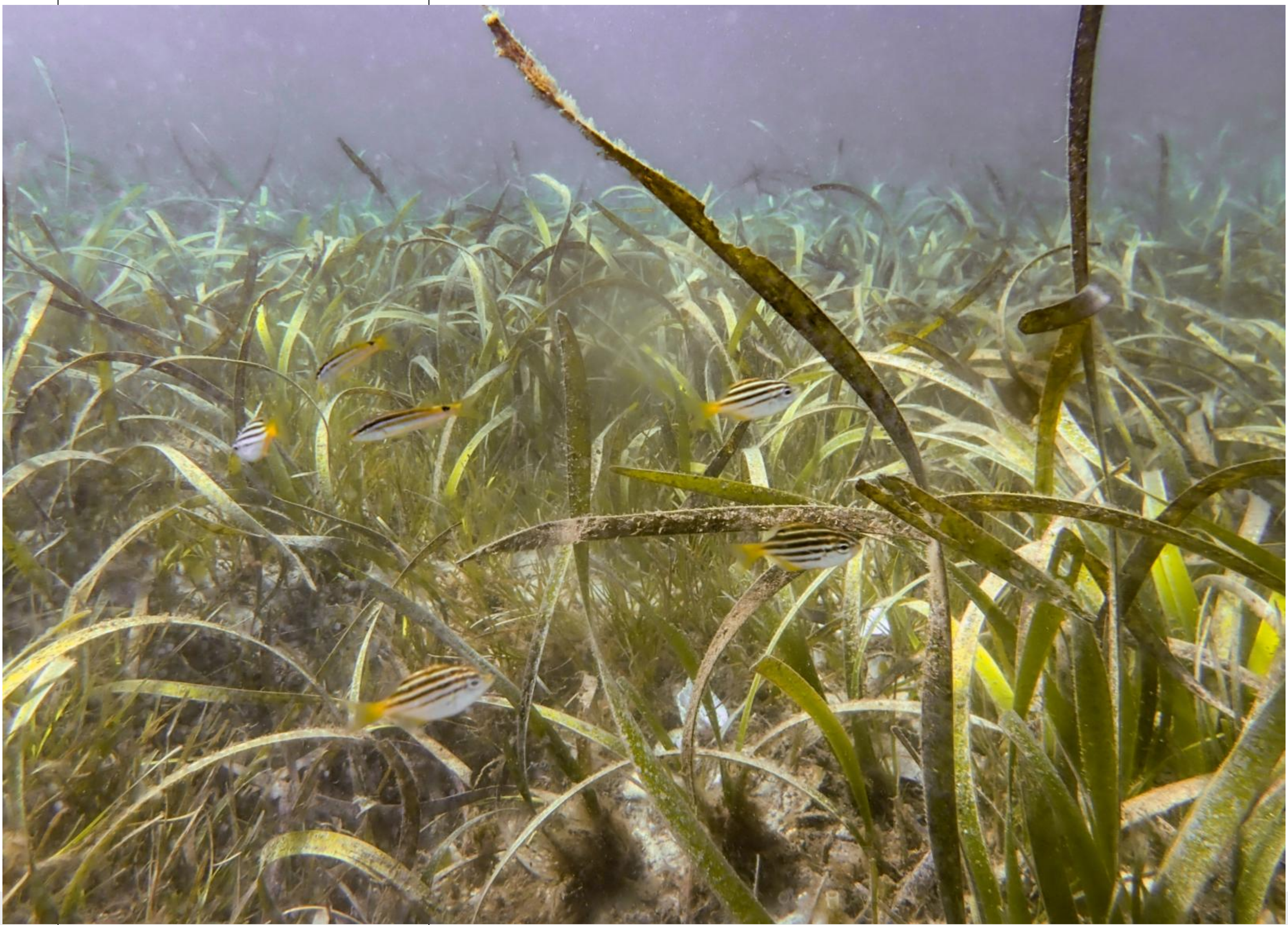
Transport for NSW

Kamay Ferry Wharves project

Seagrass Translocation, Rehabilitation and Monitoring

Seagrass Monitoring Report 5

December 2024



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Acknowledgement of Country

Transport for NSW acknowledges the Bidjigal and Gweagal clans who traditionally occupied Kamay (Botany Bay).

We pay our respects to Elders past and present and celebrate the diversity of Aboriginal peoples and their ongoing cultures and connections to the lands and waters of NSW.

Many of the transport routes we use today – from rail lines, to roads, to water crossings – follow the traditional Songlines, trade routes and ceremonial paths in Country that our nation's First Peoples followed for tens of thousands of years.

Transport for NSW is committed to honouring Aboriginal peoples' cultural and spiritual connections to the land, waters and seas and their rich contribution to society.

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Terms and acronyms

Term /acronym	Description
AWS	Automatic weather station
Benthic	Living in or associated with the bottom of a body of water.
BOM	Bureau of Meteorology
cm	Centimetres
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DGPS	Differential global positioning system
DPE	Department of Planning and Environment
DPHI	Department of Planning, Housing and Infrastructure
DPIRD Fisheries	NSW Department of Primary Industries and Regional Development - Fisheries
EIS	Environmental impact statement
EP&A Act	Environmental Planning and Assessment Act 1979 (NSW). Provides the legislative framework for land use planning and development assessment in NSW.
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999 (Commonwealth). Provides for the protection of the environment, especially matters of national environmental significance, and provides a national assessment and approvals process.
Epiphyte	Plant or plant-like organism that grows on the surface of seagrass leaves.
FM Act	Fisheries Management Act 1994 (NSW)
GLM	Generalized linear model
GPS	Global positioning system
Habitat	An area or areas occupied, or periodically or occasionally occupied by a species, population, or ecological community, including any biotic or abiotic component.
Halophila	Seagrass species within the genus *Halophila*, commonly known as paddleweed.
IMOS	Australia's Integrated Marine Observing System
km/h	Kilometres per hour
m	Metres
m2	Square metres
MBOS	Marine Biodiversity Offset Strategy
mm	Millimetres
Naturally detached *Posidonia australis*	*Posidonia australis* shoots that, through natural processes, have detached from a seagrass meadow and are generally washed up on the shoreline.
NSW	New South Wales
PERMANOVA	Permutational multivariate analysis of variance
Posidonia	Seagrass species *Posidonia australis*, commonly known as strapweed.
Posidonia australis	Seagrass species commonly known as strapweed.
Project	Kamay Ferry Wharves project

Term /acronym	Description
Reference site	An area of natural *Posidonia australis* meadow located nearby the rehabilitation sites that can provide an indication of the influence of landscape-scale environmental variables on both restored and naturally occurring *Posidonia australis*.
Rehabilitation site	An area that has or is planned to be restored with transplanted *Posidonia australis.*
Scar	Degraded habitat area attributed to damage from a traditional block and chain boat mooring.
Shoot (seagrass)	Bundles of seagrass leaves that emerge from the root-like structure (rhizome) that is buried under the sediment.
Significant wave height	Average wave height, from trough to crest, of the highest one-third of the waves.
SIMPER	Similarity percentage
Success criteria	Measurable attributes that provide the basis for evaluating the performance of the *Posidonia australis* offsetting strategy for the project.
TEC	Threatened Ecological Community
Translocation	The deliberate transfer of organisms (e.g. seagrass) from a natural population to a new location.
Transport for NSW	Transport for New South Wales
UNSW	University of New South Wales
Zostera	Seagrass species within the genus *Zostera*, commonly known as eelgrass.

Executive summary

The New South Wales (NSW) government is reinstating the wharves at La Perouse and Kurnell to provide a valuable recreational resource for the community, and to allow for future ferry connection between both sides of Kamay Botany Bay National Park. The Kamay Ferry Wharves project is being delivered by Transport for NSW.

During the development of the Kamay Ferry Wharves project, marine biodiversity offsets were identified for the *Posidonia australis* Threatened Ecological Community which is protected under NSW and Commonwealth legislation. *Posidonia australis* is a slow-growing seagrass which is susceptible to losses due to its limited ability to recover from disturbances. Seagrass meadows provide important ecosystem services in coastal environments including coastal protection, nutrient cycling, carbon capture, provision of habitat and economic value by supporting commercial and recreational fisheries species.

The Marine Biodiversity Offset Strategy (MBOS) identifies two key direct offset actions that aim over ten years (2023-2033) to rehabilitate and improve at least 536 m^2 of *Posidonia australis* habitat to achieve a minimum 2:1 ratio of offsetting area to account for impacts resulting from the project:

1) Translocating *Posidonia australis* from the area expected to be impacted during construction of the new wharf at Kurnell to nearby degraded habitats (completed in early July 2023)
2) Rehabilitating degraded habitat by replanting naturally detached *Posidonia australis* fragments collected from Botany Bay (ongoing since late July 2023).

The MBOS includes a ten-year monitoring program to monitor the performance of the *Posidonia australis* rehabilitation efforts. Monitoring commenced in July-August 2023 and is expected to conclude at the end of 2033.

This report documents the results of the fifth monitoring event of the ten-year monitoring program. Monitoring surveys were carried out in December 2024, about two months following the previous monitoring surveys completed in October 2024. This monitoring represents a supplementary monitoring event to the overall monitoring program, with the key objective of assessing any short-term impacts to seagrass density or condition resulting from the dense epiphytic algal bloom that affected the Kamay Botany Bay area during October and November 2024.

Monitoring involved in-situ surveys of rehabilitation sites where *Posidonia australis* transplanting has occurred and surrounding *Posidonia australis* meadow (reference) sites in Kurnell. The monitoring surveys quantified *Posidonia australis* shoot density and condition (maximum leaf length and cover of epiphytic algae) and benthic composition.

The key findings from this monitoring report are:

- Transplanting with naturally detached *Posidonia australis* during the period October - December 2024 occurred at Scar D, where 167 shoots were transplanted to restore 4 m^2 of degraded habitat
- In rehabilitation sites, *Posidonia australis* shoot densities showed no significant negative short-term response to the algal bloom, with sites recording minor increases or decreases in shoot densities between the pre-algal bloom (October) and post-algal bloom (December) monitoring surveys
- Shoot densities at most reference sites varied little between the October and December monitoring surveys
- *Posidonia australis* maximum leaf lengths increased at all rehabilitation sites and all except one reference site over the period coinciding with the algal bloom, indicating no negative response in this attribute to the event
- *Posidonia australis* epiphyte cover declined, although not significantly so, at all rehabilitation sites, while reference sites showed little change in epiphyte cover between the pre- and post-algal bloom monitoring surveys
- Seagrass cover increased at all except two rehabilitation sites and all reference sites over the two-month period of October to December 2024, and this was largely driven by increases in cover of *Posidonia australis.*

1. Introduction

1.1 Overview of the project

The NSW Government is reinstating the wharves at La Perouse and Kurnell to provide a valuable recreational resource for the community, and to allow for future ferry connection between both sides of Kamay Botany Bay National Park. The wharves will improve access for locals and visitors in small commercial and recreational boats and for people to swim, dive, fish, walk and enjoy the local sights. Importantly, through the incorporation of stories of Country into the design of the wharves and shelter structures, the project recognises the rich culture and ongoing importance of the area to Aboriginal people.

The project forms part of the Kamay Botany Bay National Park, Kurnell Master Plan, which aims to improve visitor experience and access to the park and is being delivered by Transport for NSW and the NSW National Parks and Wildlife Service.

Construction of the wharves commenced in July 2023 and is expected to be completed by early 2025.

1.2 The Marine Biodiversity Offset Strategy

The Kamay Ferry Wharves EIS assessed how likely the project is to impact on the area's marine ecology and biodiversity values. The EIS determined that some impacts to marine biodiversity due to the project could not be fully avoided, including direct and indirect impacts to *Posidonia australis* Threatened Ecological Community (TEC).

Posidonia australis TEC is protected under both the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act, Commonwealth) and *Fisheries Management Act 1994* (FM Act, NSW). In order to mitigate these unavoidable impacts, a process known as 'ecological offsetting' is implemented under State and Commonwealth legislation.

The Marine Biodiversity Offset Strategy (MBOS) provides a strategy for managing and mitigating the residual impacts on marine ecology and biodiversity identified in the EIS. The MBOS identifies appropriate offset requirements under the EPBC Act and FM Act and documents how Transport for NSW will meet its marine offset obligations. It also describes how these actions will be implemented in consultation with NSW Department of Primary Industries and Regional Development - Fisheries (DPIRD Fisheries), Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW) and other stakeholders to result in a net gain in environmental outcomes for Botany Bay as a priority and the Sydney Bioregion more broadly where suitable offset sites are not available in Botany Bay.

The MBOS has an operational life of ten years and will be reviewed and updated as required and recommended by the MBOS Implementation Reference Panel. The MBOS Implementation Reference Panel was established in early 2023 and comprises representatives from Transport for NSW, DPIRD Fisheries Coastal Systems and Threatened Species Division, an independent scientist and observers from the NSW Department of Planning, Housing and Infrastructure (DPHI) (formerly Department of Planning and Environment, DPE).

1.3 *Posidonia australis* offset requirements

The MBOS identifies the offsets required under State and Commonwealth policies to mitigate direct and indirect impacts to *Posidonia australis* resulting from the project. The MBOS identifies two key direct offset actions that aim to rehabilitate and improve existing *Posidonia australis* habitat:

1) Translocating *Posidonia australis* from the area expected to be impacted during construction of the project at Kurnell to nearby degraded habitats (detailed in Implementation Plan 1 (UNSW, 2023a) at Appendix 4 of the MBOS Rev4)
2) Rehabilitating seagrass meadows by replanting naturally detached beach-cast *Posidonia australis* fragments (detailed in Implementation Plan 2 (UNSW, 2023b) at Appendix 5 of the MBOS Rev4).

These direct offset actions aim over ten years to rehabilitate and improve at least 536 m^2 of *Posidonia australis* habitat to satisfy the FM Act requirements for a minimum 2:1 ratio of offsetting area to account for impacts to *Posidonia australis* resulting from the project.

1.4 Implementing the *Posidonia australis* offset strategy

Posidonia australis rehabilitation efforts for the project will be carried out in stages. Stage one involving translocating harvested *Posidonia australis* from the project impact area at Kurnell to nearby rehabilitation sites commenced in mid-June 2023 and was completed in early July 2023.

Briefly, this process involved Scientific Divers removing by hand, quantifying and recording all of the *Posidonia australis* shoots located within the project impact area at Kurnell and immediately replanting the shoots at six nearby rehabilitation sites. Two methods were used for transplanting: (a) transplanting shoots into biodegradable jute mats deployed to the seabed and securing the rhizomes with metal pins; and (b) transplanting shoots directly into bare sediment and securing the rhizomes with metal pins. *Posidonia australis* was transplanted at a density equivalent to the overall mean shoot density of the *Posidonia australis* patches that were harvested and relocated (about 42 shoots per m^2). The translocation process resulted in a total rehabilitated area of about 302 m^2. This work was carried out in accordance with the methods detailed in the MBOS (refer to Implementation Plan 1 (UNSW, 2023a) at Appendix 4 of the MBOS) and a permit under section 37 of the FM Act obtained from DPIRD Fisheries.

Stage two of the rehabilitation efforts involves collecting naturally detached *Posidonia australis* fragments from shorelines in Botany Bay and transplanting them in rehabilitation sites at Kurnell. This stage commenced in mid-July 2023 and will continue at regular intervals for about eight years until about mid-2031.

1.5 Monitoring program

A ten-year monitoring program will monitor the performance of the *Posidonia australis* rehabilitation efforts. Monitoring of rehabilitation sites with restored *Posidonia australis* and reference sites will occur four times per year for the first year (2023-2024) and twice per year for the next four years (Figure 1-1). Monitoring will occur annually after five years with the program completing by about the end of 2033. Monitoring reports will document the outcomes of the offset strategy for *Posidonia australis* by assessing against success criteria. The monitoring program is detailed in the MBOS (refer to Implementation Plan 1 (UNSW, 2023a) at Appendix 4 of the MBOS).

Baseline monitoring surveys were carried out immediately following completion of the *Posidonia australis* translocation stage in July-August 2023. Monitoring for the ten-year monitoring program began in October 2023. The monitoring surveys carried out for this report represent the fifth round of monitoring, about 17 months after the *Posidonia australis* translocation stage (Figure 1-1). This monitoring represents a supplementary monitoring event to the overall monitoring program, with the key objective of assessing any short-term impacts of the dense epiphytic algal bloom that affected the Kamay Botany Bay area during October and November 2024.

Monitoring reports will be provided to the MBOS Implementation Reference Panel, NSW DPHI, DCCEEW and published on the Kamay Ferry Wharves project website.

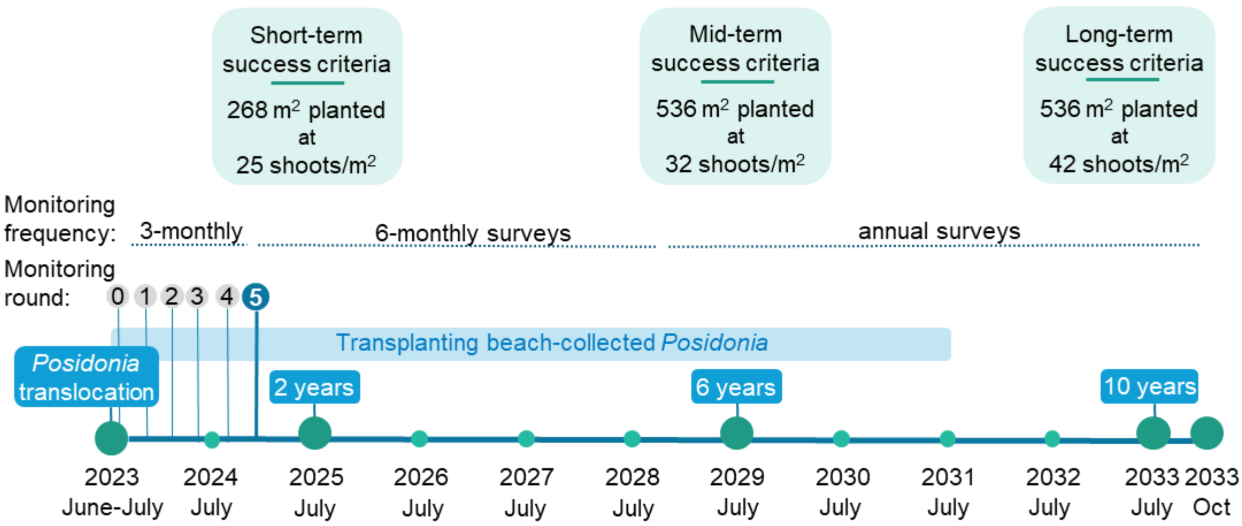

Figure 1-1: Overview of the stages and timing for the *Posidonia australis* translocation, rehabilitation and monitoring activities in the context of the success criteria for the offset strategy.
Monitoring round 5 carried out in December 2024 which is the subject of this report, is highlighted in blue.

1.6 Purpose of this seagrass monitoring report

This report documents the results of the fifth monitoring event of the ten-year monitoring program. Monitoring surveys were carried out in mid-December 2024, about two months following the previous surveys in October 2024. This monitoring represents a supplementary monitoring event to the overall monitoring program, with the key objective of assessing any short-term impacts of the dense epiphytic algal bloom that affected the Kurnell area during October and November 2024.

Monitoring involved in-situ surveys to:

- Survey the density and condition of transplanted *Posidonia australis* in rehabilitation sites
- Survey the density and condition of *Posidonia australis* in reference sites
- Record the benthic composition of rehabilitation and reference sites.

This report constitutes a health check of the transplanted and natural *Posidonia australis* at Kurnell rather than an assessment of rehabilitation efforts against the success criteria. Instead, this report presents an assessment of monitoring results for before and after the occurrence of the algal bloom at Kurnell.

2. Monitoring methods

2.1 Location and timing of monitoring

Surveys were carried out at seven rehabilitation sites where transplanting of translocated and naturally detached *Posidonia australis* shoots has occurred. The rehabilitation sites are located within the main *Posidonia australis* meadow to the west of the project boundary at Kurnell at depths of about 2-4 m (Figure 2-1). Surveys were also carried out at six reference sites to enable comparisons between the density, condition and benthic composition of natural *Posidonia australis* meadows and *Posidonia australis* in rehabilitation sites. A detailed description and assessment of the rehabilitation and reference sites is provided in the Site Selection and Validation Report (UNSW, 2023c) in the MBOS.

Monitoring surveys were carried out in mid-December 2024, about two months since the previous monitoring surveys that were completed at the early onset of the algal bloom at Kurnell. Monitoring was carried out by experienced marine ecologists from UNSW using SCUBA. A summary of monitoring carried out to date is provided in Table 2-1.

Table 2-1: Monitoring events in the seagrass monitoring program completed to date

Monitoring round	Timing	Report reference
Initial surveys	July-August 2023	UNSW, 2023d
Round 1	October-November 2023	UNSW, 2024a
Round 2	February 2024	UNSW, 2024b
Round 3	May and July 2024	UNSW, 2024c
Round 4	September-October 2024	UNSW, 2024d
Round 5	December 2024	This report

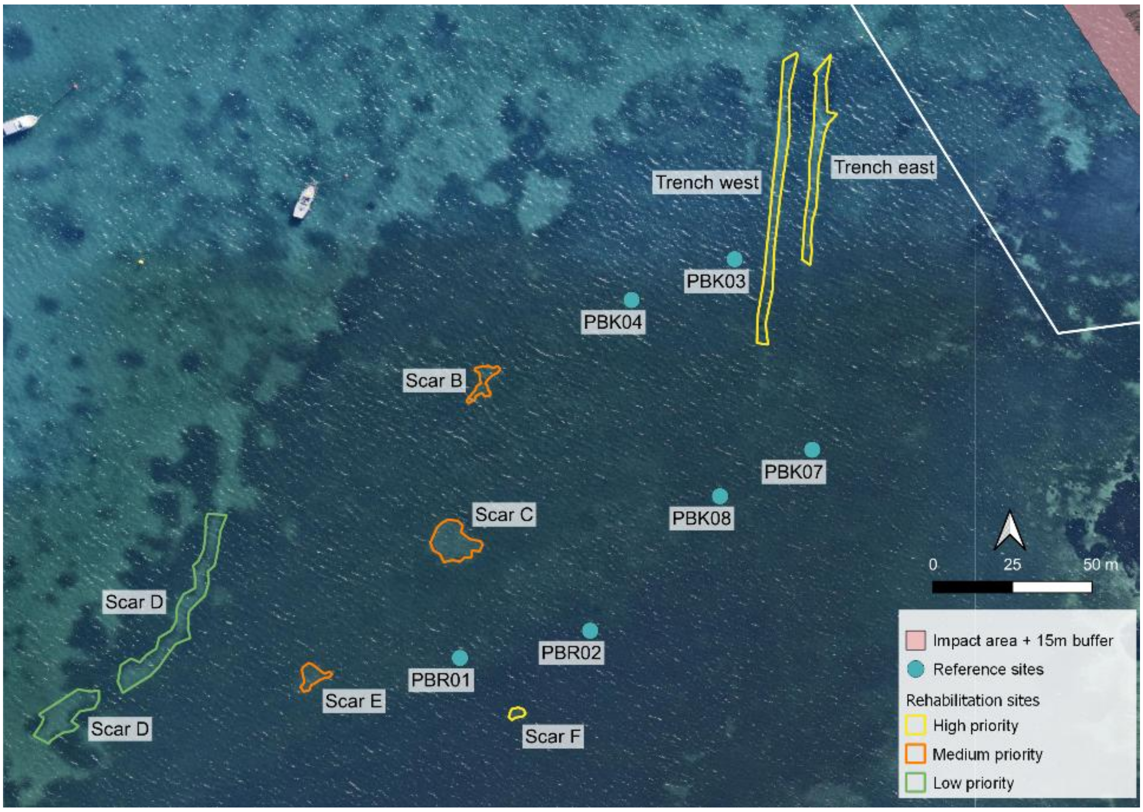

Figure 2-1: Overview of the survey area at Kurnell (Gamay Botany Bay)

2.2 *Posidonia australis* surveys

2.2.1 Density, leaf length and epiphyte cover of *Posidonia australis*

Monitoring of *Posidonia australis* density and condition (leaf length and epiphyte cover) was carried out at the seven rehabilitation and six reference sites. Each site was located using a GPS (DGPS accuracy 3-5m) and marked with a float.

Posidonia australis was surveyed within randomly placed 0.25 m^2 quadrats (0.5 m x 0.5 m). The number of quadrats surveyed in rehabilitation sites was based on the size of the area transplanted within the site and ranged from five (Scar F) to fifteen (Scar C) with ten quadrats surveyed in all other sites. Ten quadrats were sampled at all reference sites. In each quadrat, the number of *Posidonia australis* shoots was quantified, and maximum leaf length and estimate of epiphyte cover (using a one to five scale, where one indicated minimal and five indicated heavy epiphyte cover) was recorded for three shoots per quadrat. Photos and general observations of the sites were also recorded.

2.2.2 Benthic cover

A digital camera was used to record a photograph of each survey quadrat for post-hoc analysis of total seagrass cover and benthic composition in rehabilitation and reference sites. Photos were captured at an angle as vertical as possible about 50 cm above the seafloor, ensuring the entire 0.25 m^2 quadrat was within the frame.

2.3 Data analysis

2.3.1 Analysis of *Posidonia australis* density, leaf length and epiphyte cover

Data on *Posidonia australis* shoot density, leaf length and epiphyte cover recorded during the surveys of *Posidonia australis* in the rehabilitation and reference sites were analysed to obtain summary descriptive statistics. The mean (± standard error) of these variables were calculated for each site and plotted for visual interpretation of the results.

Time series plots of trends in shoot density, maximum leaf length and epiphyte cover at rehabilitation and reference sites were compiled from the entire monitoring program dataset. Generalised linear models (GLM) were used to test for changes in these variables through time at rehabilitation sites. GLMs were run on each rehabilitation site separately using monitoring round as a factor. GLMs for shoot density were run using a negative binomial distribution due to data being overdispersed. Maximum leaf lengths and epiphyte cover were modelled using a gamma and binomial distribution, respectively. Model assumptions and fit were checked by examining plots of residuals and Akaike Information Criterion values, and likelihood ratio tests were used to calculate p-values. Where model results indicated significance of the monitoring round factor, Tukey pairwise comparisons of shoots densities, maximum leaf lengths and epiphyte cover between monitoring rounds were carried out. Analyses and plots were prepared using the packages MASS (Venables and Ripley, 2002), lmtest (Zeileis and Hothorn, 2002), multcomp (Hothorn et al., 2008) and ggplot (Wickham, 2016) in R version 4.4.1 (R Core Team, 2024).

2.3.2 Analysis of benthic cover

Digital photographs of survey quadrats captured during the monitoring event were analysed for percentage of biotic (seagrass, kelp, other macroalgae, invertebrates) and abiotic (sand, pebbles, rock) benthic cover using the image analysis program Coral Point Count with Excel extensions (Kohler and Gill, 2006). Total seagrass cover as well as benthic composition for each quadrat was estimated using the random point method. Thirty random points were allocated to each photoquadrat and the seagrass species, other biota and substrate type under each point was identified. The mean percentage cover of all seagrass and the different benthic types were calculated for each rehabilitation and reference site and plotted to visual temporal trends.

Three-factor PERMANOVAs were used to test for univariate differences in total seagrass cover and multivariate differences in benthic composition among all four monitoring events carried out in 2024 (to allow inclusion of Scar D where rehabilitation began in February 2024) at rehabilitation and reference sites. The PERMANOVA treated site type (reference or rehabilitation) and monitoring event as fixed factors and site as a random factor nested in site type. A Euclidean distance (total seagrass cover) or Bray-Curtis (benthic composition) similarity matrix was constructed and the PERMANOVAs were run under a reduced model with Type III sum of squares and 999 permutations. Post-hoc pairwise tests were carried out to investigate significant main effects. The similarity percentage (SIMPER) routine was performed to determine which benthic categories contributed most to dissimilarities in benthic composition between the period of interest, October and December 2024 (Clarke, 1993). Analyses were carried out in Primer v6 with PERMANOVA+ add on (Clarke and Gorley, 2006; Anderson et al., 2008).

3. Results

3.1 *Posidonia australis* density and condition

The overall mean values for *Posidonia australis* shoot density, leaf length and epiphyte cover for the rehabilitation and reference sites captured by the December 2024 monitoring surveys are provided in Table 3-2. Site-level data for the entire monitoring period is provided in Appendix A. Detailed results of statistical tests are provided in Appendix B.

Transplanting with naturally detached *Posidonia australis* during the period October - December 2024 occurred at Scar D only (Table 3-1). A total of 167 naturally detached *Posidonia australis* shoots were transplanted at this site to restore 4 m^2 of degraded habitat.

Table 3-1: Summary of transplanted *Posidonia australis* shoots through time at rehabilitation sites at Kurnell. Each time point represents a monitoring event. Listed are the number of shoots transplanted and, in parentheses, density that the shoots were transplanted at in the new area restored. All shoots reported for the August 2023 time point (except Scar F) were translocated. Scar F total for the initial time point includes 70 naturally detached shoots. Subsequent times used naturally detached shoots only.

	Shoots transplanted (transplanted density, shoots per m^2)					
Shoot type:	Translocated	Naturally detached				
Site	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Scar B	2448 (51)	83 (41)	45 (22)	-	-	-
Scar C	6480 (43)	-	59 (59)	-	-	-
Scar E	1445 (38)	132 (33)	-	-	-	-
Scar F	254 (25)	55 (27)	-	-	-	-
Trench East	1174 (42)	-	-	-	-	-
Trench West	1215 (35)	-	-	-	-	-
Scar D	-	-	1968 (45)	1292 (46)	602 (43)	167 (42)
Total	**13,016**	**270**	**2072**	**1292**	**602**	**167**

The overall mean shoot density of *Posidonia australis* in rehabilitation sites quantified in the December 2024 monitoring surveys was 41 shoots per m^2 with a range among sites of 26 to 46 shoots per m^2, representing an increase of 2 shoots per m^2 since the previous monitoring surveys in October 2024 (Table 3-2, Figure 3-1a, Appendix A, Table A-1). Conversely, the overall mean *Posidonia australis* shoot density for reference sites decreased from 170 to 167 shoots per m^2 over the same period.

Maximum leaf lengths of *Posidonia australis* in rehabilitation sites were 13 cm shorter on average than in reference sites (Table 3-2). Maximum leaf lengths in both rehabilitation and reference sites showed increases of about 10 cm since the monitoring surveys carried out in October 2024 (Table A-2). Some individual rehabilitation sites had maximum leaf lengths closely resembling those of reference sites (e.g. Scar B, Scar E; Figure 3-1b).

The overall mean epiphyte cover of *Posidonia australis* was lower in December 2024 compared to October 2024, being 2.7 and 3.3, respectively. In December 2024, mean epiphyte cover in rehabilitation sites was generally less than 3 (i.e., moderate), with Scar F being the exception (3.1) (Figure 3-1c, Table A-3). Reference sites showed minimal change in epiphyte cover between October and December 2024, the overall mean values in these two time periods being 3.1 and 3.2, respectively.

Table 3-2: Summary (mean ± standard error) of *Posidonia australis* characteristics quantified in rehabilitation and reference sites at Kurnell during the monitoring event in December 2024.

Site type (number of sites)	Shoot density (m^{-2})	Leaf length (cm)	Epiphyte cover (1-5 scale)
Rehabilitation (7)	41 (±1.8)	45 (±1.1)	2.7 (±0.1)
Reference (6)	167 (±7.3)	58 (±0.8)	3.2 (±0.1)

Of the seven rehabilitation sites, four (Scar F, Trench East, Trench West and Scar D) showed increases in *Posidonia australis* shoot densities of about 1-10 shoots per m^2 over the October to December 2024 period (Figure 3-2a, Table A-1). The remaining three rehabilitation sites (Scar B, Scar C and Scar E) showed minor decreases in shoot densities of about 1-3 shoots per m^2 over this period. Variation in shoot densities through time was significant at rehabilitation sites Scar B and Scar E only (Table B-1). Measured shoot densities at these two sites were significantly greater ($p<0.001$ for both) in the initial round of monitoring surveys in August 2023 in comparison to any subsequent monitoring period (Table B-3). Shoot densities at the other rehabilitation sites were relatively stable through time with no statistically significant variation registered. Among reference sites, PBK03 and PBR02 displayed decreases in shoot densities (about 12 and 20 shoots per m^2, respectively), while little variation occurred at the other sites between October and December 2024 (Figure 3-2b).

There was significant variation through time in *Posidonia australis* maximum leaf lengths at all rehabilitation sites ($p<0.001$ in all cases except Scar F: $p<0.01$; Table B-1). This was driven by measured maximum leaf lengths being significantly greater In December 2024 than all other time points, except at Scar F where the pattern was less consistent (Figure 3-3a; Table B-3). Maximum leaf lengths were otherwise relatively stable through time at rehabilitation sites. The pattern was repeated at reference sites, where five out of six sites (PBR02 being the exception) recorded the longest maximum leaf lengths in December 2024 (Figure 3-3a).

Epiphyte cover varied significantly through time at all rehabilitation sites except Trench West (Figure 3-3b; Table B-1). There was a tendency for epiphyte cover to be lower in the initial months following translocation (August to October 2023) in comparison to the period seven to eleven months later (February to May 2024; Table B-3). Epiphyte cover decreased at all rehabilitation sites between October and December 2024, but not significantly so. In reference sites, epiphyte cover appeared to remain stable (four sites) or increase (two sites) over the same period (Figure 3-3b).

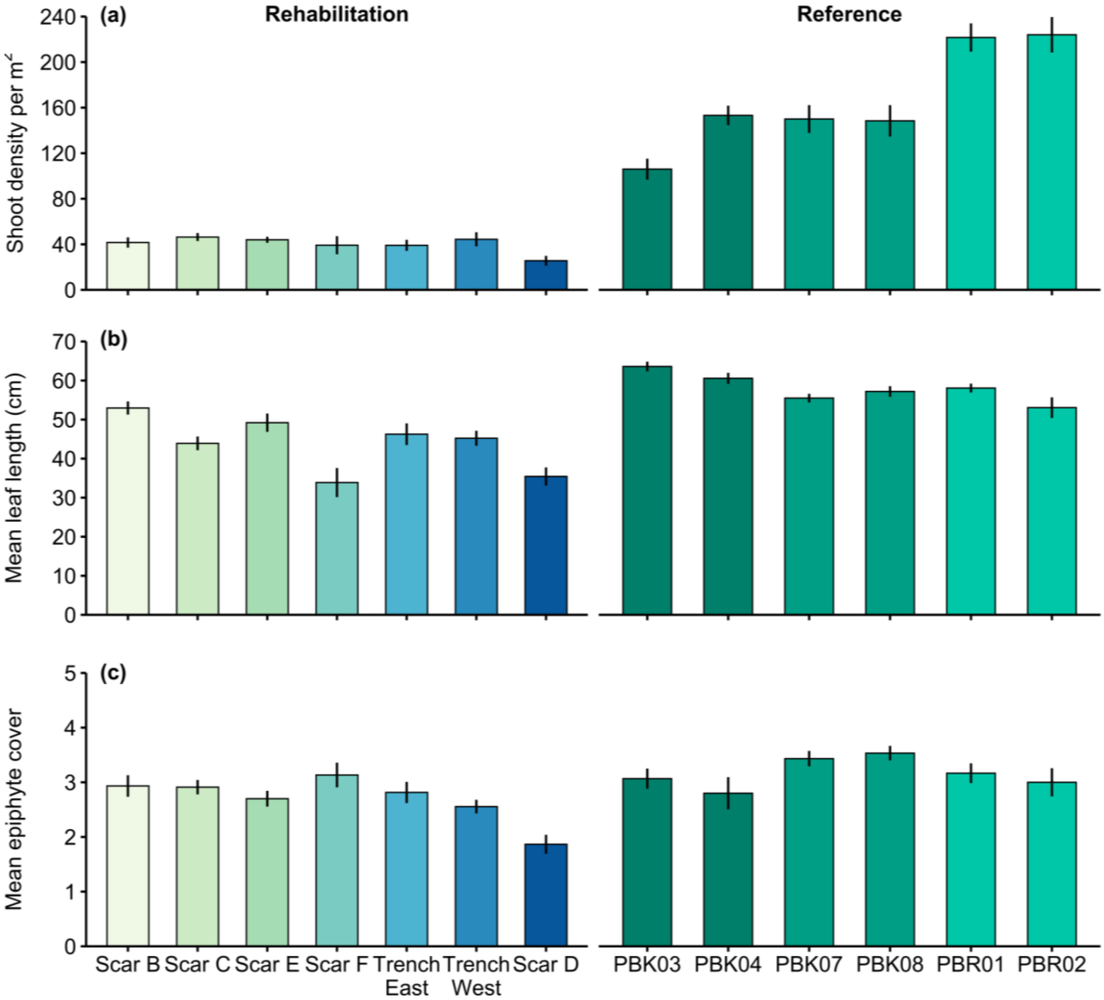

Figure 3-1: *Posidonia australis* characteristics at seven rehabilitation and six reference sites at Kurnell captured during the monitoring surveys in December 2024: (a) shoot density, (b) leaf length and (c) epiphyte cover.
Shown are mean values (± standard error) for translocated *Posidonia australis* in rehabilitation sites, except Scar D; Scar D consists of naturally detached *Posidonia australis* shoots only.

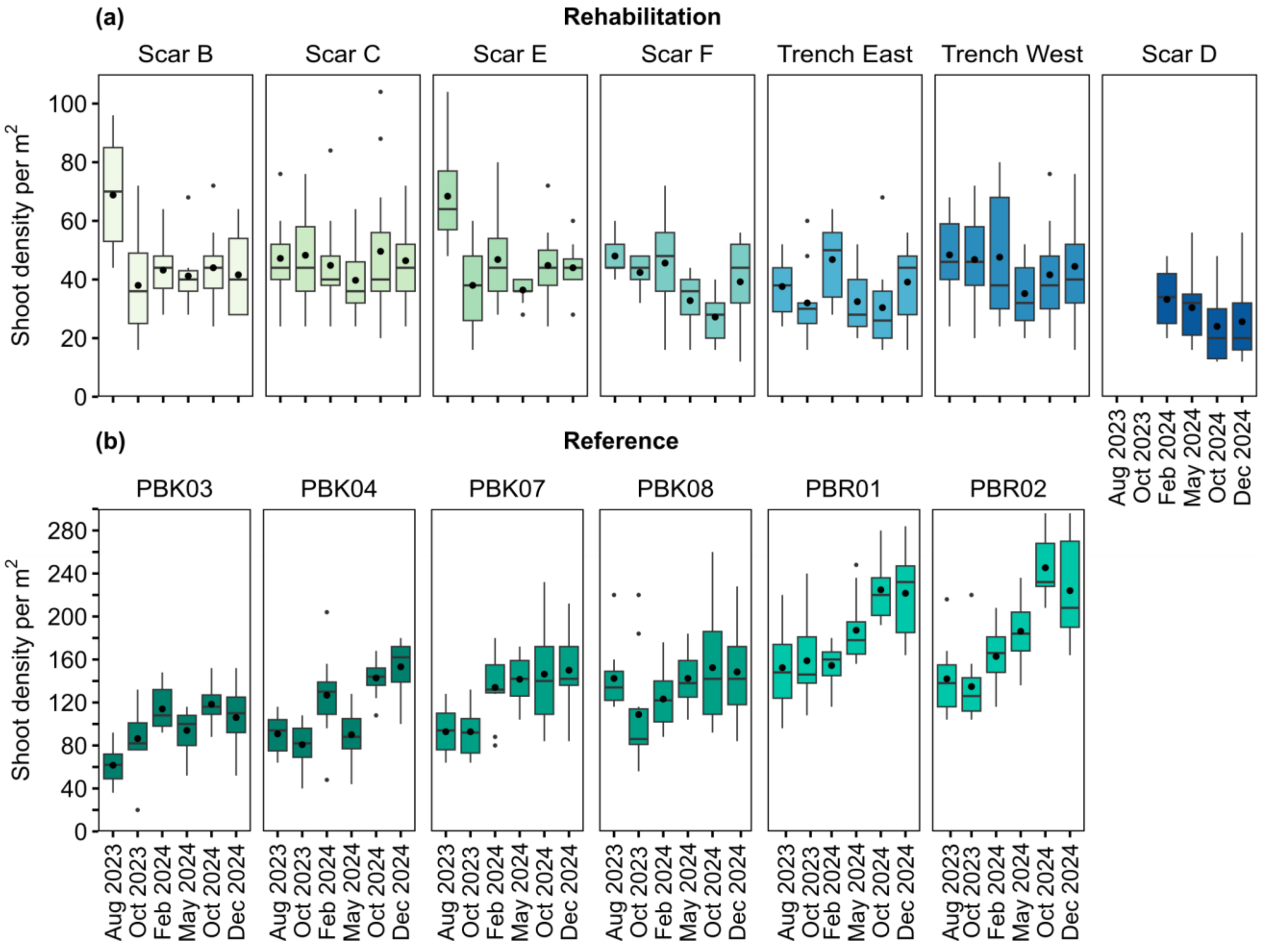

Figure 3-2: Shoot density through time at the (a) rehabilitation sites and (b) reference sites.
Each time point represents a monitoring event. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* began in February 2024. In (a) shoot density is shown for translocated *Posidonia australis* in rehabilitation sites, except Scar D; Scar D consists of naturally detached *Posidonia australis* shoots only. The box-whisker represents the median (line), interquartile range (box), range (whiskers) and outliers (dots). Means are represented by large black circles. Note different scales for shoot density between plots.

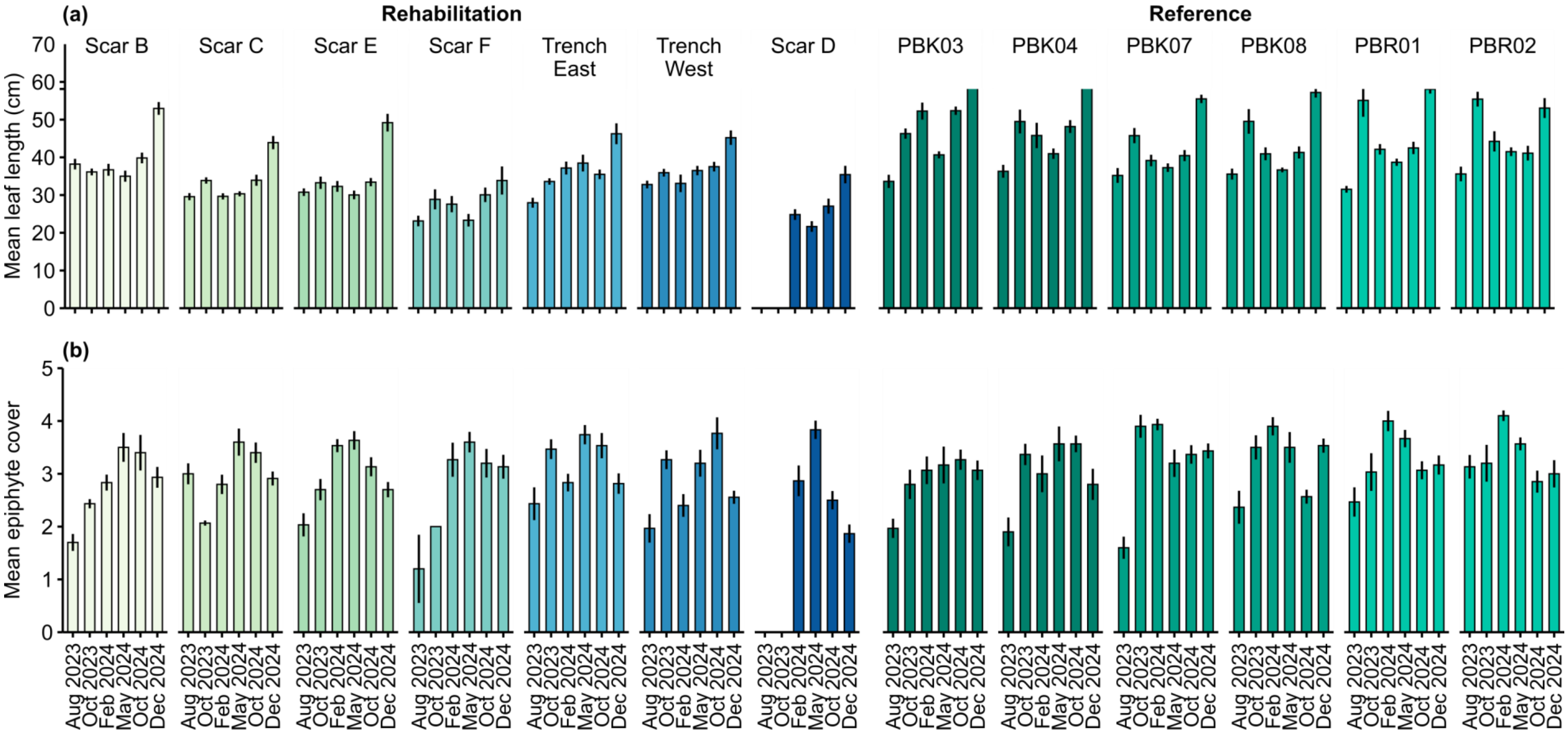

Figure 3-3: *Posidonia australis* condition through time at seven rehabilitation and six reference sites at Kurnell: (a) maximum leaf length and (b) epiphyte cover.
Each time point represents a monitoring event. Shown are mean values (± standard error) for translocated *Posidonia australis* in rehabilitation sites, except Scar D; Scar D consists of naturally detached *Posidonia australis* shoots only.

3.2 Benthic cover in rehabilitation and reference sites

The overall mean values for total seagrass and benthic type cover for rehabilitation and reference sites captured during the monitoring surveys carried out in December 2024 are presented in Table 3-3. Site-level data for the entire monitoring period to date is provided in Appendix A. Detailed results of statistical tests are provided in Appendix B.

Total seagrass cover for rehabilitation and reference sites significantly varied among monitoring events and there was a significant interaction between monitoring event and site (p=0.015 and p=0.001, respectively; Table B-4). Investigation of the interaction term indicated that apart from rehabilitation site Trench East and reference site PBK03 where little variation in seagrass cover occurred through time, all sites showed significant variation in seagrass cover among multiple monitoring time points (Table B-5). For the period of interest, October to December 2024, three rehabilitation sites (Scar C, Scar F and Trench West) and all reference sites except PBK03 recorded a significant difference in total seagrass cover. In all cases this was due to an increase in total seagrass cover between October and December 2024 (Figure 3-5a).

Comparisons of benthic composition among monitoring events for sites followed a similar pattern to that for total seagrass cover, with significant variation occurring among monitoring events and a significant interaction between monitoring event and site (p=0.001 in both cases; Table B-6). Comparing the October and December 2024 survey data, two of seven rehabilitation sites (Scar C and Trench West) and five of six reference sites (PBK03 the exception) recorded significantly different benthic compositions (Table B-7). At the rehabilitation sites, a reduction in cover of bare sand between October and December 2024 contributed most to the shift in benthic composition over this period (Figure 3-5b, Table B-8). In reference sites, the variation was primarily due to an increase in cover of *Posidonia australis* from October to December 2024.

Table 3-3: Summary of benthic cover (mean ± standard error) quantified in rehabilitation and reference sites at Kurnell during the monitoring surveys in December 2024.

	Percentage cover				
Site type (number of sites)	Total seagrass	*Posidonia australis*	*Zostera sp.*	*Halophila sp.*	Sand
Rehabilitation (7)	64.9 (±2.2)	35.8 (±2.2)	18.7 (±2.1)	10.4 (±1.1)	35.0 (±2.2)
Reference (6)	90.9 (±1.2)	85.9 (±1.5)	4.3 (±0.9)	0.7 (±0.2)	9.1 (±1.2)

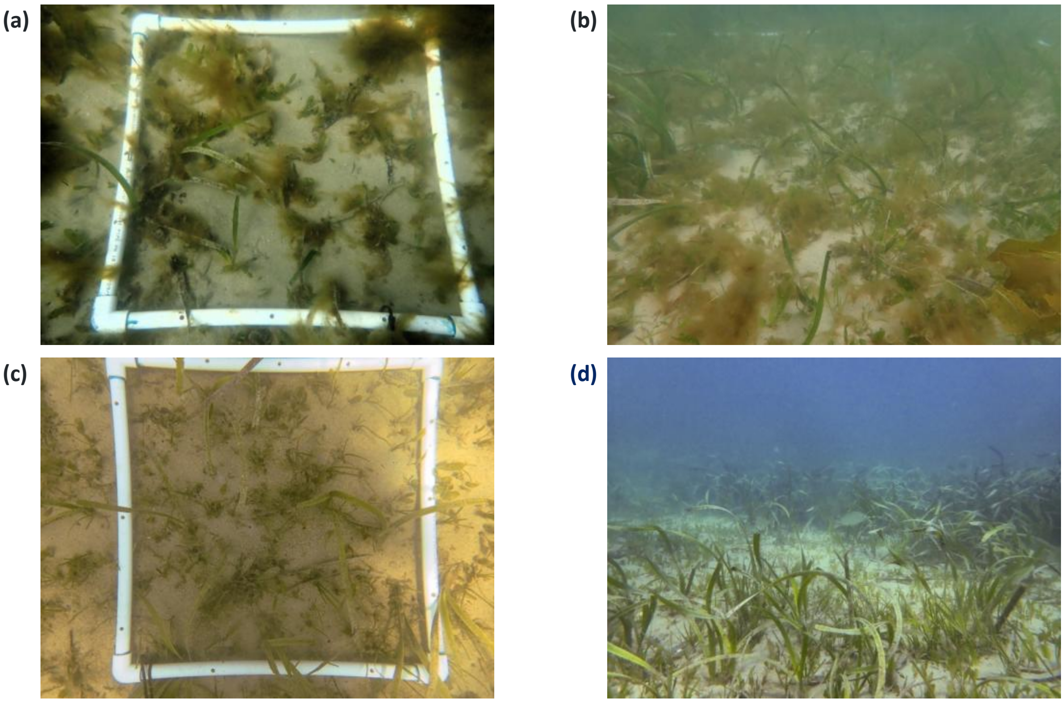

Figure 3-4: Photos showing (a, b) epiphytic algae attached to seagrass in rehabilitation site Scar D in October 2024 and (c, d) seagrass in Scar D and Scar E clear of algae in December 2024.

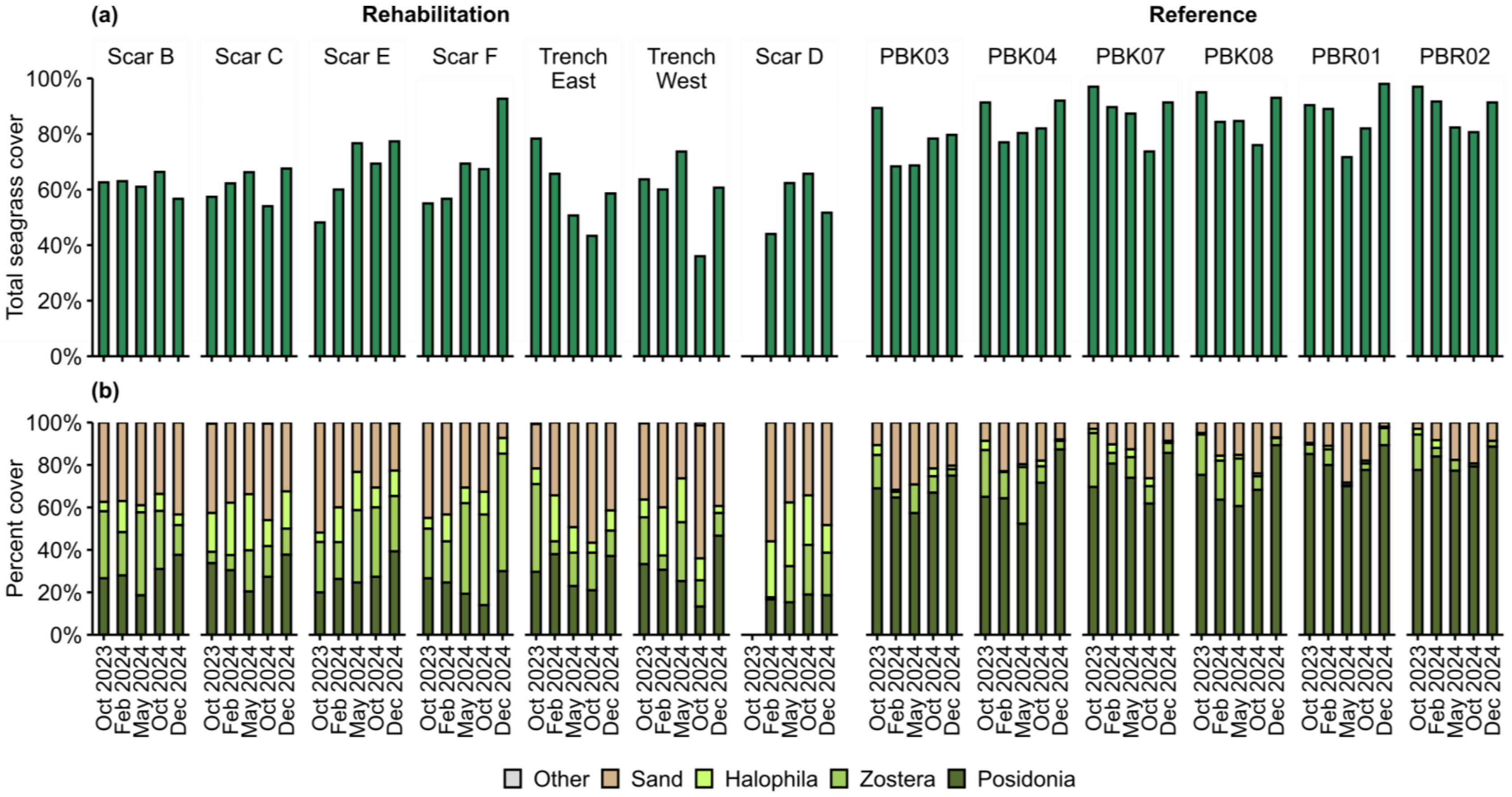

Figure 3-5: Comparison of (a) total seagrass cover and (b) benthic composition at the seven rehabilitation and six reference sites at Kurnell through time.
Each time point represents a monitoring event. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* commenced in early February 2024.

4. Discussion

This report documents the findings of seagrass monitoring surveys of rehabilitation and reference sites at Kurnell in December 2024. The purpose of the monitoring surveys was to collect data that would allow any short-term (about two-month) impacts of the algal bloom on the density, condition and benthic composition of the *Posidonia australis* meadow at Kurnell to be detected. This is discussed further in the following sections.

4.1 Epiphytic algal blooms and seagrasses

Seagrass meadows in coastal areas worldwide experience excessive growth of epiphytic and fast-growing drift algae, with declines in some seagrass meadows associated with algal blooms (Han and Liu, 2014). Generally associated with excess nutrient inputs in coastal areas, algal blooms can form thick mats that reduce the light reaching seagrasses, cause smothering, create anoxic sediments and restrict seagrass growth (Hauxwell *et al*., 2001; McGlathery, 2001; Nelson and Lee, 2001). Algal blooms may also have direct physical effects on seagrasses, for example heavy epiphytic growth on leaf surfaces increases the vulnerability of leaves to damage by wave action (Cambridge *et al*., 1986; Trautman and Borowitzka, 1999).

Several short-term (about one to three-month) epiphytic algal blooms have been observed affecting the Kurnell, and wider Gamay, seagrass meadows since the seagrass monitoring program began in July 2023: in August and November 2023, and February and September 2024. The frequency of these events over the first year of the monitoring program suggests that given the combination of environmental conditions conducive to its growth, blooms of the opportunistic algae are anticipated to continue to occur over the course of the *Posidonia australis* rehabilitation efforts and monitoring.

In Kurnell, the most recent epiphytic algal bloom first developed in late September 2024 and by mid-October had formed a thick covering over the seagrass meadow. The epiphytic algae attached to seagrass leaves and formed large clumps on areas of bare sediment. The algal bloom appeared to be less dense in the seagrass meadow surrounding the rehabilitation sites, suggesting that areas of dense *Posidonia australis* may have greater resistance to epiphytic algae due to greater leaf movement (Lavery *et al.,* 2007). Alternatively, it may be that natural *Posidonia australis* has greater resistance to epiphytic algae than transplanted *Posidonia australis.* The algal bloom was no longer present at the time of the monitoring surveys in mid-December and visual reports suggest the bloom broke down by late November, indicating the duration of the algal bloom was about 8 weeks.

4.2 *Posidonia australis* density, condition and seagrass composition

Monitoring results indicated that there was no significant short-term negative effect of the algal bloom on *Posidonia australis* shoot densities in rehabilitation sites at Kurnell. Minor increases in shoot densities were recorded at four of seven rehabilitation sites over the period immediately prior to the onset of the algal bloom to within about two weeks of its disappearance. Declines in *Posidonia australis* shoot densities at three rehabilitation sites over this period fell within the rate of standard error (less than 3 shoots per m^2). In the natural meadow (reference) sites, *Posidonia australis* shoot densities appeared to be largely unaffected by the algal bloom, with two of six sites showing small (about 9 percent) decreases in shoot density. The lack of a significant short-term effect of the algal bloom on *Posidonia australis* shoot densities may be explained by the seagrass' physical attributes (e.g. wide leaves and underground root structure) that minimise losses of entire shoots. Alternatively, the relatively short duration of the algal bloom may have contributed to the apparent resilience of *Posidonia australis* to this event.

Assessments of maximum leaf length and epiphyte cover, as indicators of *Posidonia australis* condition, similarly revealed no significant negative effect of the algal bloom on *Posidonia australis* in rehabilitation or reference sites at Kurnell. *Posidonia australis* maximum leaf lengths increased at all rehabilitation sites and all except one reference site over the period coinciding with the algal bloom. The growth in leaf lengths during this period also coincided with the peak growth period (Spring) for the species (Kirkman, 2014) which likely explains this result. Further, the method for measuring this attribute means that it captures data for only a small subsample of *Posidonia australis* leaves and may not be presenting a complete picture. Visual observations noted that some leaves in rehabilitation sites showed signs of physical damage, however it cannot be determined whether this was a result of shading, burial or wave action due to heavy fouling.

Posidonia australis epiphyte cover declined at all rehabilitation sites between the pre- and post-algal bloom monitoring surveys, although declines were not significant. The three sites that displayed the greatest declines (up to 30 percent) in epiphyte cover, Trench East, Trench West and Scar D, provide a snapshot of the effect of the algal bloom on leaf condition, as surveys at these sites were conducted in the early onset of the bloom. Epiphyte cover in reference sites generally showed minimal change over the period of interest. Removal of the heavy epiphytic algae load from the *Posidonia australis* leaves could have been facilitated by wind-generated swell as there were multiple occurrences of consecutive days of moderately strong to strong (>30 km/h with gusts of up to 60km/h) wind conditions recorded at Kurnell during November 2024 (Bureau of Meteorology, 2024).

Seagrass cover increased at all except two rehabilitation sites and all reference sites over the two-month period of October to December 2024, and this was largely driven by increases in cover of *Posidonia australis.* The short-term nature of the algal bloom combined with timing of the monitoring surveys meant that the opportunity to capture data about percentage cover of the algal bloom in the sites was missed. Observations during the algal bloom noted that the algae tended to attach to the tips of leaves of *Posidonia australis* in rehabilitation sites, while in reference sites the algae tended to form mats below the *Posidonia australis* canopy, close to the benthos. In dense *Posidonia australis* meadows, water circulation under the seagrass canopy is reduced compared to the water column above (Trautman and Borowitzka, 1999) and may explain why the algal mats tend to clump towards the benthos in the natural meadow.

4.3 Conclusions

Overall, the assessment indicates there was no significant negative effect of the algal bloom on *Posidonia australis* shoot density, condition and seagrass composition in rehabilitation or references sites in Kurnell, at least over the short period considered. The findings from the assessment were contrary to expectations based on studies of algal bloom impacts on *Posidonia* species (Cambridge *et al*., 1986; Cummins *et al*., 2004; Ballesteros *et al*., 2007). However, as outlined, several factors may have influenced the assessment findings, and repeated monitoring of similar events is required to allow conclusions to be made (Raffaelli *et al*., 1998). Furthermore, while there appeared to be no short-term negative impact of the algal bloom on the morphological attributes of *Posidonia australis* measured here, physiological responses such as nutrients and carbohydrate content and photosynthetic ability, as well as responses by seagrass-associated fauna may have occurred but were not investigated. Nonetheless, the long-term persistence of the extensive *Posidonia australis* meadow at Kurnell and other locations in Gamay suggests that the species is reasonably resilient and/or adapted to the relatively frequent fluctuations in local environmental conditions.

The Gamay catchment area includes several riverways that discharge stormwater and sewer overflow directly into the bay, delivering pollutants and nutrient loads into the bay (Tippler *et al*., 2012), including directly into Kurnell. These discharges are greater following rain and storm events and are likely key drivers of the episodic algal blooms that occur in Gamay. However, to date there are no known studies of algal bloom events and their ecological consequences for *Posidonia australis* in NSW estuaries. With the frequency of algal blooms in coastal estuaries increasing in frequency and persistence in many locations (Raffaelli *et al*., 1998) combined with increasing frequency of intense storms with climate change, there is a need to understand the potential impact of changes in nutrient dynamics on *Posidonia australis* in Gamay and other NSW estuaries where *Posidonia australis* is endangered.

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Appendix A

Survey data for rehabilitation and reference sites

Table A-1: Mean (± standard error) *Posidonia australis* shoot density at rehabilitation and reference sites over the course of the monitoring program.

		Shoot density (per m²)					
Site	Site type	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Overall	Rehabilitation	53.0 (±2.3)	41.0 (±2.0)	45.7 (±2.0)	36.0 (±1.2)	39.0 (±2.2)	40.5 (±1.8)
Overall	Reference	114.0 (±5.6)	110.0 (±5.7)	135.9 (±4.3)	142.2 (±6.5)	170.4 (±7.5)	167.2 (±7.3)
Scar B	Rehabilitation	68.8 (±5.8)	38.0 (±5.6)	43.2 (±3.2)	41.2 (±3.3)	44.0 (±4.3)	41.6 (±4.5)
Scar C	Rehabilitation	47.2 (±3.2)	48.3 (±4.1)	44.8 (±3.8)	39.7 (±2.6)	49.6 (±5.7)	46.4 (±3.5)
Scar E	Rehabilitation	68.4 (±5.2)	38.0 (±4.9)	46.8 (±4.8)	36.4 (±1.3)	44.8 (±4.2)	44.0 (±2.7)
Scar F	Rehabilitation	48.0 (±3.6)	42.4 (±3.0)	45.6 (±9.4)	32.8 (±5.0)	27.2 (±4.3)	39.2 (±7.9)
Trench East	Rehabilitation	37.6 (±3.0)	32.0 (±4.1)	46.8 (±4.2)	32.4 (±3.4)	30.4 (±5.0)	39.1 (±4.8)
Trench West	Rehabilitation	48.4 (±4.6)	46.8 (±4.8)	47.6 (±6.8)	35.2 (±3.5)	41.6 (±5.4)	44.4 (±6.2)
Scar D	Rehabilitation	-	-	33.2 (±3.2)	30.4 (±3.6)	24.0 (±4.2)	25.6 (±4.3)
PBK03	Reference	61.6 (±5.4)	86.4 (±9.8)	114.0 (±6.4)	94.0 (±6.4)	118.4 (±6.2)	106.0 (±9.2)
PBK04	Reference	90.8 (±5.8)	80.8 (±6.4)	126.8 (±12.8)	90.0 (±7.5)	142.8 (±5.7)	153.2 (±8.5)
PBK07	Reference	92.8 (±6.8)	92.8 (±7.6)	134.0 (±10.0)	141.6 (±7.2)	146.4 (±14.9)	150.0 (±12.3)
PBK08	Reference	142.4 (±9.7)	108.8 (±16.7)	123.2 (±8.5)	142.4 (±8.0)	152.4 (±17.5)	148.4 (±13.8)
PBR01	Reference	152.4 (±12.6)	158.8 (±12.6)	154.4 (±6.2)	187.2 (±10.1)	224.8 (±9.7)	221.6 (±12.4)
PBR02	Reference	142.0 (±10.7)	134.8 (±11.1)	162.8 (±10.1)	198.0 (±15.2)	245.3 (±9.2)	224.0 (±15.6)

Table A-2: Mean (± standard error) maximum *Posidonia australis* leaf length at rehabilitation and reference sites over the course of the monitoring program.

		Leaf length (cm)					
Site	Site type	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Overall	Rehabilitation	31.0 (±0.7)	34.0 (±0.5)	32.9 (±0.8)	31.2 (±0.8)	34.2 (±0.7)	44.5 (±1.1)
Overall	Reference	35.0 (±0.7)	50.0 (±1.2)	44.1 (±1.0)	39.3 (±0.5)	44.4 (±0.8)	58.0 (±0.8)
Scar B	Rehabilitation	38.2 (±1.4)	36.1 (±0.9)	36.7 (±1.6)	35.0 (±1.5)	39.8 (±1.4)	53.0 (±1.7)
Scar C	Rehabilitation	29.6 (±0.9)	33.9 (±0.8)	29.7 (±0.8)	30.3 (±0.7)	33.9 (±1.5)	43.9 (±1.8)
Scar E	Rehabilitation	30.8 (±1.0)	33.3 (±1.6)	32.3 (±1.4)	30.0 (±1.1)	33.4 (±1.1)	49.2 (±2.3)
Scar F	Rehabilitation	23.1 (±1.4)	28.9 (±2.7)	27.6 (±2.2)	23.3 (±1.7)	30.1 (±1.9)	33.9 (±3.7)
Trench East	Rehabilitation	28.0 (±1.3)	33.6 (±0.9)	37.2 (±1.7)	38.5 (±2.2)	35.5 (±1.3)	46.3 (±2.8)
Trench West	Rehabilitation	32.8 (±1.0)	35.9 (±1.0)	33.1 (±2.3)	36.5 (±1.2)	37.5 (±1.3)	45.2 (±1.9)
Scar D	Rehabilitation	-	-	24.8 (±1.4)	21.7 (±1.4)	27.1 (±2.0)	35.4 (±2.3)
PBK03	Reference	33.6 (±1.8)	46.3 (±1.4)	52.3 (±2.3)	40.7 (±0.9)	52.4 (±1.1)	63.6 (±1.2)
PBK04	Reference	36.3 (±1.7)	49.5 (±3.2)	45.8 (±3.4)	41.0 (±1.4)	48.2 (±1.7)	60.6 (±1.4)
PBK07	Reference	35.2 (±2.0)	45.8 (±2.0)	39.2 (±1.5)	37.3 (±1.1)	40.5 (±1.5)	55.5 (±1.1)
PBK08	Reference	35.6 (±1.5)	49.5 (±3.3)	40.9 (±1.7)	36.7 (±0.6)	41.3 (±1.6)	57.2 (±1.4)
PBR01	Reference	31.5 (±0.9)	55.1 (±4.3)	42.1 (±1.4)	38.7 (±1.0)	42.5 (±1.6)	58.1 (±1.1)
PBR02	Reference	38.2 (±1.4)	55.4 (±2.0)	44.2 (±2.7)	41.5 (±1.2)	41.1 (±2.0)	53.1 (±2.6)

Table A-3: Mean (± standard error) *Posidonia australis* epiphyte cover at rehabilitation and reference sites over the course of the monitoring program.

		Epiphyte cover (1-5 scale)					
Site	Site type	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Overall	Rehabilitation	2.2 (±0.1)	2.7 (±0.1)	2.9 (±0.1)	3.6 (±0.1)	3.3 (±0.1)	2.7 (±0.1)
Overall	Reference	2.2 (±0.1)	3.3 (±0.1)	3.7 (±0.1)	3.4 (±0.1)	3.1 (±0.1)	3.2 (±0.1)
Scar B	Rehabilitation	1.7 (± 0.2)	2.4 (±0.1)	2.8 (±0.2)	3.5 (±0.3)	3.4 (±0.3)	2.9 (±0.2)
Scar C	Rehabilitation	3.0 (± 0.2)	2.1 (±0)	2.8 (±0.2)	3.6 (±0.3)	3.4 (±0.2)	2.9 (±0.1)
Scar E	Rehabilitation	2.0 (± 0.2)	2.7 (±0.2)	3.5 (±0.1)	3.6 (±0.2)	3.1 (±0.2)	2.7 (±0.1)
Scar F	Rehabilitation	1.2 (± 0.6)	2.0 (±0)	3.3 (±0.3)	3.6 (±0.2)	3.2 (±0.3)	3.1 (±0.2)
Trench East	Rehabilitation	2.4 (± 0.3)	3.5 (±0.2)	2.8 (±0.2)	3.7 (±0.2)	3.5 (±0.2)	2.8 (±0.2)
Trench West	Rehabilitation	2.0 (± 0.3)	3.3 (±0.2)	2.4 (±0.2)	3.2 (±0.3)	3.8 (±0.3)	2.6 (±0.1)
Scar D	Rehabilitation	-	-	2.9 (±0.3)	3.8 (±0.2)	2.5 (±0.2)	1.9 (±0.2)
PBK03	Reference	2.0 (± 0.2)	2.8 (±0.3)	3.1 (±0.3)	3.2 (±0.3)	3.3 (±0.2)	3.1 (±0.2)
PBK04	Reference	1.9 (± 0.3)	3.4 (±0.2)	3.0 (±0.3)	3.6 (±0.3)	3.6 (±0.2)	2.8 (±0.3)
PBK07	Reference	1.6 (± 0.2)	3.9 (±0.2)	3.9 (±0.1)	3.2 (±0.3)	3.4 (±0.2)	3.4 (±0.1)
PBK08	Reference	2.4 (± 0.3)	3.5 (±0.2)	3.9 (±0.2)	3.5 (±0.3)	2.6 (±0.1)	3.5 (±0.1)
PBR01	Reference	2.5 (± 0.3)	3.0 (±0.4)	4.0 (±0.2)	3.7 (±0.2)	3.1 (±0.2)	3.2 (±0.2)
PBR02	Reference	3.1 (± 0.2)	3.2 (±0.3)	4.1 (±0.1)	3.6 (±0.1)	2.9 (±0.2)	3.0 (±0.3)

Table A-4: Mean percentage total seagrass cover at rehabilitation and reference sites over the course of the monitoring program. Benthic cover data collection commenced in monitoring round 1 in October 2023.

Site	Site type	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Overall	Rehabilitation	61.4	61.7	65.5	56.5	64.9
Overall	Reference	93.4	83.3	79.4	78.9	90.9
Scar B	Rehabilitation	62.6	63.0	61.0	66.3	56.7
Scar C	Rehabilitation	57.4	62.2	66.2	54.0	67.6
Scar E	Rehabilitation	48.1	60.0	76.7	69.3	77.3
Scar F	Rehabilitation	55.0	56.7	69.3	67.3	92.7
Trench East	Rehabilitation	78.3	65.7	50.7	43.3	58.6
Trench West	Rehabilitation	63.7	60.0	73.7	36.0	60.7
Scar D	Rehabilitation	-	44.0	62.3	65.7	51.7
PBK03	Reference	89.3	68.3	68.7	78.3	79.7
PBK04	Reference	91.3	77.0	80.3	82.0	92.0
PBK07	Reference	97.0	89.7	87.3	73.7	91.3
PBK08	Reference	95.0	84.3	84.7	76.0	93.0
PBR01	Reference	90.4	89.0	71.7	82.0	98.0
PBR02	Reference	97.0	91.7	82.3	80.7	91.3

Table A-5: Mean percentage cover of benthic categories at rehabilitation and reference sites over the course of the monitoring program. Benthic cover data collection commenced in monitoring round 1 in October 2023.

Site	Site type	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024	Oct 2023	Feb 2024	May 2024	Oct 2024	Dec 2024
Overall	Rehabilitation	29.1	30.2	21.0	22.8	35.8	23.2	11.8	26.2	22.3	18.7	9.2	19.8	18.2	113	10.4	38.3	38.2	34.5	43.2	35.0
Overall	Reference	73.4	72.9	64.8	71.1	85.9	17.4	8.3	13.3	5.6	4.3	2.5	2.2	1.3	2.1	0.7	6.6	16.7	20.1	21.1	9.1
Scar B	Rehabilitation	26.7	28.0	18.7	31.0	37.7	31.5	20.3	39.0	27.3	14.0	4.4	14.7	3.3	8.0	5.0	37.4	37.0	39.0	33.7	43.3
Scar C	Rehabilitation	33.8	30.4	20.4	27.3	37.8	5.2	7.1	19.3	14.4	12.2	18.3	24.7	26.5	12.2	17.6	42.1	37.8	33.8	45.6	32.4
Scar E	Rehabilitation	20.0	26.3	24.7	27.3	39.3	23.7	17.3	34.0	32.7	26.0	4.4	16.3	18.0	9.3	12.0	51.9	40.0	23.3	30.7	22.3
Scar F	Rehabilitation	26.7	24.7	19.3	14.0	30.0	23.3	19.3	42.7	42.7	55.3	5.0	12.7	7.3	10.7	7.3	45.0	43.3	30.7	32.7	7.3
Trench East	Rehabilitation	29.7	38.0	23.0	21.0	37.1	41.3	6.0	15.7	17.7	11.9	7.3	21.7	12.0	4.7	9.5	21.0	34.3	49.3	56.7	41.4
Trench West	Rehabilitation	33.3	30.7	25.3	13.3	46.7	22.0	6.7	27.7	12.3	10.7	8.3	22.7	20.7	10.3	3.3	36.0	40.0	26.3	62.7	39.3
Scar D	Rehabilitation	-	16.7	15.3	19.0	18.7	-	1.0	17.0	23.3	20.0	-	26.3	30.0	23.3	13.0	-	56.0	37.7	34.3	48.3
PBK03	Reference	69.0	64.7	55.7	67.0	75.0	15.7	2.7	13.0	7.7	3.0	4.7	1.0	0.0	3.7	1.7	10.7	31.7	28.3	21.7	20.3
PBK04	Reference	65.0	64.3	52.3	71.7	87.3	22.0	12.3	26.7	7.7	4.0	4.3	0.3	1.3	2.7	0.7	8.7	23.0	19.7	18.0	8.0
PBK07	Reference	69.7	80.7	74.0	61.9	85.7	25.3	5.0	9.7	8.1	4.7	2.0	4.0	3.7	3.7	1.0	3.0	10.3	12.7	26.3	8.7
PBK08	Reference	75.3	63.7	60.7	68.3	89.3	19.0	18.3	22.3	6.3	3.3	0.7	2.3	1.7	1.3	0.3	5.0	15.7	15.3	24.0	7.0
PBR01	Reference	85.2	80.0	70.0	77.7	89.3	4.4	7.3	0.4	3.0	8.0	0.7	1.7	1.3	1.3	0.7	9.6	11.0	28.3	18.0	2.0
PBR02	Reference	77.7	84.0	77.3	79.3	88.7	16.7	4.0	5.0	1.3	2.7	2.7	3.7	0.0	0.0	0.0	3.0	8.3	17.7	19.3	8.7

Appendix B

Supplementary results

Table B-1: Results of Generalised Linear Models (GLM) for differences in *Posidonia australis* shoot density, maximum leaf length and epiphyte cover in rehabilitation sites through time. Table gives degrees of freedom (df), Akaike Information Criterion (AIC), Likelihood Ratio Test statistic (χ^2) and P-value. **Bold** font indicates a statistically significant result.

		Shoot density			Leaf length			Epiphyte cover		
	df	AIC	χ^2	P-value	AIC	χ^2	P-value	AIC	χ^2	P-value
Scar B										
Null	2	507.35			408.99			172.73		
Monitoring round	7	494.27	23.08	**<0.001**	358.74	60.25	**<0.001**	164.37	18.36	**<0.01**
Scar C										
Null	2	733.60			586.47			244.10		
Monitoring round	7	738.91	4.69	0.45	519.43	77.04	**<0.001**	237.59	16.51	**<0.01**
Scar E										
Null	2	500.51			412.54			158.59		
Monitoring round	7	480.29	30.22	**<0.001**	357.84	64.70	**<0.001**	153.91	14.68	**0.01**
Scar F										
Null	2	249.99			194.19			95.95		
Monitoring round	7	251.47	8.52	0.13	188.13	16.06	**<0.01**	87.44	18.51	**<0.01**
Trench East										
Null	2	465.88			397.59			155.83		
Monitoring round	7	465.31	10.57	0.06	361.03	46.56	**<0.001**	155.15	10.68	0.06
Trench West										
Null	2	497.24			379.43			170.56		
Monitoring round	7	502.16	5.08	0.41	356.00	33.43	**<0.001**	159.51	21.05	**<0.001**
Scar D										
Null	2	312.22			273.60			119.86		
Monitoring round	5	314.32	3.90	0.27	254.08	25.52	**<0.001**	106.50	19.36	**<0.001**

Table B-2: Summary output results from GLM for *Posidonia australis* shoot density, maximum leaf length and epiphyte cover in rehabilitation sites over the monitoring program to date. **Bold** font indicates a statistically significant result.

	Shoot density		Leaf length		Epiphyte cover	
Monitoring round	z value	P-value	t value	P-value	z value	P-value
Scar B						
(Intercept) Aug 2023	46.78	**<0.001**	27.57	**<0.001**	-2.22	**0.03**
Oct 2023	-4.48	**<0.001**	1.08	0.28	1.48	0.14
Feb 2024	-3.55	**<0.001**	0.78	0.44	2.26	**0.02**
May 2024	-3.89	**<0.001**	1.70	0.09	3.52	**<0.001**
Oct 2024	-3.41	**<0.001**	-0.82	0.42	3.33	**<0.001**
Dec 2024	-3.82	**<0.001**	-6.23	**<0.001**	2.45	**0.01**
Scar C						
(Intercept) Aug 2023	49.07	**<0.001**	30.75	**<0.001**	1.72	0.09
Oct 2023	0.20	0.84	-2.93	**<0.01**	-2.27	**0.02**
Feb 2024	-0.47	0.64	-0.07	0.95	-0.50	0.62
May 2024	-1.53	0.13	-0.55	0.58	1.55	0.12
Oct 2024	0.45	0.65	-2.98	**<0.01**	1.02	0.31
Dec 2024	-0.15	0.88	-8.32	**<0.001**	-0.22	0.82
Scar E						
(Intercept) Aug 2023	53.84	**<0.001**	24.17	**<0.001**	-1.31	0.19
Oct 2023	-5.06	**<0.001**	-1.33	0.19	1.33	0.18
Feb 2024	-3.33	**<0.001**	-0.83	0.41	2.97	**<0.01**
May 2024	-5.41	**<0.001**	0.41	0.68	3.16	**<0.01**
Oct 2024	-3.70	**<0.001**	-1.42	0.16	2.18	**0.03**
Dec 2024	-3.85	**<0.001**	-7.68	**<0.001**	1.33	0.18
Scar F						
(Intercept) Aug 2023	26.55	**<0.001**	12.31	**<0.001**	-2.46	**0.01**
Oct 2023	-0.60	0.55	-1.91	0.07	1.20	0.23
Feb 2024	-0.25	0.80	-1.53	0.14	2.84	**<0.01**
May 2024	-1.81	0.07	-0.08	0.94	3.25	**<0.01**
Oct 2024	-2.66	**<0.01**	-2.25	**0.03**	2.76	**0.01**
Dec 2024	-0.97	0.33	-3.22	**<0.01**	2.67	**0.01**
Trench East						
(Intercept) Aug 2023	33.98	**<0.001**	22.13	**<0.001**	-0.19	0.85
Oct 2023	-1.06	0.29	-2.85	**0.01**	2.08	**0.04**
Feb 2024	1.47	0.14	-4.38	**<0.001**	0.80	0.42
May 2024	-0.94	0.35	-4.80	**<0.001**	2.57	**0.01**
Oct 2024	-1.39	0.17	-3.69	**<0.001**	2.22	**0.03**
Dec 2024	0.26	0.80	-7.38	**<0.001**	0.74	0.46
Trench West						
(Intercept) Aug 2023	34.40	**<0.001**	23.75	**<0.001**	-1.50	0.13
Oct 2023	-0.21	0.83	-1.53	0.13	2.57	**0.01**
Feb 2024	-0.10	0.92	-0.15	0.88	0.87	0.38
May 2024	-1.97	**<0.05**	-1.79	0.08	2.44	**0.01**
Oct 2024	-0.94	0.35	-2.26	**0.03**	3.54	**<0.001**
Dec 2024	-0.52	0.60	-5.18	**<0.001**	1.15	0.25

Monitoring round	Shoot density z value	Shoot density P-value	Leaf length t value	Leaf length P-value	Epiphyte cover z value	Epiphyte cover P-value
Scar D						
(Intercept) Feb 2024	27.71	**<0.001**	15.26	**<0.001**	1.03	0.30
May 2024	-0.49	0.62	1.47	0.15	2.03	**0.04**
Oct 2024	-1.78	0.07	-0.93	0.36	-0.74	0.46
Dec 2024	-1.44	0.15	-3.74	**<0.001**	-1.99	**0.05**

Table B-3: Results of Tukey pairwise comparisons from GLM for *Posidonia australis* shoot density, maximum leaf length and epiphyte cover between monitoring rounds at rehabilitation sites where monitoring round was found to be a significant factor. **Bold** font indicates a statistically significant result.

Monitoring round	Shoot density z value	Shoot density P-value	Leaf length z value	Leaf length P-value	Epiphyte cover z value	Epiphyte cover P-value
Scar B						
Oct 2023 - Aug 2023	-4.48	**<0.001**	1.08	0.89	1.48	0.68
Feb 2024 - Aug 2023	-3.55	**<0.01**	0.78	0.97	2.26	0.21
May 2024 - Aug 2023	-3.89	**<0.01**	1.70	0.53	3.52	**0.01**
Oct 2024 - Aug 2023	-3.41	**<0.01**	-0.82	0.96	3.33	**<0.01**
Dec 2024 – Aug 2023	-3.82	**<0.01**	-6.23	**<0.001**	2.45	0.14
Feb 2024 - Oct 2023	0.95	0.93	-0.30	1.00	0.80	0.97
May 2024 - Oct 2023	0.59	0.99	0.62	0.99	2.15	0.26
Oct 2024 - Oct 2023	1.08	0.89	-1.90	0.40	1.95	0.37
Dec 2024 – Oct 2023	0.67	0.99	-7.24	**<0.001**	1.00	0.92
May 2024 - Feb 2024	-0.35	1.00	0.92	0.94	1.38	0.74
Oct 2024 - Feb 2024	0.14	1.00	-1.60	0.60	1.17	0.85
Dec 2024 – Feb 2024	-0.28	1.00	-6.96	**<0.001**	0.20	1.00
Oct 2024 - May 2024	0.49	1.00	-2.51	0.12	-0.22	1.00
Dec 2024 – May 2024	0.07	1.00	-7.80	**<0.001**	-1.18	0.85
Dec 2024 – Oct 2024	-0.42	1.00	-5.46	**<0.001**	-0.97	0.93
Scar C						
Oct 2023 - Aug 2023			-2.93	**0.04**	-2.27	0.21
Feb 2024 - Aug 2023			-0.07	1.00	-0.50	1.00
May 2024 - Aug 2023			-0.55	0.99	1.55	0.63
Oct 2024 - Aug 2023			-2.98	**0.03**	1.02	0.91
Dec 2024 – Aug 2023			-8.32	**<0.001**	-0.22	1.00
Feb 2024 - Oct 2023			2.87	0.05	1.79	0.47
May 2024 - Oct 2023			2.39	0.16	3.72	**<0.01**
Oct 2024 - Oct 2023			-0.04	1.00	3.24	**0.02**
Dec 2024 – Oct 2023			-5.57	**<0.001**	2.06	0.31
May 2024 - Feb 2024			-0.48	1.00	2.03	0.33
Oct 2024 - Feb 2024			-2.91	**0.04**	1.51	0.66
Dec 2024 – Feb 2024			-8.26	**<0.001**	0.28	1.00
Oct 2024 - May 2024			-2.43	0.14	-0.53	0.99
Dec 2024 – May 2024			-7.82	**<0.001**	-1.76	0.49
Dec 2024 – Oct 2024			-5.53	**<0.001**	-1.24	0.82

	Shoot density		Leaf length		Epiphyte cover	
Monitoring round	z value	P-value	z value	P-value	z value	P-value
Scar E						
Oct 2023 - Aug 2023	-5.06	**<0.001**	-1.33	0.76	1.33	0.77
Feb 2024 - Aug 2023	-3.33	**<0.05**	-0.83	0.96	2.97	**0.04**
May 2024 - Aug 2023	-5.41	**<0.001**	0.41	1.00	3.16	**0.02**
Oct 2024 - Aug 2023	-3.70	**<0.01**	-1.42	0.71	2.18	0.25
Dec 2024 – Aug 2023	-3.85	**<0.01**	-7.68	**<0.001**	1.33	0.77
Feb 2024 - Oct 2023	1.75	0.50	0.50	1.00	1.71	0.53
May 2024 - Oct 2023	-0.35	1.00	1.74	0.50	1.92	0.39
Oct 2024 - Oct 2023	1.38	0.74	-0.09	1.00	0.88	0.95
Dec 2024 – Oct 2023	1.23	0.82	-6.49	**<0.001**	0.00	1.00
May 2024 - Feb 2024	-2.10	0.29	1.24	0.81	0.22	1.00
Oct 2024 - Feb 2024	-0.37	1.00	-0.59	0.99	-0.85	0.96
Dec 2024 – Feb 2024	-0.53	1.00	-6.94	**<0.001**	-1.71	0.53
Oct 2024 - May 2024	1.73	0.51	-1.83	0.44	-1.07	0.89
Dec 2024 – May 2024	1.58	0.61	-8.04	**<0.001**	-1.92	0.39
Dec 2024 – Oct 2024	-0.15	1.00	-6.41	**<0.001**	-0.88	0.95
Scar F						
Oct 2023 - Aug 2023			-1.91	0.39	1.20	0.84
Feb 2024 - Aug 2023			-1.53	0.64	2.84	**0.05**
May 2024 - Aug 2023			-0.08	1.00	3.25	**0.01**
Oct 2024 - Aug 2023			-2.25	0.21	2.76	0.06
Dec 2024 – Aug 2023			-3.22	**0.02**	2.67	0.08
Feb 2024 - Oct 2023			0.39	1.00	1.77	0.48
May 2024 - Oct 2023			1.84	0.44	2.23	0.22
Oct 2024 - Oct 2023			-0.35	1.00	1.68	0.54
Dec 2024 – Oct 2023			-1.38	0.73	1.59	0.61
May 2024 - Feb 2024			1.45	0.69	0.51	1.00
Oct 2024 - Feb 2024			-0.74	0.98	-0.10	1.00
Dec 2024 – Feb 2024			-1.77	0.48	-0.20	1.00
Oct 2024 - May 2024			-2.18	0.25	-0.61	0.99
Dec 2024 – May 2024			-3.15	**0.02**	-0.70	0.98
Dec 2024 – Oct 2024			-1.03	0.91	-0.10	1.00
Trench East						
Oct 2023 - Aug 2023			-2.85	**0.05**		
Feb 2024 - Aug 2023			-4.38	**<0.001**		
May 2024 - Aug 2023			-4.80	**<0.001**		
Oct 2024 - Aug 2023			-3.69	**<0.01**		
Dec 2024 – Aug 2023			-7.38	**<0.001**		
Feb 2024 - Oct 2023			-1.58	0.61		
May 2024 - Oct 2023			-2.07	0.30		
Oct 2024 - Oct 2023			-0.86	0.96		
Dec 2024 – Oct 2023			-4.81	**<0.001**		
May 2024 - Feb 2024			-0.53	0.99		
Oct 2024 - Feb 2024			0.72	0.98		
Dec 2024 – Feb 2024			-3.32	**0.01**		
Oct 2024 - May 2024			1.23	0.82		
Dec 2024 – May 2024			-2.71	0.07		
Dec 2024 – Oct 2024			-4.00	**<0.001**		

	Shoot density		Leaf length		Epiphyte cover	
Monitoring round	z value	P-value	z value	P-value	z value	P-value
Trench West						
Oct 2023 - Aug 2023			-1.53	0.64	2.57	0.10
Feb 2024 - Aug 2023			-0.15	1.00	0.87	0.95
May 2024 - Aug 2023			-1.79	0.47	2.44	0.14
Oct 2024 - Aug 2023			-2.26	0.21	3.54	**0.01**
Dec 2024 – Aug 2023			-5.18	**<0.001**	1.15	0.86
Feb 2024 - Oct 2023			1.38	0.74	-1.74	0.51
May 2024 - Oct 2023			-0.26	1.00	-0.14	1.00
Oct 2024 - Oct 2023			-0.73	0.98	1.09	0.89
Dec 2024 – Oct 2023			-3.74	**<0.01**	-1.40	0.73
May 2024 - Feb 2024			-1.64	0.57	1.60	0.60
Oct 2024 - Feb 2024			-2.10	0.28	2.76	0.06
Dec 2024 – Feb 2024			-5.04	**<0.001**	0.30	1.00
Oct 2024 - May 2024			-0.47	1.00	1.23	0.82
Dec 2024 – May 2024			-3.49	**0.01**	-1.27	0.80
Dec 2024 – Oct 2024			-3.04	**0.03**	-2.42	0.15
Scar D						
May 2024 - Feb 2024			1.47	0.45	2.03	0.18
Oct 2024 - Feb 2024			-0.93	0.79	-0.74	0.88
Dec 2024 – Feb 2024			-3.74	**<0.001**	-1.99	0.19
Oct 2024 - May 2024			-2.38	0.08	-2.72	**0.03**
Dec 2024 – May 2024			-5.06	**<0.001**	-3.84	**<0.001**
Dec 2024 – Oct 2024			-2.86	**0.02**	-1.27	0.58

Table B-4: PERMANOVA table of results comparing total seagrass cover among four monitoring events carried out in 2024 (Febraury, May, October and December) at rehabilitation and reference sites. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Monitoring round	3	7205	3.82	**0.015**
Site type	1	53561	44.79	**0.001**
Site(site type)	11	13575	7.58	**0.001**
Monitoring round x site type	3	2468	1.31	0.273
Monitoring round x site(site type)	33	2130000	3.97	**0.001**
Residuals	462	75201		
Total	513	18000000		

Table B-5: Results (p-values) of pairwise tests for the significant interaction term monitoring round x site(site type) for the PERMANOVA comparing total seagrass cover among four monitoring events in 2024 for rehabilitation and reference sites. **Bold** font indicates a statistically significant result. The time period of interest to this report, October to December 2024 is highlighted.

Site	Feb - May	Feb - Oct	Feb - Dec	May - Oct	May - Dec	Oct - Dec
Scar B	0.84	0.63	0.43	0.56	0.63	0.28
Scar C	0.34	**0.04**	0.25	**0.01**	0.80	**<0.01**
Scar E	**0.01**	0.18	**<0.01**	0.29	0.93	0.19
Scar F	0.08	0.27	**0.01**	0.84	**0.01**	**0.03**
Trench East	0.09	**0.01**	0.39	0.37	0.48	0.07
Trench West	**0.04**	**<0.01**	0.95	**<0.01**	0.08	**<0.01**
Scar D	**0.03**	**0.03**	0.28	0.67	0.07	0.07
PBK03	0.91	0.09	0.15	**0.01**	0.11	0.90
PBK04	0.60	0.42	**0.02**	0.63	**0.01**	**0.01**
PBK07	0.50	**0.02**	0.71	**0.02**	0.11	**<0.01**
PBK08	0.94	0.11	**0.01**	0.14	**0.04**	**<0.01**
PBR01	**0.01**	**0.01**	**<0.01**	0.05	**<0.01**	**<0.01**
PBR02	0.05	**0.01**	1.00	0.79	0.05	**0.01**

Table B-6: PERMANOVA table of results comparing benthic composition among four monitoring events carried out in 2024 (Febraury, May, October and December) at rehabilitation and reference sites. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Monitoring round	3	26047	9.41	**0.001**
Site type	1	242990	70.27	**0.001**
Site(site type)	11	39285	8.90	**0.001**
Monitoring round x site type	3	6198	2.24	**0.038**
Monitoring round x site(site type)	33	31123	2.35	**0.001**
Residuals	462	185400		
Total	513	543460		

Table B-7: Results (p-values) of pairwise tests for the significant interaction term monitoring round x site(site type) for the PERMANOVA comparing benthic composition among four monitoring events in 2024 for rehabilitation and reference sites. **Bold** font indicates a statistically significant result. The time period of interest to this report, October to December 2024 is highlighted.

Site	Feb - May	Feb - Oct	Feb - Dec	May - Oct	May - Dec	Oct - Dec
Scar B	**0.03**	0.44	0.11	0.15	**0.02**	0.19
Scar C	0.08	**0.02**	0.15	**0.02**	**0.01**	**0.01**
Scar E	**0.02**	0.05	**<0.01**	0.58	0.11	0.13
Scar F	0.05	0.10	**0.01**	-	0.09	0.11
Trench East	**0.02**	**<0.01**	0.55	0.27	0.43	0.05
Trench West	**0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Scar D	**0.01**	**0.01**	**<0.01**	0.51	**0.03**	0.10
PBK03	0.17	0.10	0.18	0.07	**0.03**	0.14
PBK04	0.12	0.22	**<0.01**	**<0.01**	**<0.01**	**<0.01**
PBK07	0.33	**0.02**	0.55	0.05	0.05	**<0.01**
PBK08	0.84	0.20	**<0.01**	0.14	**<0.01**	**0.01**
PBR01	**0.03**	0.22	0.06	0.08	**<0.01**	**<0.01**
PBR02	0.06	**0.03**	0.16	0.66	**0.03**	**0.01**

Table B-8: Contributions of benthic categories to dissimilarities in benthic composition between monitoring events in October and December 2024 at rehabilitation and reference sites as determined by SIMPER analysis of percentage cover data. Results shown only for sites where a significant difference in benthic composition between monitoring events was detected by pairwise tests (refer to Table B-7).

Scar C - Average similarity: 73.33

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Sand	39.00	32.46	44.26
Posidonia australis	32.56	24.78	33.79
Halophila sp.	14.89	10.03	13.68

Trench West - Average similarity: 73.17

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Sand	51.00	41.81	57.13
Posidonia australis	30.00	21.47	29.35
Halophila sp.	6.83	5.28	7.21

PBK04 - Average similarity: 87.70

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Posidonia australis	79.50	74.26	84.67
Sand	13.00	9.70	11.06

PBK07 - Average similarity: 80.95

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Posidonia australis	74.39	67.20	83.02
Sand	17.02	11.11	13.73

PBK08 - Average similarity: 81.70

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Posidonia australis	78.83	70.37	86.13
Sand	15.50	10.15	12.42

PBR01 - Average similarity: 89.96

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Posidonia australis	83.50	79.34	88.19
Sand	9.99	8.70	9.67

PBR02 - Average similarity: 89.70

Benthic category	Mean cover (%)	Mean similarity (%)	Contribution to dissimilarity (%)
Posidonia australis	84.00	79.81	88.98
Sand	14.00	9.26	10.32