetated intertidal habitats and are known to forage directly on seagrass fronds. As a result, their distribution is often linked to the availability and extent of suitable vegetation. However, changes in saltmarsh structure, such as the encroachment of Spartina at the upper shore, have previously been suggested to reduce the capacity of sites to support large numbers of waterfowl, including Brent Geese (Percival, 1998). This highlights the importance of monitoring habitat change at Spurn, particularly where Spartina islands are increasing in size and may alter feeding opportunities.

Eurasian Oystercatchers *(Haematopus ostralegus)* are indirectly associated with seagrass habitats through their reliance on benthic invertebrates, particularly bivalves such as cockles. Denser seagrass has been shown to support more abundant macroinvertebrate communities, which can benefit Oystercatcher foraging success (Atrill et al., 2000). Despite this, Oystercatchers are often observed foraging in areas adjacent to dense seagrass, possibly reflecting tidal influences where bare mudflat becomes exposed earlier than vegetated areas. This suggests that site use by Oystercatchers may reflect a balance between prey availability and tidal accessibility, rather than vegetation cover alone.

Red Knot *(Calidris canutus)* are more commonly associated with open mudflats and are often observed in northern areas away from seagrass at Spurn. However, evidence from the Wadden Sea indicates that both Red Knot and Oystercatchers may preferentially use vegetated areas for feeding under certain conditions (Horn et al., 2020). This suggests that Red Knot responses to seagrass presence may be context-dependent, influenced by prey availability, sediment characteristics, and broader site conditions. Examining site-level differences in abundance may therefore help clarify whether seagrass-associated habitats contribute meaningfully to Red Knot use at Spurn.

Redshank *(Tringa totanus)* frequently forage within seagrass habitats at Spurn and appear to be less prevalent in areas without vegetation. Recent evidence suggests that seagrass can moderate the limiting effects of tidal cycles on Redshank foraging opportunities, as well as for other wading birds such as Oystercatcher and Dunlin (Butterworth, 2025). This buffering effect may allow Redshank to exploit feeding areas for longer periods during the tidal cycle, potentially leading to higher site fidelity in vegetated areas.

Given these species-specific differences in foraging ecology and habitat associations, this analysis focuses on comparing the abundance of four shorebird species, Brent Goose, Eurasian Oystercatcher, Red Knot, and Redshank, across three survey sites at Spurn. By examining spatial differences in abundance, the study aims to identify whether particular sites consistently support higher numbers of specific species, thereby providing insight into how habitat characteristics may influence bird distribution within the study area.

Key findings:

- Brent Goose was most abundant at the south site, which supported significantly higher numbers than both the north and mid sites.
- Red Knot was concentrated at the north and mid sites, with very low numbers recorded at the south site.
- Eurasian Oystercatcher showed no clear preference for any one site based on the available data.
- Redshank tended to be more numerous at the south site, but this pattern was not statistically confirmed.

These results indicate that site-specific habitat use differs among species, with some birds showing strong spatial preferences and others displaying more variable distributions.

Brent Goose

Brent Goose abundance differed significantly among survey sites ($p = 0.018$, Fig.30). Pairwise comparisons showed that the south site supported significantly higher Brent Goose counts than both the north and mid sites ($p = 0.043$ for both comparisons). No significant difference was detected between the north and mid sites.

Red Knot

Red Knot abundance also differed significantly among sites ($p = 0.009$, Fig.30). Pairwise tests indicated that the south site had significantly lower Red Knot counts than both the north and mid sites ($p = 0.040$ for both comparisons). The difference between north and mid sites was not statistically significant.

Eurasian Oystercatcher

No significant difference in Eurasian Oystercatcher abundance was detected among survey sites ($p = 0.779$, **Fig.30**). Counts varied substantially between years, particularly at the north site, but no consistent site-level pattern was identified.

Redshank

Redshank abundance did not differ significantly among sites at the 0.05 level ($p = 0.104$, Fig.30). Although higher counts were often recorded at the south site, variability among years meant that this pattern was not statistically supported.

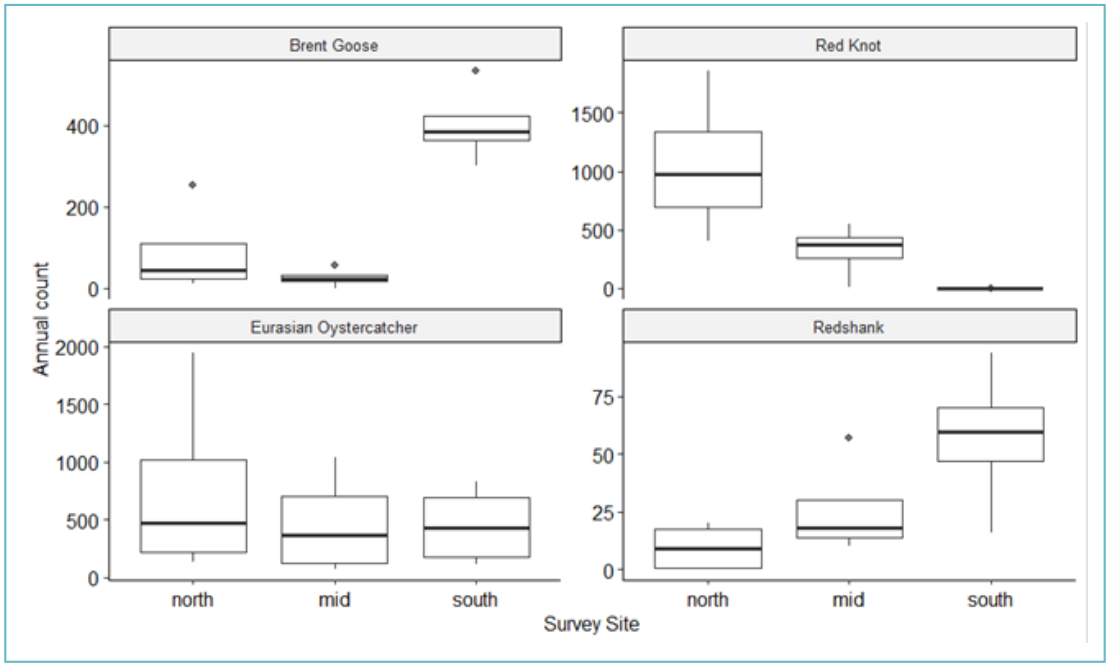


Figure 30 *Mean annual abundance (± SE) of four shorebird species across north, mid, and south survey sites at Spurn (2022–2025). Bars show mean annual counts for each species at each site, with error bars indicating standard error.*

Discussion

Overall spatial and temporal patterns

Bird assemblages at Spurn varied across space and time, reflecting differences in habitat configuration and tidal exposure within a relatively small estuarine landscape. Species richness increased significantly over time across all survey sites, with no significant differences among site categories and no site × year interaction. This indicates that the temporal rise in richness occurred consistently across the study area rather than being driven solely by restoration status. The increase in richness without a corresponding rise in total abundance suggests diversification of the bird assemblage rather than intensification of site use, with additional species incorporated into the community through time without an overall increase in bird numbers.

The relatively weak spatial differentiation among sites may reflect the small spatial scale of the study. All three survey sectors are located within the same estuarine system and in close proximity, allowing birds to redistribute easily between habitats over tidal cycles. Shorebirds are highly mobile and frequently adjust their spatial distribution in response to tidal exposure and prey dynamics (Colwell, 2010). Ecological patterns are strongly scale-dependent (Wiens, 1989; Levin, 1992), and habitat effects are often more detectable across broader landscape gradients than within fine-scale mosaics. The low proportion of variance explained by site in the PERMANOVA analysis is therefore consistent with processes operating at larger spatial scales than the individual restoration sites.

Spatial variation in habitat use

Spatial variation in bird communities likely reflects differences in habitat characteristics and tidal exposure patterns among sites. The north (control) site contains sparse and small seagrass patches and is located adjacent to a large, established saltmarsh meadow. Saltmarshes provide critical feeding habitat, roosting sites, and refuge from predators for wading birds (Bird Aware Solent, 2022), which may contribute to the elevated bird abundances observed at this site. Additionally, the north site is exposed first on the outgoing tide, allowing wading birds early access to feeding grounds, as they likely use the nearby saltmarsh to roost at high tide. Shorebirds actively move outward from the high tide line as mudflats become exposed with the receding tide (Burger & Niles, 2017), maximizing foraging opportunities on newly available habitat. Red Knot *(Calidris canutus)* have been observed to maximize foraging time by exploiting spatial variation in tidal cycles; in the Wadden Sea, individuals extended their feeding period from 12 to 17 hours by initially foraging at sites exposed 2 hours earlier in the tidal cycle, then sequentially moving to progressively later exposing locations (van Gils et al., 2005). This foraging strategy is consistent with the patterns observed at Spurn Point, where surveys conducted at the beginning of the outgoing tide captured knot utilizing the earliest exposed sites (north and mid). The extensive bare mudflat at north site likely supports abundant invertebrate prey, including polychaete worms and bivalves such as Macoma and Cerastoderma species, which are important food resources for red knot and other waders (Piersma et al., 1993). Dunlin (Calidris alpina) were the dominant species at both the north and mid sites, which could be linked to observed sediment type, as dunlin will feed in areas of softer mud where it is easier for their bill to penetrate the sediment, and therefore to access prey species (Kelsey & Hassall 1989 a&b).

The mid site showed intermediate characteristics – it has some seagrass meadows, though less extensive than those at the south site, restored via seed planting beginning in 2023. The proportional abundance of species at this site was similar to the control site, including higher abundance of knot compared to the south site. Red knot (Calidris canutus) are specialized mollusc feeders that forage primarily on mudflats, probing for bivalves, gastropods, and other hard-shelled prey (van Gils et al., 2005). The similarity in community composition between the mid and north sites may reflect comparable mudflat characteristics and invertebrate prey availability, despite differences in seagrass cover.

In contrast, the south site represents the most developed seagrass habitat within the study area.

The early restoration south site contains the largest, densest, and oldest seagrass meadow in the study area, where restoration efforts via seed planting began in 2021–2022. This site is the last to be exposed by the outgoing tide. The statistically higher abundance of brent geese at the south site, compared to the north and mid sites, is likely explained by the presence of extensive seagrass. Brent geese (Branta bernicla) are heavily dependent on seagrass (Zostera spp.) during migration and winter, feeding almost exclusively on these plants in shallow water or at low tide (Ganter, 2000; Percival & Evans, 1997). The importance of seagrass to brent geese is well documented, with historical population crashes coinciding with seagrass wasting disease events in the 1930s (Ganter, 2000).

Higher counts of redshank (Tringa totanus) were often observed at the south site, although in abundance they did not statistically differ to the north and mid sites. In previous studies, redshank have been found at higher densities on seagrass, with seagrass habitats suspected to moderate the limiting effect of tidal changes (Butterworth, 2025). This could explain the higher counts found in the areas with denser seagrass at Spurn Point.

Taken together, the significant responses of Brent Goose and Red Knot illustrate contrasting habitat associations within the estuarine mosaic. These patterns reinforce the importance of maintaining interconnected mudflat, seagrass, and saltmarsh habitats rather than maximising a single habitat type.

Implications and future directions

The distinct patterns of species dominance among sites highlight the importance of maintaining habitat heterogeneity in coastal systems. The strong association between brent geese and the established seagrass meadow at the south site demonstrates that restoration can

successfully create functional habitat for specialist species. Future monitoring presents several opportunities to assess community responses to ongoing restoration. Seagrass planting at the north site beginning in 2026 will allow evaluation of how bird communities respond to habitat change at a currently mudflat dominated site. As seagrass meadows expand at the mid site and patches spread northward, monitoring whether brent geese and other seagrass associated species exhibit broader spatial distribution will provide insight into threshold effects in habitat use, specifically whether a minimum patch size or density of seagrass is required to attract and support these populations. Long term monitoring will be essential for detecting temporal trends as restoration matures and for identifying potential trade-offs between seagrass associated species and mudflat specialists such as knot and dunlin.

Seagrass Biodiversity uplift – Finfish

Seagrass meadows are ecologically important habitats that support diverse infaunal communities and provide structural refuge for numerous fish species, functioning as critical nursery grounds (OSPAR Commission, 2008). The presence of *Zostera noltii* beds has been shown to increase species richness of transient fishes on tidal flats in the Wadden Sea and to influence the composition of juvenile fish assemblages (Polte & Asmus 2006a). In addition to their nursery function, Z. noltii meadows also act as important spawning habitats; densities of herring *(Clupea harengus)* spawn have been recorded at approximately 20 times higher in seagrass beds compared to adjacent brown algal patches (Polte & Asmus 2006b). Beyond supporting abundance and recruitment, seagrass meadows shape the structural and functional composition of fish communities. A significant shift in fish community structure was observed following the collapse of a Z. noltii meadow in the Mira Estuary, Portugal, demonstrating the sensitivity of fish assemblages to seagrass presence and condition (Castro et al. 2019).

Together, this evidence indicates that fish abundance, species richness, recruitment patterns, and functional composition are closely linked to seagrass extent and health, making fish communities a robust ecological indicator of restoration success.

Fish Survey Method

Juvenile finfish surveys were conducted at Spurn Point using a microseine net to assess patterns in fish abundance and species richness across contrasting seagrass habitats **(Fig.31)**. Two habitat treatments were surveyed: established seagrass and restored seagrass (seed planting took place 2021-2022). Sampling was conducted across two years (2024–2025) during peak juvenile finfish presence in shallow coastal habitats, with surveys undertaken in July–August 2024 and May–July 2025. This design captured inter-annual variability and seasonal progression from spring to mid-summer, although seasonal coverage was broader in 2025 than in 2024. At each site and survey date, a microseine net was deployed three replicate times. All juvenile finfish captured were identified to species where possible, and the number of individuals per species was recorded for each deployment.





Figure 31 *The team seine netting at Spurn Point & a tray of gobies, flatfish and shrimp caught in the seagrass restoration site at Spurn Point.*

Spatial and Temporal analysis of fish species richness and abundance

Key findings

Finfish abundance and species richness did not differ between restored and natural seagrass sites. Total finfish abundance declined significantly over time across all sites, while species richness remained stable. This decline in overall abundance was driven predominantly by goby family Gobiddae, which showed a marked reduction in numbers over time. In contrast, flatfish/flounder family Pleuronectidae, increased in abundance in 2025 compared to 2024 **(Fig.32).**

Overall finfish abundance did not differ between restored and natural seagrass sites (p = 0.807, **Fig. 33**). Similarly, species richness showed no significant difference between site types (**Fig. 34**, p = 0.796). These results indicate that, during the study period, restored seagrass supported comparable numbers of individual fish and species to natural seagrass.

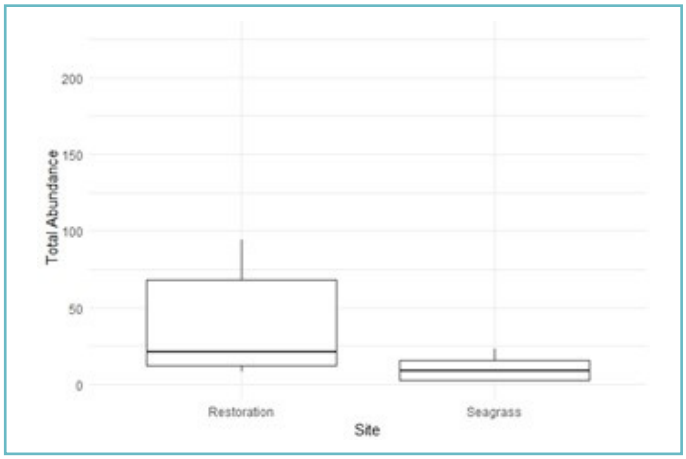


Figure 33 *Total abundance at restoration and natural seagrass sites. Boxplots show the median (central line), interquartile range (boxes), and 1.5× interquartile range (whiskers).*

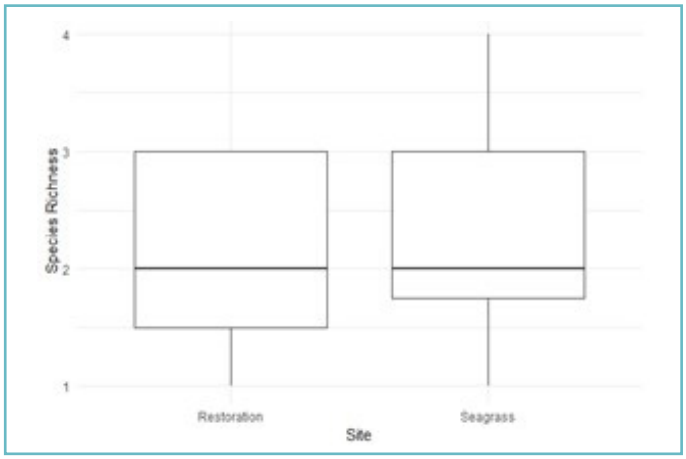


Figure 34 *Total species richness at restoration and natural seagrass sites. Boxplots show the median (central line), interquartile range (boxes), and 1.5× interquartile range (whiskers).*

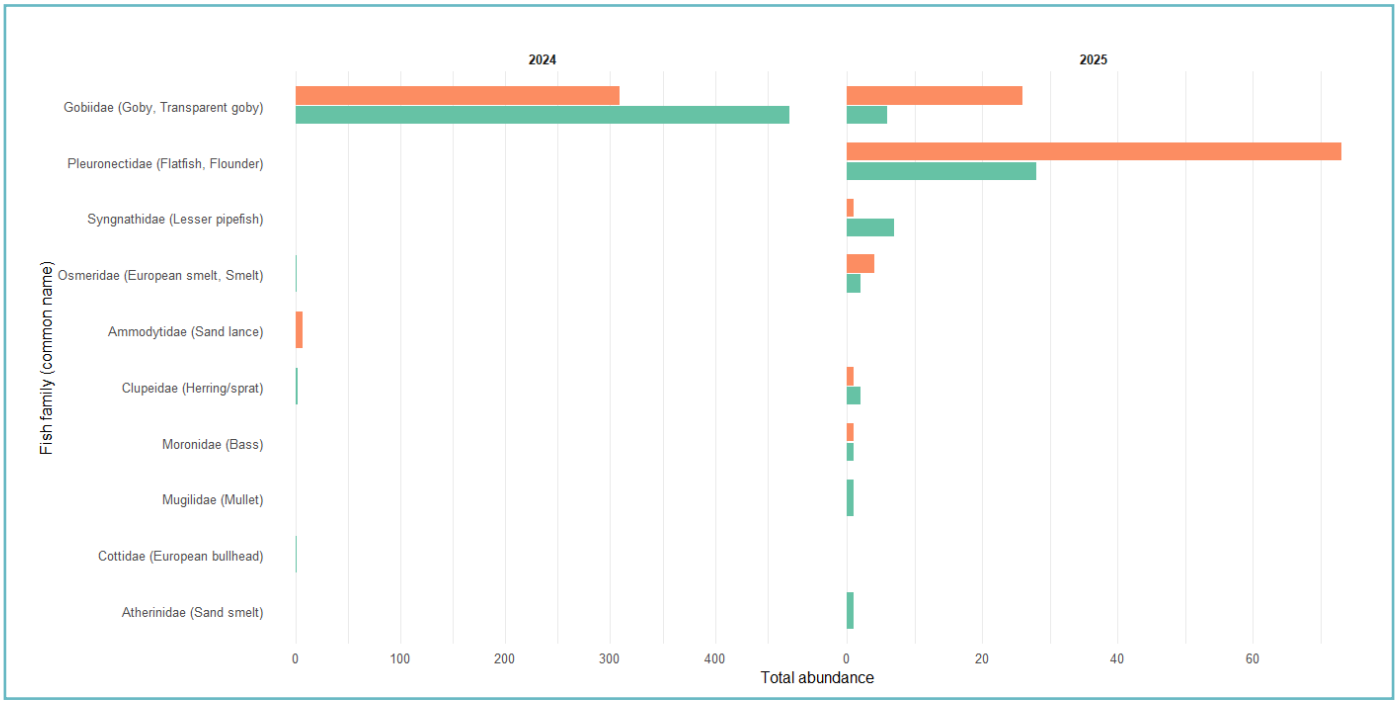


Figure 32 *Total abundance of fish families recorded at Spurn Point in 2024 and 2025, comparing restoration sites and natural seagrass habitats. Bars represent the sum of individuals (total abundance) for each fish family within each year and habitat. Fish families are labelled on the y-axis with their corresponding common names. Colours indicate habitat type: green = natural seagrass, orange = seagrass restoration site. Panels are separated by year to facilitate comparison of family composition and relative abundance between habitats and sampling years.*

Total finfish abundance declined significantly over time across all sites ($p < 0.001$, **Fig. 35**). This decline was driven primarily by a marked reduction in goby abundance (family Gobiidae), indicating that the observed decrease does not reflect declines across the entire finfish community. In contrast, flatfish and flounder (family Pleuronectidae) increased in abundance in 2025 compared with 2024; however, this increase was masked in the overall abundance trend by the dominant decline in gobies. Although species richness showed a slight increasing trend, this pattern was not statistically supported ($p = 0.111$, **Fig. 36**), suggesting that the number of species present remained relatively stable despite declining abundance.

There was no significant interaction between year and site for total abundance or species richness (both $p > 0.05$), indicating that temporal changes in abundance and species richness were consistent across sites.

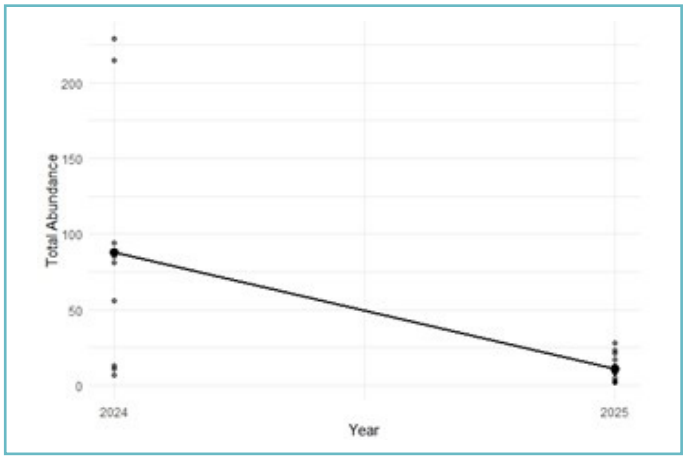


Figure 35 *Temporal trend in total abundance across the study period. Points represent observed total abundance values by year. The solid line shows the fitted mean from a negative binomial model.*

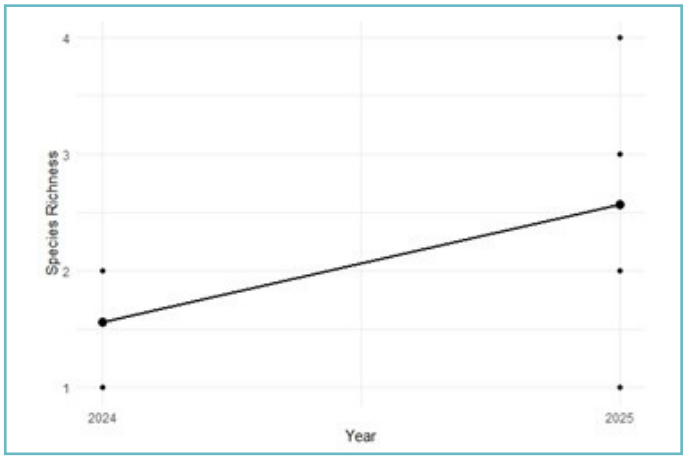


Figure 36 *Temporal trend in species richness across the study period. Points represent observed total abundance values by year. The solid line shows the fitted mean from a negative binomial model.*

Finfish community composition

Key findings:

- Fish community composition differs between restored and natural seagrass habitats and changes through time. Restored and natural seagrass habitats follow different temporal trajectories.
- Restored site was more variable in community composition than natural seagrass sites, suggesting ongoing community development.
- Multivariate differences are driven by species identities, relative abundances, and variability, not by the number of species present.

Results

Differences in fish community composition among sites

PERMANOVA revealed a significant effect of habitat and time on fish community composition ($R^2 = 0.433$, $p = 0.001$). This indicates that habitat type and year together explained approximately 43% of the variation in fish community composition.

Marginal PERMANOVA tests showed that the Habitat* Year interaction was significant ($R^2 = 0.090$, $F = 3.03$, $p = 0.012$). This result shows that fish communities changed through time differently in restored and natural seagrass habitats. In other words, temporal change in community composition depended on habitat type.

Differences in within-group variability

PERMDISP revealed a significant difference in dispersion between habitats ($F = 9.85$, $p = 0.006$). This indicates that restored sites were more variable in community composition than natural seagrass sites. Therefore, differences detected by PERMANOVA reflect differences in community structure, including both shifts in composition and differences in heterogeneity among sites.

Diversity, and evenness

Shannon diversity and Evenness increase through time (all $p<0.005$),but did not differ between restored and natural seagrass habitats (all $p>0.05$). In other words, as time went on, the communities became more diverse and less dominated by just a few species.

Ordination (NMDS)

The NMDS ordination provided a good representation of fish community dissimilarities (stress = 0.079, **Fig. 37**) and showed that fish communities changed through time differently in restored and natural seagrass habitats, indicating that temporal change in community composition depended on habitat type, consistent with the PERMANOVA results.

Functional and feeding guilds

Functional and feeding guilds have been used in the Transitional Fish Classification Index (TFCI) to inform the assessment of the fish fauna within an estuary (Water Framework Directive – United Kingdom Technical Advisory Group, 2014 & Elliot & Hemingway, 2002). Functional and feeding guilds help us better understand community composition by focusing on the ecological role's species perform rather than just their taxonomic identity. Grouping species into categories such as benthic invertivores, zooplanktivores, or piscivores allows us to interpret patterns in energy flow, nutrient cycling, and trophic structure. This approach can reveal functional changes that species lists alone may miss, such as shifts linked to disturbance, habitat restoration, or habitat complexity. By examining guild structure, we gain clearer insight into ecosystem functioning, resilience, and how environmental factors shape biological communities.

Functional guilds

Functional guilds reflect species' life-history strategies and habitat use:

- **ER – Estuarine Resident:** Species that complete their entire life cycle within estuarine or coastal environments and are typically associated with shallow, sheltered habitats. These species are generally tolerant of fluctuating salinity and temperature and often dominate early-stage or simplified assemblages.
- **AN – Anadromous:** Species that hatch in freshwater, migrate to the ocean to grow and mature, and then return to freshwater to spawn. Their presence reflects connectivity between estuarine and marine habitats and often increases as habitat complexity and accessibility improve.
- **FW – Freshwater:** Species primarily associated with freshwater environments that occasionally occur in estuarine or coastal habitats, usually at the margins of their distribution or during specific life stages.
- **MJ – Marine Juvenile:** Juvenile stages of marine species that use estuarine or shallow coastal habitats as nursery areas. This guild is commonly associated with increased habitat complexity and nursery function.

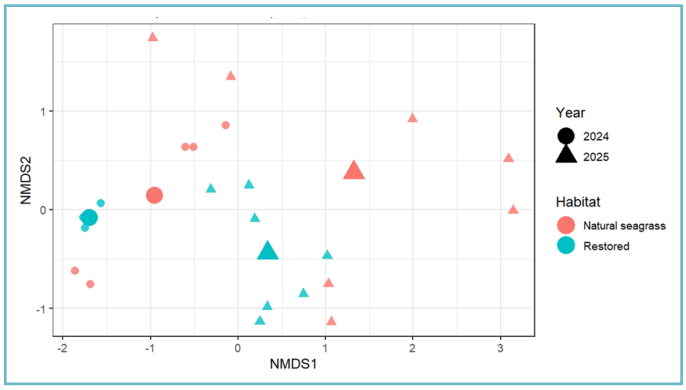


***Figure 37 N**MDS ordination of fish community composition based on Bray–Curtis dissimilarities from raw abundance data. Points represent individual samples, coloured by habitat type (natural and restored seagrass) and shaped by year (2024 and 2025). The low stress value (0.079) indicates a good representation of community dissimilarities.*

Key findings

From 2024 to 2025, both Restoration and Seagrass sites shift from near-complete dominance by ER to a more diverse community composition. While ER remains the dominant guild in 2025, its relative abundance decreases, and AN and MJ increase-especially in the Seagrass habitat, where the change is more pronounced. Overall, the pattern indicates increasing functional diversity over time **(Fig.38).**

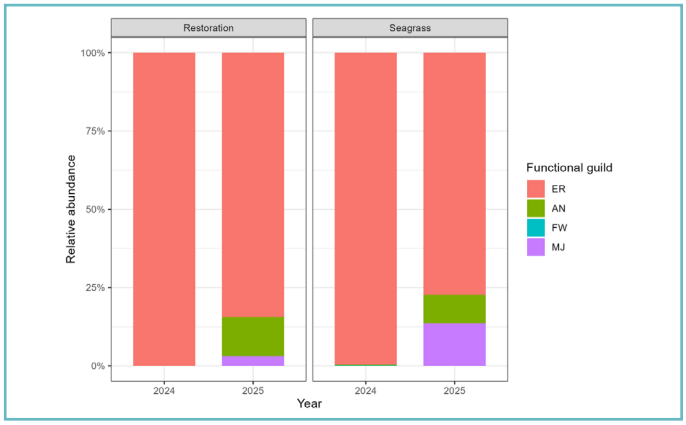


***Figure 38** Mean relative abundance of functional guilds on Seagrass Spurn sites by year.*

Feeding guilds

Pre-liminary analysis

Feeding guilds group species into categorises according to their principal feeding strategies within estuarine and coastal systems. Species were classified as benthic invertivores (BI), zooplanktivores (Z), detritivores (D), or piscivores (P).

- **BI - Benthic invertivores:** Feed mainly on bottom-dwelling invertebrates and crustaceans.
- **Z – Zooplanktivores:** Consume zooplankton in the water column.
- **D – Detritivores:** Feed on detritus and associated microorganisms.
- **P- Piscivores:** Predators that primarily eat other fish.

Key findings

Overall, fish feeding guild structure shifted from a simplified, benthic-invertivore-dominated assemblage in 2024 to a more trophically diverse assemblage including zooplanktivorous and piscivorous species in 2025 **(Fig. 39)**. This shift differed between habitats, with restoration sites showing clearer evidence of convergence toward a stable and diversified feeding guild structure. These results provide strong evidence that restoration habitats are developing increased trophic complexity over time, consistent with a positive ecological trajectory.

Results

Feeding guild composition differed significantly among treatment–year combinations (R^2 = 0.62, p = 0.026, **Fig. 39**), indicating that changes in trophic structure over time differed between restoration and seagrass habitats, with over 60% of the variation in feeding guild composition explained by the interaction between treatment and year. Tests of multivariate dispersion showed no significant differences among groups (p = 0.29), confirming that observed differences were driven by shifts in feeding guild composition rather than differences in variability among samples.

In 2024, fish assemblages in both restoration and seagrass habitats were strongly dominated by benthic invertivores, with very limited representation of other feeding guilds. Feeding guild richness was low, and assemblages were compositionally similar between habitats, indicating limited trophic differentiation during the first sampling year. Ordination results showed that samples from 2024 clustered closely along a single dominant gradient, reflecting this strong functional dominance. By contrast, feeding guild structure in 2025 showed clear evidence of trophic diversification. Zooplanktivorous and piscivorous guilds were recorded across multiple sampling dates, resulting in increased feeding guild richness and greater compositional differentiation between habitats. PCoA indicated that most of the variation in feeding guild composition was explained by a primary axis representing a transition from benthic invertivore dominance toward a broader trophic structure incorporating pelagic and higher-trophic-level feeders **(Fig. 40)**. Restoration site in 2025 clustered more tightly in ordination space and had lower distances to group centroids than seagrass habitats, reflecting greater temporal consistency in feeding guild structure. Seagrass habitats were more variable, especially early in the study. Overall, while trophic complexity increased in both habitats, restoration areas showed a more coherent and directional compositional shift.

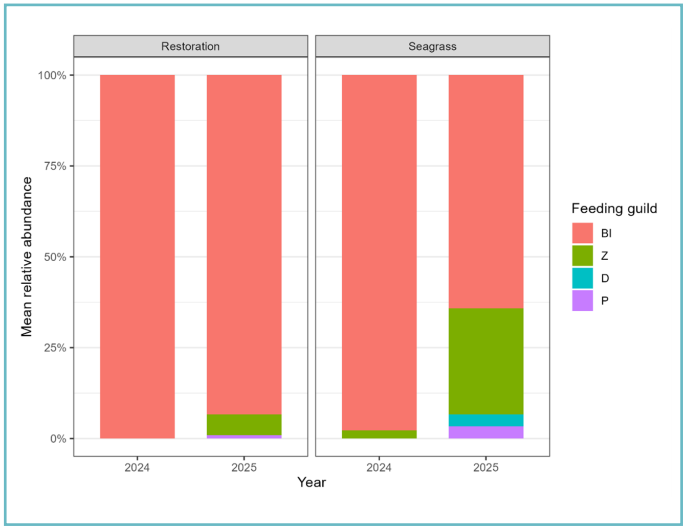


Figure 39 *Mean relative abundance of feeding guilds by year and site.*

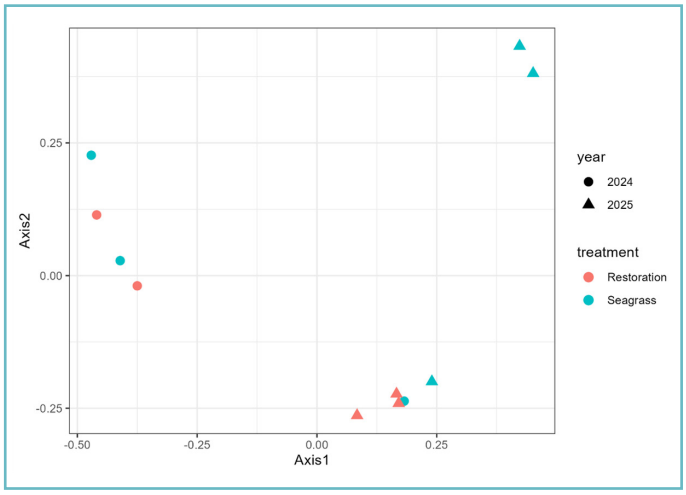


Figure 40 *Principal coordinates analysis (Bray–Curtis) of feeding guild composition by treatment and year. Axis 1 represents a trophic gradient from benthic invertivore dominance to increased feeding guild diversity. The ordination is supported by the dominance of the first axes based on eigenvalues.*

Fish age analysis

Seagrass meadows are widely recognised as important nursery habitats, providing juveniles with reduced predation risk, enhanced food availability, and higher growth rates compared to unvegetated habitats (Heck et al., 2003). *Zostera noltii* has also been shown to influence the composition of juvenile fish assemblages (Polte & Asmus 2006a), making age structure a meaningful indicator of habitat function.
To assess nursery use, individual fish were measured for total length (TL), with up to three individuals per species recorded per survey. Fish were classified as juvenile or adult using species-specific length thresholds obtained from published literature and online databases (see reference list). These classifications were used to calculate the proportion of juveniles and adults at each site and year for subsequent analysis.

Results

Key findings

- Fish abundance differed mainly by life stage, with juveniles far more abundant than adults across all sites.
- Habitat type had little effect: juvenile abundance was slightly higher in restoration sites, while adult abundance was similar in restoration and seagrass habitats.
- Overall, both habitats were strongly juvenile-dominated, suggesting restoration sites support juvenile fish as effectively as natural seagrass but do not increase adult abundance.

Life stage was the strongest predictor of fish abundance, with adults far less abundant than juveniles overall ($p < 0.001$, **Fig. 41**). Juvenile abundance showed weak evidence of being higher in restoration than seagrass sites ($p = 0.063$, Fig. 41), whereas adult abundance did not differ between treatments ($p = 0.80$), and the life stage × treatment interaction was not significant ($p = 0.79$, Fig. 41). Within both habitats, juveniles were an order of magnitude more abundant than adults (restoration: 13.7×, $p < 0.001$; seagrass: 11.6×, $p < 0.001$, **Fig. 41**).

Overall, fish assemblages were strongly juvenile-dominated, with restoration sites supporting juvenile abundances comparable to natural seagrass but little response in adults.

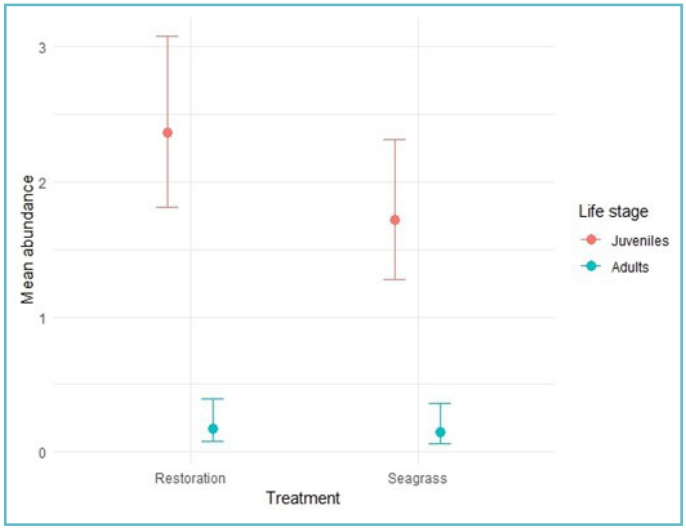


Figure 41 *Mean fish abundance (± SE) by life stage and habitat treatment.*

Discussion

Trends in fish abundance and community composition

The decrease in fish abundance shown by these results is driven by a decrease in the abundance of gobies. Their abundance dropped significantly between 2024 and 2025, and there could be several potential causes for this. The Met Office stated that 2025 was the warmest year on record for the UK, with below average rainfall. Drought causes higher salinities in estuarine environments due to reduced freshwater input (Scharler et al., 2022).

Compared to the sand goby which prefer deeper, higher salinity marine environments, common gobies tolerant to a wide range of salinities and temperatures (Dolbeth et al., 2007), and are most likely the species found at Spurn Point, preferring estuaries and saltmarsh (Riley, 2003). Therefore, when salinities at the estuary mouth are higher, they may disperse further upstream to take advantage of additional food sources and to avoid competition with sand gobies as they have a high diet overlap (Dolbeth et al., 2007; Leitão et al., 2006). A prolonged decrease in salinity was shown to lead to an increase in fecundity and egg size of common gobies (Pampoulie et al., 2000). Therefore, a prolonged increase in salinity may result in the opposite, lowering the fecundity per spawning event and limiting recruitment. Alternatively, the gobies may be travelling further upstream to areas of lower salinity to reproduce there instead.

In contrast, juvenile flatfish increased in abundance in 2025. Juvenile flatfish are highly associated with bare mudflat, using it as a nursery area at high tide (OSPAR Commission, 2009). This increase was seen particularly in the restored seagrass meadow, which while planting is still underway remains patchy with large areas of bare mud, and they therefore may be using these patches of mud more. Commercially important flatfish such as plaice have been recorded in abundance utilising areas of seagrass meadow as a nursery for juveniles (Bertelli & Unsworth, 2014), as well as areas of mud and sand adjacent to seagrass meadows (Gibson et al., 1998). Our results show that juvenile flatfish, whilst typically associated with mudflat, may be utilising seagrass as a juvenile nursery to a greater extent than previously thought.

These changes in abundance represent a change in the structural composition of the seagrass meadows. Specific seagrass traits such as structural complexity and seagrass cover have been shown to drive changes in fish assemblages (Jones et al., 2021) and therefore increases in seagrass cover through restoration may be promoting the presence of different fish. This may be in combination with other environmental factors that may be drivers behind fish abundance, in particular that of gobies.

Functional and feeding guilds

Analysis of the functional guilds show us that fish assemblages are dominated by estuarine residents (ER) such as gobies, and flatfish such as flounder. Marine juveniles and anadromous fish make up the rest of fish assemblages found over the seagrass at Spurn Point. The presence of marine juveniles (MJ) such as sand smelts, bass, herring, sprat, and plaice reinforces the fact that the seagrass meadow, both established and restored, is functioning correctly. The only anadromous (AN) species found in our surveys was European smelt, which move into rivers and estuaries to spawn (Barnes et al., 2008). European smelt were found both on the restored seagrass meadow and established meadow, suggesting that juveniles are utilising the meadow after spawning, once again reinforcing the meadow's ecological functioning.

Analysis of the feeding guilds shows us that fish feeding on benthic invertebrates dominate the fish assemblages within the seagrass meadow. Mudflats are known to support large amounts of benthic invertebrates (OSPAR Commission, 2009), however seagrass meadows have been shown to also be a refuge for invertebrates such as crustaceans and polychaetes (Whitlow & Grabowski, 2012). The study by Whitlow & Grabowski (2012) showed that seagrass beds and the surrounding mudflat have much higher abundances of invertebrate prey, compared to areas of bare mudflat further away. This will therefore attract species which feed on these invertebrates and explains why we have recorded large numbers of these in the seagrass meadows at Spurn Point. This may also be an additional explanation as to why we saw an increase in juvenile flatfish. Juvenile flounder were recorded feeding on a large variety of macroinvertebrates while in a nursery area of an estuary (Mendes et al., 2014). Therefore, if the seagrass meadow is supporting large numbers of the prey invertebrates in comparison to the surrounding mudflat, this would be a preferential area to feed for the juvenile flatfish.

Uninterrupted seagrass habitats have been shown to have high levels of productivity, and support diverse zooplankton assemblages (Ismail et al., 2021). The diversity of zooplanktivores recorded over the established seagrass meadow included European smelt, herring, sprat, lesser pipefish, and sand smelt. The presence of these species indicates that the meadow is functioning and supporting high levels of productivity and zooplankton, and in turn the presence of important fish species.

Age structure of fish assemblages

Our results show a fish assemblages dominated by juvenile fish, with 87% of the fish measured and identified to species level in 2025 being juveniles. This is in line with what we would expect to see in a seagrass meadow, due to their role in acting as a nursery habitat (Polte & Asmus, 2006) and aligns with results from other studies done on *Zostera noltii* beds (Polte et al., 2005). This once again reinforces that the seagrass meadow at Spurn Point is functioning well and supporting large numbers of juvenile fish.

Seagrass Spurn eDNA

Environmental DNA (eDNA) monitoring undertaken in September 2025 to assess biodiversity within the seagrass restoration area in comparison to an adjacent sandy/muddy intertidal control site (Full report – Appendix 1). Sediment and water samples were analysed to characterise microbial, invertebrate and vertebrate communities present within the seagrass habitat.

Sediment eDNA analysis recorded higher overall taxonomic richness within the seagrass restoration area compared with the control site. The seagrass area supported diverse microbial communities and a broad range of benthic invertebrates, including annelids, molluscs, arthropods and nematodes. In contrast, the sandy/muddy intertidal control site recorded lower overall taxonomic richness, consistent with the comparatively uniform nature of unvegetated sediments.

Water eDNA detected a similar number of fish and bird taxa across the seagrass and control sites, likely reflecting tidal exchange and shared use of the wider estuarine environment. In total, 28 fish species were recorded at Spurn Point. The critically endangered European eel *(Anguilla anguilla)* was detected within the seagrass restoration area but was not recorded at the control site. Bird species of conservation concern were also detected, including Eurasian oystercatcher *(Haematopus ostralegus)*, recorded across Spurn sites, and Bar-tailed godwit *(Limosa lapponica)*, which was detected within the seagrass restoration area. These detections indicate use of the seagrass and adjacent intertidal environment by mobile vertebrate species. Overall, the September 2025 survey indicates measurable differences in taxonomic richness between the seagrass restoration area and adjacent sandy/muddy intertidal habitat.

Seagrass Water quality

Water quality monitoring was undertaken at Spurn to compare restored and established seagrass meadows with a mixed sandy–mudflat control site. The objectives were to evaluate estuarine condition, assess ecosystem health, detect potential pollution, and examine differences in key water quality parameters among habitats that may be associated with restoration status.

First key finding is potential correlation between air temperature and limited seed availability in 2025. Year 2025 was among the top three warmest years on record in the UK, with Met Office data showing it joined 2022 and 2023 in the warmest ranks since records began in 1884 (Met Office, 2026). In *Zostera noltii*, the timing and duration of flowering and seed production correlate with seasonal temperature patterns, suggesting that temperature is an important environmental cue influencing reproductive phenology (Accoroni et al, 2021). Three of the four UK heatwaves occurred during critical phases of *Zostera noltii* sexual reproduction. The second (27 June–2 July) and third (9–15 July) heatwaves aligned with low tides towards the middle of the day, likely increasing thermal and desiccation stress on exposed plants. The fourth (11–17 August) heatwave occurred during a spring tide, also exposing the meadow during peak temperatures. Historically, most seed collection has occurred in September, indicating that these extreme conditions likely had an impact on flowering and seed development **(Fig.42)**.

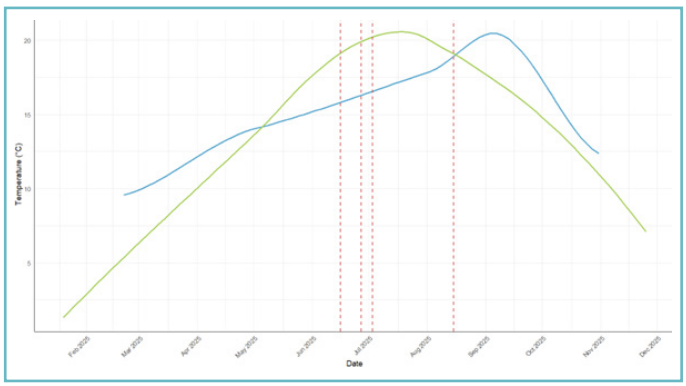


Figure 42 *Temporal trends of seawater (blue line) and air (green line) temperature recorded through water quality monitoring in 2025.*

In addition to high temperatures, the year 2025 was relatively dry, receiving approximately 90% of the long-term average rainfall. This made it the driest year since 2010, in marked contrast to the comparatively wetter conditions recorded in 2023 and 2024 (Carbon Brief, 2026). Reduced freshwater input may therefore have influenced *Zostera noltii* seed production by altering salinity conditions. Germination and early seedling development in Zostera spp. are sensitive to salinity and temperature, with lower salinities enhancing germination and elevated salinity or thermal stress reducing viability (Hootsmans et al., 1987; Greve et al., 2004; van Katwijk et al., 2016). As part of our ongoing monitoring, we will more closely track seed production annually alongside seasonal density changes, this combined with environmental data will give us a better understanding of what could affect seed production at the Spurn site and allow for better harvest planning.

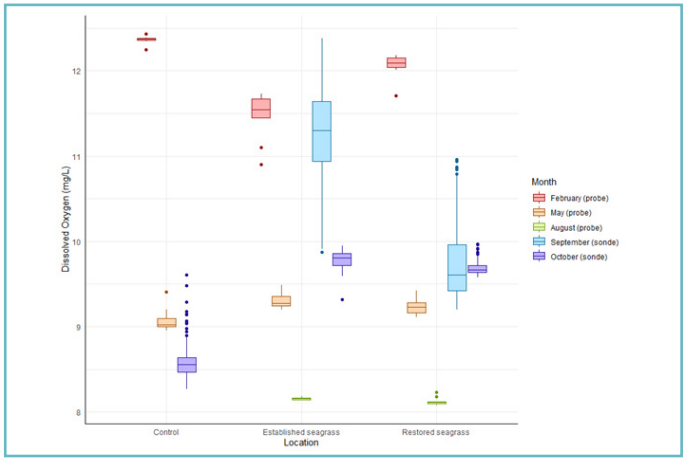


Figure 44 *Dissolved oxygen levels (mg/L) measured throughout 2025 at the established seagrass site, restored seagrass site, and control, using both a probe and a sonde. Control data is missing for August and September.*

Finally, variability in dissolved oxygen (DO) across months was observed, particularly high levels in February and September **(Fig.44)**. The elevated DO recorded in February is likely associated with a large diatom bloom observed near the seagrass meadow at Spurn Point **(Fig. 45)**. Although the specific species present was not identified and its ecological impact remains unknown, phytoplankton blooms play a significant role in coastal and estuarine ecosystem functioning (Carstensen et al., 2015). Across Europe, early spring blooms typically occur between February and March and are frequently dominated by diatoms (Carstensen et al., 2015). Increased primary production during such blooms can enhance oxygen concentrations in the water column through photosynthesis.

In September, dissolved oxygen levels were notably higher in the established seagrass meadow compared to the restored site, which may reflect greater seagrass cover and enhanced photosynthetic activity within the more mature meadow. Seagrass ecosystems are highly productive and can generate substantial oxygen fluxes to the surrounding water through photosynthesis, with productivity closely linked to canopy density and biomass (Duarte et al., 2010; Hemminga and Duarte, 2000). The decline in DO observed in October may be associated with increased rainfall and runoff, which can elevate turbidity and reduce light penetration. Light availability is a primary control on seagrass photosynthesis and estuarine primary production (Cloern, 2001; Kemp et al., 2004), and reductions in water clarity are known to limit photosynthetic oxygen generation in submerged vegetation such as seagrass (Orth et al., 2006).



Figure 45 *Photographs of a diatom bloom seen at Spurn Point in February 2025. Credit: Georgia Bennett.*

Seagrass Studies – 2026 Programme Overview

In 2026, we will deliver a coordinated programme of research to strengthen and refine seagrass restoration at Spurn Point. These studies address seed biology, ecosystem function, habitat mapping, and planting techniques to improve long-term resilience and restoration success **(Table 3)**. We will scope out further potential seagrass restoration sites across the estuary, including working with relevant landowners and partners. We will also consider 'industrial' locations and the use of innovative technology to enable restoration within these challenging settings.

Table 3 *The 2026 adaptive research programme designed to improve restoration efficiency, enhance spatial monitoring accuracy, and assess functional recovery of restored seagrass meadows.*

Theme	What we measure	How we measure it	Scientific aim
Drone-Based Seagrass Mapping (NDVI Refinement) – Project Seagrass	Seagrass extent; density classes; small patch detection	High-resolution drone surveys; NDVI modelling; supervised classification to distinguish seagrass from mud/sand; expanded ground-truth quadrats	Improve precision of large-scale spatial monitoring and detect emerging patches
Microbiome / Functional Recovery Study – PhD David Terrey	Sediment microbial community composition (restored vs natural vs bare sediment)	Sediment cores; high-resolution eDNA sequencing	Assess functional equivalence of restored systems at microbial level
International Seed Germination Study (2026)- University of Groningen (Netherlands)	Seed viability; germination under reduced salinity conditions	Controlled laboratory germination trials	Identify environmental triggers influencing germination success to optimise seed-based restoration
Single-Shoot Planting Trial (MSc Study – Georgia Bennett)	Establishment success; survival; early growth	Experimental single-shoot planting design	Assess effectiveness of planting technique for restoration
Transplant Configuration & Density (MSc Study – Georgia Bennett)	Survival; lateral spread; patch formation under varied clump sizes & layouts	Controlled transplant configuration experiment	Identify optimal transplant configuration for rapid meadow consolidation

Oysters

Background

Globally, oyster reefs are among the most threatened marine habitats, with an estimated 85% lost worldwide due to overexploitation, habitat degradation, disease, and declining water quality (Beck et al., 2011). Once widespread along temperate coastlines, oysters have experienced dramatic population declines, with consequences for estuarine ecosystems including reduced water quality, diminished biodiversity, and weakened ecosystem resilience (Lotze et al., 2006). European seas are among the most heavily impacted marine environments, with centuries of intensive exploitation and industrialisation driving severe declines in native oyster populations across much of their historical range (Airoldi & Beck, 2007).

Historically, native oysters were a critical component of the Humber estuary ecosystem, but overfishing and poor water quality associated with industrialisation led to their regional extinction by the 1950s (Pogoda et al. 2019, **Fig. 46**). Their absence has removed not just the species, but the ecosystem services oysters provide. As ecosystem engineers, native oysters improve water quality, create structurally complex habitats, and support biodiversity (Hughes et al 2023). Through reef formation, oysters generate three-dimensional structures that enhance habitat complexity in otherwise soft-sediment environments (zu Ermgassen et al., 2012). Each adult oyster can filter up to 200 litres of water per day, reducing turbidity and supporting healthier, more resilient estuarine conditions (Marine Conservation Society, 2025).

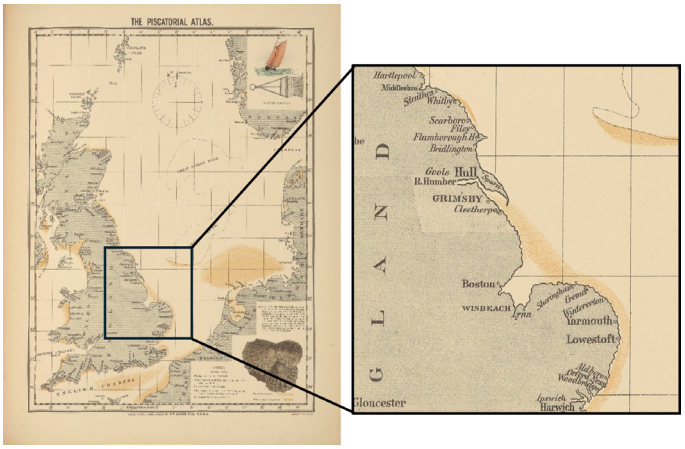


Figure 46 *Oyster reef locations depicted in Olsen's Piscatorial Atlas (1883), illustrating the historic extent of oyster habitats and nearby fisheries in the North Sea.*



Figure 47 *Intertidal oysters at the Brancaster Bay, Norfolk (Author unknown)*

Oyster reefs also provide substrate, refuge, and feeding opportunities for a wide range of species. In UK waters, reefs support diverse invertebrates such as polychaete worms, amphipods, crabs (e.g., *Carcinus maenas*), sponges, bryozoans, and ascidians, as well as juvenile fish including gobies (*Pomatoschistus spp.*), blennies, and European seabass (*Dicentrarchus labrax*) (Natural England, 2024). Reefs may also facilitate the recovery of other bivalves, including blue mussels (Mytilus edulis), further enhancing ecosystem function (Smaal A.C., Kamermans, P. and Kleissen, F. 2017). These benefits are currently lost from the Humber estuary and the North Sea, highlighting the potential ecological value of reintroducing native oysters.

Native oysters *(Ostrea edulis)* are demonstrably both an intertidal and subtidal species **(Fig. 47)**, despite a widespread contemporary perception that they are restricted to subtidal waters. Multiple authoritative sources confirm that O. edulis historically occupied habitats ranging from the low intertidal zone to deeper subtidal areas. Habitat reviews explicitly state that the species occurs "from the low intertidal to approximately 80 m depth" (MarLIN, 2019). Peer-reviewed studies have documented functioning intertidal oyster populations forming three-dimensional reef structures, demonstrating that oysters can persist, grow, and provide habitat above chart datum (Kregting et al., 2020; Smyth et al., 2023). Historical ecological research provides further compelling evidence: classic nineteenth-century accounts of oyster reef ecology describe oysters as integral components of shallow and intertidal systems, including trophic interactions with shorebirds. Notably, Möbius' foundational work on oyster banks in the German Wadden Sea describes oyster reefs as accessible to predators such as oystercatchers, implying regular exposure within the intertidal zone (Möbius, 1877). This historical evidence is synthesised and cited in modern assessments of oyster reef collapse, including zu Ermgassen et al. (2024), which draw directly on Möbius and other early ecological sources to demonstrate that oysters formerly occupied intertidal habitats across north-west Europe. While oysters have largely disappeared from intertidal areas within living memory due to overexploitation, pollution, and habitat modification, the absence of recent experience does not reflect historical reality. Instead, a substantial body of historical, ecological, and contemporary empirical evidence demonstrates that native oysters were once widespread and ecologically functional components of intertidal ecosystems.

Native oyster habitats are listed as a protected sub-feature of mixed-sediment substrates (DEFRA, 2025), yet they are not currently designated in the Humber due to historical loss. While current legislation does not specifically protect native oysters in the Humber-largely because they were already absent when protections were introduced. This does not mean they do not belong here, particularly within the mosaic of intertidal habitats that characterise estuarine systems. Restoring oysters in this context can reinstate critical ecosystem functions and support future habitat recognition and protection.

Consents, Delivery and Monitoring Considerations

From a delivery and operational perspective, intertidal oyster restoration is more practical and cost-effective. Sites are accessible at low tide, reducing the need for vessels, specialist equipment and dive teams, and lowering costs and health & safety risks. This accessibility also enables volunteer-led deployment and monitoring, increasing stakeholder participation, raising awareness of coastal habitat degradation, and fostering local stewardship.

Additionally, intertidal oyster restoration typically involves a simpler consenting pathway than subtidal deployment. Intertidal sites are often on land owned by private landowners or managed by organisations such as Natural England, meaning permission is primarily required from the landowner and relevant authority. In contrast, subtidal projects usually require a marine licence from the Marine Management Organisation and seabed agreements with The Crown Estate, alongside wider stakeholder consultation.

Wilder Humber Intertidal Oyster Experiment

Yorkshire Wildlife Trust, in collaboration with PhD researcher Fiona Woods (University of Southampton), secured consent in May 2025 to deliver the UK's largest experimental intertidal native oyster reintroduction to date. In 2025, approximately 280,000 oysters were successfully deployed in the Humber. This report outlines the successful completion of the project and provides an overview of the experiment's design, delivery, and monitoring.

The 2025 intertidal oyster experiment was designed to test the feasibility of intertidal native oyster restoration within the Humber Estuary by evaluating how deployment method, oyster age class, stocking density, and substrate treatment influence survival, establishment, and early reef development. The broader purpose of the project is to shift the restoration baseline by demonstrating that intertidal restoration can be achieved within a dynamic, turbid, and historically impacted estuarine system, and to provide an evidence base that can inform similar initiatives elsewhere in the UK.

The Humber is considered a recruitment-limited system, where natural settlement of native oysters is currently insufficient to support population recovery. For this reason, the introduction of reproductively mature oysters is expected to be important for initiating local larval supply and supporting wider estuarine recruitment. Adult oysters provide immediate reproductive potential and have already passed early-life mortality bottlenecks, but sourcing and deploying large numbers of adults is costly and logistically constrained. The experiment therefore includes multiple age classes, including adult oysters, hatchery-produced spat-on-shell, and juvenile oysters, to assess which life stage supports the most stable establishment under intertidal conditions and which approaches may be most scalable.

Adult oysters used in the experiment were originally sourced from Loch Ryan, a system with comparatively lower pollution levels than the Humber. Historical contamination is recognised as one of several pressures contributing to oyster decline in the Humber Estuary, and it is therefore important to understand how oysters originating from lower-contaminant environments perform when established within a historically impacted system. Although the adult oysters had already undergone a period of acclimation within the Humber for several years prior to this experiment, their initial introduction to the estuary, when held on trestles before deployment at Greedy Gut.

In addition to adult oysters, the experiment trials hatchery-produced spat-on-shell and juvenile oysters sourced from the Oyster Restoration Company (TORC), to explore approaches that may support improved acclimation and a more cost-effective restoration pathway. Deploying oysters from earlier life stages allows individuals to establish within the Humber from juvenile phases, enabling assessment of performance under local salinity regimes, turbidity, sediment dynamics, temperature variability, and contaminant exposure. Early-life exposure to these conditions may improve acclimation and longer-term resilience relative to transplanted adult oysters, while also offering a pathway that is potentially less constrained by cost and supply.

The experiment is designed to evaluate outcomes beyond survival and growth by explicitly quantifying ecosystem functioning, biodiversity uplift, sediment carbon dynamics, and habitat use by higher trophic levels. Ecosystem function will be assessed using seasonal respiration chamber experiments to quantify respiration rates, nutrient flux, and particulate removal associated with oyster presence. Biodiversity uplift will be evaluated through repeated monitoring of epibenthic and infaunal communities, fish assemblages, and bird use of the intertidal habitat, allowing assessment of whether oyster addition enhances species richness, abundance, functional diversity, and habitat utilisation relative to control plots. Sediment organic carbon will also be quantified to assess whether intertidal reef development promotes carbon accumulation and retention within the intertidal pool, and to support interpretation of potential relevance within strategic compensation and emerging marine net gain framework.

The experiment addresses the following research questions:

- which oyster age class supports the highest survival and most stable establishment under intertidal conditions;
- how stocking density influences survival and early reef stability;
- how deployment treatments influence benthic biodiversity, fish assemblages, bird use of the habitat, and overall ecological uplift;
- how oyster addition alters nutrient flux, particulate removal, and broader ecosystem functioning;
- whether intertidal oyster restoration enhances sediment organic carbon accumulation;
- what early indicators of reef development, ecological recovery, and suitability for marine environmental net gain or strategic compensation can be detected.

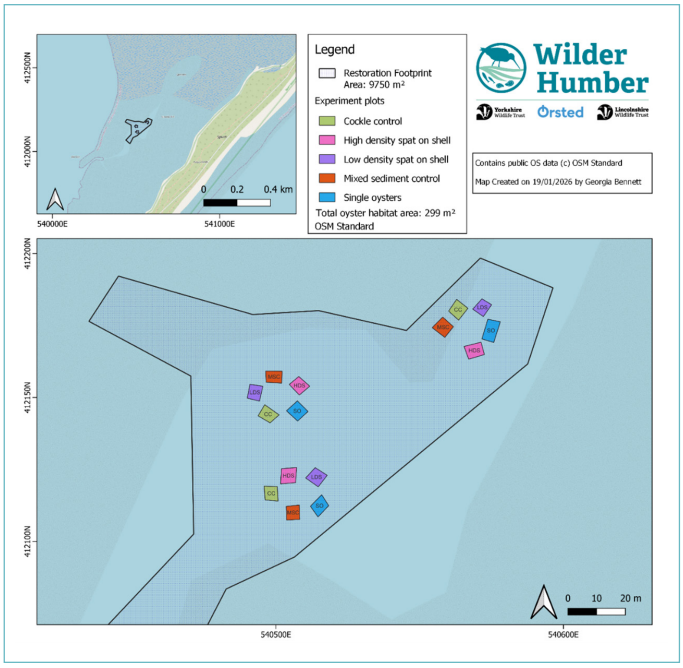


Figure 48 *Wilder Humber Intertidal Oyster Experiment Experimental Design.*



Figure 49 *Photos of deployment of high density spat on shell oyster in Greedy Gut – Autumn 2025.*

Experimental Design

A total of 15 intertidal plots (5 m × 5 m) were established across the restoration site – Greedy Gut, with a minimum spacing of 3 m between plots to maintain independence among replicates **(Fig.48)**. Five treatments were implemented; each replicated three times:

1. Adult oysters deployed individually on cockle shell (n ~ 3,000 individuals)
2. Low-density spat-on-shell deployed on cockle shell (n ~ 25,000 spat)
3. High-density spat-on-shell deployed on cockle shell (n ~ 250,000 spat, **Fig. 49**)
4. Cockle shell control (cultch only, no oysters)
5. Mixed sediment control (no cultch, no oysters)

To create suitable reef habitat, approximately six tonnes of cockle shell cultch were distributed across 12 treatment plots. Shell was spread evenly to increase structural complexity, slightly elevate the substrate, and provide calcium carbonate surfaces suitable for larval settlement and biofilm development. The remaining three plots were left as untreated mixed sediment controls.

The inclusion of two control treatments allowed separation of oyster-driven effects from those associated with cultch addition alone. The mixed sediment control represents existing background conditions, while the shell-only control tests whether substrate enhancement independently alters benthic community structure or sediment dynamics.

Oyster deployment was conducted in two phases during 2025: low-density treatments were installed in summer, followed by high-density treatments in late autumn. The phased approach was determined by stock availability, funding constraints, and consenting requirements.

The original high-density plan projected deploying ~1 million spat across 25 Rapid Reef units. However, hatchery found there was a production constraint— by the time production timelines were confirmed, there was insufficient time within the biological production window to generate the higher spat volume anticipated in the business case. As winter deployment approached, we chose to retain spat longer to increase size and robustness, prioritising survivability and reef establishment. Early monitoring confirms this approach was successful: despite lower numbers, larger spat achieved higher-than-expected survival and strong establishment. The Humber Estuary SSSI consent of Natural England reflected the lower figure (~250,000), with no changes to the footprint, location, number of units, or overall physical extent of the works.

Site location

Greedy Gut **(Fig.50)** was selected as the experimental oyster restoration site due to its geomorphological history, existing hard substrate, and practical suitability for intertidal restoration. The site lies within a wide intertidal channel forming a mixed-sediment tidal pool within Spurn Bight. Historically, this area supported a mussel bed, although little shell material remains today. Its collapse is likely linked to broader environmental pressures within the Humber estuary, including historical industrial contamination and wider national declines in mussel populations. The former presence of a biogenic reef structure indicates that the site has previously supported reef-forming bivalves, suggesting ecological suitability for oyster reintroduction.

Sediment core analysis confirmed a heterogeneous substrate composed of silt (44.9–52.8%), clay (10.6–14.3%), sand (12.0–18.3%), and gravel (18.2–30.9%). The relatively high gravel fraction indicates areas of increased hydrodynamic energy and provides structural stability, while the mixed sediment matrix prevents excessive sinking compared to surrounding mudflats. This heterogeneity creates suitable conditions for oyster establishment without the need for artificial gravel addition, reducing both cost and site manipulation. The site's morphology further supports its experimental value. A channel retains water at low tide, forming a shallow tidal pool (up to ~40 cm depth at lowest tides), which limits desiccation and thermal stress while maintaining intertidal accessibility. This allows direct observation, monitoring, and low-cost deployment, key advantages for experimental comparison and adaptive management.

Although natural shell availability is currently low and may limit larval settlement, this constraint was addressed through the deployment of cockle shell cultch to enhance available substrate. The combination of historic reef presence, naturally occurring hard substrate, retained tidal water, and logistical accessibility makes Greedy Gut an appropriate and strategically advantageous experimental restoration site.

Baseline surveys & long term-monitoring

Prior to deployment, baseline surveys were undertaken to characterise environmental conditions and establish a reference framework against which ecological and physical change could be assessed. All monitoring was subsequently designed in accordance with the recommendations set out in the European Native Oyster Habitat Restoration Handbook, ensuring the use of standardised metrics and approaches (Preston et al., 2020). This alignment reflects recognised good practice and allows for comparison with subtidal oyster restoration projects.

Environmental and Physical Baseline

Sediment cores were collected for particle size analysis (PSA) to determine substrate composition and assess suitability for oyster establishment. Baseline physical conditions and site morphology were quantified using shoreline profile surveys, which measured elevation, intertidal pool form, and sediment distribution. These data provide an initial measure of site structure and sediment dynamics.

Water quality measurements, including nitrate, suspended solids, and ammonium, were collected to characterise nutrient status and suspended material within the system. Environmental parameters, including water temperature, salinity, dissolved oxygen, turbidity, and pH, were also recorded. Together, these measurements provide contextual information on background environmental variability and support longer-term assessment of ecological trends at the site.

Biodiversity Baseline

Baseline biodiversity was assessed across multiple components of the intertidal ecosystem. Epibenthic communities were surveyed using quadrat sampling to document species presence, abundance, and community structure, including targeted assessment for invasive non-native species (INNS). Benthic sediment cores were collected to characterise infaunal assemblages and were similarly screened for INNS to identify existing biosecurity risks and establish a reference condition

.

Bird assemblages were monitored through monthly surveys conducted since 2023 to quantify species presence, abundance, and patterns of habitat use within and around the site. These surveys establish baseline patterns of avian utilisation against which future changes in abundance, foraging behaviour, and community composition can be evaluated.

Environmental DNA (eDNA) sampling from both water and sediment provided a complementary assessment of species presence across taxa, including fish species that may not be reliably detected through traditional survey methods (Appendix 1). These data provide a pre-deployment reference for fish assemblages within the system.

Together, these datasets establish a robust environmental and ecological baseline against which responses to intertidal oyster restoration can be quantitatively assessed. Seine netting surveys will be introduced post-deployment to enable direct assessment of fish assemblages. Repeated surveys throughout the duration of the experiment will enable evaluation of temporal change, reef development, and site stability. Monitoring components and sampling frequency are summarised in **Table 4**.



Figure 50 *Experimental site location – Greedy Gut, Spurn, Humber Estuary.*

Oysters Morphometrics Monitoring

To quantify growth and survival, a randomly selected subsample comprising 10% of deployed oysters was tagged and measured at the time of deployment **(Fig. 51)**. Morphometric measurements included:

- Shell length, width, and height (depth)
- Growing edge
- Wet weight

Both the low-density spat-on-shell treatments and the adult oyster deployments comprised mixed age classes. For high-density spat-on-shell treatments, where individuals were approximately 0.1 mm at settlement, individual morphometric measurements were not feasible. Instead, spat counts were conducted on scallop shells where possible to estimate initial density.

Ecosystem Function Assessment

Beyond survival and growth, the experiment quantifies ecosystem functioning. Seasonal respiration chamber experiments measure ecological processes associated with oyster presence. Water samples are collected at time zero (T_0) prior to chamber closure and at six hours (T_6) following final oxygen measurements. Samples are analysed for nitrate, nitrite, phosphate, ammonium, and particulates to estimate nutrient flux, filtration rates, and biogeochemical cycling. The initial respiration assessment was conducted prior to deployment. Subsequent seasonal measurements will compare oysters from high- and low-density plots to evaluate treatment-level differences in ecological functioning.

Table 4 *Summary of monitoring components and sampling frequency.*

Survey type	Frequency	Data Collected	Survey Method
Environmental Monitoring	Monthly	Dissolved oxygen, nitrates, nitrite, phosphate, ammonium, turbidity, pH, salinity, temperature	Sonde / water sampling
	Biannual	Shoreline profile / elevation	Ranging poles; tracks sediment stability, reef structure, and potential erosion mitigation
	Continuous	Tidal inundation	Hobo G logger
	Continuous	Light / Temperature	Hobo temp/light logger
	Annual	Organic carbon	Sediment cores
	Annual	Particle size sediment composition	Sediment cores
Oyster Monitoring	Seasonal	Cultch coverage	Quadrat transects
	Seasonal	Oyster coverage	Quadrat transects
	Seasonal	Oyster mortality	Tagged individuals and spat-on-shell
	Seasonal	Oyster growth (length, width, height, weight, growing edge)	Biometric measurements
	Seasonal	Oyster displacement	Mean displacement from original plot location
Biodiversity Monitoring	Seasonal	Epibenthic biodiversity	Quadrat transects
	Annual	Benthic macrofaunal biodiversity	Sediment cores
	Annual	Fish biodiversity	Seine netting (from 2026)
	Annual	Marine biodiversity / community DNA	eDNA water sampling
	Annual	Oyster microbiome	Microbial DNA from sediment
	Monthly	Bird biodiversity	Vantage point surveys
Ecosystem Function	Seasonal	Oyster respiration, nutrient flux, particulate flux	Closed respiration chambers, water sampling (T0/T6)



Figure 51 *Measuring adult oyster and spat on shell for growth records (summer 2025)*

Pre-liminary results

Environmental monitoring

Shoreline profile data shows uneven depth across the site, with the southern, landward side being significantly higher than the northern and seaward sides **(Fig. 52)**. Oyster and cultch trial plots have been deployed evenly across this site since the baseline survey was conducted and may create a distinctly different depth plot of the site. Ongoing monitoring will provide a comprehensive record of the changes to the site as a result of oyster restoration trials, and general site mobility.

Oyster monitoring

Morphometric monitoring completed in January–February 2026 showed positive growth and strong survival across both deployed cohorts. Low-density spat-on-shell (SOS) deployed to the Humber in July 2025 demonstrated rapid first-year growth, with mean shell length increasing by approximately 122% and shell width by 113% by February 2026 **(Fig. 53).** This substantial proportional increase reflects strong juvenile performance over late summer, followed by continued development through autumn and winter. Survival of low-density spat on shell was 85% (28 lost from 190 sampled). The European Native Oyster Habitat Restoration Monitoring Handbook reports that first-year spat survival commonly varies widely between sites (often in the range of ~50–80%, depending on environmental conditions and predation pressure), so the 85% survival recorded here is within, and towards the upper end of, commonly reported ranges.

Adult oysters showed more modest but consistent increases over the same period, with mean shell length increasing by 1.5%, width by 2.0%, height/depth by 1.9%, and wet weight by 2.4% (Fig.54). Given that deployment occurred in July and monitoring encompassed the end of the main growing season followed by autumn and winter, when growth rates naturally slow, these incremental gains are consistent with expected seasonal growth patterns for established oysters in temperate estuarine systems. Adult survival was 98% (one mortality recorded), which is consistent with the high short-term survival rates reported for successful restoration deployments in the Handbook.

Plot displacement

Tidal flow, particularly during channel drainage at low tide, influenced the stability of intertidal restoration plots following July deployment. Displacement was measured in September to assess how tidal forces affect different stock types and densities, as reef formation depends on structural stability. Mean displacement across three replicate plots was 13.80 m (±4.72 SD) for adult oysters and 7.25 m (±5.61 SD) for low-density spat-on-shell. Continued monitoring will determine which deployment method provides greater resistance to movement and supports biogenic reef development.

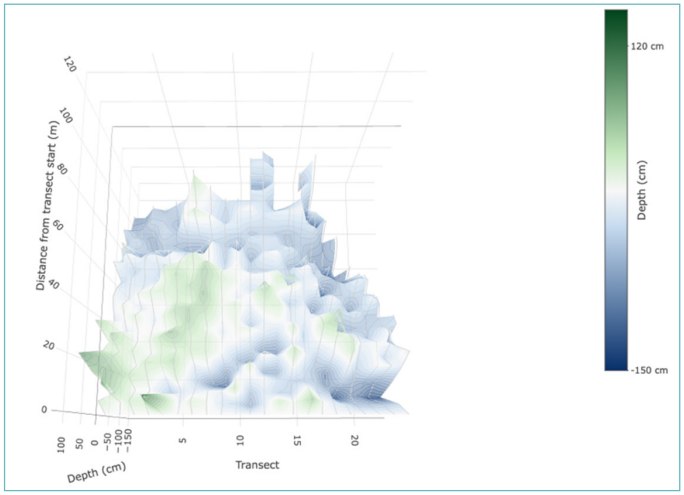


Figure 52 *Depth plot of greedy gut restoration site in April 2025, prior to any oyster or cultch restoration activities.*

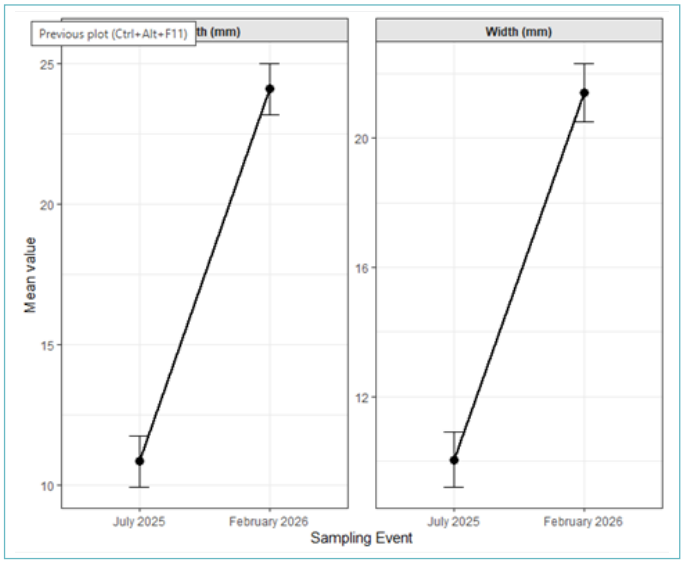


Figure 53 *Mean (± SE) shell length and width of low density spat on shell oysters measured in July 2025 and February 2026. Points represent mean values pooled across all individuals, with vertical error bars indicating standard error of the mean (SE). Lines connect sampling events to illustrate temporal change. Panels are shown with independent y-axis scales.*

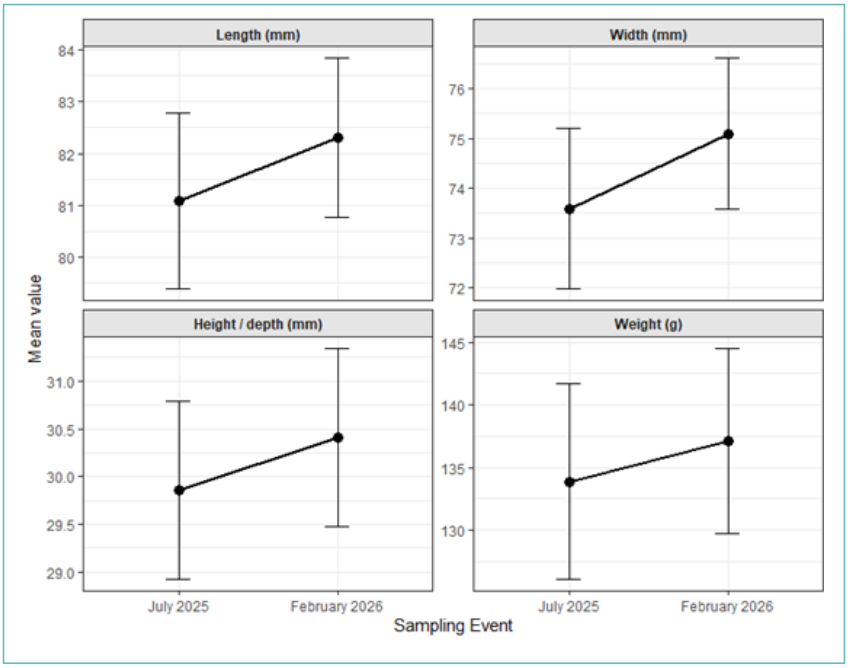


Figure 54 *Mean (± SE) shell length, width, height/depth, and wet weight of adult oysters measured in July 2025 and February 2026. Points represent mean values pooled across all individuals, with vertical error bars indicating standard error of the mean (SE). Lines connect sampling events to illustrate temporal change. Panels are shown with independent y-axis scales.*

Biodiversity monitoring

Epibenthic biodiversity – quadrats

The epibenthic community, assessed through quadrat surveys, comprised **10 mobile and 16 sessile taxa (Fig. 55 and 56)**. Of these, three taxa were identified as non-native: *Austrominius modestus* (Darwin's barnacle), *Magallana gigas* (Pacific oyster), and *Crepidula fornicata* (slipper limpet). Among the sessile assemblage, *Semibalanus balanoides* (northern rock barnacle) had the highest mean cover (21.0%), followed by the non-native *A. modestus* (7.8%) and *Fucus vesiculosus* (bladderwrack; 5.5%). The mobile assemblage was dominated by *Littorina littorea* (edible periwinkle), with a mean abundance of 23.9 individuals per quadrat, compared with 1.3 individuals per quadrat for *Littorina saxatilis* (rough periwinkle), the next most abundant taxon. The non-native mobile taxa *C. fornicata* and *M. gigas* occurred at relatively low mean abundances of 0.64 and 0.18 individuals per quadrat, respectively. Overall, the baseline epibenthic assemblage was dominated by a small number of native taxa, while non-native taxa were present at comparatively lower cover or abundance.

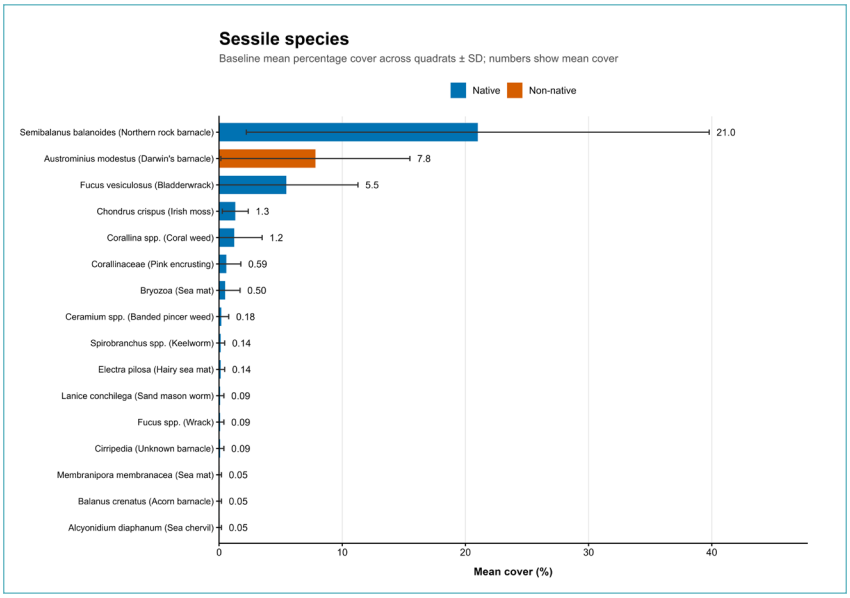


Figure 55 *Mean percentage cover of sessile species recorded during baseline biodiversity quadrat monitoring at Greedy Gut. Bars show mean percentage cover across quadrats and error bars represent ±1 standard deviation (SD), illustrating variation among quadrats (n=11). Values displayed beside each bar indicate the mean percentage cover. Native species are shown in blue and non-native species in orange.*

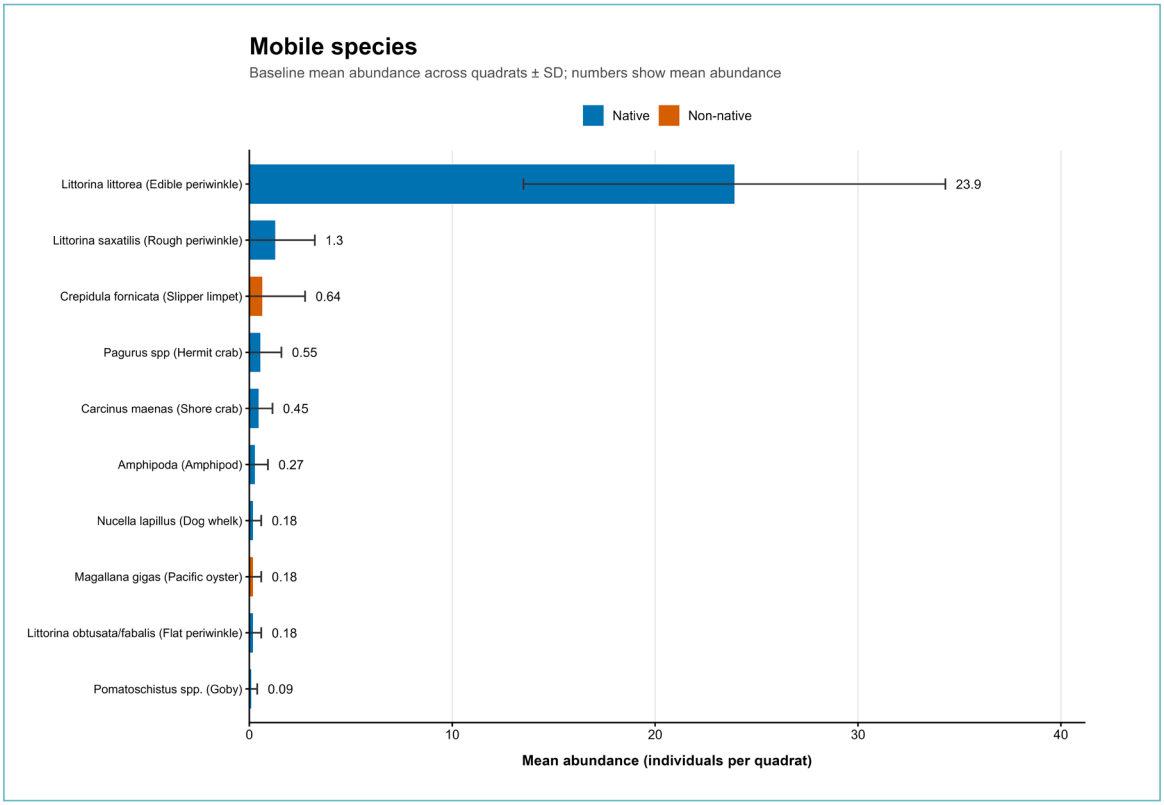


Figure 56 *Mean abundance of mobile species recorded during baseline biodiversity quadrat monitoring at Greedy Gut. Bars show mean abundance (individuals per quadrat) across quadrats and error bars represent ±1 standard deviation (SD), illustrating variation among quadrats (n=11). Values displayed beside each bar indicate the mean abundance. Native species are shown in blue and non-native species in orange.*

Benthic macrofaunal biodiversity

Prior to deployment, benthic macrofaunal biodiversity was assessed to establish a baseline, and this survey will be repeated in summer 2026 to enable comparison.

Biodiversity of the benthic community, assessed via core samples, was moderate overall, with a moderate number of species present but relatively low evenness, indicating that the community was dominated by a small number of species **(Fig. 57)**. A. modestus was the most abundant species. Native species were present, including Tharyx maryae, nematodes, and Ampharete baltica, although these occurred in lower abundances. Overall, the findings suggest a community with some existing ecological value but clear dominance by a limited number of taxa, indicating potential for improvement through restoration.

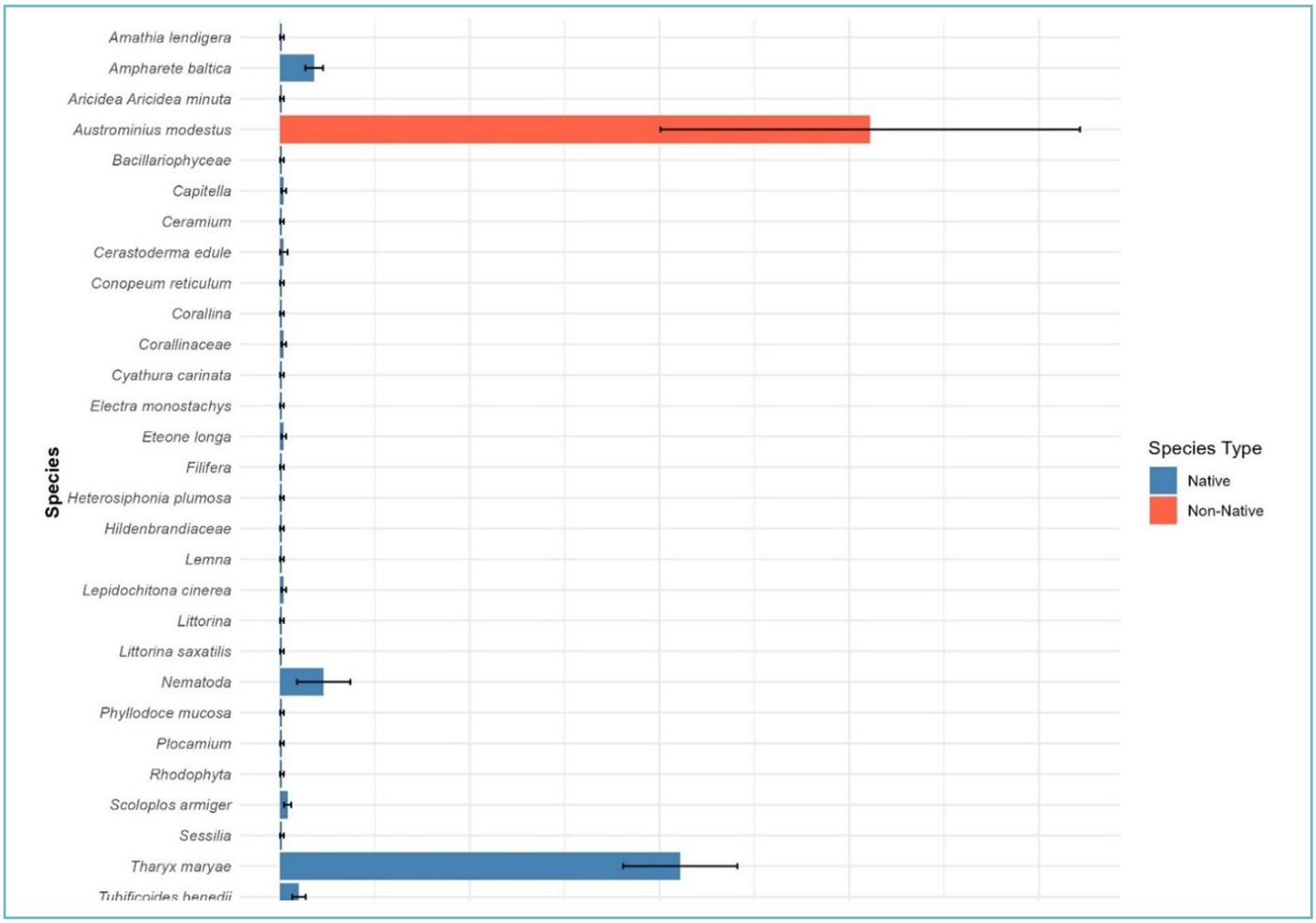


Figure 57 *Mean proportion abundance with standard error calculated for native and invasive sessile species observed during quadrat surveys of epibenthic communities (n=5). Coloured bars indicate mean proportion abundance per species (blue are native species and red are invasive); error bars indicate ± standard error (SE).*

Bird biodiversity

Wild bird population trends have been found to be effective biodiversity and ecosystem health indicators (Gregory & van Strien 2010). This could be said for oyster reefs as they are ecosystem engineers which offer substrate, spawning grounds, food and shelter for many species, making them a hotspot of biodiversity (OSPAR Commission 2021). In an intertidal system, this biodiversity can provide a valuable food source for many coastal birds (Herbet et al. 2018). There is little research on the impact on birds from European flat oyster *Ostrea edulis* restoration as it has mostly taken place in the subtidal until now, however we can draw comparisons from other intertidal restoration studies. In the intertidal the Eastern oyster *Crassostrea virginica*, reef restoration led to an increase in epifauna, benthic invertebrates, sessile macroinvertebrates and mobile macroinvertebrates (Rodney 2007). Another example from the same species of Eastern oyster, showed that benthic abundance on restored reefs became similar to natural reefs within 6 months. After three years, the abundances, behaviours and assemblages of birds on restored reefs were similar to those of natural reefs (Copertino et al. 2022). There is also evidence to suggest that Eastern oyster reef restoration does not affect the avian community, with no difference found between restored, natural and damaged, however the frequency of foraging by birds was significantly greater on restored and natural reefs than damaged, most commonly by birds that probe the sediment for prey (Shaffer et al. 2019).

In the UK, research has been conducted on the invasive Pacific oyster *Magallana gigas* which also occupies the intertidal space. Results indicate that these Pacific oyster reefs can provide valuable supplementary feeding areas for some species, such as curlew and oystercatcher which had greater success and biomass intake rates on the oyster reef than on mudflat, however, were avoided by other bird species (Herbet et al. 2018). Despite the Pacific and native oysters fulfilling similar ecological roles, this is not to say that they will provide the same feeding grounds for bird species. A study in Northern Ireland with sympatric populations of the two species, found that there was a significant difference in the species of epibiont present on the Pacific and Native oysters, with significantly lower epibiont richness on Pacific oysters (Guy et al. 2018). This stark difference between the two oyster species present in the UK, coupled with the lack of research on the impact of Ostrea edulis reefs on bird communities, highlights the importance of our biodiversity monitoring data at Spurn.

Monthly bird surveys were conducted at Greedy Gutt from 2023 to December 2025 to establish a baseline of species richness and abundance prior to oyster deployment. Surveys were carried out at low tide and will continue for five years to assess potential restoration impacts. Analyses examine temporal and seasonal trends in bird abundance and richness.

Results

Overall temporal patterns

Across all seasons combined, negative binomial GLMs revealed significant declines in both total abundance and species richness over time (Wald z-tests, both $p < 0.001$, **Fig. 58 & 59**). Seasonal models indicated that these overall declines were driven by significant negative temporal trends in spring (abundance and richness, both $p < 0.001$), summer (abundance $p = 0.001$; richness $p = 0.003$), and autumn (both $p < 0.001$). In contrast, no significant temporal trends were detected in winter (abundance $p = 0.48$; richness $p = 0.36$). Overall, declines were concentrated during spring–autumn, whereas winter bird communities remained relatively stable over the study period.

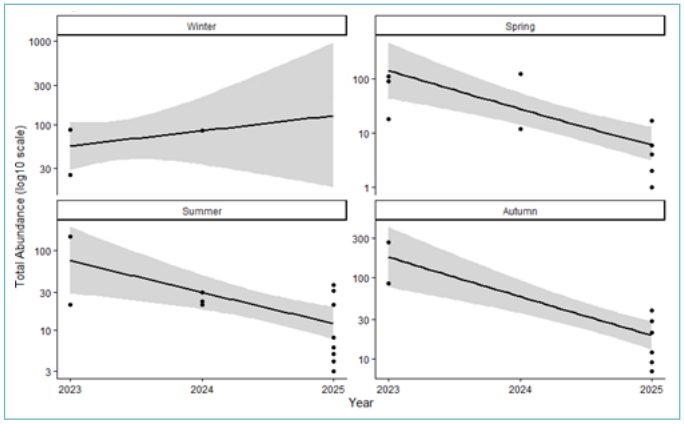


Figure 58 *Season-specific temporal trends in total abundance estimated using negative binomial generalised linear models (GLMs) with Year fitted as a numeric predictor. Solid lines show model-predicted trends, and shaded areas indicate 95% confidence intervals. Panels are shown separately for winter, spring, summer, and autumn. A constant of one was added to abundance values for visualisation purposes only to allow inclusion of zero counts on the log scale*

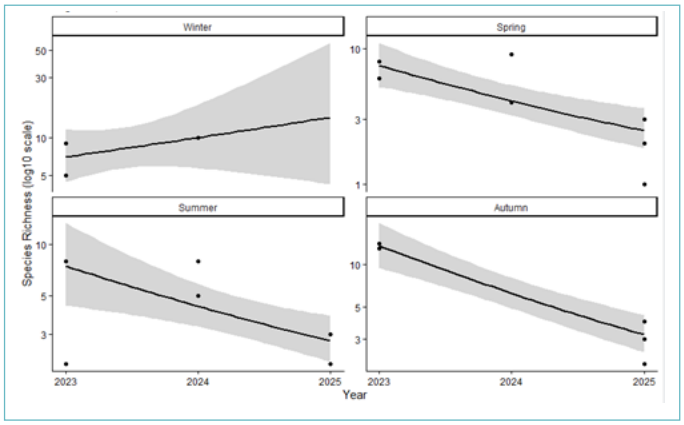


Figure 59 *Season-specific temporal trends in species richness estimated using negative binomial generalised linear models (GLMs) with Year fitted as a numeric predictor. Solid lines show model-predicted trends, and shaded areas indicate 95% confidence intervals. Panels are shown separately for winter, spring, summer, and autumn. A constant of one was added to abundance values for visualisation purposes only to allow inclusion of zero counts on the log scale.*

Marine biodiversity / community DNA

Environmental DNA monitoring was also undertaken within the oyster restoration area at Spurn Point (Full report available- Appendix 1). At the time of sampling (September 2025), this site represented an early-stage restoration area following a small oyster deployment in July 2025.

Sediment eDNA analysis recorded a diverse assemblage of microbial taxa and benthic invertebrates, including annelids, molluscs, arthropods and nematodes. Overall taxonomic richness at the oyster restoration site was comparable to previous monitoring periods, consistent with its early-stage status.

Water eDNA detected fish, bird and marine mammal taxa within the oyster restoration area. The critically endangered European eel *(Anguilla anguilla)* was detected at this site. Marine mammal DNA, including Harbour seal *(Phoca vitulina)*, was also recorded, indicating use of the wider intertidal and nearshore environment.
As oyster restoration activities were recently initiated, the September 2025 survey provides a baseline dataset against which future biodiversity changes associated with oyster reef development can be assessed.

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Remote setting – survival results

A follow-up survey in September 2025 assessed longer-term survival of oysters from the 2024 remote-setting trial. Out of the 20,000-day-old larvae deployed in July 2024 (assumed evenly distributed between granite and scallop shell treatments), initial settlement in September 2024 was 18% (SE ±4.3%), close to the 20% target, equating to approximately 3,600 settled spat overall across shell and granite. Four weeks post-deployment, survival was 35% (SE ±8.7%) on granite rock and 28% (SE ±7.5%) on scallop shell. By September 2025 (approximately 14 months post-settlement), no oysters remained on rock trestles, while 78 individuals persisted on scallop shells **(Fig.60)**. This represents a post-settlement survival of approximately 4.3% on shell and an overall survival of 0.8% from the original larval cohort allocated to shell. The complete loss on exposed granite suggests excessive desiccation at low tide, whereas shells retained within oyster boxes likely benefited from improved moisture retention. Final survival was substantially lower than the 50–80% first-year survival commonly reported in the European Native Oyster Habitat Restoration Monitoring Handbook, highlighting the strong influence of deployment method and site-specific exposure on restoration outcomes.



Figure 60 *Front and reverse of juvenile oyster from the remote setting demonstrator taken September 2025*

Sand Dunes

Sand dune biodiversity enhancement – Spurn Point

Spurn's sand dunes form part of a narrow and highly dynamic coastal system at the mouth of the Humber Estuary. Within this shifting landscape, dune habitats provide important ecological value, supporting specialist plants, invertebrates and breeding birds.

The purpose of dune management at Spurn is to maintain and enhance habitat condition while working within these natural processes. Key pressures include scrub encroachment, invasive non-native species, disturbance and the increasing impacts of coastal erosion and climate change. Management is therefore focused on practical, targeted interventions, including conservation grazing, vegetation control, invasive species removal and breeding bird protection, guided by regular ecological monitoring.

Sand dune management is supported by Countryside Stewardship as part of the Government's Agri-Environment Scheme, and we work in partnership with RSPB on the Beach Nesting Bird Project at Spurn.

Wildflower Meadow Grazing and Cutting

Wildflower rich grassland forms an important component of the dune system at Spurn **(Fig.61)**, contributing to botanical diversity and great invertebrate interest. Management is focused on maintaining structural variation while preventing dominance of dense scrub and coarse grasses.

Winter grazing continued across the fenced fields at Chalk Bank, Potato fields, Hide field, Triangle field and Swallow Barn field **(Fig.62)**. Hebridean sheep were used to maintain a short sward height, creating the low nutrient conditions required for summer flowering species to thrive. Long term grazing at Chalk Bank and Potato Fields has led to visible improvements in botanical diversity, demonstrating the benefit of consistent management. Bee orchids, absent for 30 years, have now returned on the reserve's chalk meadow.

Exceptionally low rainfall in 2025 influenced species composition across the meadows. A reduction in typical abundance of species such as bird's foot trefoil, lady's bedstraw and rest harrow was seen. In response, this year's winter grazing intensity was reduced to allow recovery and avoid additional stress on the sward. A revised botanical survey programme has been developed by the team, focusing on botanical species presence. This will inform grazing decisions in future seasons, ensuring management remains responsive to climate variations.

In areas unsuitable for grazing, including around the former RNLI houses, passageways and land adjacent to the jetty at the Point, vegetation was managed through cutting. Electric brush cutters were used and all arisings were removed to prevent nutrient enrichment. Parade Ground continues to support strong wildflower displays, maintained through consistent cutting and removal of cut material. This area is also managed for sea buckthorn encroachment to keep this area maintained for wildflowers. Tree popper tools have also been very effective in managing this.



Figure 62 *Map with winter grazed fields parcel in Spurn along with locations of invasive species (Russian vine & Duke of Argyll.*







Figure 61 *Wildflower meadow on Spurn Sand dunes*

GPS No-Fence Grazing

Grazing is also being used to manage scrub and improve habitat structure at the Point. Six pastures were managed using GPS no-fence collar technology **(Fig.63).**

Two Highland cattle and five Belted Galloways were used to open up dense scrub, reduce dominant fast-growing species and increase plant diversity in previously cleared areas. Their natural grazing and trampling have also helped push into uncleared areas, further opening up the dense scrub habitat **(Fig.62).**

The GPS system allows livestock to be managed without installing permanent fencing. This reduces cost, avoids fragmenting habitat and allows grazing areas to be adjusted easily as conditions change. It provides a flexible and practical tool for managing a dynamic dune landscape.





Figure 65 *Volunteers supporting invasive species removal in Spurn.*



Figure 63 *Map showing parcel with no fence grazing applied.*

Invasive Species Management

Like many coastal sites, Spurn is affected by invasive and non-native species. These include Rosa rugosa, Duke of Argyll's tea tree, Russian vine and brown-tail moth **(Fig.62 & 67)**. Left unmanaged, these species can outcompete native plants and reduce species diversity. Most clearance work has been delivered through volunteer task days and corporate groups, allowing us to tackle larger areas each season **(Fig.65).**

For Russian vine and Duke of Argyll's tea tree, we have been trialling a combined approach. Plants are cut back or hand pulled during autumn and winter, followed by targeted herbicide treatment in early spring to deal with new growth. Winter grazing has also helped suppress regrowth. This method has reduced their spread, and follow up herbicide treatment is planned for spring 2026 to maintain control. Rosa rugosa remains localised at Spurn, which gives us a good opportunity to contain it. During winter we trialled pulling and cutting in mapped areas using tree popper tools to remove deep roots more effectively. Regrowth will be monitored over the summer to assess success.

Russian vine, which had previously smothered alder trees in parts of the reserve, was largely removed in summer 2024. No significant regrowth was recorded in 2025, although monitoring will continue.



Figure 64 *Spurn landscape with no fence grazing.*

Beach Nesting Bird Project

From April to October, we continued working in partnership with the RSPB to protect breeding birds across wash over areas. Little Tern and Ringed Plover are declining species that depend on undisturbed shingle beaches with low levels of predation. Within the Humber Estuary, Beacon Lagoons currently supports the only Little Tern colony and a viable Ringed Plover population. However, this site is vulnerable to coastal change and erosion. The aim at Spurn is to provide additional suitable habitat to increase resilience across the estuary **(Fig.66)** and monitoring showed nesting attempts extending further along the peninsula.

We installed electric fenced enclosures over key nesting habitat on the wash over, to reduce disturbance and predation **(Fig.67)**. In 2025, solar powered energisers were used to improve reliability of the fence. Additionally, predator- crow control was carried out early in the season under Natural England approval through nest disturbance. Species recovery funding has been secured for 2026, allowing protection and monitoring work.

Chalk removal

The potential to strip sections of chalk along transects to help reconnect saltmarsh from the upper to the lower shore was explored further in 2025. Full removal of the chalk deposit is currently logistically challenging due to the large volume of material, access and vehicle constraints at Spurn Point, and the requirement to remove material from site, including waste consent considerations. Instead in 2026, work will focus on attempting small trial removal plots (approximately 10m in scale) using support of volunteers, to help inform longer-term management decisions.



Figure 66 *Photos of beach nesting project volunteers (top) & Common Ringed Plover (bottom)*



Figure 67 *Map showing location of beach nesting birds project in Spurn.*

Sand dune biodiversity enhancement – Horseshoe Point

Discussions with Natural England (NE) through 2024 into 2025 identified various condition issues for the sand dunes and activities that would enhance them at Horseshoe Point. Japanese rose (Rosa rugosa) and sea buckthorn (Hippophae rhamnoides, **Fig. 68**) are both highly competitive species that can significantly alter the structure and function of dune ecosystems. Both of these species outcompete native dune grasses and herbs, and this dominance not only reduces biodiversity but also changes the natural movement and accumulation of sand, disrupting dune formation and succession. In the dunes found at Horseshoe Point, these invasive species have become widespread, prompting the Wilder Humber team to formulate a management plan, working with Natural England, aimed at removing the majority of Japanese rose and some of the sea buckthorn **(Fig. 69)**. Drawing on lessons from the Dynamic Dunescapes project and guidance in the Sand Dune Managers Handbook (Second Edition) (Natural England, 2024), planned scrub clearance will restore native dune vegetation, enhance wildlife habitat, and support natural dune dynamics, while minimising disturbance. A detailed work plan is in development, with landowner permission secured via Natural England. Delivery is scheduled for 2026–2027, alongside the creation of a long-term, volunteer-supported management plan.



Figure 68 *The sea buckthorn found on the dunes at Horseshoe Point. Credit: James Horan*

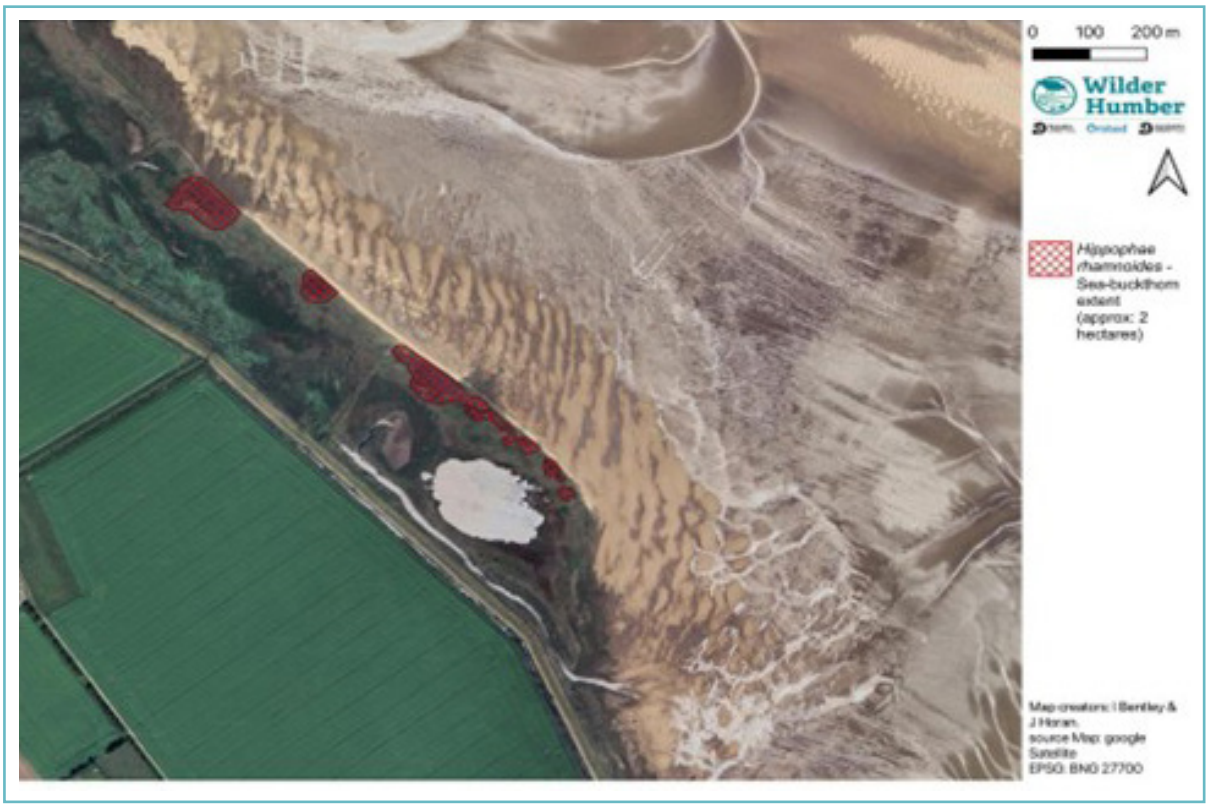


Figure 69 *The extent of sea buckthorn, Hippophae rhamnoides, found on the dunes at Horseshoe Point, Lincolnshire.*

Saltmarsh

Sea couch turf cutting trials

Natural England is currently establishing saltmarsh management trials on The Wash and has expressed interest in developing a comparator site at Horseshoe Point. This creates an opportunity for shared learning and aligned methodology. It will also benefit Ørsted, as legacy cabling impacts on the saltmarsh at The Wash remain an ongoing issue. Evidence generated through these trials, alongside plant propagation work under the Wilder Humber project, may help identify practical and scalable restoration solutions. The trials will also provide an evidence base for refining national saltmarsh management policy going forward.

The Wash trial is comparing a mixture of various manual cutting and livestock grazing stocking densities across a series of areas including a control site. This is being undertaken by Dyson Farming, and the initial contact between NE and Dyson Farming in this regard was facilitated by Lincolnshire Wildlife Trust. Our strong working relationship with Dyson Farming has brought them into the Lincolnshire Wash Landscape Recovery Project in Round 1 of the Environmental Land Management Scheme (ELMS), which is led by RSPB and in the 20-year contracting phase. The aim is to maximise sward diversity through manging down invasive species, and Horseshoe Point will act as a direct comparator.

Sea couch *(Elymus spp.)* is a dominant species in the upper extent of the Horseshoe Point saltmarsh, where it reduces sward diversity limiting opportunities for other native flora and fauna. Mechanical cutting, designed to mimic grazing pressure, has been proposed as a management intervention to maintain and enhance saltmarsh biodiversity. Similar trials have demonstrated that reducing dominant grasses can increase floristic diversity and provide benefits for invertebrate and bird populations (Chen et al., 2020).

A walkover survey at Horseshoe Point identified suitable trial locations, taking into account topography and site conditions. A series of 10 × 10 m (100 m²) plots were established across the upper marsh and the mid–upper transition zone, recorded and mapped to support monitoring and comparison **(Fig. 70).**

The trial will involve a controlled cutting regime, with plots allocated as follows:

- Early-season cutting: 4 plots (2 upper marsh, 2 mid-upper marsh)
- Late-season cutting: 4 plots (2 upper marsh, 2 mid-upper marsh)
- Combined early and late-season cutting: 4 plots (2 upper marsh, 2 mid-upper marsh)
- Control plots: 4 plots (2 upper marsh, 2 mid-upper marsh)

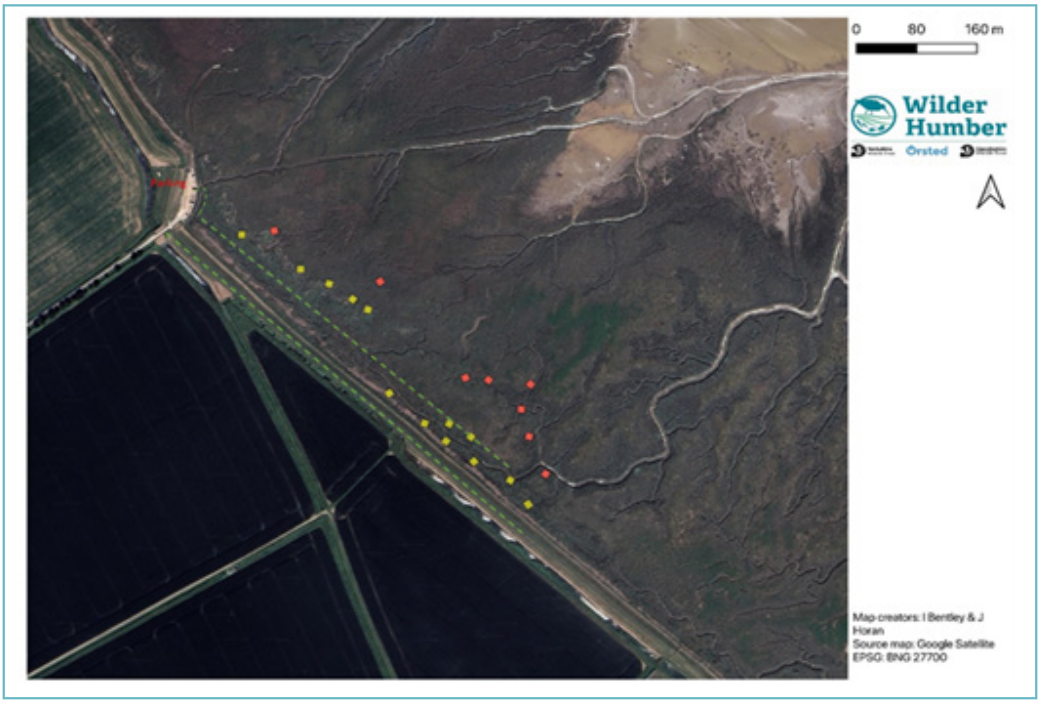


Figure 70 *Map of Horseshoe Point showing mapped areas of sea couch in the upper marsh (yellow plots) and the mid marsh (red plots), including access routes marked in green.*

Monitoring will be conducted pre- and post-cutting, with parameters including vegetation species composition; floristic density; invertebrate diversity; vegetation litter, cover, and height; and breeding bird activity with a particular interest in oystercatcher and redshank. Protocols are designed to be simple, repeatable, and consistent across plots to ensure reliable comparisons, and to enable long-term management activities working with volunteers. Continuous observation of breeding birds will minimise disturbance during operations.

Implementation will involve:

- Baseline surveys: record vegetation, invertebrate, and bird data
- Cutting interventions: implement early- and late-season cutting according to the experimental design
- Post-cutting surveys: monitor changes in vegetation, invertebrates, and breeding bird activity
- Data analysis: compare results across cutting regimes and control plots to inform management recommendations for HSP

Scientific benefit: compare results with those on The Wash, and those on the Wadden Sea, and look to prepare a scientific paper in partnership with NE and other delivery partners in The Wash
The full methodology to underpin a consent has been produced and was submitted in 2025 to enable roll out in 2026. From the trials an ongoing management plan will be developed to continue to manage the HSP saltmarsh with volunteer support in the future.

Saltmarsh creation

Discussions with a landowner and their Trust Board got underway in regard to securing a 30-year lease for a section of land near South Ferriby. If this is secured, it will provide an area to harden off saltmarsh plug plants from the nursery, and over time see conversion from freshwater grassland to saltmarsh.

Further optioneering got underway in late 2025 in regards to identifying other potential realignment sites on the South Humber bank, as saltmarsh units are in short supply for various nature markets. The science gained through the South Ferriby trial, will help inform any found, alongside the ongoing monitoring evidence being collated at Pye's Hall in the Outer Humber, by the Trust on behalf of the Environment Agency. This was a managed realignment scheme.

Sea View Farm Nursery and Seed Bank – Capital build

The capital investment at Saltfleetby continued throughout 2025 **(Fig.71),** with the power connection being installed by the distribution provider in March that enabled contractors to lay the power and water infrastructure within the compound prior to launch event. All weather paths were laid within the compound, which ensure movement throughout is fully accessible, and follow-up works post launch have now ensured the compound can be accessed by all. Construction and fit-out work advanced to the second-fix stage, with all electrics, plumbing, and water heating systems successfully installed to support day-to-day operations.

Since the launch, work has continued to complete and equip the compound with a focus on staff and volunteer welfare, efficiency, and cost-effectiveness. The volunteer hub and seed bank now feature durable, non-slip polyurethane resin flooring with insulating and hydrophobic properties, providing a safe, low-maintenance solution for long-term use. The storage room has been fitted with a robust interlocking tile system made from recycled materials **(Fig.72),** designed to withstand heavy foot traffic in commercial settings.



Figure 71 *Photos showing progress of the capital build including the picnic area and polytunnels and the main building (credit: Sam Dawson).*

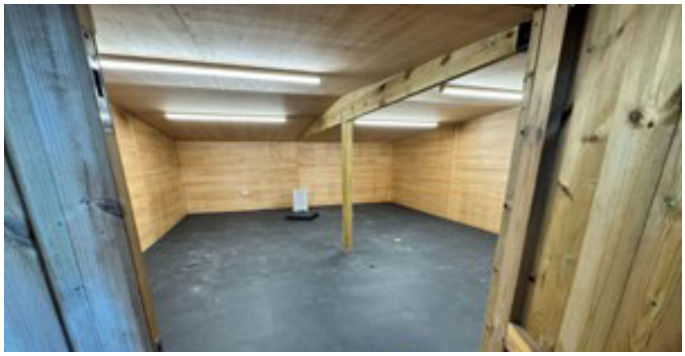


Figure 72 *Ecotile flooring in the store room at Sea View Farm Nursery, Saltfleetby. Credit: Imogen Bentley.*

The interior design of the seed bank's working spaces has now been finalised, informed by research into the required scientific equipment and site visits to comparable facilities. Completion of the volunteer hub and seed bank is underway. Detailed irrigation plans for the polytunnels were initially developed with a Lincolnshire-based company but proved costly. Drawing on expertise from the national Wildlife Trust Seed Bank & Plant Propagation Network, established by Lincolnshire Wildlife Trust in 2021–22, and further supplier research, a more cost-effective installation plan has now been produced **(Fig.73).** Installation is currently underway with an expected completion by April 2026.

Seed collection and banking

Work is underway to establish a fully functional seed bank, informed by specialist training from the Kew Millennium Seed Bank (MSB) and a site visit to the National Seed Bank of Wales. The team is carefully sourcing equipment and drafting detailed protocols to support all stages of seed conservation, including collection, cleaning, drying, storage, viability testing, and robust metadata management. This approach reflects best practice from established national seed banks while creating a practical facility tailored to local restoration and research needs, ensuring high standards of viability, traceability, and long-term conservation.

In parallel, a comprehensive seed collection strategy has been developed, drawing on internal expertise within Lincolnshire Wildlife Trust, including experience from the Love Lincs Plants NLHF Project delivered in partnership with the Natural History Museum. The strategy is now in its final quality assurance stage and will underpin the necessary consents for collecting saltmarsh and sand dune species. Submission in early 2026 will enable a full seed collection season from 2026 onwards.

Plant propagation

During the winter of 2025-26 bought seed of relevant coastal species will be used to test the flow of the operational nursery, so that all kit and processes have been trialled. These propagated plants can then be used in public engagement work and training of volunteers. The species that will be bought in and grown from seed include sea aster, thrift, samphire, viper's bugloss, and wild carrot.

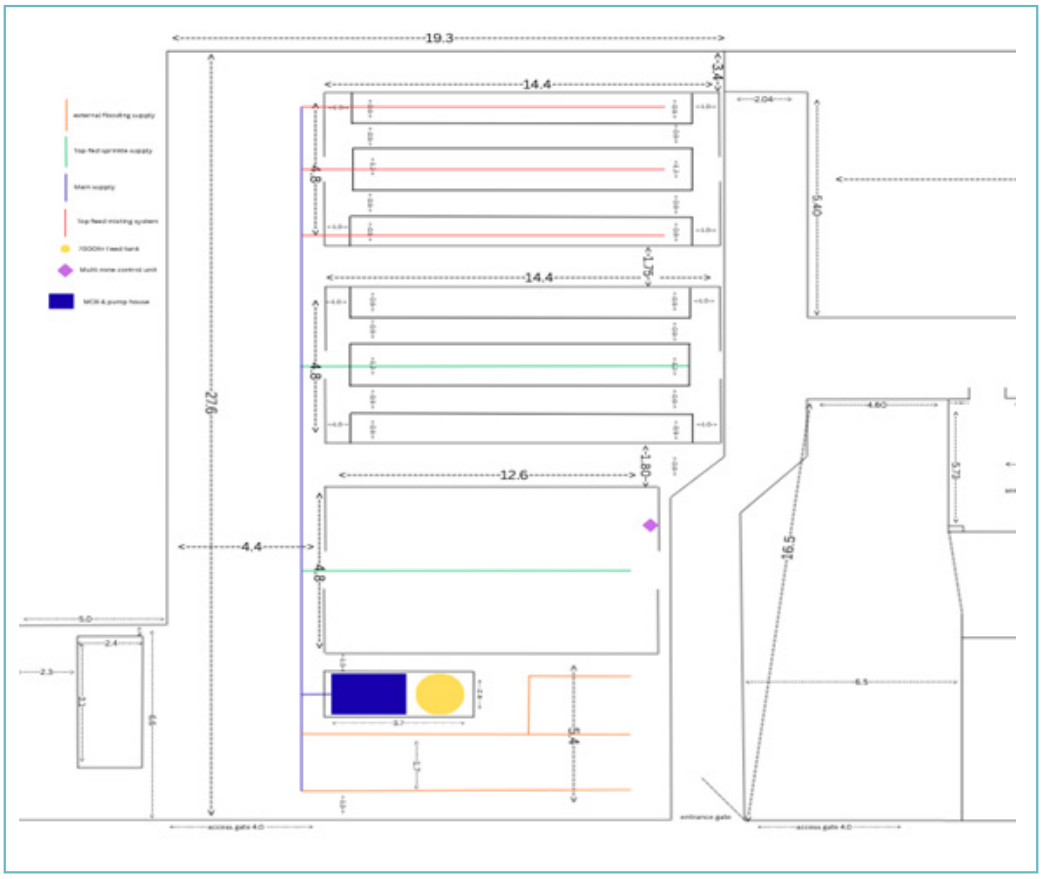


Figure 73 *Details of the irrigation plan for Sea View Farm nursery, with a key (top left). Plan created by James Horan.*

Staff Training

Lincolnshire Wildlife Trust's strong partnership with the Kew Millennium Seed Bank (MSB) enabled a member of the Wilder Humber team to undertake specialist technical training in seed conservation. The placement covered all stages of seed banking, including field collection, representative sampling, processing, drying, viability and germination testing, metadata recording, and long-term storage, all to international standards. The long-term aim is to deposit saltmarsh and sand dune seed collected by the Wilder Humber team at MSB to safeguard genetic diversity, alongside undertaking direct biodiversity enhancement work onsite. Further specialist ecological training included coastal bird identification (Field Studies Council), herbarium techniques (Love Lincs Plants project), marine mammal medic training (BDMLR), wetland bird monitoring (BTO), Flower-Insect Timed (FIT) counts, and advanced invertebrate identification. Site visits strengthened practical knowledge exchange. At Salix River & Wetland Services (Norfolk and South Wales), the team observed bioengineering approaches to river and wetland restoration, including saline nursery production for coastal projects. A visit to the National Botanic Garden of Wales, home to the Welsh National Seed Bank, provided further insight into seed collection, processing, and genetic preservation protocols. The team also visited the Green Shores Project at the University of St Andrews, observing saltmarsh restoration across the Eden Estuary, Tay Estuary, and Dornoch Firth. Key learning included the use of nature-based coastal protection measures and effective techniques for hardening off and planting nursery-grown saltmarsh plants to maximise establishment and resilience.

eDNA – Horseshoe Point

Environmental DNA (eDNA) monitoring was carried out at Horseshoe Point in September 2025 to assess biodiversity across two intertidal mudflat locations: a previously designated seagrass restoration area (where seagrass establishment has unfortunately not been successful) and an adjacent control area (Full report – appendix 1). At the time of sampling, both monitored locations comprised unvegetated mudflat habitat. Sediment and water samples were analysed to characterise microbial, invertebrate and vertebrate communities present at each location.

Sediment eDNA analysis recorded higher overall taxonomic richness at the previously designated restoration area compared with the control area, although both sites were characterised by mudflat sediments. Taxa detected included diverse microbial communities alongside a broad range of benthic invertebrates such as annelids, molluscs, arthropods and nematodes. The relative distribution of non-microbial phyla was broadly similar between the two sites, indicating comparable community composition at higher taxonomic levels, with differences primarily in overall richness rather than distinct assemblages.

Low-frequency detections of taxa associated with harmful algal blooms were recorded. In addition, DNA from the non-native barnacle, Austrominius modestus, was detected at low frequency at the control site. Water eDNA detected a greater number of taxa at the previously designated restoration area compared with the control area. It should be noted that water sampling conditions at the control site were less optimal due to limited water depth during high tide, which may have influenced detection rates.

Fish, bird and marine mammal taxa were detected in water samples at both sites. The critically endangered European eel (Anguilla anguilla) was detected at the previously designated restoration area but was not recorded at the control site. A greater number of bird species were detected at this site compared with the control. Marine mammal DNA was also detected, including Harbour seal (Phoca vitulina) and Grey seal (Halichoerus grypus), indicating use of the wider intertidal and nearshore environment.

Communications & Engagement

Since its launch almost three years ago, Wilder Humber has steadily built public interest and media recognition, establishing itself as a leading voice in marine and coastal restoration. In 2025, the project saw notable successes in communication and engagement, with significant growth in both media coverage and social media outreach. This section of the report highlights the key achievements of the Wilder Humber communications strategy, reflects on lessons learned over the year, and identifies opportunities to strengthen future engagement with audiences, stakeholders, and the wider public.

Aims of Wilder Humber Communications

The Wilder Humber communications aim to broaden public awareness of the importance of marine restoration in the Humber estuary. By educating local communities, businesses, and key stakeholders through regular updates and engagement activities, the project fosters a deeper understanding of its significance and impact. Additionally, it strives to position Wilder Humber as a pioneering example of marine restoration in the North Sea, gaining national and international recognition as a model for innovative and effective restoration efforts.

Through these efforts, the communications strategy supports the project's overarching goal of restoring seagrass meadow and piloting integrated habitat restoration in the Humber estuary.

2025 Communication Highlights and Key Achievements

Pioneering Native Oyster Experiment (Fig.74):

In July 2025, Wilder Humber achieved a major communications milestone by highlighting its pioneering trial comparing remote set oysters with traditional restoration techniques at Spurn Point Nature Reserve. This innovative method, where larvae are settled onto scallop shells near the restoration site before deployment, was yet to be trialled against the traditional method of releasing individual adult oysters. Through a dedicated media release and press day at Spurn the achievement attracted national and international attention, with significant media coverage, including TV, radio, and print. The press day resulted in sustained coverage for over a month, generating interest from new audiences and stakeholders.



Figure 74 *Oyster spat settled on scallop shells released in the Greedy Gut experiment site at Spurn Point. Credit Finn Varney.*

BBC Countryfile Feature (Fig.75):

The project's growing recognition led to a feature on BBC Countryfile, broadcast nationally on Sunday 29th June and reaching an estimated 6 million viewers. The episode highlighted Wilder Humber's work restoring native oysters and enhancing marine biodiversity, demonstrating the broader value of nature-based solutions for climate change and biodiversity loss. The national exposure significantly strengthened the project's profile as a leading example of large-scale marine restoration in the UK.



Figure 75 *Crew from BBC's Countryfile filming a UTV rescue drill. Credit: Cate Holborn*

Samara, 25th Anniversary Celbration of Kew Millenium Seed Bank:

The Lincolnshire Wildlife Trust established a national network across the Wildlife Trust family with Kew Millennium Seed Bank back n 2021-22. This included forming a strong bond through annual site visits hosted by one of the network partners, which has informed this project from the outset and the high standards trying to be achieved. The recognition By KMSB of these efforts were made by inviting us to submit an article and provide material for their 25th Anniversary, of this internationally renown facility. This included producing an article for their special addition of their global publication, Samara, where Wilder Humber was the case study used to highlight the networks impact. Samara was picked up nationally and internationally by various media institutes.

Growing Academic Recognition

Wilder Humber's academic engagement expanded in 2025, with the team presenting at conferences across the UK and Europe:

- Marine Biological Association Postgraduate Conference- hosted by University of Hull. Presentation on Wilder Humber and the strategy of the seascape scale restoration.
- ReMeMaRe Conference – poster on native oyster restoration and presentation on the wider seascape restoration strategy.
- UK Seagrass Symposium 2025- presented findings from the Spurn seagrass planting trials **(Fig.76).**
- 6th International NORA (Native Oyster Restoration Alliance) Conference, Spain- presented outcomes from native oyster restoration work.
- Sand Dune & Shingle Network Conference- contributed to knowledge exchange on the conservation and management of sand dune, machair, and shingle habitats, with a focus on emerging threats, applied case studies, and policy-relevant research.
- Institute of Fisheries Management (IFM) Conference- presented two posters on the role of seagrass and saltmarsh as important juvenile fish habitats and shared learning on fish monitoring techniques, strengthening links with fisheries scientists and industry practitioners.
- Online workshop on nature credits for blue carbon ecosystems – Presenting on the Wilder Humber Programme and potential for nature-based credits.

These engagements and more including the East Yorkshire of Riding Local Authority annual conference, showcased Wilder Humber's leadership, strengthened international collaborations, and reinforced the project's scientific credibility.



Figure 76 *Marine Restoration Officer, Andy Jayes, delivers a presentation at the Seagrass Symposium 2025. Credit: Georgia Bennett*

Media Appearances:

- **Television:** total, an estimated **8 - 10 million viewers** saw coverage of the Wilder Humber project across **six national and regional television features** this year, including ITV Calendar, BBC Look North, ITV News at 10, BBC News at 10, and BBC Countryfile. This extensive broadcast reach has greatly enhanced public awareness of the project's pioneering marine restoration work and its contribution to restoring the Humber estuary's vital coastal ecosystems.
- **Radio:** Wilder Humber also achieved strong regional radio coverage this year, with **six features broadcast** across BBC Radio Humberside, BBC Radio Leeds, BBC Radio Sheffield, BBC Radio York, BBC Radio Lincolnshire, and Beverley FM. Together, these stations reach an estimated 500,000 – 600,000 listeners, providing an excellent platform to share updates on the project's progress and ambitions with communities across Yorkshire and Lincolnshire. The interviews helped raise awareness of marine restoration in the Humber estuary, inspiring local engagement and reinforcing Wilder Humber's position as a leading example of collaborative, nature-based action in the region.
- **Press:** Wilder Humber was mentioned in **37** articles, achieving an Advertising Value Equivalent of **£2.36 million** and a press Opportunity to See (OTS) of **67,159,400 readers**. Coverage included a BBC article, two Yorkshire Post articles, an Energy Voice article and one MSN article.

Social Media Growth:

Wilder Humber continued to strengthen its digital presence in 2025, significantly expanding its reach and engagement across social media platforms and connecting with a broader and more diverse audience.

- On **Facebook**, Wilder Humber published 67 posts during the year, generating over 407,000 impressions and more than 5,400 reactions. This represents a 161% increase in impressions compared to 2024 (156,000 impressions) and a 135% increase in reactions (up from 2,300). Posting frequency also increased by 26%, supporting greater visibility and audience engagement with Wilder Humber's restoration activities and community initiatives.
- **Instagram** also demonstrated strong growth in 2025 **(Fig.77).** Across 102 posts, reels, and stories, content reached 105,000 people, engaging a younger and more diverse audience. Monthly reach more than doubled over the year, rising from approximately 6,500 people at the start of the year to over 14,500 in December, an increase of around 123%. This growth highlights the effectiveness of visual storytelling and short-form content in communicating Wilder Humber's work. Overall, social media has become an increasingly important tool for Wilder Humber, driving awareness, promoting engagement opportunities, and broadening public understanding of coastal habitat restoration across the Humber.

Website Traffic:

The Wilder Humber website continued to grow as a key digital platform for sharing the project's progress, data, and restoration stories with the public. In 2025, the website recorded 3,341 visits, more than doubling the 1,493 visits received in 2024. This sharp increase reflects the success of wider communications and media activity throughout the year, including national television coverage, social media campaigns, and new documentary videos that directed audiences to explore the website in more depth. The platform has become an engaging and accessible way for people to visualise restoration work across the Humber estuary, helping to build greater understanding and support for the project's long-term aims.

Documentary Videos:

This year, Wilder Humber's documentary contractor produced four professional short films highlighting key aspects of the project's pioneering marine restoration work. The videos explored the importance of saltmarsh habitats and the project's efforts to enhance them, detailed the steps of the native oyster restoration experiment, demonstrated innovative seagrass planting methods, and explained the crucial role of water quality testing in supporting healthy marine ecosystems. Each film was designed to bring the science and purpose of restoration to life, helping audiences understand the project's wider ecological impact. The documentaries were shared across Wilder Humber's social media channels and website, and Yorkshire Wildlife Trust's YouTube channel, where they achieved strong engagement and positive feedback, significantly enhancing public understanding and appreciation of the project's work across the Humber estuary.

Engagement Events:

In 2025, Wilder Humber delivered or participated in 19 engagement events, reaching around 5,200 people, a significant 53% increase from 3,400 in 2024. These events included four restoration conference presentations, as well as a range of community events and talks aimed at raising awareness of coastal restoration.
Hands-on activities such as oyster painting, seagrass seed bag making, and community presentations encouraged public involvement and understanding of marine habitat restoration. Wilder Humber also showcased its work through academic posters, further strengthening connections between science, conservation, and local communities.

Engagement event highlights:

- Lincolnshire County Show **(Fig.78)**
- Colliderfest, Hull's inaugural science festival
- Wilder Humber's annual Seagrass Festival at The Deep **(Fig. 79)**
- Yorkshire Wildlife Trust's Puffin Festival

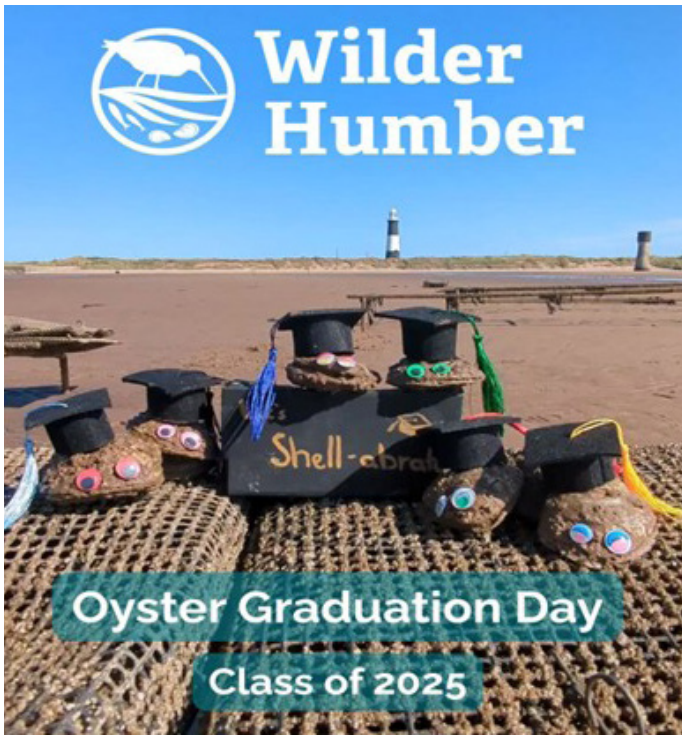


Figure 77 *The cover image for a social media reel aimed at making the release fun and engaging to a wider audience. Credit: Cate Holborn*



Figure 78 *Ryan Beaman (Marine Futures Intern), Imogen Bentley (Wilder Humber Project Officer), Joshua Brown (Marine Futures Intern), and James Horan (Wilder Humber Project Officer) at the marine stall in Lincolnshire Wildlife Trust's tent at Lincolnshire Show, June 2025. Credit: Rachel Shaw.*



Figure 79 *Marine Restoration Assistant, Georgia Bennett, demonstrates how to create a seagrass seed bag at the Seagrass Festival at The Deep. Credit: Cate Holborn*

Sea View Farm Nursery Launch event:

On 14th – 15th May 2025, Sea View Farm Nursery was officially opened with a two-day launch event, bringing together the Wilder Humber partnership, regulators, local authorities, contractors, industry professionals, and experts **(Fig.80).** The event showcased the nursery's development and role in future conservation, while providing an opportunity to thank those involved in its delivery and supportive local neighbours. At the launch, the Chair of Natural England, Dr Tony Juniper CBE, praised the partnership's ambition, stating: "It is fantastic to see this level of activity and ambition being taken forward by the Wilder Humber partnership – this is nature recovery in action."

The evening reception in Grimsby and onsite activities at Saltfleetby enabled attendees to network and learn more about the wider Wilder Humber programme. Interviews conducted by former BBC Radio presenter Melvyn Prior were compiled with Lincolnshire Wildlife Trust's Communications Team into a podcast, available here: https://www.youtube.com/watch?v=5IqestafSr

Volunteering Opportunities:

In 2025, **98 volunteers supported the Wilder Humber project,** with 78 contributing to 54 task days at Spurn and 22 supporting activities at Sea View Farm Nursery. At Spurn, volunteers assisted with seagrass seed collection and planting, oyster deployment, and oyster monitoring **(Fig.81)**. A structured induction programme was introduced at the nursery to equip volunteers with the knowledge and confidence to contribute safely and effectively, at the regular task days which are now established to support nursery development and restoration activities.

Looking ahead, Wilder Humber aims to provide in-depth training for volunteers in specialist areas such as seed collection and processing, plant husbandry, herbarium collection, juvenile fish surveys, and bird surveys. This approach will allow volunteers to expand their skills, engage in diverse aspects of the project, and align their personal goals with Wilder Humber's wider restoration efforts.

Social Return on Investment

In 2025, Wilder Humber created a volunteer survey using methodology developed by Ryan Beaman, Marine Future Intern funded by The Crown Estate and employed by Lincolnshire. This was to research the impact of nature conservation and restoration projects on social capital (Full results of the survey – Appendix 2, MFI Beaman report- **Appendix 3**).

Seven volunteers responded to the Wilder Humber survey at Spurn, representing a broad range of ages from 18–24 to 65+, with a balanced mix of genders. Respondents included people in full-time and part-time work, retirees and a student, indicating that volunteering opportunities are accessible to individuals at different life stages. Volunteers travelled varying distances to attend activities at Spurn, often for seagrass, oyster restoration or both. All respondents reported that they "enjoyed it a lot" and felt tasks were clear, and that they were safe, welcomed and well supported throughout their volunteering experience.

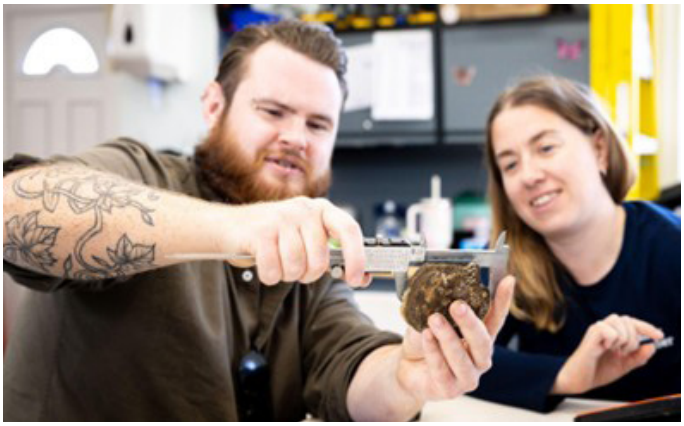


Figure 81 *Volunteer helps to measure and record an adult oyster before it is deployed into the Greedy Gut experiment site. Credit: Finn Varney*



Figure 80 *Launch event at Sea View Farm Credits: Melvyn Prior and Sam Dawson*



Feedback highlighted strong enjoyment of hands-on conservation and habitat restoration, with volunteers valuing the opportunity to connect with nature, develop skills and contribute to a meaningful project. Suggestions for improvement were minimal, with occasional comments around transport access and clearer task outlines at booking. Volunteers primarily heard about opportunities through social media and the Spurn Discovery Centre, and all respondents said they were likely or very likely to continue volunteering or engaging with Wilder Humber activities over the next year, demonstrating high satisfaction and potential for continued involvement.

MFI Beaman report, goes another step in trying to calculate value on return through working with academics and the national lead within the Wildlife Trusts on developing this method. It is full transferable to nature recovery projects, and will be used at the nursery to capture return volunteer value.

Influencing, Partnerships and Legacy

- Wilder Seas parliamentary reception- engaged MPs and key sector stakeholders.
- Corporate volunteer day with National Grid – combined presentations, site tours, and practical engagement to strengthen partnerships.
- National seed banking network – led with Kew Millennium Seed Bank to build genetic resilience and propagation expertise for challenging species such as sea lavender, with Sea View Farm as a trial site.
- Global recognition – featured in the Millennium Seed Bank 25th Anniversary journal.

Marine Net Gain project – Wilder Humber contributed practical guidance on restoring intertidal and subtidal habitats and strategic seascape approaches.

Communication and Engagement Development: Lessons Learned

Localised Storytelling Drives Engagement: Personal, place-based stories, especially those highlighting community action or local species recovery, have proven far more effective than general updates. Audiences respond most strongly when communications reflect their local landscapes, people, and successes.

Digital Platforms Require Continuous Adaptation Changes in social media algorithms and user behaviour in 2025 highlighted the need for agile and creative communication strategies. Wilder Humber adapted through shorter videos, interactive content, and local influencer collaborations to stay relevant and visible. Humour and quirk proved especially effective in boosting engagement. Light-hearted posts, from witty captions to surprising wildlife facts, increased reach and helped key conservation messages resonate with broader audiences. This balance of entertainment and education made communications more relatable and shareable, demonstrating that environmental messaging can be impactful without always being serious.

Looking Ahead to 2026

As Wilder Humber continues to grow its impact, communications in 2026 will focus on sharing the project's scientific achievements, restoration progress, and community stories with wider audiences. The aim is to build on strong media momentum and further connect people with the importance of restoring the Humber's marine and coastal habitats. Key communications priorities for the year include:

Seagrass Planting Trial Results: Launching the results of the seagrass planting methods trial through a press release and regional media coverage, highlighting innovation and success in habitat restoration.

Documentary Video Releases: Producing and releasing three new short films focusing on the importance of seagrass, the value of saltmarsh habitats, and how restored species help protect our coastline.

Marine Newsletter Launch: Introducing a new digital newsletter to share project updates, restoration milestones, and opportunities for public engagement.

Influencer and Media Partnerships: Expanding engagement with social media, podcast, and blog influencers to reach new audiences and inspire greater public interest in nature-based restoration across the Humber estuary.

Conclusion

In 2025, Wilder Humber significantly strengthened its profile as a leading voice in marine and coastal restoration, achieving record levels of public visibility, community engagement, and academic recognition. Through strategic storytelling, high-impact media partnerships, and innovative digital content, the project successfully connected diverse audiences with the importance of restoring the Humber's estuarine habitats. National broadcast features, international conference contributions, and a growing suite of documentary films all helped translate complex science into accessible narratives that resonate with local communities, policymakers, and global restoration practitioners alike.

Engagement efforts this year not only broadened public understanding but also deepened participation. Events, volunteer programmes, and hands-on activities built meaningful connections with people across the region, fostering a sense of shared ownership in the Humber's recovery. The launch of Seaview Farm Nursery in Lincolnshire and the continued expansion of the volunteer network further demonstrated the power of collaboration and community in driving large-scale environmental change.

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