Transport
for NSW

Kamay Ferry Wharves project

Seagrass Translocation, Rehabilitation and Monitoring

Seagrass Monitoring Report 4

October 2024

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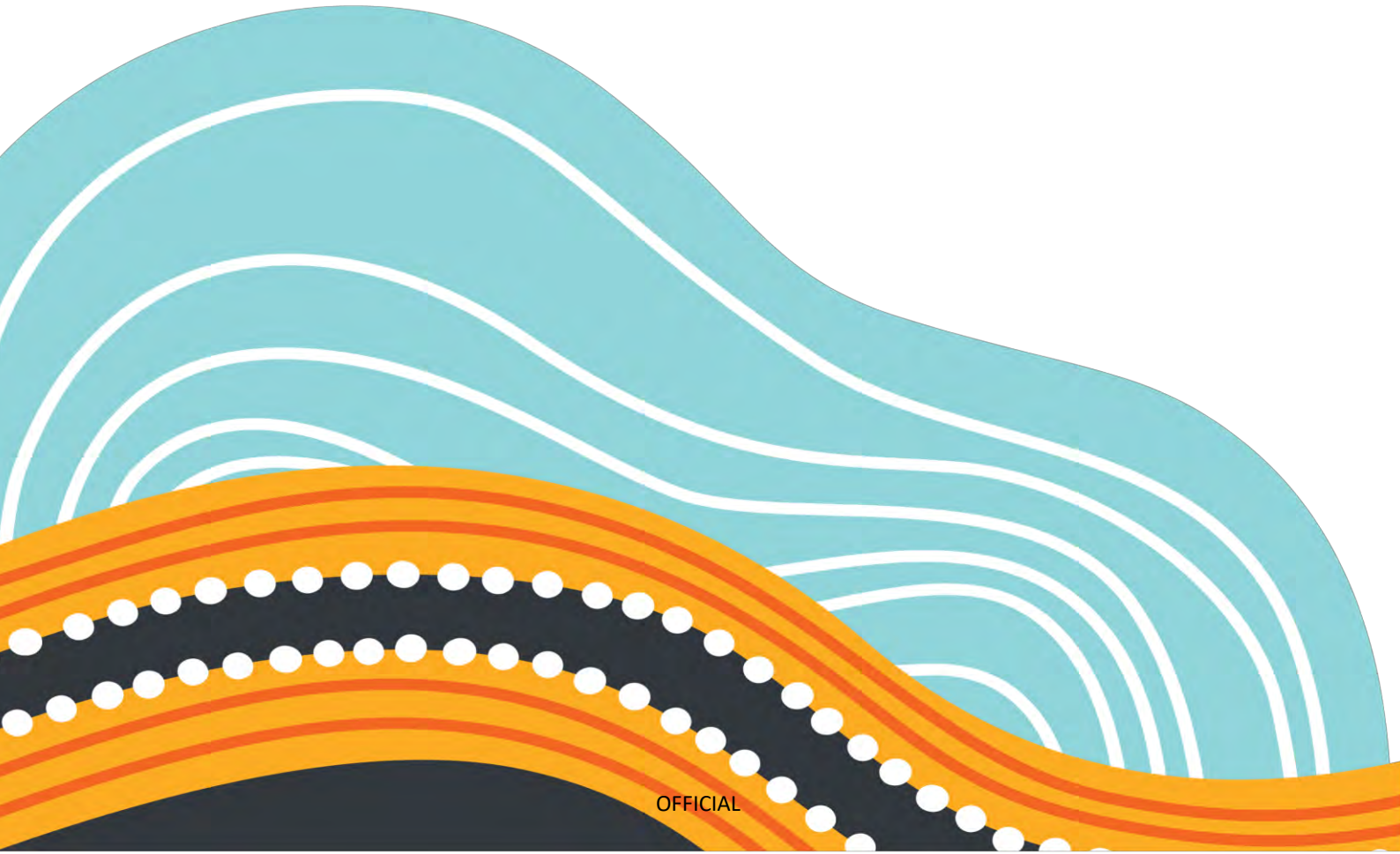

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Terms and acronyms

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. The monitoring program includes success criteria that provide readily measurable attributes that will indicate changes in the status of transplanted and nearby naturally occurring *Posidonia australis* meadows through time: *Posidonia australis* areal extent and shoot density. Monitoring results are evaluated in the context of the targets set out in the success criteria to provide an indication of how the rehabilitation efforts are performing through time.

This report documents the results of the fourth monitoring event (September-October 2024) of the ten-year monitoring program. Monitoring involved in-situ surveys and mapping of rehabilitation sites where *Posidonia australis* transplanting has occurred and surrounding *Posidonia australis* meadow (reference) sites in Kurnell, Botany Bay. The monitoring surveys quantified *Posidonia australis* shoot density and condition (maximum leaf length and cover of epiphytic algae), benthic composition and extent of the replanted areas. The report also provides a summary of rehabilitation efforts carried out to date.

The key findings from this monitoring report are:

- *Posidonia australis* shoot density in six of seven rehabilitation sites exceed the short-term (two-year) success criteria for shoot density, of which four sites meet or exceed the long-term (ten-year) success criteria
- Two rehabilitation sites showed significant decreases in *Posidonia australis* shoot densities in the current monitoring surveys compared to previous surveys, while five sites maintained relatively stable shoot densities through time
- *Posidonia australis* maximum leaf lengths showed little change since the previous monitoring surveys in May 2024 and those in rehabilitation sites remain about 25 percent shorter than reference sites
- Epiphyte cover of *Posidonia australis* in all sites was in the moderate range and marginally lower on average in comparison to the monitoring surveys carried out in May 2024
- Total seagrass cover was about 20 percent lower in rehabilitation sites than reference sites and differences in benthic composition between the two site types was due to substantially lower *Posidonia australis* cover in rehabilitation sites
- Between June and October 2024, 14 m^2 of degraded seagrass habitat was improved by transplanting naturally detached *Posidonia australis* in rehabilitation site Scar D
- The total area replanted with *Posidonia australis* exceeds the short-term (two-year) success criteria at this time point.

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 late 2024.

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 (section 5).

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 fourth round of monitoring, about 14 months after the *Posidonia australis* translocation stage. Monitoring results detailed in this report are evaluated in the context of the short-term (two-year) success criteria for the offset strategy (Figure 1-1).

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

The monitoring program is detailed in the MBOS (refer to Implementation Plan 1 (UNSW, 2023a) at Appendix 4 of the MBOS).

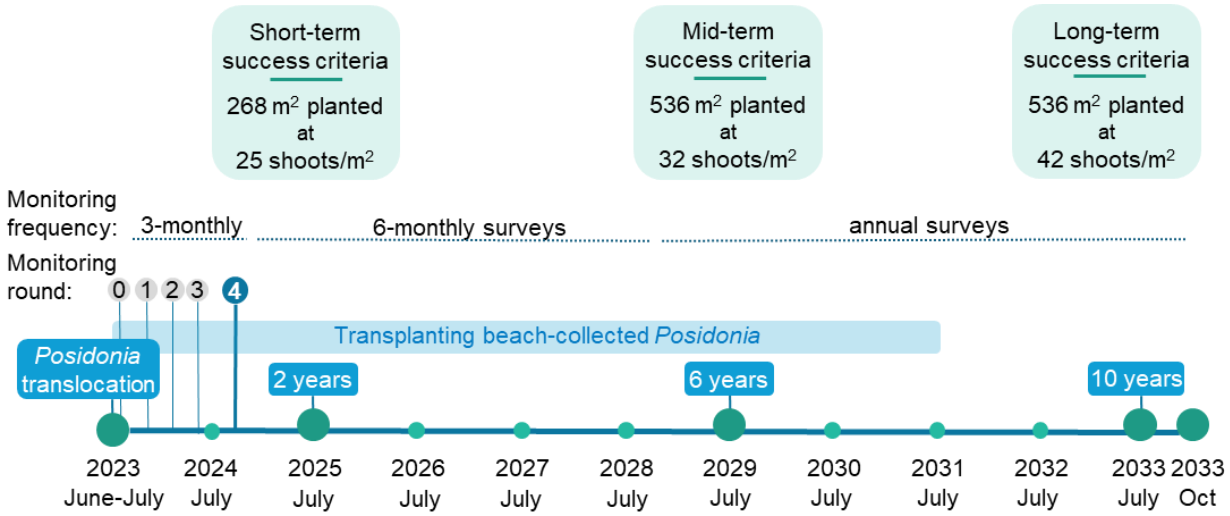

Figure 1-1: Overview of the stages and timing for the *Posidonia australis* translocation, rehabilitation and monitoring activities in the context of the success criteria for the offset strategy.
Monitoring round 4, which is the subject of this report, is highlighted in blue.

1.6 Purpose of this seagrass monitoring report

This report documents the results of the fourth monitoring event of the ten-year monitoring program. Monitoring was carried out in late September – early October 2024 and involved in-situ surveys and mapping 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
- Survey and confirm the area of rehabilitation sites restored with *Posidonia australis*.

An assessment of the results of the monitoring against the success criteria for the *Posidonia australis* offset strategy was carried out.

2. *Posidonia australis* restoration progress

2.1 Restoration using naturally detached *Posidonia australis*

Since completion of the translocation stage in July 2023, the focus of ongoing rehabilitation efforts is to continue transplanting *Posidonia australis* to supplement the area already restored to gradually over time create a minimum of 536 m^2 of restored seagrass habitat in Botany Bay. Because *Posidonia australis* cannot be removed from existing meadows, this stage relies on sourcing viable donor material that is naturally detached from meadows in Botany Bay. To achieve this, weekly beach surveys to collect naturally detached *Posidonia australis* shoots are carried out in Botany Bay. Beach surveys involve thoroughly searching shorelines and nearby waters for viable shoots that are deposited on the sand or floating in the water. Survey effort, timing and locations are tailored according to recent weather (e.g. wind/swell strength and direction) and tidal conditions that influence where naturally detached *Posidonia australis* shoots accumulate (Liddell, 2022).

Collected *Posidonia australis* shoots are temporarily stored (generally for 4-6 weeks) in outdoor aquaria at the Sydney Desalination Plant in Kurnell before being transplanted in rehabilitation sites (Figure 3-1). Decision-making about locations where transplanting occurs considers recent monitoring data and in situ observations – for example, to compensate for *Posidonia australis* losses in existing sites or restore newly identified bare areas. Naturally detached *Posidonia australis* shoots are transplanted at a density of about 42 shoots per m^2 to maintain consistent density across the restored areas.

A summary of rehabilitation efforts carried out in the period following the previous monitoring event, June to October 2024, is outlined in the following sections. These activities were carried out by marine scientists from the University of New South Wales (UNSW) and the Gamay Rangers.

2.2 *Posidonia australis* collections

There were 26 beach surveys to collect naturally detached *Posidonia australis* shoots carried out at seven locations in Botany Bay from June to September 2024 (Table 2-1, Figure 2-1). This period coincided with winter and thus search efforts were confined to shorelines and did not include in-water searches for floating shoots. As a result, there were fewer surveys and survey hours overall during this period compared to previous monitoring periods.

All 26 beach surveys included Kurnell and there were also 17 surveys carried out at the nearby Towra Point Aquatic Reserve refuge zone (Figure 2-1). Few surveys were carried out elsewhere in Botany Bay during this period.

A total of 1171 naturally detached *Posidonia australis* shoots were collected from beaches during this period (Table 2-1). One substantial collection of >200 shoots occurred in early June and three collections of >80 shoots occurred during August. Outside of these occasions, beach surveys produced moderate collections of about 15 shoots per hour of effort. The large accumulation of shoots in early June followed consecutive days of gusty winds that reached >65 km/h. The consistent supply of naturally detached *Posidonia australis* shoots in August may be related to wind direction rather than strength, since winds during this month were generally from the north-west and this likely assisted in washing shoots onshore at Kurnell. Weather conditions are discussed further in section 5.1.

Table 2-1: Summary of naturally detached *Posidonia australis* shoot collections for November 2023 to September 2024. The period of interest, June to September 2024, is highlighted.

Period	Beach surveys	Estimated survey hours	Shoots collected
November 2023	6	12	78
December 2023	4	8	57
January 2024	7	21	444
February 2024	14	50	2047
Monitoring period total	**31**	**91**	**2626**
March 2024	16	37	847
April 2024	9	25	690
May 2024	9	30	812
Monitoring period total	**34**	**92**	**2349**
June 2024	5	13	386
July 2024	7	17	256
August 2024	8	20	379
September 2024	6	14	150
Monitoring period total	**26**	**64**	**1171**
Grand total	**91**	**247**	**6146**

Figure 2-1: Locations and number of beach surveys carried out at each location to collect naturally detached *Posidonia australis* shoots from June to September 2024.

2.3 *Posidonia australis* transplanting

Since restoration efforts began in June 2023, 17,252 *Posidonia australis* shoots have been transplanted at rehabilitation sites at Kurnell. This total includes 12,946 shoots translocated from the wharf construction footprint and 4306 naturally detached shoots collected from Botany Bay. Six rehabilitation sites were restored using translocated *Posidonia australis* in June-July 2023. Restoration using naturally detached shoots began in July 2023 and has subsequently occurred at four of the six rehabilitation sites that received translocated shoots (Table 2-2, Figure 2-2). Restoration of an additional rehabilitation site, Scar D, began in February 2024. It is anticipated that Scar D will be restored using naturally detached shoots only.

Transplanting during the period June-October 2024 occurred at Scar D only (Table 2-2). A total of 602 naturally detached *Posidonia australis* shoots were transplanted at this site to restore 14 m^2 of degraded habitat. The area planted during this period was moderate compared to previous periods and relates to fewer naturally detached shoots being collected over the winter months. Further details about the area restored in rehabilitation sites are provided in section 4.3.

Table 2-2: 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 (refer to Figure 2-2 and Table 4-3 for the new area restored at each time point). 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
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)
Total	**13,016**	**270**	**2072**	**1292**	**602**

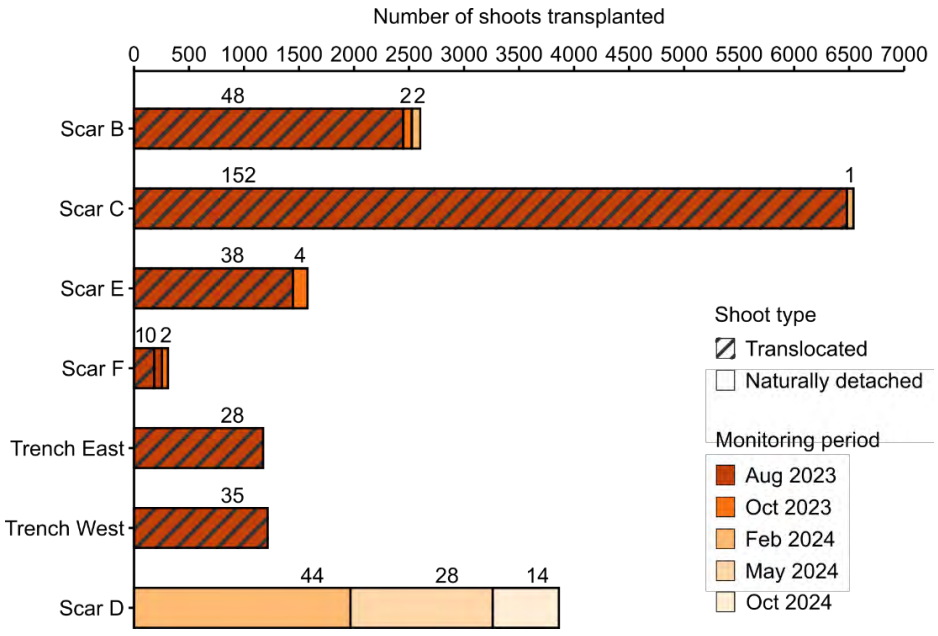

Figure 2-2: Cumulative number of *Posidonia australis* shoots transplanted at rehabilitation sites at Kurnell through time. Bars indicate the number of translocated or naturally detached *Posidonia australis* shoots transplanted at each time point. Numbers above bars indicate the area planted (in m^2). Where there is no data for a time point, no transplanting occurred.

3. Monitoring methods

3.1 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 3-1).

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. The reference sites are located at least 130 m from the project boundary at Kurnell and distributed to ensure they represent healthy natural *Posidonia australis* meadows with similar exposure, tidal range, depth and physical characteristics to the 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.

Surveys and mapping for monitoring round 4 were carried out in late September and early October 2024. This represents a period of about 14 months since completion of the *Posidonia australis* translocation stage. Monitoring was carried out by experienced marine ecologists from UNSW using SCUBA. A summary of monitoring carried out to date is provided in Table 3-1.

Table 3-1: 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	This report

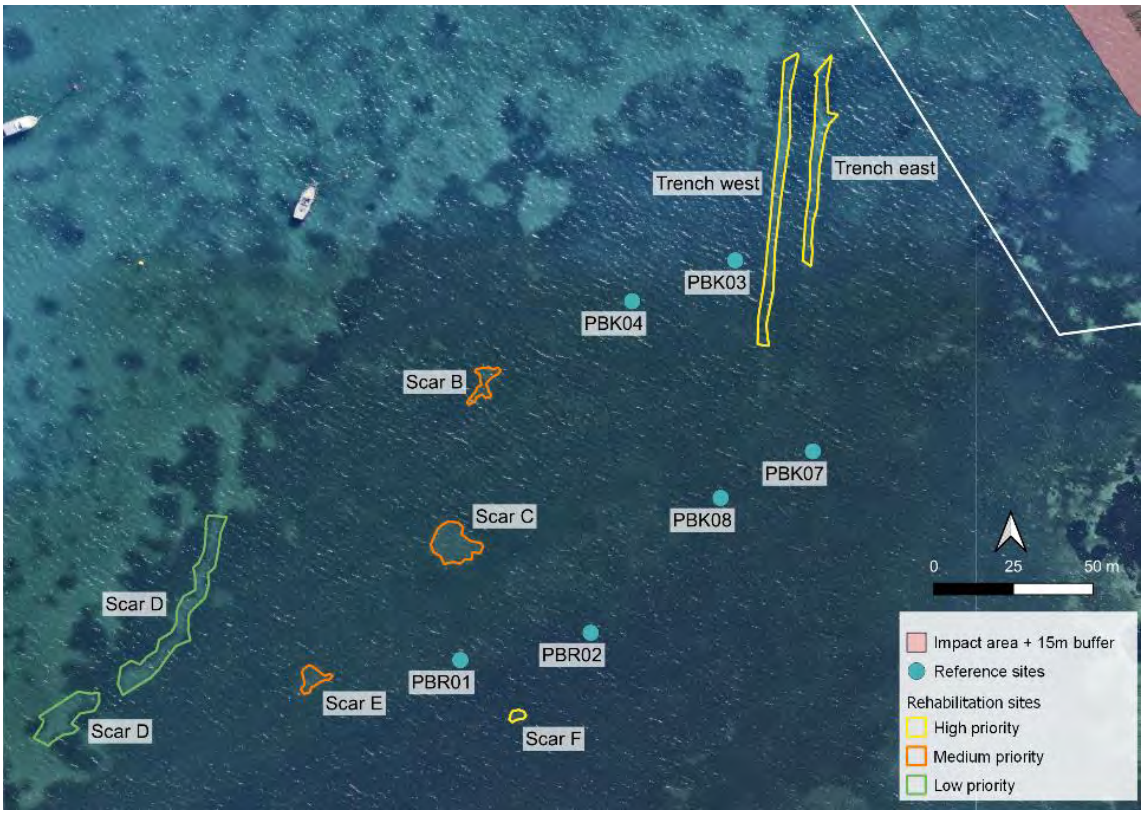

Figure 3-1: Overview of the survey area at Kurnell (Gamay Botany Bay)

3.2 *Posidonia australis* surveys

3.2.1 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. The round 4 monitoring period coincided with transplanting activities at rehabilitation site Scar D. To reduce bias associated with the timing of this transplanting, density and condition were not quantified for this newly transplanted area of naturally detached *Posidonia australis*. 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.

3.2.2 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.

3.3 Mapping rehabilitation sites

3.3.1 Field-based mapping of *Posidonia australis* in rehabilitation sites

Transplanting of naturally detached *Posidonia australis* between June and October 2024 (post the previous monitoring event) occurred at rehabilitation site Scar D only (Figure 3-1).

Water visibility at Kurnell permitted GPS-based mapping methods to be used to map the replanted area in Scar D. The mapping exercise involved installing metal reinforcing bars around the perimeter of the restored areas within the site. Transect tapes were temporarily placed around the marked-out perimeter to aid the visibility of a snorkeler at the surface. The snorkeler, using the transect tapes as a guide, swam the perimeter of the planted area while towing by hand a dive float with a handheld GPS (accuracy 3-5 m) attached that was set in tracking mode.

3.4 Data analysis

3.4.1 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. Differences in these three characteristics between site type (rehabilitation and reference) and among sites were tested statistically using univariate permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001). The two-factor PERMANOVA treated site type as a fixed factor and site as a random factor nested within site type. Euclidean distance matrices were constructed from untransformed shoot density, length and epiphyte cover data and the PERMANOVA was run under a reduced model, Type III sum of squares and 999 permutations. All PERMANOVA were carried out using PRIMER-E and PERMANOVA+ software (Clarke and Gorley, 2001; Anderson et al., 2008).

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 *Posidonia australis* shoot density at rehabilitation sites through time. GLMs were run on each rehabilitation site separately using monitoring round as a factor. Data were overdispersed so a negative binomial distribution was used. Model assumptions and fit were checked by examining plots of residuals and Akaike Information Criterion (AIC) values, and likelihood ratio tests were used to calculate p-values. Where model comparisons indicated significance of the monitoring round factor, Tukey

pairwise comparisons of shoots densities 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 the R programming language version 4.4.1 (R Core Team, 2024).

3.4.2 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. Time series were plotted to allow any temporal trends to be detected and visualised.

A one-factor PERMANOVA was used to test for differences in benthic composition between rehabilitation and reference sites. The PERMANOVA treated site type (reference or rehabilitation) as a fixed factor. A Bray-Curtis similarity matrix was constructed from square root transformed mean benthic cover data and the PERMANOVA was run with unrestricted permutation of the raw data, Type III sum of squares and 999 permutations. The similarity percentage (SIMPER) routine was performed to determine which benthic categories contributed most to dissimilarities in benthic composition between site types (Clarke, 1993).

3.4.3 Extent of *Posidonia australis* restored area in rehabilitation sites

The GPS data collected during the in-situ mapping of Scar D was reviewed in GIS software. Polygons were produced to depict the approximate area within the site replanted with *Posidonia australis*. Polygons depicting the replanted areas of the seven rehabilitation sites were overlaid on high-resolution Nearmap imagery of the area captured in September 2024 and maps of the sites were produced for visual interpretation.

The new area planted with *Posidonia australis* since the previous monitoring event (round 3, May 2024) was quantified and site-level and overall restored area values were calculated.

3.4.4 Local climate and environmental conditions in Botany Bay

Climate data for the Botany Bay region was retrieved from Bureau of Meteorology (BOM) weather stations (http://www.bom.gov.au/climate/data/). Rainfall and air temperature data were obtained for the Sydney Airport AMO weather station (66037) which is located about 7.5 km north-west of the seagrass restoration area at Kurnell. Solar exposure and wind data were obtained for the Kurnell automatic weather station (AWS) (66043) which is located on the Ampol wharf at Kurnell, about 200m west of the restoration area. Monthly and daily data records for the climate parameters were examined and time series plots were produced.

Significant wave height data recorded by the Sydney offshore wave data buoy (station code WAVESYD) operated by Manly Hydraulics Laboratory was obtained from the Australian Open Data Network Portal (https://portal.aodn.org.au/search?uuid=b299cdcd-3dee-48aa-abdd-e0fcdbb9cadc, Integrated Marine Observing System (IMOS), 2024a). The buoy is moored offshore from Curl Curl (33°46’26”S, 151°24’42”E) at a depth of about 85m and measures wave height on a continuous real-time basis (Manly Hydraulics Laboratory, 2023). Maximum daily significant wave height data was extracted from the dataset and a time series plot produced.

High resolution water temperature data was retrieved from a HOBO pendant temperature data logger installed at rehabilitation site Scar F. Temperature data recorded by the data logger at 10-minute intervals was aggregated into daily values for mean, minimum and maximum water temperature at the site for the period 5 August 2023 to 22 June 2024 (268 days due to some missing data) when data recording ended. A time series plot of the water temperature data was produced.

Sea surface current and temperature and chlorophyll-a maps of southern NSW were obtained from IMOS OceanCurrent (https://oceancurrent.aodn.org.au/product.php, IMOS, 2024b) to gain an understanding of local to regional oceanographic conditions during the period of interest. IMOS OceanCurrent combines all available sources into a map-based visualisation: satellite sea surface temperature, altimeter-derived currents, Argo profilers, Surface Velocity Program drifters, ocean-surface radar, and mooring currents through the water column (Bailey et al., 2019).

Significant wave height data, sea surface temperature and chlorophyll-a maps were sourced from Australia’s IMOS – IMOS is enabled by the National Collaborative Research Infrastructure strategy.

4. Results

4.1 *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 during monitoring round 4 are provided in Table 4-1. Site-level data for the entire monitoring period is provided in Appendix A. Detailed results of statistical tests are provided in Appendix B. Photos captured in rehabilitation and reference sites are presented in Figure 4-4.

The overall mean shoot density of restored *Posidonia australis* in rehabilitation sites quantified during monitoring round 4 was 39 shoots per m^2 (Table 4-1). Among rehabilitation sites, shoots densities ranged from 24 shoots per m^2 at Scar D to 50 shoots per m^2 at Scar C (Figure 4-1a). Excluding rehabilitation site Scar D which has been restored with naturally detached *Posidonia australis* shoots only, the mean shoot density of translocated *Posidonia australis* in rehabilitation sites was 41 shoots per m^2. *Posidonia australis* shoot densities at reference sites were significantly greater (p=0.001, pseudo-F=48.6) than rehabilitation sites (Appendix B, Table B-1). Shoot densities in reference sites were 170 shoots per m^2 on average and ranged from 118-245 shoots per m^2. There was significant variation in shoot densities among sites within site types (p=0.001, pseudo-F=15.9) (Table B-1). Among rehabilitation sites, shoot densities at Scar F and Scar D tended to be lower than most other sites (Table B-2). Among reference sites, *Posidonia australis* shoot densities at the shallow sites PBR01 and PBR02 were greater than all other sites (Table B-2).

Maximum leaf lengths of *Posidonia australis* in rehabilitation sites were significantly less than reference sites (p=0.003, pseudo-F=17.1) (Table B-3), being 10 cm shorter on average (Table 4-1). Maximum leaf lengths showed variation among sites within the two site types (p=0.001, pseudo-F=8.4) (Table B-3). Differences in leaf lengths among rehabilitation sites closely matched those for shoot densities, that is, restored *Posidonia australis* in Scar F and Scar D tended to have shorter leaves than most other sites (Figure 4-1b). Among reference sites, maximum leaf lengths ranged 41-52 cm, and sites PBK03 and PBK04 had significantly longer *Posidonia australis* leaves than all other sites (Table B-4).

The mean epiphyte cover of *Posidonia australis* (Table 4-1) did not vary between rehabilitation and reference sites, but did vary among sites (p=0.002, pseudo-F=3.2) (Table B-5). Epiphyte cover was significantly lower at Scar D compared to all other rehabilitation sites, while site PBK08 generally had lower epiphyte cover relative to other reference sites (Figure 4-1c, Table B-6).

Table 4-1: Summary (mean ± standard error) of *Posidonia australis* characteristics quantified in rehabilitation and reference sites at Kurnell during the round 4 monitoring event in October 2024.

Site type (number of sites)	Shoot density (m^{-2})	Leaf length (cm)	Epiphyte cover (1-5 scale)
Rehabilitation (7)	39 (±2.2)	34 (±0.7)	3.3 (±0.1)
Reference (6)	170 (±7.5)	44 (±0.8)	3.1 (±0.1)

Restored *Posidonia australis* shoot densities showed no significant change at rehabilitation sites Scar C, Trench West and Scar D over the course of monitoring to date (Figure 4-2a, Table B-7). Scar C and Trench West consistently met or exceeded the long-term (ten-year) shoot density success criteria of 42 shoots per m^2 at each monitoring event, except for Scar C in round 3 (May 2024). At Scar D, the density of transplanted naturally detached *Posidonia australis* declined at each monitoring event, but not significantly so. The round 4 monitoring surveys indicated that the mean shoot density at this site fell marginally below the short-term success criteria of 25 shoots per m^2.

At rehabilitation sites Scar B and Scar E, significant variation in restored *Posidonia australis* shoot densities through time was attributed to initial measured shoot densities being higher than all subsequent periods (p<0.001 in both cases) (Figure 4-2a, Table B-8). There was no significant change in restored *Posidonia australis* shoot densities at these sites over the 12-month period of October 2023 to October 2024 and densities remained close to or greater than the long-term success criteria.

Changes through time in *Posidonia australis* shoot densities at Scar F and Trench East were marginally significant (p=0.04 and p=0.03, respectively) (Table B-7). Shoot densities at Scar F showed a gradual decline through time and the difference between the initial and most recently quantified shoot density at this site (48 vs 27 shoots per m^2) was significant (p=0.03) (Figure 4-2a, Table B-9). At Trench East, shoot densities differed significantly (p=0.03) only between those quantified in round 2 (February 2024) and round 4 (October 2024) but were otherwise relatively stable (Table B-9). Restored *Posidonia australis* shoot densities at these two sites met the short-term success criteria (25 shoots per m^2) during the most recent monitoring surveys Figure 4-2a).

The shallow (PBR01 and PBR02) and mid-depth (PBK07 and PBK08) location reference sites showed gradual increases in mean *Posidonia australis* shoot density over the monitoring carried out to date (Figure 4-2b). These four sites have maintained shoot densities of close to or >100 shoots per m^2 through time. Reference sites PBK03 and PBK04 showed increases and decreases in shoot densities through time, indicative of the irregular distribution of *Posidonia australis* at these two sites.

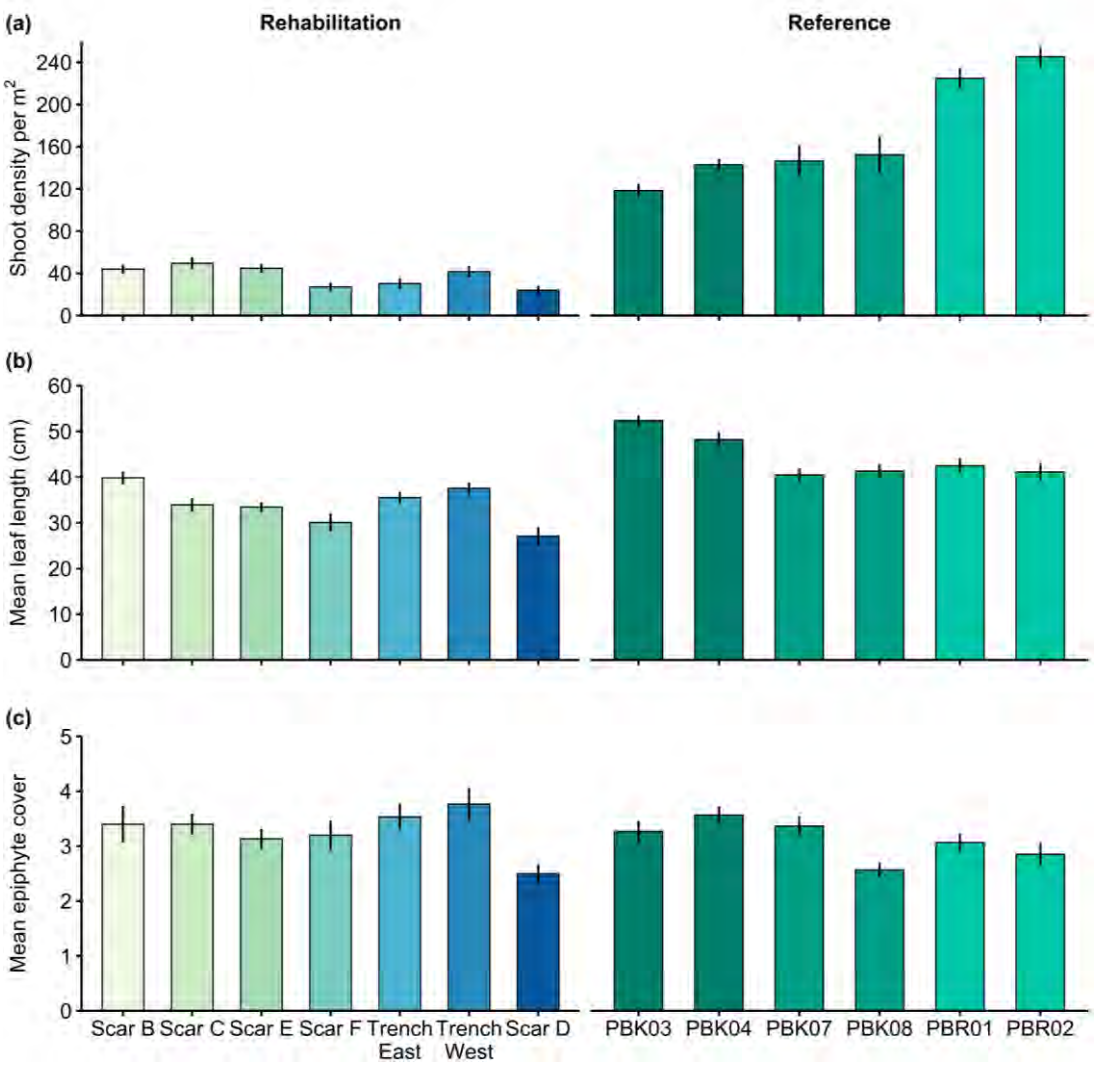

Figure 4-1: *Posidonia australis* characteristics at seven rehabilitation and six reference sites at Kurnell captured during the round 4 monitoring event in October 2024: (a) shoot density, (b) leaf length and (c) epiphyte cover.
Shown are mean values (± standard error) for translocated *Posidonia australis* in rehabilitation sites, except Scar D; Scar D consists of naturally detached *Posidonia australis* shoots only.

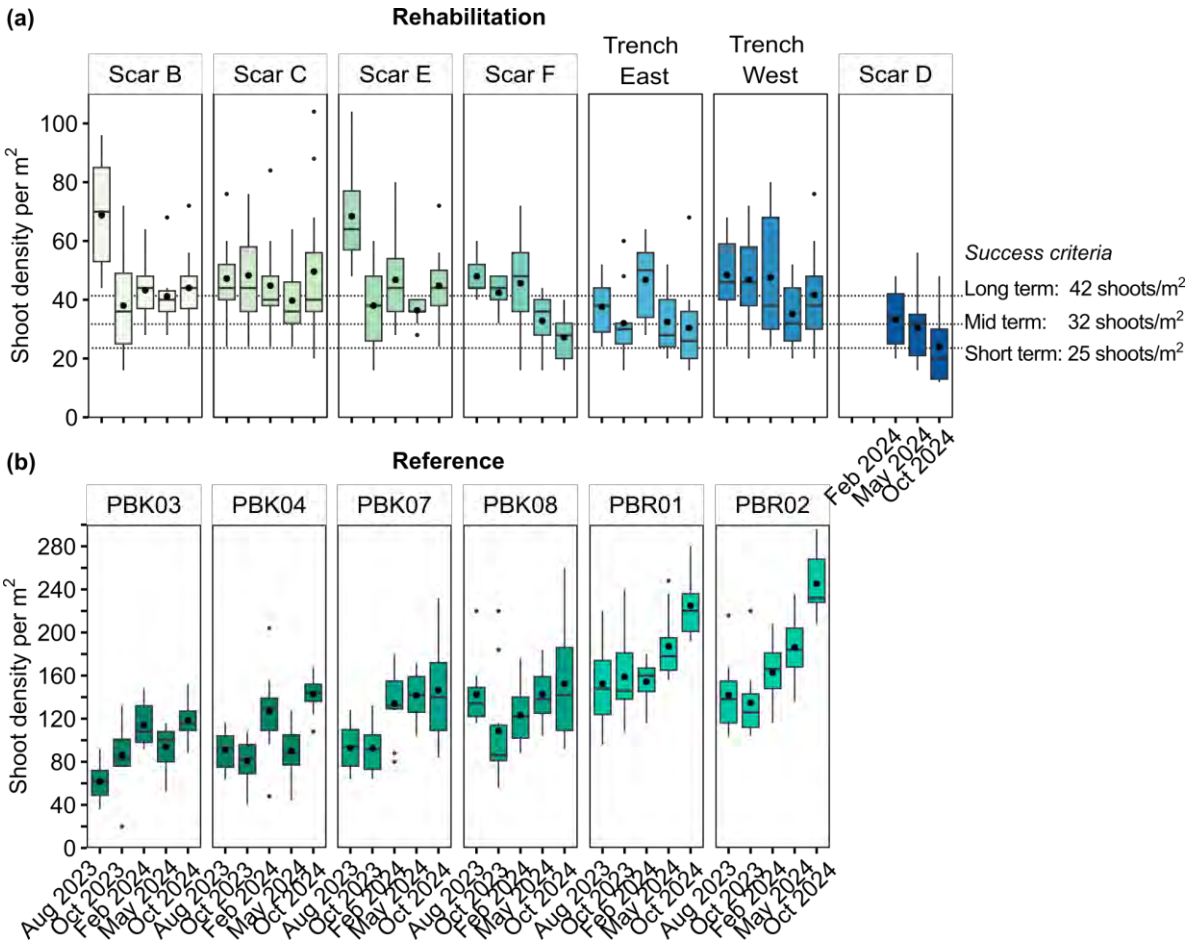

Figure 4-2: Shoot density through time at the (a) rehabilitation sites in relation to the success criteria and (b) reference sites. Each time point represents a monitoring event. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* began in February 2024. In (a) shoot 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.

Posidonia australis leaf lengths appeared to be relatively stable through time at rehabilitation sites (Figure 4-3a, Table A-2). Through time, rehabilitation sites showed incremental changes in mean maximum leaf lengths of about 1-2 cm. Except for Trench East, all rehabilitation sites recorded their greatest or equal greatest mean leaf length in the round 4 monitoring surveys. *Posidonia australis* leaf lengths in reference sites were noticeably more variable through time, with mean values fluctuating by up to 20 cm but more generally by about 5-10 cm between monitoring surveys (Figure 4-3a, Table A-2). Most reference sites recorded the greatest mean maximum leaf length in the October 2023 monitoring surveys.

Rehabilitation and reference site *Posidonia australis* demonstrated similar trends in epiphyte cover through time (Figure 4-3b, Table A-3). Epiphyte cover tended to gradually increase between August 2023 and February 2024 (reference sites) or May 2024 (rehabilitation sites) when epiphyte cover peaked before declining over the following months, showing a strong seasonal pattern.

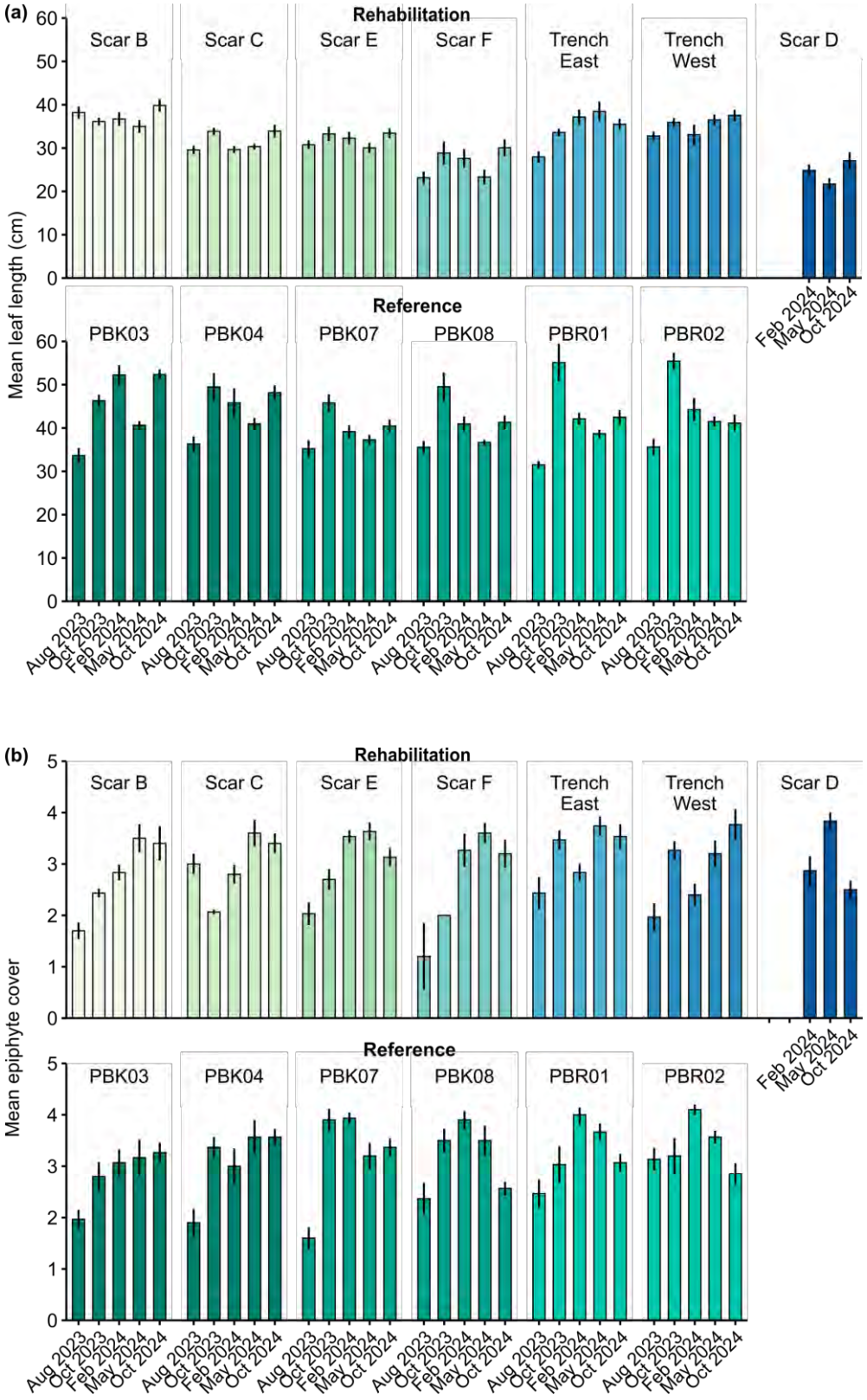

Figure 4-3: *Posidonia australis* condition through time at seven rehabilitation and six reference sites at Kurnell: (a) leaf length and (b) epiphyte cover.
Each time point represents a monitoring event. Shown are mean values (± standard error) for translocated *Posidonia australis* in rehabilitation sites, except Scar D; Scar D consists of naturally detached *Posidonia australis* shoots only.

4.2 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 round 4 monitoring event are presented in Table 4-2. 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.

Three seagrasses contributed to total seagrass cover in the sites: *Posidonia australis*, *Zostera sp*. and *Halophila sp*. Total seagrass cover was lower in rehabilitation sites compared to reference sites (57% vs 79%) (Table 4-2). However, four of seven rehabilitation sites had seagrass cover approaching that of reference sites, with values of >65% cover (Figure 4-4a, Appendix A, Table A-4). Total seagrass cover at reference sites ranged from 74-82%.

There was little variation in overall mean seagrass cover across all rehabilitation sites during the first year of monitoring (October 2023 to October 2024), with cover ranging from 56-65% over this period (Appendix A, Table A-4). Among individual rehabilitation sites, total seagrass cover remained stable (two sites), increased (three sites) or decreased (two sites) over the 12-month period (Figure 4-4a, Table A-4). Similar patterns were observed for the reference sites, with individual sites showing either increases or decreases in total seagrass cover over the past year.

Rehabilitation and reference sites showed significant differences ($p<0.01$, pseudo-$F=45.6$) in benthic compositions based on the round 4 monitoring surveys (Appendix B, Table B-9). SIMPER analysis revealed moderate dissimilarity of 49% in benthic composition between site types (Table B-10). Dissimilarities were primarily attributed to variation in cover of *Posidonia australis* which was substantially lower in rehabilitation sites (23%) relative to reference sites (71%) (Table 4-2, Figure 4-4b). In rehabilitation sites the overall mean cover of *Zostera sp.* and *Posidonia australis* were similar while *Halophila sp.* was less prominent. Cover of *Zostera sp.* and *Halophila sp.* were relatively low in reference sites, each being <6% on average.

No obvious patterns in cover of the three seagrasses at rehabilitation sites emerged from the 12 months of monitoring survey data. *Posidonia australis* cover remained relatively stable at five rehabilitation sites, but declined at Scar F and Trench West by about 12% and 20% respectively over the 12-month period (Figure 4-4b, Table A-5). *Zostera sp*. maintained a relatively consistent level of cover at Scar F, Scar B and Scar E through time. This role was filled by *Halophila sp.* at Scar C and Scar D. Seagrass composition at the trench scars was more variable through time. At reference sites, *Posidonia australis* cover tended to decline during the middle of the 12-month monitoring period before increasing again in the most recent surveys in October 2024 (Figure 4-4b, Table A-5).

Table 4-2: Summary of benthic cover (mean ± standard error) quantified in rehabilitation and reference sites at Kurnell during the round 4 monitoring event in October 2024.

	Percentage cover				
Site type (number of sites)	Total seagrass	*Posidonia australis*	*Zostera sp.*	*Halophila sp.*	Sand
Rehabilitation (7)	56.5 (±2.3)	22.8 (±1.4)	22.3 (±2.1)	11.3 (±1.2)	43.2 (±2.3)
Reference (6)	78.9 (±1.3)	71.1 (±1.8)	5.6 (±0.9)	2.1 (±0.4)	21.1 (±1.3)

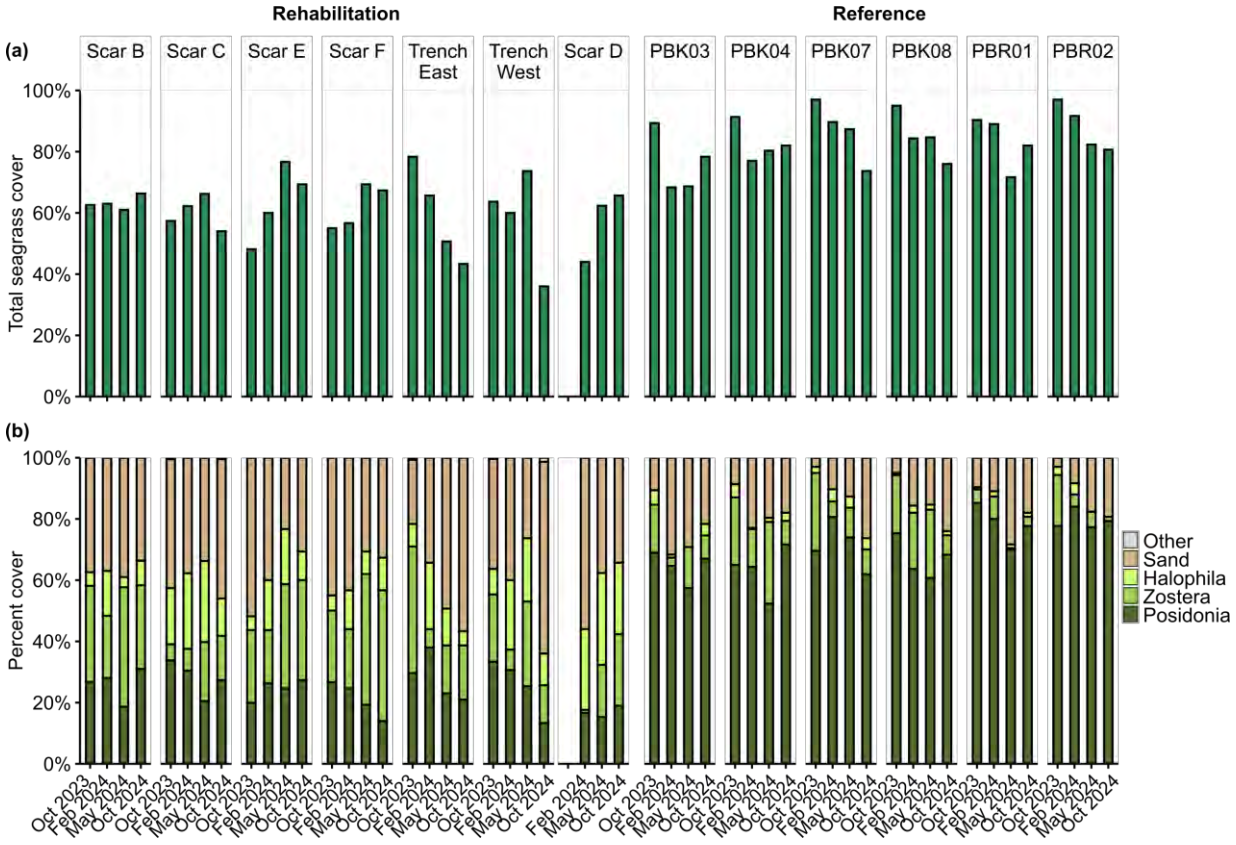

Figure 4-4: Comparison of (a) total seagrass cover and (b) benthic composition at the seven rehabilitation and six reference sites at Kurnell through time.
Each time point represents a monitoring event; monitoring of benthic cover commenced in monitoring round 1 in October 2023. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* commenced in early February 2024.

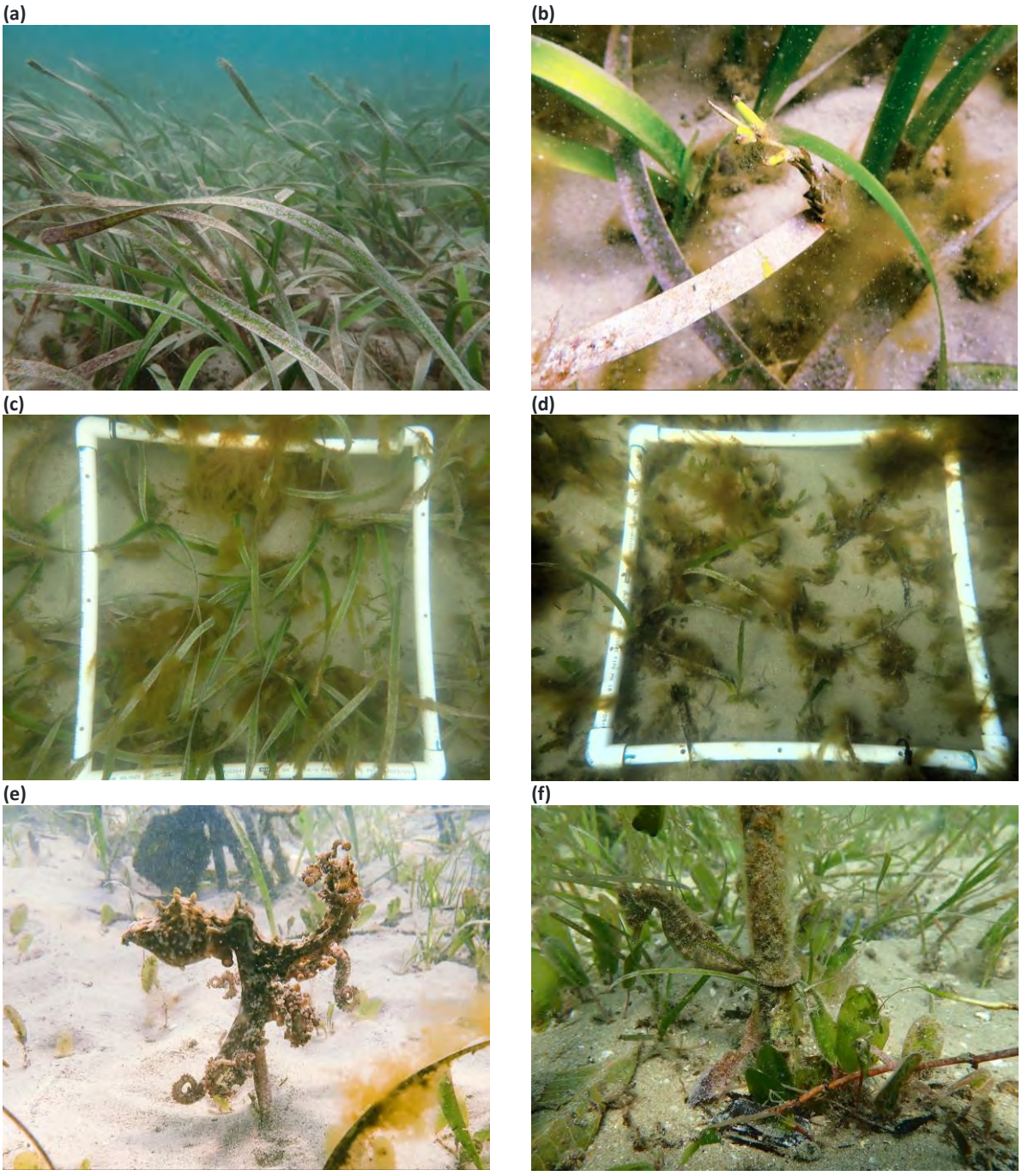

Figure 4-5: Photos capturing rehabilitation and reference at Kurnell.
Photos showing (a) dense *Posidonia australis* at reference site PBK07, (b) *Posidonia australis* flower and fruits in the meadow surrounding rehabilitation site Scar D, (c) filamentous algae attached to seagrass in reference site PBK03 and (d) in Scar D, (e) an octopus puts on a show in Trench East and (f) a seahorse clings to a *Posidonia australis* restoration plot marker in Scar C.

4.3 Areal extent of restored *Posidonia australis* in rehabilitation sites

The total area of restored *Posidonia australis* quantified as of monitoring round 4 in October 2024 was 408 m^2, equating to an increase of 14 m^2 since the previous monitoring round in May 2024 (Table 4-3, Figure 4-6). Transplanting during the current monitoring period was carried out only at rehabilitation site Scar D. Here, 602 naturally detached *Posidonia australis* shoots were transplanted over an area of 14 m^2(Figure 4-7).

Visual observations during the monitoring surveys did not detect any obvious changes in the restored areas at the other rehabilitation sites. Polygons representing the approximate areas of the seven rehabilitation sites restored with *Posidonia australis* are displayed in Figure 4-8.

Table 4-3: Time series of change in restored *Posidonia australis* area at rehabilitation sites over the entire monitoring period. Each time point represents a monitoring event. Listed for each time point is the cumulative area restored and, in parentheses, the number of naturally detached *Posidonia australis* shoots transplanted in the new area restored, where relevant.

Site	Restored area, m^2 (no. naturally detached shoots transplanted)					Change in area (m^2) since previous
	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024	
Scar B	48	50 (83)	52 (45)	52	52	-
Scar C	152	152	153 (59)	153	153	-
Scar E	38	42 (132)	42	42	42	-
Scar F	10 (70)	12 (55)	12	12	12	-
Trench East	28	28	28	28	28	-
Trench West	35	35	35	35	35	-
Scar D	-	-	44 (1968)	72 (1292)	86 (602)	+14
Total	**311 (70)**	**319 (270)**	**366 (2072)**	**394 (1292)**	**408 (1894)**	**+14**

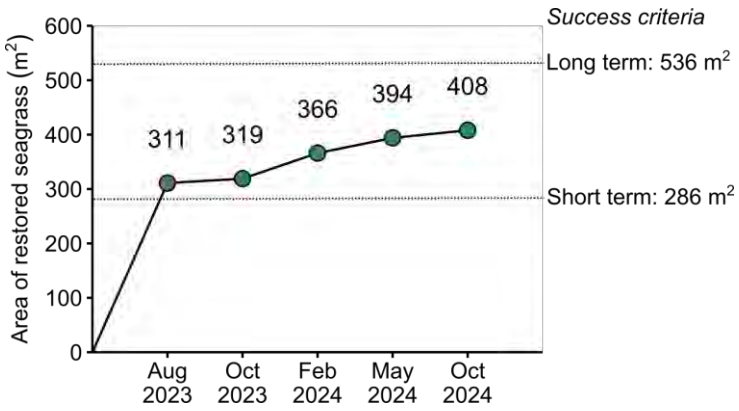

Figure 4-6: Time series of change in total area of restored *Posidonia australis* at rehabilitation sites at Kurnell in relation to the success criteria.
Each time point represents a monitoring event. The major increase in restored area occurred during the *Posidonia australis* translocation stage. All area restored after August 2023 was achieved by transplanting naturally detached *Posidonia australis*.

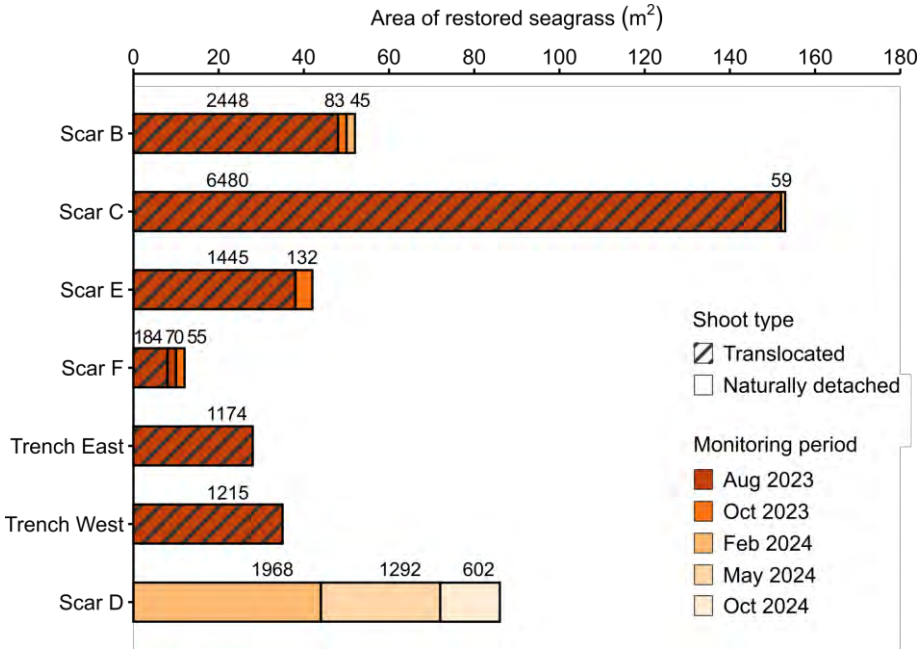

Figure 4-7: Cumulative *Posidonia australis* area restored at rehabilitation sites at Kurnell through time. Bars indicate the area restored (m²) at each time point. Numbers above bars indicate the number of translocated and/or naturally detached *Posidonia australis* shoots transplanted at each time point. Where there is no data for a time point, no transplanting occurred.

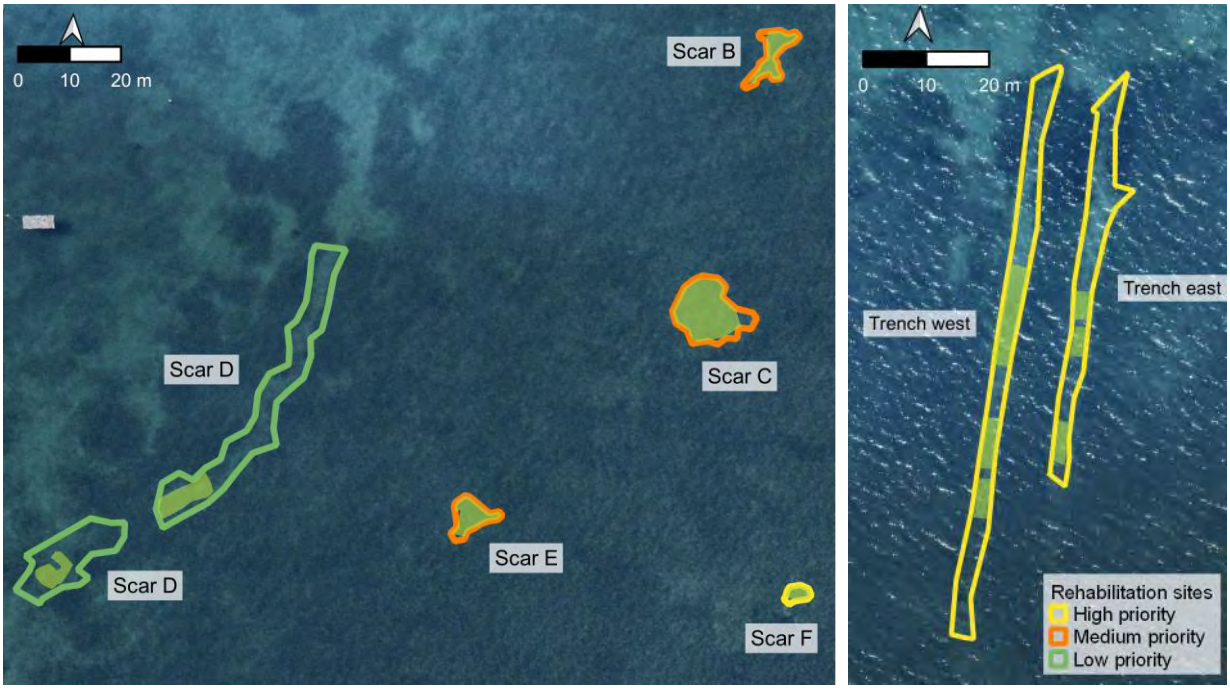

Figure 4-8: Map of Kurnell showing the approximate areas (shaded) within the seven rehabilitation sites restored with *Posidonia australis*.

4.4 Botany Bay climate patterns

Seasonal (winter) climate conditions in the Botany Bay region were wetter and warmer than average and punctuated by short periods of storms or unsettled weather. Monthly rainfall recorded at the Sydney Airport AMO weather station (66037; BOM, 2024a) showed that the June rainfall was more than twice the long-term mean with more than 300 mm of rain falling during the month (Figure 4-9a). The winter period included three days in June with rainfall >60 mm while half of all July days recorded rainfall. Despite little rain in August, the overall winter rainfall was 156% of the long-term winter average (BOM, 2024b).

Maximum winter temperatures were 0.9°C higher than the long-term mean and the Sydney Airport AMO weather station set a new record for highest winter temperature (31.6°C) in August (BOM, 2024b). This pattern continued in September when maximum air temperatures were 2.5°C above average and Sydney Airport AMO weather station recorded the highest monthly temperature (31.5°C) for the Greater Sydney region (BOM, 2024b,c) (Figure 4-9b).

Global solar exposure is the total amount of solar energy falling on a horizontal surface (BOM, 2020) and at a local level, it can be used as a proxy for the amount of light reaching seagrasses. Solar exposure records from the Kurnell AWS (66043) (BOM, 2024d) showed that solar exposure declined to its lowest level in June before gradually increasing over the following months to levels closely matching the long-term mean (Figure 4-9c).

Wind data recorded at Kurnell AWS (BOM, 2024d) showed that mean wind speeds gradually increased from March to July before dipping from August 2024 onwards (Figure 4-9d). One-third of June days and half of July days had 9am wind speeds >25 km/h, while two-thirds of days in these two months recorded wind gusts >40 km/h. Winds were predominantly from the west and north-west between June and September. Short periods of strong southerly winds were often associated with substantial rainfall and this occurred on three occasions in early and mid-June and again in early July.

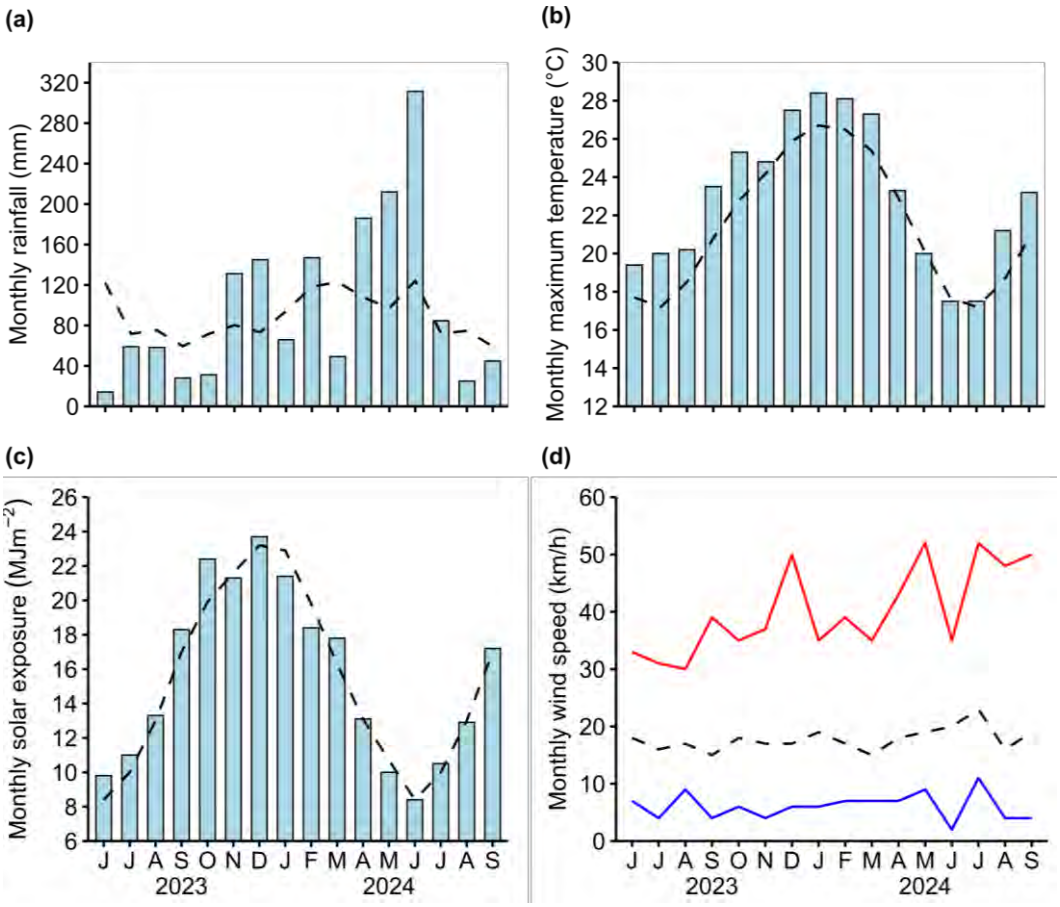

Figure 4-9: Monthly climate data for Botany Bay for June 2023 to September 2024: (a) total rainfall, (b) maximum air temperature, (c) mean solar exposure and (d) mean, minimum and maximum wind speed.
Dashed line in a, b and c indicates the long-term mean. Rainfall and air temperature records at Sydney Airport AMO commenced in 1929 and 1939 respectively. Solar exposure monitoring at Kurnell AWS commenced in 2007.

Wave data recorded by the Sydney offshore waverider buoy reflected some of the wind conditions recorded at Kurnell. Maximum daily wave heights reached 4-5m during periods of strong southerly winds in early and mid-June (Figure 4-10, IMOS, 2024a). There were two occasions in September when wave heights exceeded 3.5 m for consecutive days, but outside of this, conditions were generally subdued. August wave heights were generally <2m. Data was unavailable for July 2024.

Water temperature data recorded by the data logger installed at rehabilitation site Scar F was only available for a period from mid-May to late June. The data indicated that the water temperature had continued on the downward trajectory that began in March (Figure 4-11a). By the end of June the mean water temperature had declined to about 17°C, representing a cooling of about 6°C from the peak warmth in February 2024.

The IMOS OceanCurrent (IMOS, 2024b) sea surface current and sea surface temperature map of southern NSW captured in early August shows cool (14-15°C) surface water being pushed inshore towards Sydney while warmer East Australian Current surface waters sit offshore (Figure 4-11b). Satellite images of estimated chlorophyll-a concentrations in coastal waters can indicate phytoplankton and/or suspended sediments levels present in the water. Chlorophyll-a mapping captured after two significant rain events affecting Sydney in June shows high chlorophyll-a concentrations (>4mg/m^3) in inshore waters that suggest high nutrient loads and poor water quality (Figure 4-11c).

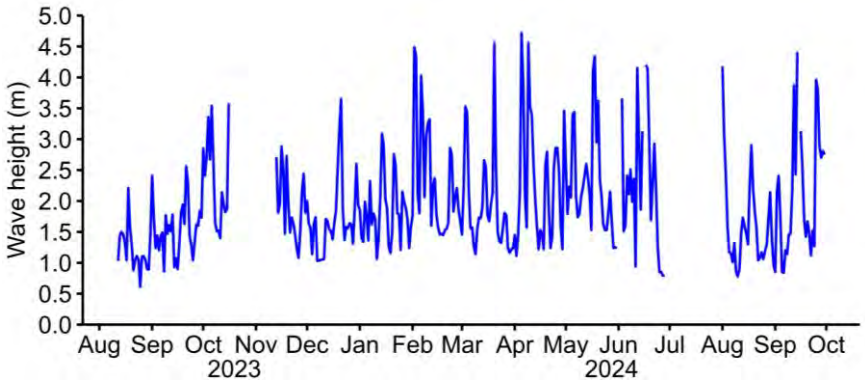

Figure 4-10: Daily maximum significant wave height recorded by the Sydney offshore waverider buoy (SYDDOW) from August 2023 to September 2024.

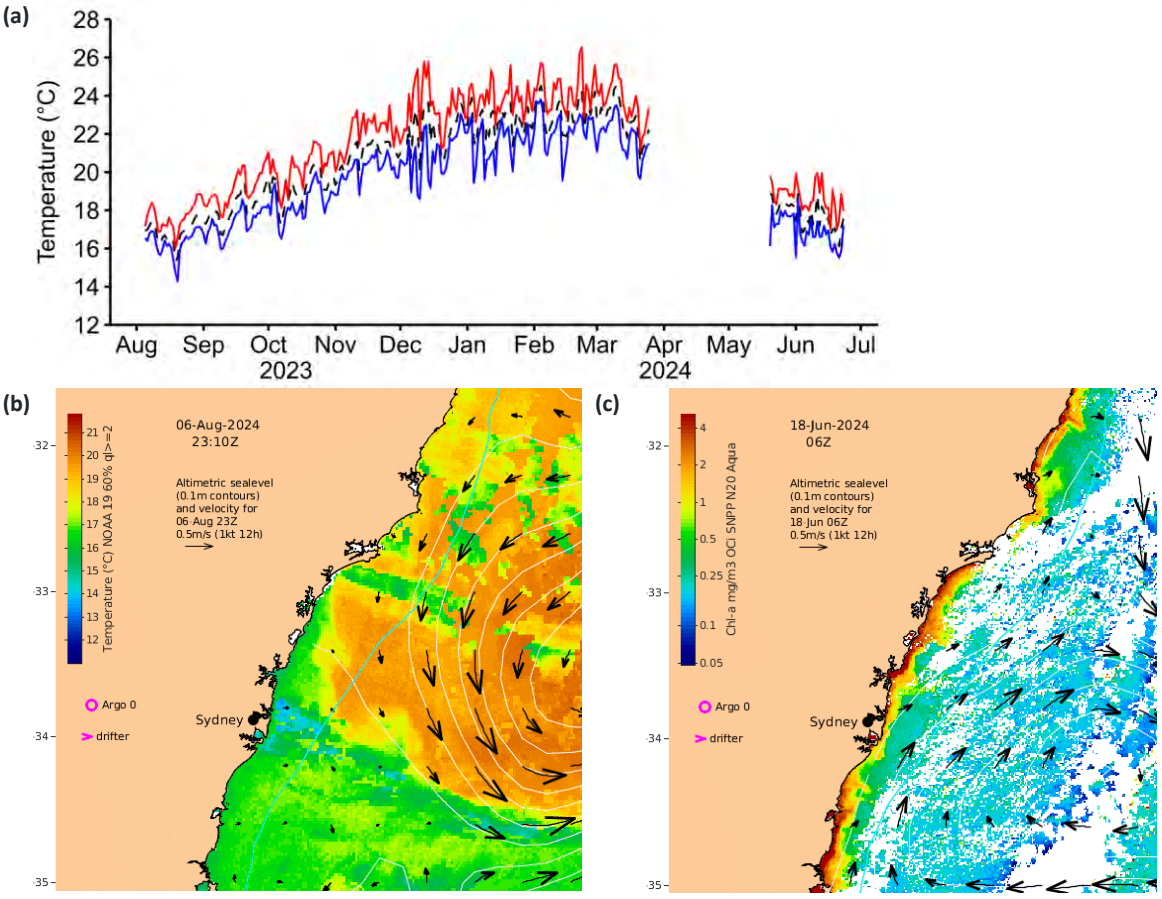

Figure 4-11: (a) Daily mean, maximum and minimum water temperature recorded between 5 August 2023 and 22 June 2024 by a data logger installed at Scar F, (b) Sea surface temperature near the Sydney coast in August 2024 and (c) Chlorophyll-a concentration near the Sydney coast in June 2024.
In (a) daily mean, maximum and minimum water temperature are indicated by dashed, red and blue lines respectively. Data was unavailable for 26 March to 19 May 2024. Source for b, c: https://oceancurrent.aodn.org.au/product.php

5. Discussion

5.1 Assessment against success criteria

Success criteria for monitoring the performance of the *Posidonia australis* restoration efforts were established in consultation with the MBOS Implementation Reference Panel and other key project stakeholders (refer to the MBOS for the full criteria). The success criteria provide readily measurable structural attributes that will indicate changes in the status of transplanted and nearby naturally occurring *Posidonia australis* meadows through time: *Posidonia australis* areal extent and shoot density. The performance of the offsetting strategy can be evaluated by comparing the monitoring data with these targets.

An evaluation of the monitoring results detailed in this report against the short-term (two year) success criteria is summarised in Table 5-1.

Table 5-1: *Posidonia australis* offsetting success criteria and measures for the short-term period of the restoration program

Criteria	Measure	Description of success	Outcome of restoration work
Increase in area of *Posidonia.*	Areal extent of restored *Posidonia australis* meets EPBC offset requirements.	Areal extent of restored *Posidonia australis* is to a 1:1 ratio of area removed from the impact area.	Transplanting of naturally detached *Posidonia australis* in rehabilitation site Scar D improved 14 m^2 of degraded seagrass habitat over the period June-October 2024. The total area planted exceeds the short-term success criteria at this time point.
Long term (10-year) goal: 536 m^2	Short term (two-year) goal:	268 m^2	408 m^2 **Exceeds target**
Maintain *Posidonia australis* density.	Shoot density of restored *Posidonia australis* (based on 0.25 m^2 quadrats).	Increase in shoot density in the offset sites from bare to vegetated at a minimum density of 25 shoots per square metre (>50% of the impact area density).	*Posidonia australis* density at all six rehabilitation sites restored using translocated shoots exceed the short-term shoot density success criteria of 25 shoots/m^2. Four sites meet or exceed the long-term shoot density success criteria of 42 shoots/m^2. The density of naturally detached *Posidonia australis* transplanted at Scar D was marginally below the short-term density criteria of 25 shoots/m^2.
Long term (10-year) goal: 42 shoots/m^2	Short term (two-year) goal:	25 shoots/m^2	39 shoots/m^2 (range 24-50) **Exceeds target**

Transplanting of naturally detached *Posidonia australis* between June and October 2024 resulted in 14 m^2 of degraded seagrass habitat at Kurnell being improved. These efforts brought the total area planted with *Posidonia australis* to 408 m^2, exceeding the short-term (two-year) success criteria for the offset strategy by 140 m^2 (Table 5-1). Revegetation of a further 128 m^2 of degraded *Posidonia australis* habitat is needed to achieve the long-term (ten-year) goal for area restored of 536 m^2.

Restoration efforts during the June to October 2024 period continued to target Scar D. Transplanting at this site occurred in early October, amounting to a gap of four months between transplanting events. The seasonal (winter) weather pattern played a key role in this timing. The exceptionally wet June as well as generally cool and wind-affected days during this period influenced the frequency and duration of beach surveys which in turn resulted in fewer naturally detached *Posidonia australis* shoots being collected relative to previous months: about 300 vs 780 shoots per month during autumn (March to May 2024). There was a noticeable increase in the number of naturally detached shoots collected in Towra Point Aquatic Reserve during the winter months compared to earlier periods in the year, suggesting seasonal westerly winds played a role in shoots accumulating at this location.

Some naturally detached *Posidonia australis* shoots collected during early winter remained in storage in the outdoor aquaria for a substantial period of time (up to four months) before being transplanted. About half of shoots collected between June and September were considered viable for transplanting by early October. There are benefits to a longer storage phase for naturally detached shoots, as this period can provide a screening process that naturally selects the shoots that are more likely to survive being transplanted (Balestri *et al*., 2011; Ferretto *et al*., 2023). Future research should examine if shoot survival can be enhanced by optimising elements of the existing storage solution.

Fourteen months post-translocation, all six rehabilitation sites replanted using translocated *Posidonia australis* have shoot densities that exceed the short-term (two-year) target density. Translocated *Posidonia australis* has performed particularly well at four sites, where over the 14 months of monitoring, shoot densities have remained relatively stable and within close range or above the long-term (ten-year) target density. *Posidonia australis* shoot densities have declined through time at rehabilitation sites Trench East and Scar F, although the decline was statistically significant at Scar F only. These two sites have few common characteristics, thus the reasons for these declines are unclear at this stage. Nevertheless, some recovery may occur over the following months as *Posidonia australis* enters its peak growth period in spring (Kirkman, 2014). Supplementary monitoring of these sites prior to the next monitoring event (March/April 2025) may be warranted.

Rehabilitation site Scar D appeared to experience some losses of transplanted naturally detached *Posidonia australis* since the previous monitoring event in late May 2024. Restoration activities at this site began in February 2024 which places the transplanted *Posidonia australis* within the most vulnerable phase of the restoration process (Mancini *et al.,* 2021). A decline in the shoot density of these transplants would be expected for about 12 months following transplanting. Given the timing of the next monitoring event in March/April 2025, it could be expected that any further decline in shoot density would be minimal as the most testing restoration stage would be complete for many of the transplanted shoots.

5.2 *Posidonia australis* condition and seagrass composition

The measured *Posidonia australis* condition attribute of maximum leaf length has shown minimal change through time in rehabilitation sites, although signs of growth are becoming apparent. As *Posidonia australis* enters its period of peak growth in spring (Kirkman, 2014), increases in leaf length of transplanted shoots may be captured in the next monitoring event in autumn 2025. Given *Posidonia australis'* slow-growing nature, such changes would be expected to be incremental over an extended period of time. Since being translocated about fourteen months ago, maximum leaf lengths of *Posidonia australis* in rehabilitation sites remain about 5-10 cm shorter than those in the surrounding meadow.

Epiphyte cover of *Posidonia australis* in both rehabilitation and reference sites was marginally lower on average in the most recent monitoring round relative to the previous round carried out in May 2024. This was anticipated given that the most recent surveys followed winter when epiphytic algae tends to decline (Trautman and Borowitzka, 1999). Epiphyte cover demonstrated a strong seasonal signal that mimicked changes in air and water temperature and availability of light, which are lowest in winter and highest in summer in the Botany Bay region. In general, levels of epiphyte cover through time consistently fall within the moderate range at all sites.

A qualitative assessment of *Posidonia australis* condition based on visual observations indicated a general improvement since the previous monitoring event in May 2024. While monitoring surveys carried out in May noted that *Posidonia australis* leaves appeared dull, dusted with sediment or detritus and frequently buried, few similar observations were noted in the most recent monitoring surveys. There were sporadic sightings of flowers and fruits on *Posidonia australis* in the natural meadow, coinciding with the reproductive season for the species (Kendrick *et al*., 2023). These were not observed on the *Posidonia australis* in rehabilitation sites. However, an epiphytic algal bloom developed in the seagrass meadow at Kurnell over the course of the monitoring surveys and by early October the algae was highly pronounced in the rehabilitation sites. This is discussed further in section 5.3.

Since restoration efforts began about fourteen months ago, seagrasses cover about 60 percent of the once mostly bare sand in the rehabilitation sites at Kurnell. Of this cover, *Posidonia australis* contributes about 25 percent. This represents a marked improvement in habitat quality and general state of these degraded areas through restoration. Although there are differences in seagrass composition between the rehabilitation sites and surrounding meadow, these arise due to the limited availability of donor *Posidonia australis* material which necessitates that the species is transplanted at substantially lower densities than occur naturally. Nevertheless, it is anticipated that these sites will more closely resemble the natural meadow as time progresses.

5.3 Environmental conditions and general observations during monitoring

The Botany Bay region climate during winter was both wetter and warmer than the long-term mean, defying the seasonal forecast issued by BOM (2024f). The frequent occurrence of rain hampered survey efforts to collect naturally detached *Posidonia australis* shoots for restoration and caused periodic short-term deteriorations in water quality in the Kurnell area. The greatest rainfall totals during this period occurred during June, following which rainfall levels were within the normal range for the time of year, however this dryer period coincided with unusually warm air temperatures.

This combination of climate conditions may have been the trigger for the epiphytic algal bloom that emerged in the seagrass meadow at Kurnell in late September. The algae rapidly spread across the meadow, attaching to seagrass leaves and accumulating in large clumps on the sediment. Observations of the distribution of the epiphytic algae suggest that areas of dense *Posidonia australis* appear to better resist the epiphytic algae accumulating, possibly due to greater leaf movement (Lavery *et al.,* 2007). A similar event occurred in late winter 2023, suggesting that the appearance of the algae may be an annual occurrence at Kurnell. Comparisons of the photosynthetic ability of *Posidonia australis* leaves with varying degrees of epiphytic algal growth could provide useful insight into the effect, if any, of this recurring event on seagrass health.

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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 m^2)				
Site	Site type	Aug 2023	Oct 2023	Feb 2024	May 2024	Oct 2024
Overall	Rehabilitation	53.0 (±2.3)	41.0 (±2.0)	45.7 (±2.0)	36.0 (±1.2)	39.0 (±2.2)
Overall	Reference	114.0 (±5.6)	110.0 (±5.7)	135.9 (±4.3)	142.2 (±6.5)	170.4 (±7.5)
Scar B	Rehabilitation	68.8 (±5.8)	38.0 (±5.6)	43.2 (±3.2)	41.2 (±3.3)	44.0 (±4.3)
Scar C	Rehabilitation	47.2 (±3.2)	48.3 (±4.1)	44.8 (±3.8)	39.7 (±2.6)	49.6 (±5.7)
Scar E	Rehabilitation	68.4 (±5.2)	38.0 (±4.9)	46.8 (±4.8)	36.4 (±1.3)	44.8 (±4.2)
Scar F	Rehabilitation	48.0 (±3.6)	42.4 (±3.0)	45.6 (±9.4)	32.8 (±5.0)	27.2 (±4.3)
Trench East	Rehabilitation	37.6 (±3.0)	32.0 (±4.1)	46.8 (±4.2)	32.4 (±3.4)	30.4 (±5.0)
Trench West	Rehabilitation	48.4 (±4.6)	46.8 (±4.8)	47.6 (±6.8)	35.2 (±3.5)	41.6 (±5.4)
Scar D	Rehabilitation	-	-	33.2 (±3.2)	30.4 (±3.6)	24.0 (±4.2)
PBK03	Reference	61.6 (±5.4)	86.4 (±9.8)	114.0 (±6.4)	94.0 (±6.4)	118.4 (±6.2)
PBK04	Reference	90.8 (±5.8)	80.8 (±6.4)	126.8 (±12.8)	90.0 (±7.5)	142.8 (±5.7)
PBK07	Reference	92.8 (±6.8)	92.8 (±7.6)	134.0 (±10.0)	141.6 (±7.2)	146.4 (±14.9)
PBK08	Reference	142.4 (±9.7)	108.8 (±16.7)	123.2 (±8.5)	142.4 (±8.0)	152.4 (±17.5)
PBR01	Reference	152.4 (±12.6)	158.8 (±12.6)	154.4 (±6.2)	187.2 (±10.1)	224.8 (±9.7)
PBR02	Reference	142.0 (±10.7)	134.8 (±11.1)	162.8 (±10.1)	198.0 (±15.2)	245.3 (±9.2)

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
Overall	Rehabilitation	31.0 (±0.7)	34.0 (±0.5)	32.9 (±0.8)	31.2 (±0.8)	34.2 (±0.7)
Overall	Reference	35.0 (±0.7)	50.0 (±1.2)	44.1 (±1.0)	39.3 (±0.5)	44.4 (±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)
Scar C	Rehabilitation	29.6 (±0.9)	33.9 (±0.8)	29.7 (±0.8)	30.3 (±0.7)	33.9 (±1.5)
Scar E	Rehabilitation	30.8 (±1.0)	33.3 (±1.6)	32.3 (±1.4)	30.0 (±1.1)	33.4 (±1.1)
Scar F	Rehabilitation	23.1 (±1.4)	28.9 (±2.7)	27.6 (±2.2)	23.3 (±1.7)	30.1 (±1.9)
Trench East	Rehabilitation	28.0 (±1.3)	33.6 (±0.9)	37.2 (±1.7)	38.5 (±2.2)	35.5 (±1.3)
Trench West	Rehabilitation	32.8 (±1.0)	35.9 (±1.0)	33.1 (±2.3)	36.5 (±1.2)	37.5 (±1.3)
Scar D	Rehabilitation	-	-	24.8 (±1.4)	21.7 (±1.4)	27.1 (±2.0)
PBK03	Reference	33.6 (±1.8)	46.3 (±1.4)	52.3 (±2.3)	40.7 (±0.9)	52.4 (±1.1)
PBK04	Reference	36.3 (±1.7)	49.5 (±3.2)	45.8 (±3.4)	41.0 (±1.4)	48.2 (±1.7)
PBK07	Reference	35.2 (±2.0)	45.8 (±2.0)	39.2 (±1.5)	37.3 (±1.1)	40.5 (±1.5)
PBK08	Reference	35.6 (±1.5)	49.5 (±3.3)	40.9 (±1.7)	36.7 (±0.6)	41.3 (±1.6)
PBR01	Reference	31.5 (±0.9)	55.1 (±4.3)	42.1 (±1.4)	38.7 (±1.0)	42.5 (±1.6)
PBR02	Reference	38.2 (±1.4)	55.4 (±2.0)	44.2 (±2.7)	41.5 (±1.2)	41.1 (±2.0)

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
Overall	Rehabilitation	2.2 (±0.1)	2.7 (±0.1)	2.9 (±0.1)	3.6 (±0.1)	3.3 (±0.1)
Overall	Reference	2.2 (±0.1)	3.3 (±0.1)	3.7 (±0.1)	3.4 (±0.1)	3.1 (±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)
Scar C	Rehabilitation	3.0 (± 0.2)	2.1 (±0)	2.8 (±0.2)	3.6 (±0.3)	3.4 (±0.2)
Scar E	Rehabilitation	2.0 (± 0.2)	2.7 (±0.2)	3.5 (±0.1)	3.6 (±0.2)	3.1 (±0.2)
Scar F	Rehabilitation	1.2 (± 0.6)	2.0 (±0)	3.3 (±0.3)	3.6 (±0.2)	3.2 (±0.3)
Trench East	Rehabilitation	2.4 (± 0.3)	3.5 (±0.2)	2.8 (±0.2)	3.7 (±0.2)	3.5 (±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)
Scar D	Rehabilitation	-	-	2.9 (±0.3)	3.8 (±0.2)	2.5 (±0.2)
PBK03	Reference	2.0 (± 0.2)	2.8 (±0.3)	3.1 (±0.3)	3.2 (±0.3)	3.3 (±0.2)
PBK04	Reference	1.9 (± 0.3)	3.4 (±0.2)	3.0 (±0.3)	3.6 (±0.3)	3.6 (±0.2)
PBK07	Reference	1.6 (± 0.2)	3.9 (±0.2)	3.9 (±0.1)	3.2 (±0.3)	3.4 (±0.2)
PBK08	Reference	2.4 (± 0.3)	3.5 (±0.2)	3.9 (±0.2)	3.5 (±0.3)	2.6 (±0.1)
PBR01	Reference	2.5 (± 0.3)	3.0 (±0.4)	4.0 (±0.2)	3.7 (±0.2)	3.1 (±0.2)
PBR02	Reference	3.1 (± 0.2)	3.2 (±0.3)	4.1 (±0.1)	3.6 (±0.1)	2.9 (±0.2)

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
Overall	Rehabilitation	61.4	61.7	65.5	56.5
Overall	Reference	93.4	83.3	79.4	78.9
Scar B	Rehabilitation	62.6	63.0	61.0	66.3
Scar C	Rehabilitation	57.4	62.2	66.2	54.0
Scar E	Rehabilitation	48.1	60.0	76.7	69.3
Scar F	Rehabilitation	55.0	56.7	69.3	67.3
Trench East	Rehabilitation	78.3	65.7	50.7	43.3
Trench West	Rehabilitation	63.7	60.0	73.7	36.0
Scar D	Rehabilitation	-	44.0	62.3	65.7
PBK03	Reference	89.3	68.3	68.7	78.3
PBK04	Reference	91.3	77.0	80.3	82.0
PBK07	Reference	97.0	89.7	87.3	73.7
PBK08	Reference	95.0	84.3	84.7	76.0
PBR01	Reference	90.4	89.0	71.7	82.0
PBR02	Reference	97.0	91.7	82.3	80.7

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.

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

Appendix B

Supplementary results

Table B-1: Univariate PERMANOVA table of results, comparing *Posidonia australis* shoot densities between rehabilitation and reference sites and among sites quantified during the round 4 monitoring event in October 2024. Table gives degrees of freedom (df), Sum of Squares (SS), pseudo-F, and P-values. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	553040	48.6	**0.001**
Site(Site type)	11	129810	15.9	**0.001**
Residuals	116	86179		
Total	128	769350		

Table B-2: Pairwise univariate PERMANOVA test results, comparing *Posidonia australis* shoot densities among rehabilitation sites and reference sites. **Bold** font indicates a statistically significant result.

Groups	t-value	P-value
Rehabilitation sites		
Scar F, Scar E	2.62	**0.03**
Scar F, Scar B	2.44	**0.03**
Scar F, Scar C	2.15	**0.04**
Scar F, Trench West	1.73	0.12
Scar F, Trench East	0.41	0.74
Scar F, Scar D	0.48	0.65
Scar E, Scar B	0.13	0.94
Scar E, Scar C	0.61	0.58
Scar E, Trench West	0.47	0.69
Scar E, Trench East	2.20	0.05
Scar E, Scar D	3.51	**0.01**
Scar B, Scar C	0.71	0.52
Scar B, Trench West	0.35	0.78
Scar B, Trench East	2.05	0.06
Scar B, Scar D	3.32	**0.01**
Scar C, Trench West	0.96	0.36
Scar C, Trench East	2.35	**0.03**
Scar C, Scar D	3.26	**<0.01**
Trench West, Trench East	1.52	0.14
Trench West, Scar D	2.58	**0.02**
Trench East, Scar D	0.98	0.38
Reference sites		
PBR01, PBR02	1.51	0.17
PBR01, PBK08	3.61	**0.01**
PBR01, PBK07	4.40	**<0.01**
PBR01, PBK04	7.29	**<0.01**
PBR01, PBK03	9.24	**<0.01**
PBR02, PBK08	4.51	**<0.01**
PBR02, PBK07	5.44	**<0.01**
PBR02, PBK04	9.45	**<0.01**
PBR02, PBK03	11.38	**<0.01**
PBK08, PBK07	0.26	0.82
PBK08, PBK04	0.52	0.66
PBK08, PBK03	1.83	0.09
PBK07, PBK04	0.23	0.86
PBK07, PBK03	1.73	0.10
PBK04, PBK03	2.88	**0.02**

Table B-3: Univariate PERMANOVA table of results, comparing *Posidonia australis* maximum leaf lengths between rehabilitation and reference sites and among sites quantified during the round 4 monitoring event in October 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	3321.3	17.1	**0.003**
Site(Site type)	11	2207.3	8.4	**0.001**
Residuals	116	2766.8		
Total	128	8296.7		

Table B-4: Pairwise univariate PERMANOVA test results, comparing *Posidonia australis* maximum leaf lengths among rehabilitation and reference sites. **Bold** font indicates a statistically significant result.

Groups	t-value	P-value
Rehabilitation sites		
Scar F, Scar E	1.64	0.12
Scar F, Scar B	4.01	**<0.01**
Scar F, Scar C	1.39	0.17
Scar F, Trench West	3.31	**0.01**
Scar F, Trench East	2.42	**0.04**
Scar F, Scar D	0.95	0.38
Scar E, Scar B	3.56	**<0.01**
Scar E, Scar C	0.25	0.81
Scar E, Trench West	2.44	**0.03**
Scar E, Trench East	1.24	0.25
Scar E, Scar D	2.80	**0.01**
Scar B, Scar C	2.76	**0.02**
Scar B, Trench West	1.21	0.27
Scar B, Trench East	2.28	**0.04**
Scar B, Scar D	5.22	**<0.01**
Scar C, Trench West	1.73	0.10
Scar C, Trench East	0.76	0.47
Scar C, Scar D	2.84	**0.01**
Trench West, Trench East	1.13	0.28
Trench West, Scar D	4.43	**<0.01**
Trench East, Scar D	3.58	**0.01**
Reference sites		
PBR01, PBR02	0.55	0.59
PBR01, PBK08	0.53	0.63
PBR01, PBK07	0.93	0.37
PBR01, PBK04	2.40	**0.03**
PBR01, PBK03	5.01	**<0.01**
PBR02, PBK08	0.08	0.95
PBR02, PBK07	0.27	0.80
PBR02, PBK04	2.74	**0.02**
PBR02, PBK03	5.16	**<0.01**
PBK08, PBK07	0.38	0.72
PBK08, PBK04	2.94	**0.01**
PBK08, PBK03	5.71	**<0.01**
PBK07, PBK04	3.42	**0.01**
PBK07, PBK03	6.48	**<0.01**
PBK04, PBK03	2.07	0.06

Table B-5: Univariate PERMANOVA table of results, comparing *Posidonia australis* epiphyte cover between rehabilitation and reference sites and among sites quantified during the round 4 monitoring event in October 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	0.8	0.6	0.478
Site(Site type)	11	16.3	3.1	**0.002**
Residuals	116	54.1		
Total	128	71.3		

Table B-6: Pairwise univariate PERMANOVA test results, comparing *Posidonia australis* epiphtye cover among rehabilitation and reference sites. **Bold** font indicates a statistically significant result.

Groups	t-value	P-value
Rehabilitation sites		
Scar F, Scar E	0.21	0.85
Scar F, Scar B	0.39	0.77
Scar F, Scar C	0.54	0.63
Scar F, Trench West	1.20	0.28
Scar F, Trench East	0.85	0.45
Scar F, Scar D	2.25	0.06
Scar E, Scar B	0.70	0.54
Scar E, Scar C	0.96	0.35
Scar E, Trench West	1.80	0.10
Scar E, Trench East	1.33	0.23
Scar E, Scar D	2.53	**0.03**
Scar B, Scar C	0.00	1.00
Scar B, Trench West	0.81	0.47
Scar B, Trench East	0.32	0.81
Scar B, Scar D	2.38	**0.04**
Scar C, Trench West	1.08	0.29
Scar C, Trench East	0.43	0.72
Scar C, Scar D	3.26	**0.01**
Trench West, Trench East	0.60	0.59
Trench West, Scar D	3.63	**<0.01**
Trench East, Scar D	3.49	**<0.01**
Reference sites		
PBR01, PBR02	0.80	0.45
PBR01, PBK08	2.32	0.05
PBR01, PBK07	1.23	0.29
PBR01, PBK04	2.15	0.07
PBR01, PBK03	0.78	0.51
PBR02, PBK08	1.18	0.24
PBR02, PBK07	1.90	0.10
PBR02, PBK04	2.77	**0.01**
PBR02, PBK03	1.47	0.19
PBK08, PBK07	3.65	**0.01**
PBK08, PBK04	4.87	**<0.01**
PBK08, PBK03	3.01	**0.01**
PBK07, PBK04	0.85	0.51
PBK07, PBK03	0.39	0.81
PBK04, PBK03	1.21	0.30

Table B-7: Results of Generalised Linear Models (GLM) for differences in *Posidonia australis* shoot density 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.

	df	AIC	χ^2	P-value
Scar B				
Null	2	426.3		
Monitoring round	6	412.3	22.0	**<0.001**
Scar C				
Null	2	614.2		
Monitoring round	6	617.7	4.5	0.339
Scar E				
Null	2	424.5		
Monitoring round	6	405.9	26.6	**<0.001**
Scar F				
Null	2	206.5		
Monitoring round	6	204.5	10.0	**0.040**
Trench East				
Null	2	392.2		
Monitoring round	6	389.8	10.4	**0.033**
Trench West				
Null	2	420.0		
Monitoring round	6	422.7	5.3	0.256
Scar D				
Null	2	234.8		
Monitoring round	4	235.3	3.5	0.176

Table B-8: Summary output results from GLM for *Posidonia australis* shoot density in rehabilitation sites over the monitoring program to date. **Bold** font indicates a statistically significant result.

Monitoring round	Estimate	Standard Error	z value	P-value
Scar B				
(Intercept) Aug 2023	4.231	0.089	47.589	**<0.001**
Oct 2023	-0.594	0.130	-4.554	**<0.001**
Feb 2024	-0.465	0.129	-3.604	**<0.001**
May 2024	-0.513	0.130	-3.958	**<0.001**
Oct 2024	-0.447	0.100	-3.467	**<0.001**
Scar C				
(Intercept) Aug 2023	3.854	0.072	53.781	**<0.001**
Oct 2023	0.022	0.101	0.221	0.825
Feb 2024	-0.052	0.102	-0.513	0.608
May 2024	-0.172	0.103	-1.677	0.093
Oct 2024	0.050	0.100	0.441	0.659
Scar E				
(Intercept) Aug 2023	4.225	0.083	51.17	**<0.001**
Oct 2023	-0.588	0.122	-4.830	**<0.001**
Feb 2024	-0.379	0.120	-3.172	**0.002**
May 2024	-0.631	0.122	-5.164	**<0.001**
Oct 2024	-0.423	0.121	-3.510	**<0.001**
Scar F				
(Intercept) Aug 2023	3.871	0.129	29.959	**<0.001**
Oct 2023	-0.124	0.184	-0.673	0.501
Feb 2024	-0.051	0.183	-0.280	0.780
May 2024	-0.381	0.188	-2.026	**0.043**
Oct 2024	-0.568	0.200	-2.970	**0.003**
Trench East				
(Intercept) Aug 2023	3.627	0.094	38.779	**<0.001**
Oct 2023	-0.161	0.134	-1.203	0.229
Feb 2024	0.219	0.130	1.680	0.093
May 2024	-0.147	0.138	-1.072	0.284
Oct 2024	-0.213	0.150	-1.420	0.156
Trench West				
(Intercept) Aug 2023	3.880	0.107	36.301	**<0.001**
Oct 2023	-0.034	0.151	-0.222	0.824
Feb 2024	-0.017	0.151	-0.110	0.912
May 2024	-0.318	0.154	-2.072	**0.038**
Oct 2024	-0.150	0.160	-0.971	0.332
Scar D				
(Intercept) Feb 2024	3.503	0.101	34.566	**<0.001**
May 2024	-0.088	0.144	-0.611	0.541
Oct 2024	-0.323	0.200	-1.876	0.061

Table B-9: Results of Tukey pairwise comparisons from GLM for *Posidonia australis* shoot density 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	Estimate	Standard Error	z value	P-value
Scar B				
Oct 2023 - Aug 2023	-0.59	0.13	-4.56	**<0.01**
Feb 2024 - Aug 2023	-0.47	0.13	-3.61	**<0.01**
May 2024 - Aug 2023	-0.51	0.13	-3.96	**<0.01**
Oct 2024 - Aug 2023	-0.45	0.13	-3.47	**<0.01**
Feb 2024 - Oct 2023	0.13	0.13	0.96	0.87
May 2024 - Oct 2023	0.08	0.13	0.60	0.97
Oct 2024 - Oct 2023	0.15	0.13	1.10	0.81
May 2024 - Feb 2024	-0.05	0.13	-0.36	1.00
Oct 2024 - Feb 2024	0.02	0.13	0.14	1.00
Oct 2024 - May 2024	0.07	0.13	0.50	0.99
Scar E				
Oct 2023 - Aug 2023	-0.59	0.12	-4.81	**<0.01**
Feb 2024 - Aug 2023	-0.38	0.12	-3.16	**0.01**
May 2024 - Aug 2023	-0.63	0.12	-5.14	**<0.01**
Oct 2024 - Aug 2023	-0.42	0.12	-3.51	**<0.01**
Feb 2024 - Oct 2023	0.21	0.12	1.67	0.45
May 2024 - Oct 2023	-0.04	0.13	-0.34	1.00
Oct 2024 - Oct 2023	0.16	0.13	1.31	0.68
May 2024 - Feb 2024	-0.25	0.13	-2.00	0.26
Oct 2024 - Feb 2024	-0.04	0.12	-0.35	1.00
Oct 2024 - May 2024	0.21	0.13	1.65	0.46
Scar F				
Oct 2023 - Aug 2023	-0.12	0.18	-0.67	0.96
Feb 2024 - Aug 2023	-0.05	0.18	-0.28	0.10
May 2024 - Aug 2023	-0.38	0.19	-2.02	0.25
Oct 2024 - Aug 2023	-0.57	0.19	-2.97	**0.03**
Feb 2024 - Oct 2023	0.07	0.19	0.39	1.00
May 2024 - Oct 2023	-0.26	0.19	-1.35	0.66
Oct 2024 - Oct 2023	-0.44	0.19	-2.30	0.14
May 2024 - Feb 2024	-0.33	0.19	-1.75	0.41
Oct 2024 - Feb 2024	-0.52	0.19	-2.69	0.06
Oct 2024 - May 2024	-0.19	0.20	-0.95	0.88
Trench East				
Oct 2023 - Aug 2023	-0.16	0.15	-1.08	0.82
Feb 2024 - Aug 2023	0.22	0.15	1.50	0.56
May 2024 - Aug 2023	-0.15	0.15	-0.96	0.87
Oct 2024 - Aug 2023	-0.21	0.15	-1.42	0.61
Feb 2024 - Oct 2023	0.38	0.15	2.58	0.07
May 2024 - Oct 2023	0.01	0.15	0.09	1.00
Oct 2024 - Oct 2023	-0.05	0.15	-0.34	1.00
May 2024 - Feb 2024	-0.37	0.15	-2.42	0.11
Oct 2024 - Feb 2024	-0.43	0.15	-2.92	**0.03**
Oct 2024 - May 2024	-0.07	0.16	-0.42	0.99

Table B-9: PERMANOVA table of results, comparing seagrass composition between rehabilitation and reference sites quantified during the round 4 monitoring event in October 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	2506.3	45.6	**0.002**
Residuals	11	605.0		
Total	12	3111.3		

Table B-10: Contributions of benthic categories to the dissimilarity in benthic composition between rehabilitation and reference sites as determined by SIMPER analysis of square-root transformed percentage cover data obtained from the round 4 monitoring event in October 2024.

Benthic category	Rehabilitation sites mean cover (%)	Reference sites mean cover (%)	Contribution to dissimilarity (%)
Posidonia australis	21.8	71.0	50.1
Zostera sp.	24.3	5.7	19.0
Sand	42.3	21.2	21.6