Transport
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Kamay Ferry Wharves project

Seagrass Translocation, Rehabilitation and Monitoring

Seagrass Monitoring Report 2

February 2024

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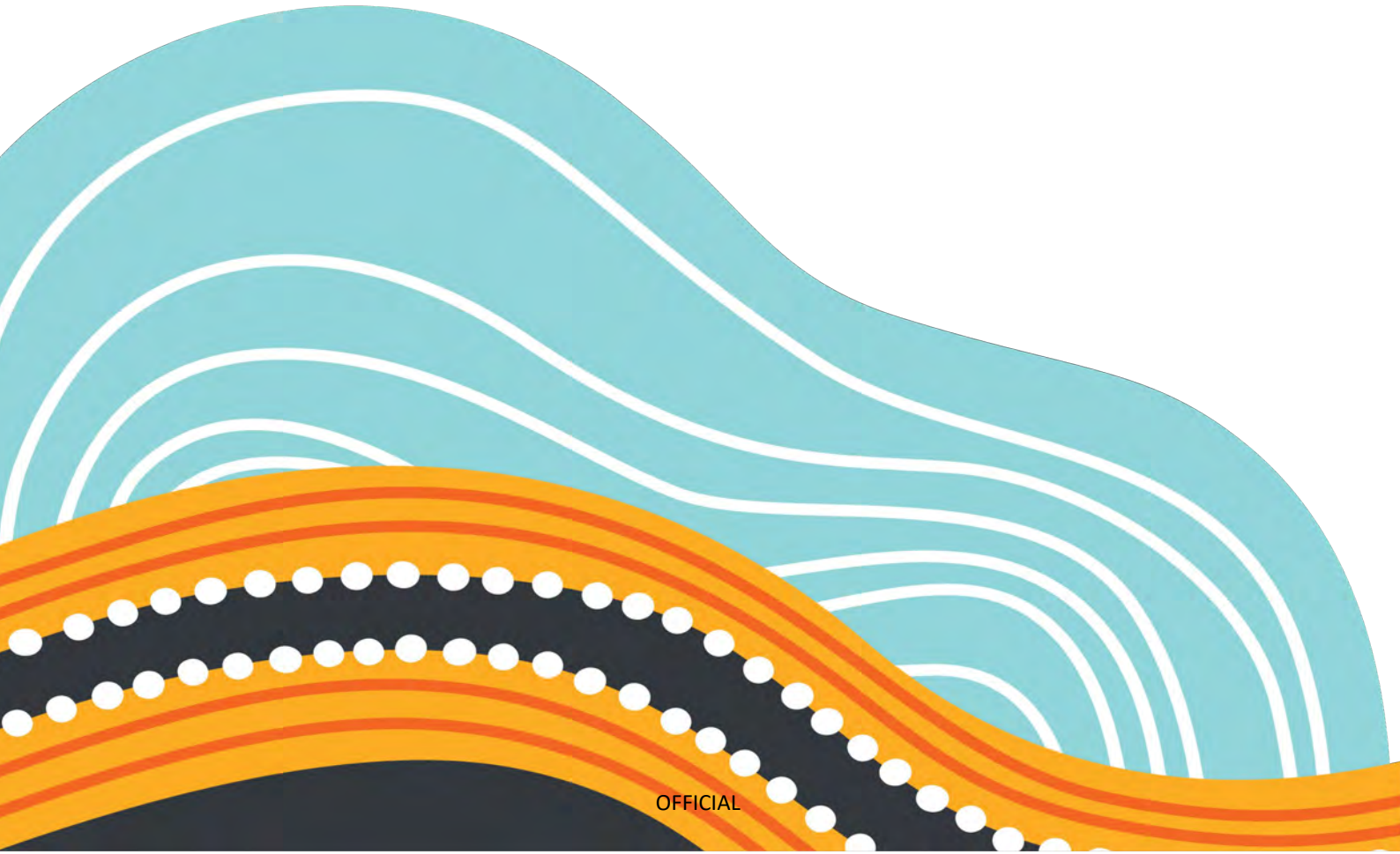

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Terms and acronyms

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
DPI Fisheries	NSW Department of Primary Industries 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
m^2	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

Term /acronym	Description
Posidonia	Seagrass species *Posidonia australis,* commonly known as strapweed.
Posidonia australis	Seagrass species commonly known as strapweed.
Project	Kamay Ferry Wharves project
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.

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 access 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 Fisheries (DPI 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, DPI 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:

a) 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)

b) 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 DPI 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. 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).

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).

1.6 Purpose of this seagrass monitoring report

This report documents the results of the second monitoring event of the ten-year monitoring program. Monitoring was carried out in February 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 (for about 1-4 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 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, November 2023 to February 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

A total of 26 beach surveys to collect naturally detached *Posidonia australis* shoots were carried out at nine locations around Botany Bay from November 2023 to February 2024 (Table 2-1, Figure 2-1). The number of beach surveys carried out was equally distributed over the four months, with surveys being carried out about twice per week and consisting of 2-4 hours of search time in each instance.

Beach surveys were concentrated at Kurnell with 21 out of 26 surveys including searches of this area, while 15 surveys of the adjacent Towra Point Aquatic Reserve refuge zone were carried out (Figure 2-1). The survey area at Kurnell is the largest in Botany Bay and consists of about 2.5 km of shoreline extending from near Bonna Point boat ramp in the west to the Kurnell ferry wharf construction area in the east. Beach surveys at Kurnell may include the entire area or target specific sections that have been identified as hotspots for accumulating naturally detached *Posidonia australis* shoots. In comparison, the next largest survey areas are Brighton-Le-Sands Beach (about 1 km) and Yarra Bay (about 750 m).

Beach surveys carried out during the four-month period resulted in collection of 2260 naturally detached *Posidonia australis* shoots (Table 2-1). The Kurnell area stands out as the most productive for naturally detached shoots. This location had both the greatest number of beach surveys and shoots collected – at least 80% of shoots (about 1800) were collected at Kurnell.

There was a substantial increase in the number of shoots collected over time from November 2023 to February 2024 (Table 2-1). The majority (75%) of shoots were collected in February: four times more shoots were collected this month compared to January, while the number of shoots collected in February was a >20 time increase compared to November and December. In February, an average of 187 shoots were collected each survey, with 544 shoots collected during a single survey. In contrast, each survey carried out in November and December yielded only 13 and 14 shoots on average, respectively.

Several factors are likely to have contributed to greater shoot numbers being collected in the first two months of 2024 compared to previous months. In January 2024 an additional method for shoot collection was introduced which involved collecting shoots found floating in the water column or water surface in the nearshore area at Kurnell. This method also tends to increase the survey effort in terms of hours. Survey teams have learnt from collection efforts to date where concentrations of naturally detached shoots can be found (such as Bonna Point Boat Ramp and east-facing breakwalls at Kurnell) and more recent survey efforts have also sought to target these areas. Weather conditions are also likely to have influenced shoot collection numbers and this is discussed further in section 5.1.

Table 2-1: Summary of naturally detached *Posidonia australis* shoot collection activities for November 2023 to February 2024

Period		Beach surveys	Estimated survey hours	Shoots collected
2023	November	6	12	78
	December	4	8	57
2024	January	7	21	444
	February*	9	30	1681
	Total	**26**	**72**	**2260**

*Data to 23 February 2024 as this was the end of the monitoring period

Figure 2-1: Locations and number of beach surveys carried out at each location to collect naturally detached *Posidonia australis* shoots from November 2023 to February 2024.

2.3 *Posidonia australis* transplanting

Since the commencement of the restoration efforts, 15,358 *Posidonia australis* shoots have been transplanted at rehabilitation sites at Kurnell, of which 12,946 were translocated from the ferry wharf construction footprint and 2412 were naturally detached shoots collected from Botany Bay (Table 2-2). Six rehabilitation sites were restored using translocated *Posidonia australis* in June-July 2023. Restoration using naturally detached shoots began in late July and has subsequently occurred at four of the six rehabilitation sites that were restored during the translocation stage (Table 2-2).

Restoration of a seventh site at Kurnell, Scar D, using naturally detached *Posidonia australis* shoots began in early February 2024 (Table 2-2, Figure 3-1). Commencement of restoration at this site was driven by a consistent abundant supply of naturally detached *Posidonia australis* shoots in early 2024 (refer to section 2.2). Scar D is unique among the rehabilitation sites as this site will be restored using naturally detached shoots only.

Between November 2023 and February 2024, restoration using naturally detached *Posidonia australis* shoots occurred at three rehabilitation sites at Kurnell: Scar D, Scar B and Scar C (Table 2-2). These efforts achieved the replanting of >2000 naturally detached *Posidonia australis* shoots, improving 47 m^2 of degraded seagrass habitat at Kurnell. Restoration during this period was concentrated at the new rehabilitation site Scar D where the majority (1968) of collected naturally detached *Posidonia australis* shoots were transplanted in two areas located in the shallow portion of the site that together totaled about 44 m^2 (Table 2-2). Monitoring of the restored areas was carried out in late February 2024 to provide baseline data for Scar D.

The scale of restoration at Scar B and Scar C during this period was minor in comparison to Scar D (Table 2-2). Transplanting of naturally detached shoots at these sites restored small bare patches (about 1-2 m^2) identified during recent work.

Further details about the area restored at the 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 shoot density estimated from area restored (refer to Table 4-3). All shoots reported for the August 2023 time point (except Scar F) were translocated from the Kurnell ferry wharf construction footprint. Scar F total for the initial time point includes 70 naturally detached shoots. Subsequent times used naturally detached shoots only.

	Shoots transplanted (shoot density per m^2)		
Shoot type:	Translocated	Naturally detached	
Site	Aug 2023	Oct 2023	Feb 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)
Total	**13,016**	**270**	**2072**

3. Monitoring methods

3.1 Location and timing of monitoring

Surveys were carried out at seven rehabilitation sites that were restored using translocated and naturally detached *Posidonia australis* shoots. 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 metres 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.

Monitoring was carried out over five days in February 2024, about six months since completion of the *Posidonia australis* translocation stage. Monitoring was carried out by experienced marine ecologists from UNSW using SCUBA. An overview 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, 2024
Round 2	February 2024	This report

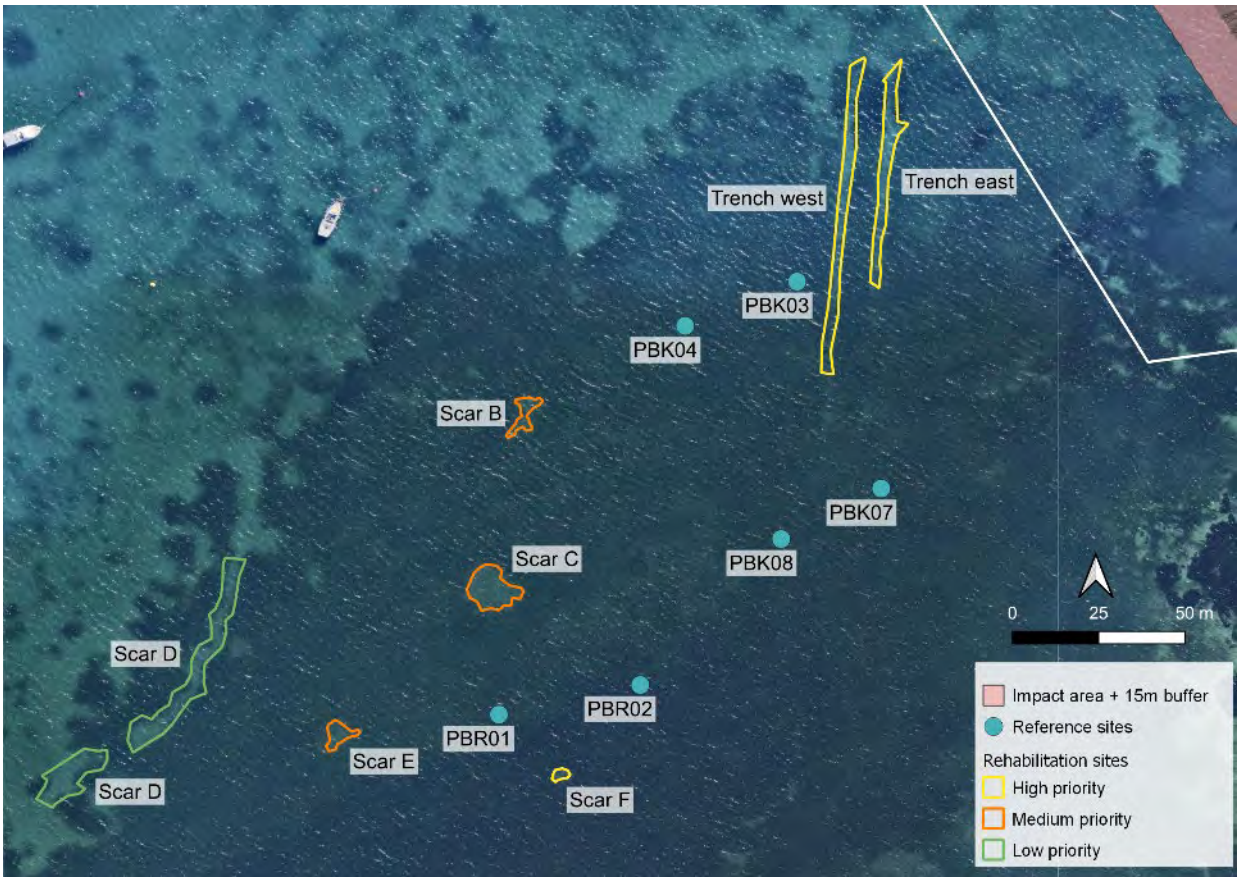

Figure 3-1: Overview of the survey area at Kurnell (Gamay Botany Bay)

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 metre x 0.5 metre). 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.

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

Restoration using naturally detached *Posidonia australis* during the period November 2023 to February 2024 (post the previous monitoring event) occurred at two existing rehabilitation sites, Scar B and Scar C, and a new rehabilitation site, Scar D (Figure 3-1). The scale of restoration at Scar D was substantially larger than the other two sites: almost 2000 *Posidonia australis* shoots were transplanted in Scar D compared to <60 at each of Scar B and Scar C (Table 2-2).

Water visibility at Kurnell was poor (about 3 m) at the time of monitoring in February 2024 and this prevented GPS-based mapping methods being used. Due to this limitation, and because restoration during this period was concentrated at Scar D, in-situ mapping was carried out at Scar D only. The mapping exercise to record the extent of the restored area of Scar D was limited to recording in-situ measurements and translating these to create approximated maps. This involved divers installing metal reinforcing bars around the perimeter of the restored areas within the site. Transect tapes were then placed around the marked-out perimeters and divers recorded measurements from the transect tapes in-situ. The position and distance of the planted areas relative to seascape features were also noted to enable maps to be produced.

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 the rehabilitation and reference sites and among sites were tested statistically using univariate permutational multivariate analysis of variance (PERMANOVA; Anderson, 2001). The two-factor PERMANOVA treated site type (reference or rehabilitation) 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 with permutations 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 at the 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. Models used poisson distribution, or where tests indicated there was overdispersion in the data 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. Rehabilitation site Scar D was excluded from GLM analysis as restoration commenced at this site in February 2024. 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 4.3.2 (R Core Team, 2023).

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 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 restored with *Posidonia australis*. Polygons depicting the restored areas of the seven rehabilitation sites were overlaid on high-resolution Nearmap imagery of the area captured in September 2023 and maps of the sites were produced for visual interpretation.

The new areas that had been restored with *Posidonia australis* since the previous monitoring event (round 1, October 2023) were quantified for the rehabilitation sites and the total area for each site and overall restored area 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 200 m west of the seagrass 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 85 m 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 31 January 2024 (180 days). A time series plot of the water temperature data was produced. Sea surface current and temperature 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 and sea surface temperature 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

A summary of the overall mean values for *Posidonia australis* shoot density, leaf length and epiphyte cover for the rehabilitation and reference sites captured during the round 2 monitoring event is provided in Table 4-1. Scar D data is presented separately as restoration using naturally detached *Posidonia australis* at this site commenced just prior to the monitoring event in February 2024. 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. Photos captured in rehabilitation and reference sites are presented in Figure 4-4.

The overall mean shoot density of restored *Posidonia australis* across the six rehabilitation sites (excluding Scar D) was 46 shoots per m^2 (Table 4-1) with a range among sites of 43-48 shoots per m^2 (Figure 4-1a). The density of recently transplanted naturally detached *Posidonia australis* shoots at Scar D was 33 shoots per m^2. Shoot densities at reference sites were considerably greater (p=0.002, pseudo-F=151.8; Appendix B, Table B-1) than rehabilitation sites with an overall mean of 136 shoots per m^2 and a range of 114-163 shoots per m^2. Shoot densities also varied among sites within the two site types (p=0.002, pseudo-F=3.38; Table B-1). Among rehabilitation sites, shoot densities at Scar D were lower than most sites (Table B-2). When comparing reference sites, *Posidonia australis* shoot densities at PBR01 and PBR02 were generally greater than other sites (Table B-2).

Maximum leaf lengths of *Posidonia australis* in the six rehabilitation sites (excluding Scar D) were 33 cm on average and varied from 28-37 cm, while Scar D was 25 cm on average (Table 4-1, Figure 4-1b). Reference site maximum leaf lengths were 44 cm on average and ranged from 41-52 cm *Posidonia australis* leaf lengths were greater in reference sites than rehabilitation sites (p=0.001, pseudo-F=24.03; Table B-3), and there was also significant variation among sites within site types (p=0.001, pseudo-F=5.54, Table B-3). Variation among rehabilitation sites was mostly driven by Scar D which had maximum leaf lengths shorter than all other rehabilitation sites except for Scar F (Table B-4). Among reference sites, site PBK03 had leaf lengths greater than most other sites (Table B-4).

Epiphyte cover of *Posidonia australis* varied significantly between site types (Table 4-1; p=0.017, pseudo-F=9.54; Table B-5), being lower in rehabilitation than reference sites. Statistical differences in epiphyte cover also occurred among sites (p=0.001, pseudo-F=4.04; Table B-5). When comparing epiphyte cover among rehabilitation sites, variation was mostly due to higher epiphyte cover of shoots at Scar E relative to other sites (Table B-6). Among reference sites, a pattern emerged of lower epiphyte cover at the two sites located furthest from shore, PBK03 and PBK04, compared to the four other 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 2 monitoring event (February 2024).

Site type (number of sites)	Shoot density (m^{-2})	Leaf length (cm)	Epiphyte cover (1-5 scale)
Rehabilitation (6)	46 (±2.0)	33 (±0.8)	2.9 (±0.1)
Scar D	33 (±3.2)	25 (±1.4)	2.9 (±0.3)
Reference (6)	136 (±4.3)	44 (±1.0)	3.7 (±0.1)

Considering restored *Posidonia australis* shoot densities at the rehabilitation sites (excluding Scar C) through time, three of six sites, Scar C, Scar F and Trench West have shown little variation in shoot densities (p=>0.05, Table B-7) and these sites have consistently exceeded the long-term (ten-year) shoot density success criteria of 42 shoots per m^2 (Figure 4-2a).

Significant changes in shoot densities through time occurred at the other three rehabilitation sites: Scar B, Scar E, and Trench East (p=<0.001, <0.001 and 0.026, respectively, Table B-7). At Scar B and Scar E, measured shoot densities were highest in the initial surveys carried out in August 2023 immediately after the translocation stage (Figure 4-2a, Table B-9). In more recent monitoring surveys, shoot densities at these two sites appear stable and remain close to or above the long-term shoot density success criteria.

At Trench East, the increase in restored *Posidonia australis* shoot density from 32 to 47 shoots per m^2 between October 2023 and February 2024 was significant (p=0.012, Table B-9, Figure 4-2a). The increase in shoot density at this site cannot be explained by supplementary transplanting of naturally detached *Posidonia australis* shoots in preceding months. A more likely explanation is that shoots were not transplanted at a uniform density across all sections of this site, and the random placing of survey quadrats leads to uneven sampling of areas of fewer or greater shoots during monitoring.

The mean density of naturally detached *Posidonia australis* shoots transplanted at Scar D measured during the February 2024 monitoring surveys (33 shoots per m^2) exceeds the mid-term (six-year) shoot density success criteria of 32 shoots per m^2 (Figure 4-2a).

Posidonia australis shoot densities showed some variation with time at reference sites PBK03, PBK04 and PBK07 and were highest (>100 shoots per m^2) in February 2024 (Figure 4-2b). In comparison, shoot densities at sites PBK08, PBR01 and PBR02 were less variable and shoot densities were consistently >100 shoots per m^2.

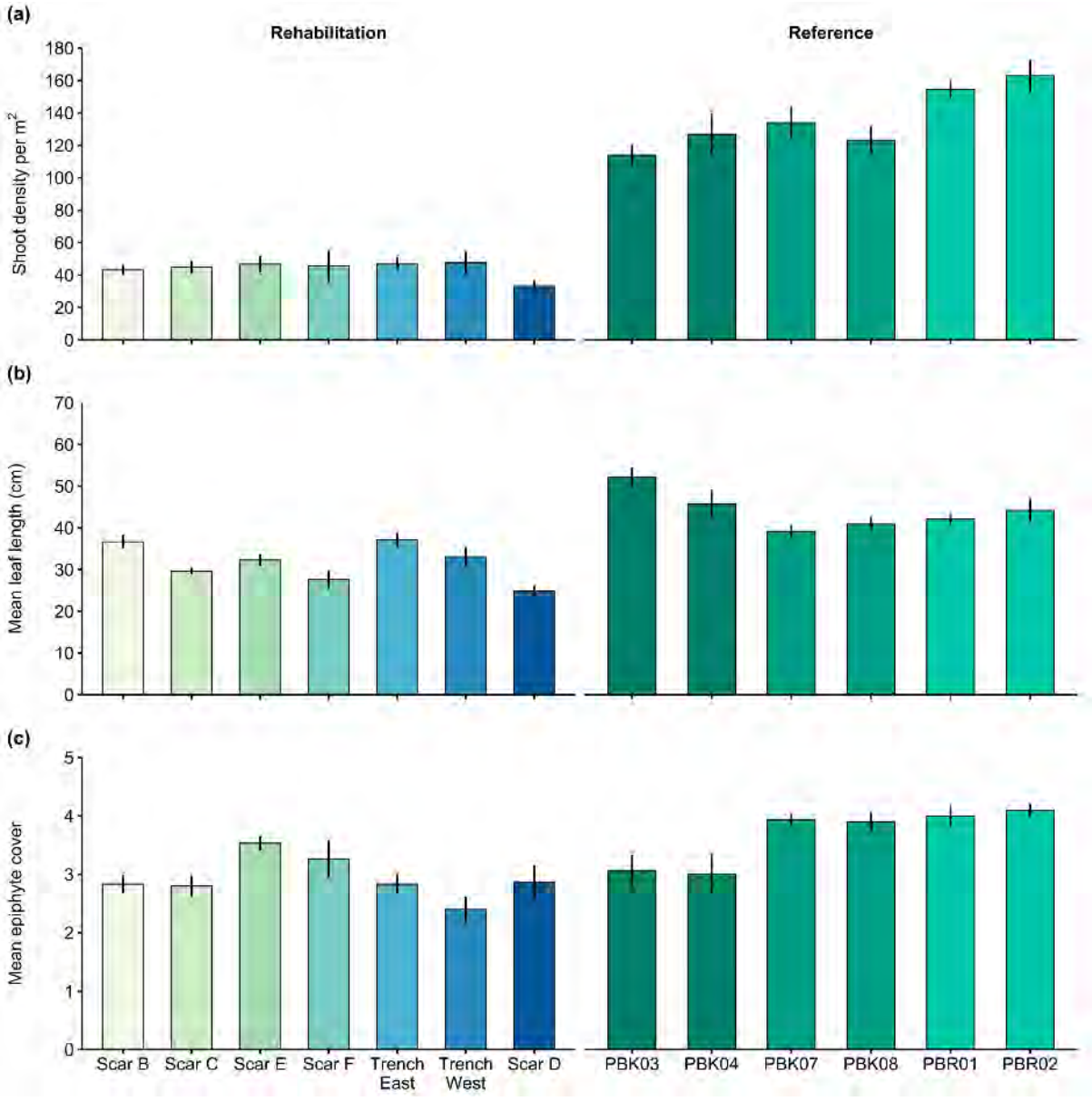

Figure 4-1: *Posidonia australis* characteristics at seven rehabilitation and six reference sites at Kurnell captured during the round 2 monitoring event in February 2024: (a) shoot density, (b) leaf length and (c) epiphyte cover.
Error bars indicate standard error of the mean.

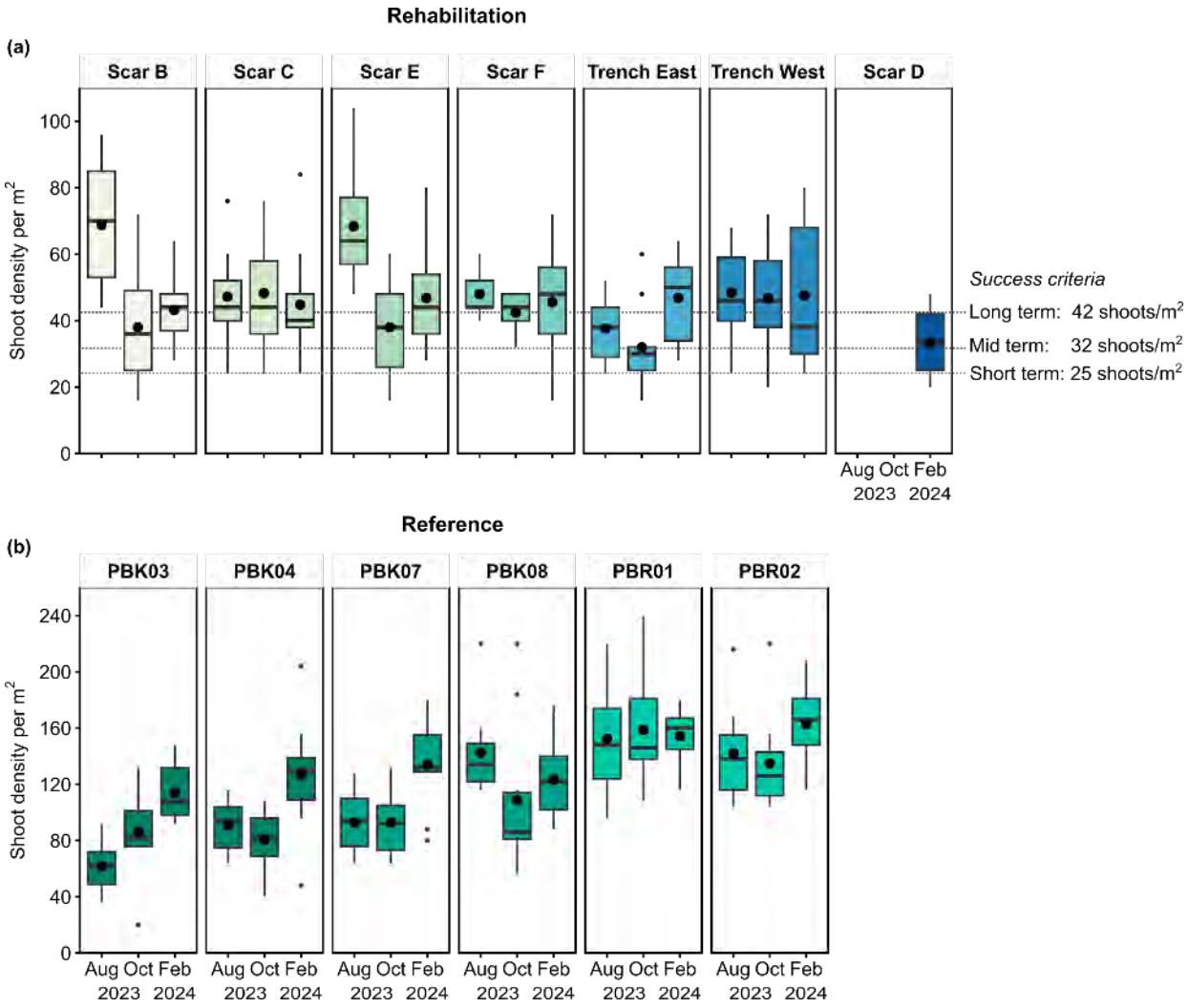

Figure 4-2: Shoot density through time at the (a) seven rehabilitation sites in relation to the success criteria and (b) six reference sites.
Each time point represents a monitoring event. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* commenced in early February 2024. The box-whisker represents the median (line), interquartile range (box), range (whiskers) and outliers (dots). Means are represented by large black circles. Note that scales for shoot density differ for rehabilitation (a) and reference (b) site plots.

4.2 Benthic cover in rehabilitation and reference sites

The overall mean values for total seagrass and benthic type cover for the rehabilitation and reference sites captured during the round 2 monitoring event are presented in Table 4-2. Scar D data is shown separately as restoration commenced at this site just prior to the monitoring event in February 2024. 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 were identified from the photoquadrats captured during the round 2 monitoring surveys: *Posidonia australis*, *Zostera sp*. and *Halophila sp*. Rehabilitation sites (excluding Scar D) had a lower proportion of seagrass cover compared to reference sites (62% vs 83%, Table 4-2). Total seagrass cover was generally similar among rehabilitation sites with a range of 57-66%, Scar D being the exception with 44% cover overall (Figure 4-3a, Appendix A, Table A-4). Reference sites had a minimum of 68% total seagrass cover and two of six sites had cover ≥ 90%.

When considering temporal patterns of total seagrass cover, the mean cover across the six rehabilitation sites was stable over the period October 2023 to February 2024, varying by <1% (Appendix A, Table A-4). Variation in total seagrass cover at individual sites was up to about 12% and this included both increases (e.g. Scar E) and reductions (e.g. Trench East) over the period (Figure 4-3a, Table A-4). Reductions in total seagrass cover were apparent at all six reference sites with the largest (>10%) recorded at the two sites located in deeper water further from shore, PBK03 and PBK04.

Benthic compositions quantified from the February 2024 monitoring surveys differed between rehabilitation and reference sites (p=0.001, pseudo-F=34.8; Table B-10). SIMPER analysis revealed that there was relatively low dissimilarity (28%) in benthic composition between site types. Differences in proportional cover of *Posidonia australis* and *Halophila sp*. contributed most to the dissimilarity (Appendix B, Table B-11). *Posidonia australis* cover in rehabilitation sites was less than half that of reference sites, on average (Table 4-2, Figure 4-3b). On the other hand, rehabilitation sites had almost an order of magnitude greater cover of *Halophila sp.* relative to reference sites.

Posidonia australis cover showed almost no variation (<1%) through time at rehabilitation sites (Table A-5). However, a pattern emerged for the other seagrasses, with cover of *Zostera sp*. decreasing and cover of *Halophila sp*. increasing at most rehabilitation sites between October 2023 and February 2024 (Figure 4-3b, Table A-5). This represented a shift in the dominant understorey seagrass at two sites, Trench East and Trench West. Cover of *Zostera sp*. also decreased at all but one reference site over the same period, but unlike the rehabilitation sites there was no corresponding increase in *Halophila sp*. at reference sites (Figure 4-3b, Table A-5).

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

	Percentage cover				
Site type (number of sites)	Total seagrass	*Posidonia australis*	*Zostera sp.*	*Halophila sp.*	Sand
Rehabilitation (6)	61.7	30.2	11.8	19.8	38.3
Scar D	44.0	16.7	1.0	26.3	56.0
Reference (6)	83.3	72.9	8.3	2.2	16.7

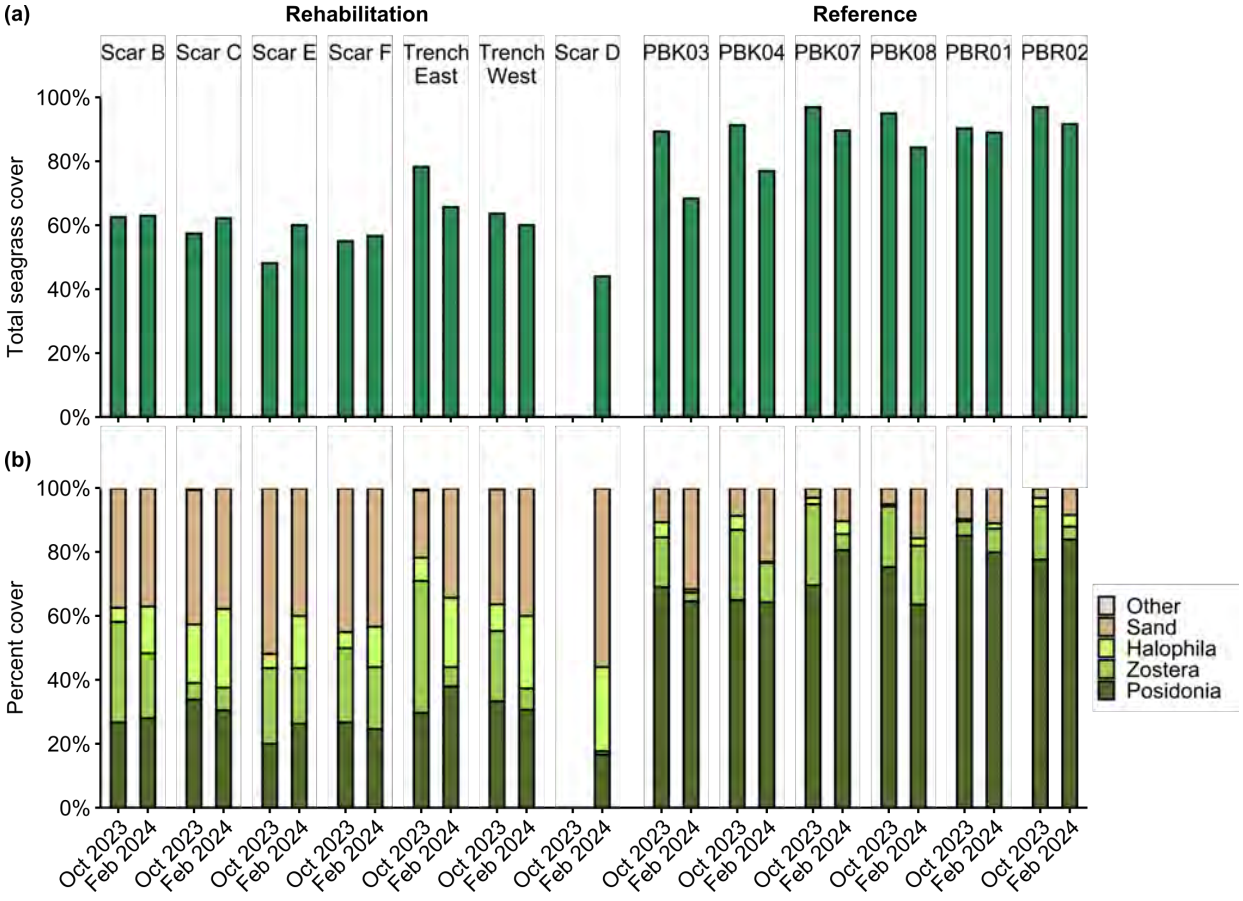

Figure 4-3: Comparison of (a) total seagrass cover and (b) benthic composition at the seven rehabilitation and six reference sites at Kurnell through time.
Each time point represents a monitoring event; monitoring of benthic cover commenced in monitoring round 1 in October 2023. Restoration at rehabilitation site Scar D using naturally detached *Posidonia australis* commenced in early February 2024.

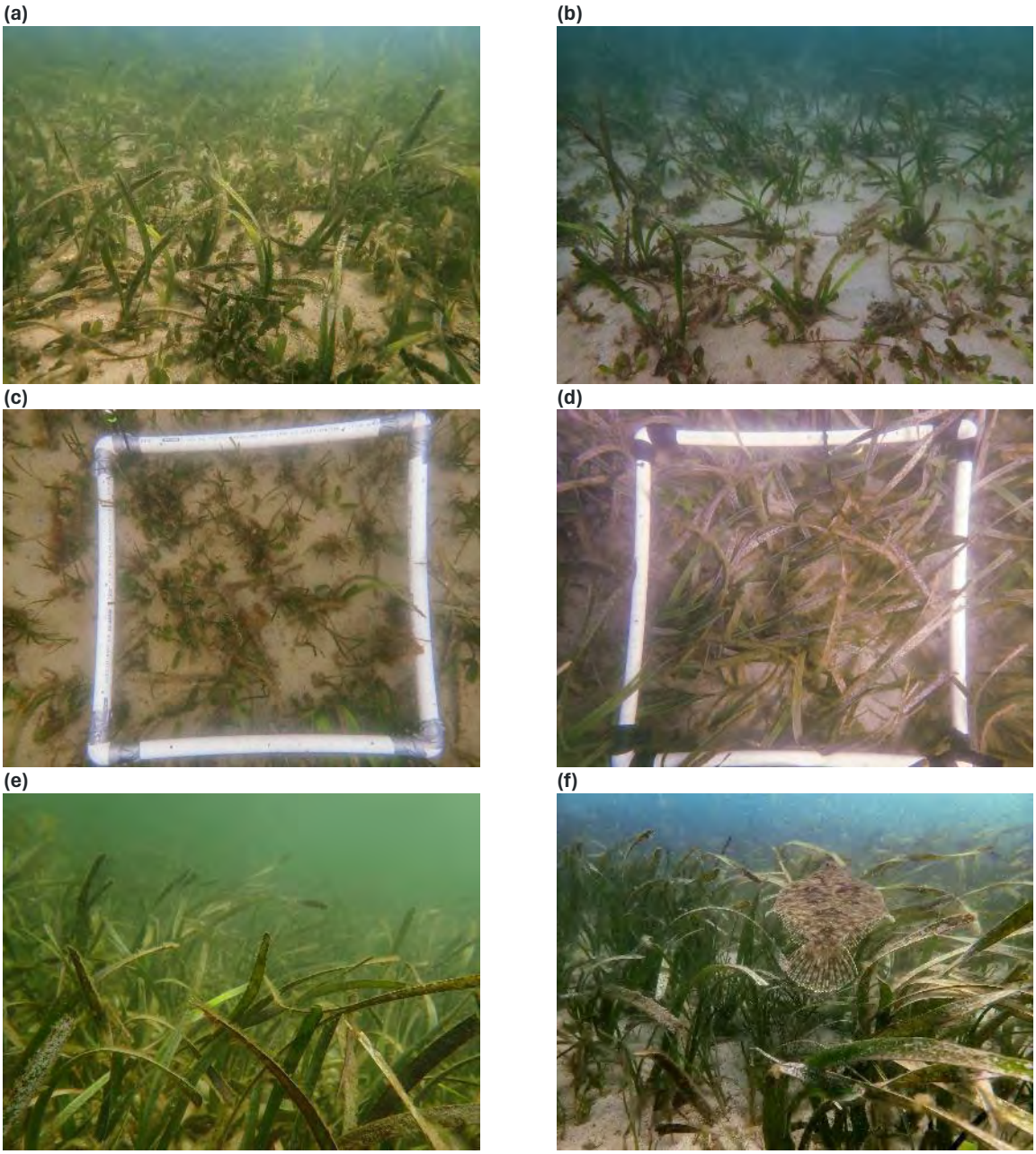

Figure 4-4: Photos of *Posidonia australis* at rehabilitation and reference sites at Kurnell.
Photos showing (a) abundance of *Halophila sp.* among restored *Posidonia australis* in Scar C, (b) jute mats no longer visible in restored area of Scar F, (c) survey quadrat in Scar B, (d) survey quadrat in reference site PBR01, (e) dense cover of *Posidonia australis* at reference site PBK07 and (f) a flounder swims through *Posidonia australis* at reference site PBK04.

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

The total area of restored *Posidonia australis* quantified from the February 2024 monitoring was 366 m^2. This comprises 309 m^2 of restored area across six rehabilitation sites that was restored using *Posidonia australis* translocated from the Kurnell ferry wharf construction footprint. Since completion of this stage in early July 2023, an additional 57 m^2 has been restored by transplanting naturally detached *Posidonia australis* shoots collected from Botany Bay (Table 4-3, Figure 4-5). Restoration during this stage has occurred at four of six sites that were restored during the translocation stage and one new rehabilitation site, Scar D. Two rehabilitation sites remain unchanged to date.

Restoration during the period November 2023 to February 2024 was carried out at three rehabilitation sites, increasing the restored area by 47 m^2 through transplanting 2072 naturally detached *Posidonia australis* shoots (Table 4-3). The major source of increase in restored area was achieved by commencing restoration of rehabilitation site Scar D; 44 m^2 of degraded habitat was

restored at this site (Table 4-3). Small bare areas within rehabilitation sites Scar B and Scar C were also restored with naturally detached shoots, resulting in minor increases in the restored area at these sites (2 m^2 and 1 m^2, respectively). From the monitoring surveys, there were no observed 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 4-5.

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 are the area restored and number of naturally detached *Posidonia australis* shoots transplanted, 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	
Scar B	48	50 (83)	52 (45)	+2
Scar C	152	152	153 (59)	+1
Scar E	38	42 (132)	42	-
Scar F	10 (70)	12 (55)	12	-
Trench East	28	28	28	-
Trench West	35	35	35	-
Scar D	-	-	44 (1968)	+44
Total	**311 (70)**	**319 (270)**	**366 (2072)**	**+47**

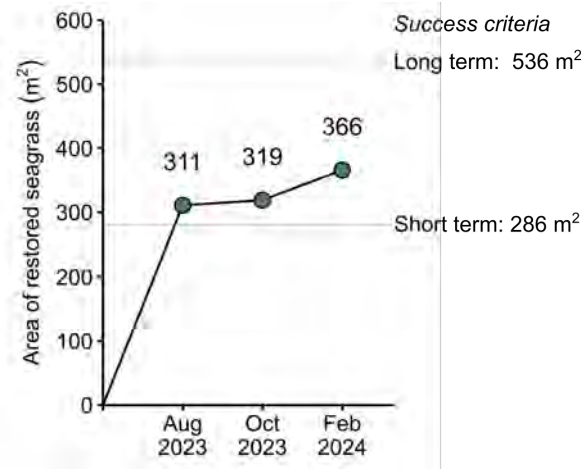

Figure 4-5: Time series of change in total area of restored *Posidonia australis* at rehabilitation sites at Kurnell in relation to the success criteria.
Each time point represents a monitoring event. The major increase in restored area occurred during the *Posidonia australis* translocation stage. All area restored after August 2023 was achieved by transplanting naturally detached *Posidonia australis*.

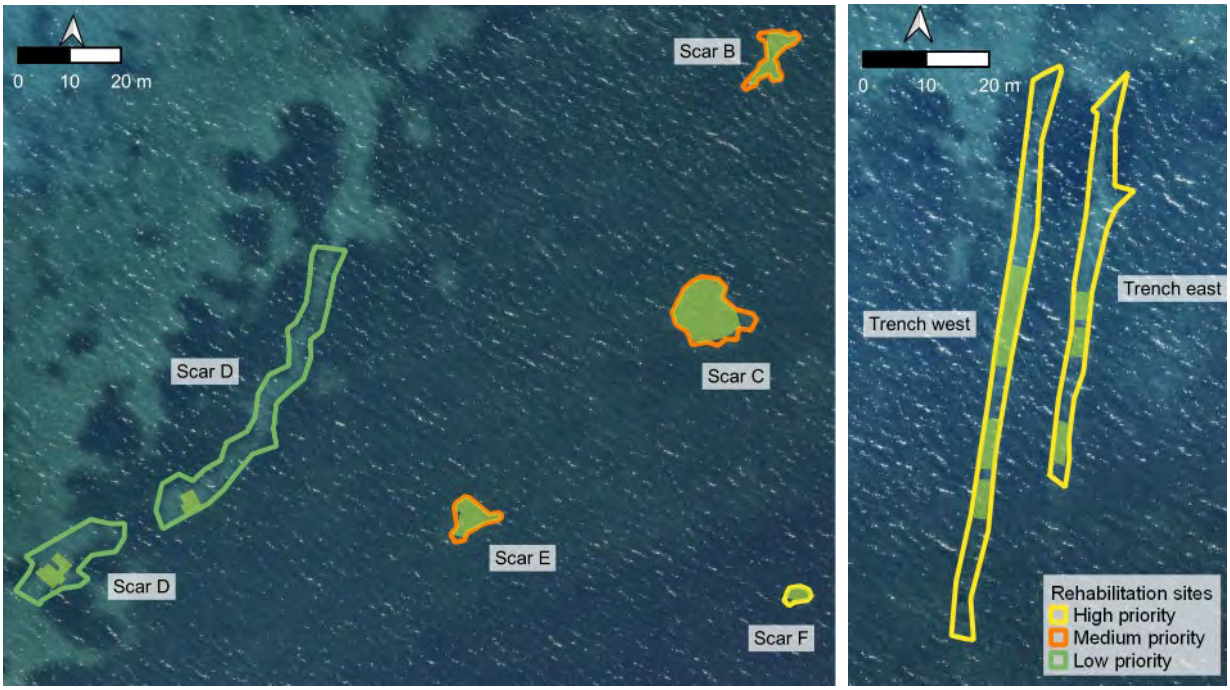

Figure 4-6: Map of Kurnell showing the approximate areas within the seven rehabilitation sites restored with *Posidonia australis*.

4.4 Botany Bay climate patterns

Monthly rainfall and air temperature data for the Sydney Airport AMO weather station (66037) sourced from BOM (BOM, 2024a; BOM, 2024b) indicated that local weather conditions during the period November 2023 to January 2024 tended to be wetter and warmer than the long term mean (Figure 4-6a, b). November and December 2023 saw a change from the longstanding dry conditions with 276 mm of rain falling over the two-month period – more than the previous five months of rainfall combined. The highest daily precipitation event of 2023 at Sydney Airport AMO occurred on 25 December when 94 mm of rain was recorded. Maximum air temperatures between November and January continued to be about 2°C warmer than the long-term mean.

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. Data recorded at the Kurnell AWS (66043) (BOM, 2024e) indicated that solar exposure levels continued on an upward trajectory and appeared to peak in December 2023 before falling slightly below the long-term mean in January 2024 (Figure 4-6c). Observations recorded at Sydney Airport AMO indicated there were greater instances of cloudy days in January compared to preceding months.

Wind data recorded at Kurnell AWS (BOM, 2023f) indicated that minimum and mean wind speeds remained at consistent levels over the period June 2023 to January 2024 (Figure 4-6d). The peak in maximum 9am wind speed in December reflects the unsettled and storm-affected conditions in Sydney's east during this month. Southerly wind gusts of >60 km/h were recorded at Kurnell AWS during these periods of unsettled weather which frequently persisted for several days. Winds were predominately from the south in December but showed no clear pattern in November or January.

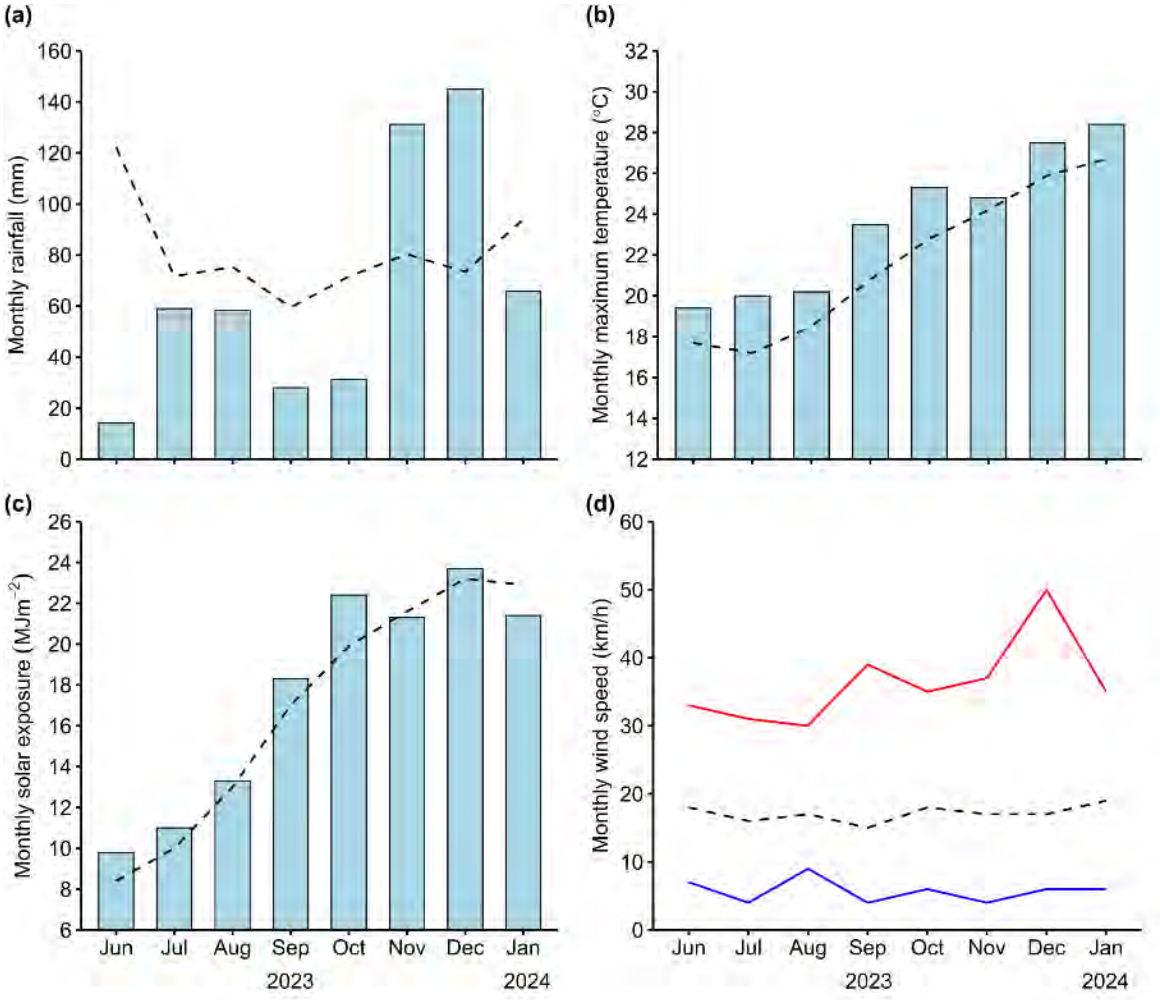

Figure 4-7: Monthly climate data for Botany Bay for June 2023 to January 2024: (a) total rainfall, (b) maximum air temperature, (c) mean solar exposure and (d) mean, minimum and maximum wind speed.
Dashed line in a, b and c indicates the long-term mean. Rainfall and air temperature records at Sydney 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 indicated that a gradual increase in maximum significant wave heights occurred between August 2023 and January 2024 (Figure 4-7). The proportion of days where maximum daily wave heights were below 1.5 metres was lower in the November to January period than the previous three-month period (28% vs 51%). However, the proportion of days with maximum daily wave heights over 2.5 m was consistent between periods, about 15% of days. These conditions are typical of Sydney's offshore waters in summer (Manly Hydraulics Laboratory, 2024).

Water temperature data obtained from the data logger installed at rehabilitation site Scar F showed there had been a gradual warming of about 5°C between August 2023 and January 2024 (Figure 4-8a). The mean water temperature for the first two months of summer (December 2023-January 2024) was 22.4°C and included six instances of daily maximums exceeding 25°C. In comparison, the mean temperature for the preceding season of spring (September-November 2023) was 19.4°C, representing a 3°C increase in temperature from spring to summer.

IMOS OceanCurrent (IMOS, 2024b) sea surface current and sea surface temperature maps of southern NSW show the East Australian Current as a tongue of warm surface water (25-26°C) flowing southwards just offshore from Sydney (Figure 4-8b, c). In mid-December and mid-January, the meandering East Australian Current appears to push warm water towards the coast, bringing warm water into inshore Sydney waters and resulting in some of the peak temperatures (≥25°C) recorded at Kurnell during the period November 2023 to January 2024.

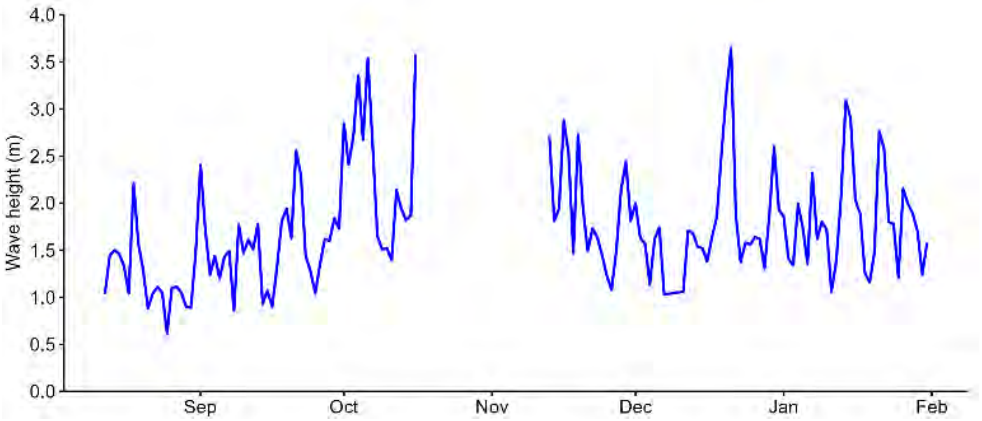

Figure 4-8: Daily maximum significant wave height recorded by the Sydney offshore waverider buoy (SYDDOW) between 12 August and 31 January 2024.
Data was unavailable for 17 October to 12 November 2023.

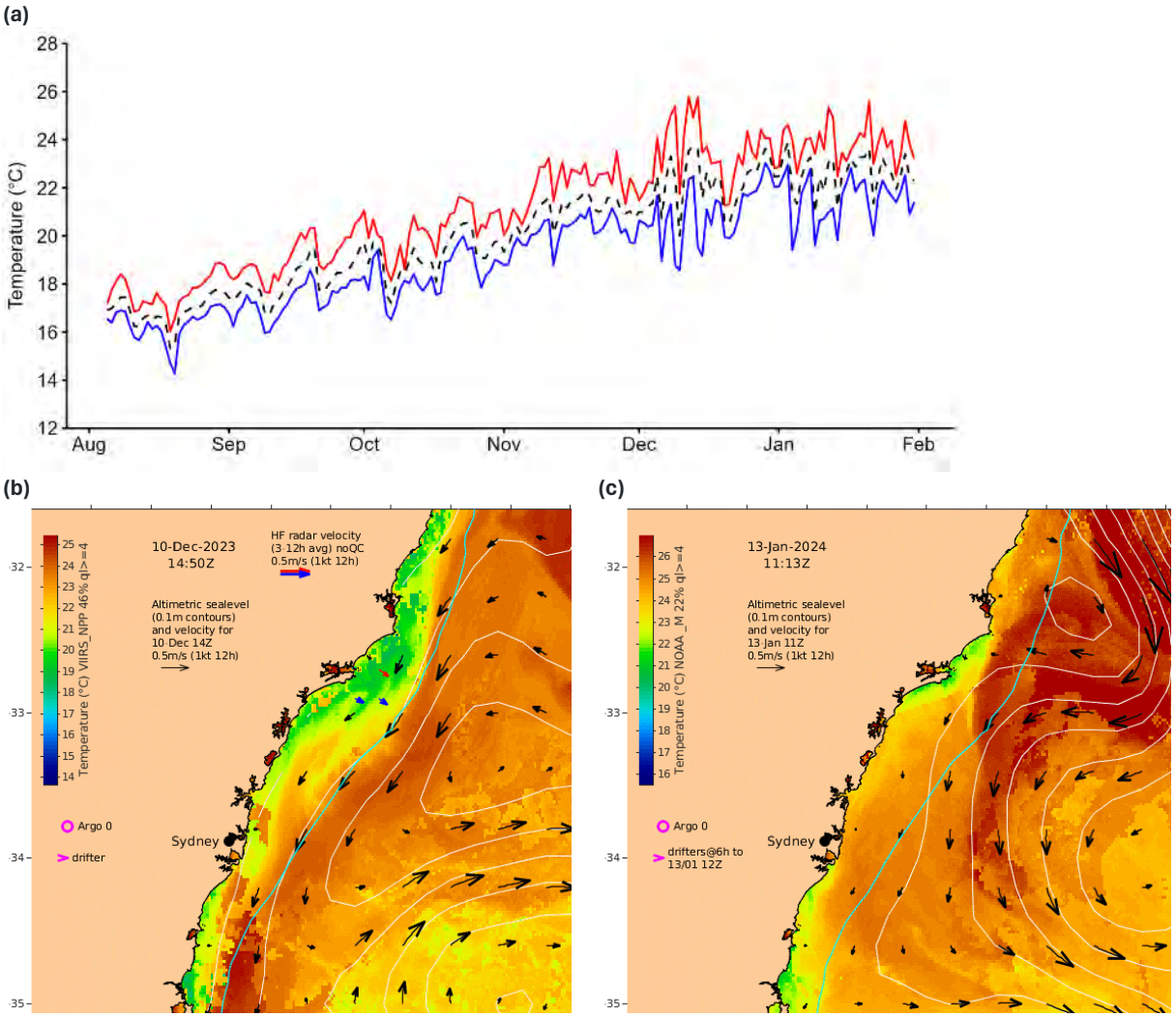

Figure 4-9: (a) Daily mean, maximum and minimum water temperature recorded between 5 August and 31January 2024 by a data logger installed at Scar F; (b) and (c) Sea surface temperature near the Sydney coast in December 2023 and January 2024. In (a) daily mean, maximum and minimum water temperature are indicated by dashed, red and blue lines respectively. Images (b) and (c) capture periods where the water temperature recorded at Kurnell was ≥25°C. Source: 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 three rehabilitation sites increased the area restored at Kurnell by 47 m^2 since the previous monitoring event in October 2023. The total area restored exceeds the short-term success criteria at this time point.
Long term (10-year) goal: 536 m^2	Minimum value:	268 m^2	366 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 meter (>50% of the impact area density).	*Posidonia australis* density at six out of seven rehabilitation sites exceeds the mean overall shoot density (42 shoots/m^2) of the *Posidonia australis* that was translocated from the Kurnell impact area. All seven sites exceed the short-term shoot density success criteria of 25 shoots/m^2.
Long term (10-year) goal: 42 shoots/m^2	Minimum value:	25 shoots/m^2	46 shoots/m^2 (range 33-48)* **Exceeds target**

*Mean overall shoot density excludes Scar D as restoration began at this site immediately prior to monitoring in February 2024.

Results from monitoring carried out in February 2024 indicate that the total area of restored *Posidonia australis* across the seven rehabilitation sites at Kurnell exceeds the short-term (two-year) success criteria for the offset strategy (Table 5-1). Restoration of degraded areas in rehabilitation sites using naturally detached *Posidonia australis* shoots achieved an overall restored area of 366 m^2, an increase of 47 m^2 in the period since the previous monitoring event. The areal extent of restored *Posidonia australis* habitat reported here exceeds the short-term success criteria target of 268 m^2 by 98 m^2. An additional 170 m^2 of restored *Posidonia australis* habitat area is required to achieve the long-term (ten-year) goal.

Achieving the long-term goal for restored area of *Posidonia australis* relies on consistent supply of naturally detached shoots that are viable for transplanting in rehabilitation sites. Considerable progress towards this goal during the reporting period was assisted by the abundance of naturally detached *Posidonia australis* shoots sourced from Botany Bay, in particular Kurnell. Several factors are likely to have contributed to the substantial number of shoots collected over the four-month period. From early January 2024, most of the beach surveys carried out at Kurnell included significant effort to search targeted shallow water areas adjacent to the shoreline that have been identified as locations where shoots tend to accumulate. Conditions were particularly favourable for naturally detached shoots accumulating in Botany Bay on multiple occasions over this period, including consecutive days with gusty northerly or southerly winds. Beach surveys were planned around these events to maximise opportunities for finding shoots. Together, these strategies led to beach surveys frequently yielding >100 naturally detached *Posidonia australis* shoots.

The abundant supply of naturally detached *Posidonia australis* shoots allowed restoration of a seventh rehabilitation site at Kurnell, Scar D, to commence in February 2024. This rehabilitation site was previously assessed as being lower priority for restoration due to its position near the edge of the main seagrass meadow, relatively narrow buffer of *Posidonia australis* to the west and depth of some sections of the site (UNSW, 2023c). Nevertheless, the presence of *Posidonia australis* surrounding the site and sparse cover of *Halophila sp.* within the site suggests that conditions are suitable for assisted recovery of *Posidonia australis* at this location. Additionally, Scar D's substantial size (about 470 m^2) allows for selective restoration of the most suitable areas within the site. Selection of the initial sections of Scar D for restoration considered these factors and the areas were chosen based on their shallower depth and size of the surrounding area of *Posidonia australis* meadow.

Scar D is the first rehabilitation site to be restored for the project using naturally detached *Posidonia australis* shoots only; all other rehabilitation sites received *Posidonia australis* translocated from the Kurnell wharf construction footprint. Restoration of Scar D provides opportunities to monitor and gain knowledge about the long-term success or otherwise of restoring degraded habitat areas in Botany Bay using naturally detached vs translocated *Posidonia australis*. This information is important for guiding decision-making around factors such as techniques, resource requirements and feasibility for restoring *Posidonia australis* locally and in other NSW estuaries where endangered populations occur.

Mean shoot densities of *Posidonia australis* exceed the long-term goal (42 shoots per m^2) at all rehabilitation sites except for Scar D, which exceeds the mid-term (six-year) goal of 32 shoots per m^2. The lower mean shoot density at Scar D can likely be attributed to the restoration method used, that is, transplanting naturally detached *Posidonia australis* shoots only and without using jute mats. This is because naturally detached *Posidonia australis* fragments tend to vary widely in shoot numbers and this decreases the likelihood that all areas are accurately planted at a fixed density. The lack of fixed planting structure provided by jute mats also tends to lead to some areas being restored less densely. Supplementary transplanting of *Posidonia australis* in this rehabilitation site may be initiated in future if ongoing monitoring indicates this action is needed.

Posidonia australis shoot densities in rehabilitation sites appear to have been stable over the past three months, with no significant change in shoot densities occurring between monitoring periods 1 and 2 at five of six sites. Furthermore, restored *Posidonia australis* shoot densities at three sites remain above the long-term goal, six months after completion of the translocation stage. It is not clear whether the apparent declines in restored *Posidonia australis* shoot densities at rehabilitation sites Scar B and Scar E over the initial three months following translocation were an artefact of monitoring survey sampling design or significant mortality. Notwithstanding, early indications from restoration monitoring carried out to date are positive and suggest generally high rates of survival of *Posidonia australis* translocated from the Kurnell ferry wharf construction footprint to rehabilitation sites.

5.2 *Posidonia australis* condition and seagrass composition

The condition (maximum leaf length and epiphyte cover) of restored *Posidonia australis* in rehabilitation sites has remained reasonably stable with time (Appendix A, Table A-2, 3). Maximum leaf lengths have varied by as little as about 10% overall on average over the six months since the translocation stage. Maximum leaf lengths of restored *Posidonia australis* are about 30% shorter than the surrounding natural meadow. Long-term monitoring of leaf lengths across seasons of the year aims to provide an indication of leaf growth rates of translocated *Posidonia australis*. Shorter *Posidonia australis* leaf lengths at Scar D relative to other rehabilitation sites is symptomatic of restoration using naturally detached shoots. The potential for *Posidonia australis* fragments to detach from meadows is expected to be greater for meadows located in areas of greater exposure to wind and wave action. In Botany Bay, leaves of *Posidonia australis* in more exposed meadows tend to be shorter, possibly as an adaptive response to their environment (Larkham, 1976). *Posidonia australis* leaves may also become damaged by wind and wave action once detached from meadows and deposited on shorelines.

Posidonia australis in rehabilitation and reference sites showed a pattern of gradually increasing epiphyte cover with time (Appendix A, Table A-3). The abundance of epiphytes can vary with leaf age and season, increasing as *Posidonia australis* leaves mature and in spring and summer (Trautman and Borowitzka, 1999). The observed increase in epiphyte cover with time may also be driven by the epiphytic algae bloom that was present throughout the seagrass meadow at Kurnell for several months in spring and summer 2023. Despite the moderate epiphyte cover, the bioindicators monitored (density, leaf length) provide no suggestion of a negative impact of epiphytes on the condition of *Posidonia australis* in restored and natural sites at Kurnell. This corresponds with recent research which found no negative association between epiphyte cover and survival of transplanted *Posidonia australis* (Ferretto et al., 2023).

Dissimilarities in benthic composition between rehabilitation and reference sites are driven by differences in densities of both *Posidonia australis* and understorey seagrass species. Natural meadow sites at Kurnell are dominated by *Posidonia australis* which is sometimes interspersed with *Zostera sp.* and *Halophila sp*. In contrast, rehabilitation sites are characterised by proportionally lower cover of *Posidonia australis* (30% vs 73%), providing space for opportunistic seagrass species to occupy. A shift in benthic composition occurred at rehabilitation sites in the three months since the previous monitoring event, with

Halophila sp. replacing *Zostera sp*. as the dominant understorey seagrass species at some sites. Future monitoring will identify if this composition shift remains permanent or if changes in species abundances frequently occur.

5.3 Environmental conditions and general observations during monitoring

Botany Bay climate conditions during late spring and early summer were mostly consistent with trends observed over preceding months - above-average air temperature and solar exposure. This is consistent with global trends with reports indicating that the global mean air temperature for the year February 2023 to January 2024 was the highest on record (BOM, 2024c). Climate models indicate that although the current El Niño appears to be weakening, the outlook for the Sydney region for March to May includes a very high likelihood of above-median maximum and minimum air temperatures and low likelihood of above-median rainfall (BOM, 2024d).

After a continuing pattern of dry conditions over many months, rainfall exceeded the long-term mean in November and December 2023. Sydney's east experienced several severe thunderstorm events characterised by damaging winds, heavy rain and localised flash flooding over this two-month period. Monitoring carried out under the NSW Government Beachwatch program (Beachwatch, 2024) indicated there were temporary declines in water quality at Kurnell following some of these heavy rainfall events. Despite the potential for nutrient-generating pollution entering Botany Bay as a result of these events, the epiphytic algae bloom that had been present across the seagrass meadow at Kurnell since winter 2023 had cleared by February 2024.

Burial of *Posidonia australis* leaves was observed at some rehabilitation and reference sites during the monitoring surveys, suggestive of sediment movement generated by wind and wave action during storm activity in recent months. Nevertheless, monitoring of reference sites provided no evidence of deterioration in density or condition of the *Posidonia australis* meadow at Kurnell.

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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. Note the February 2024 mean overall value for rehabilitation sites excludes Scar D because restoration at this site commenced just prior to the monitoring event.

		Shoot density (per m^2)		
Site	Site type	Aug 2023	Oct 2023	Feb 2024
Overall	Rehabilitation	53.0 (±2.3)	41.0 (±2.0)	45.7 (±2.0)
Overall	Reference	114.0 (±5.6)	110.0 (±5.7)	135.9 (±4.3)
Scar B	Rehabilitation	68.8 (±5.8)	38.0 (±5.6)	43.2 (±3.2)
Scar C	Rehabilitation	47.2 (±3.2)	48.3 (±4.1)	44.8 (±3.8)
Scar E	Rehabilitation	68.4 (±5.2)	38.0 (±4.9)	46.8 (±4.8)
Scar F	Rehabilitation	48.0 (±3.6)	42.4 (±3.0)	45.6 (±9.4)
Trench East	Rehabilitation	37.6 (±3.0)	32.0 (±4.1)	46.8 (±4.2)
Trench West	Rehabilitation	48.4 (±4.6)	46.8 (±4.8)	47.6 (±6.8)
Scar D	Rehabilitation	-	-	33.2 (±3.2)
PBK03	Reference	61.6 (±5.4)	86.4 (±9.8)	114.0 (±6.4)
PBK04	Reference	90.8 (±5.8)	80.8 (±6.4)	126.8 (±12.8)
PBK07	Reference	92.8 (±6.8)	92.8 (±7.6)	134.0 (±10.0)
PBK08	Reference	142.4 (±9.7)	108.8 (±16.7)	123.2 (±8.5)
PBR01	Reference	152.4 (±12.6)	158.8 (±12.6)	154.4 (±6.2)
PBR02	Reference	142.0 (±10.7)	134.8 (±11.1)	162.8 (±10.1)

Table A-2: Mean (± standard error) maximum *Posidonia australis* leaf length at rehabilitation and reference sites over the course of the monitoring program. Note the February 2024 mean overall value for rehabilitation sites excludes Scar D because restoration at this site commenced just prior to the monitoring event.

		Leaf length (cm)		
Site	Site type	Aug 2023	Oct 2023	Feb 2024
Overall	Rehabilitation	31.0 (±0.7)	34 (±0.5)	32.9 (±0.8)
Overall	Reference	35.0 (±0.7)	50 (±1.2)	44.1 (±1.0)
Scar B	Rehabilitation	38.2 (±1.4)	36.1 (±0.9)	36.7 (±1.6)
Scar C	Rehabilitation	29.6 (±0.9)	33.9 (±0.8)	29.7 (±0.8)
Scar E	Rehabilitation	30.8 (±1.0)	33.3 (±1.6)	32.3 (±1.4)
Scar F	Rehabilitation	23.1 (±1.4)	28.9 (±2.7)	27.6 (±2.2)
Trench East	Rehabilitation	28.0 (±1.3)	33.6 (±0.9)	37.2 (±1.7)
Trench West	Rehabilitation	32.8 (±1.0)	35.9 (±1.0)	33.1 (±2.3)
Scar D	Rehabilitation	-	-	24.8 (±1.4)
PBK03	Reference	33.6 (±1.8)	46.3 (±1.4)	52.3 (±2.3)
PBK04	Reference	36.3 (±1.7)	49.5 (±3.2)	45.8 (±3.4)
PBK07	Reference	35.2 (±2.0)	45.8 (±2.0)	39.2 (±1.5)
PBK08	Reference	35.6 (±1.5)	49.5 (±3.3)	40.9 (±1.7)
PBR01	Reference	31.5 (±0.9)	55.1 (±4.3)	42.1 (±1.4)
PBR02	Reference	38.2 (±1.4)	55.4 (±2.0)	44.2 (±2.7)

Table A-3: Mean (± standard error) *Posidonia australis* epiphyte cover at rehabilitation and reference sites over the course of the monitoring program. Note the February 2024 mean overall value for rehabilitation sites excludes Scar D because restoration at this site commenced just prior to the monitoring event.

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

Table A-4: Mean percentage total seagrass cover at rehabilitation and reference sites over the course of the monitoring program. Monitoring of benthic cover commenced in monitoring round 1 in October 2023. Note the February 2024 mean overall value for rehabilitation sites excludes Scar D because restoration at this site commenced just prior to the monitoring event.

Site	Site type	Oct 2023	Feb 2024
Overall	Rehabilitation	61.4	61.7
Overall	Reference	93.4	83.3
Scar B	Rehabilitation	62.6	63.0
Scar C	Rehabilitation	57.4	62.2
Scar E	Rehabilitation	48.1	60.0
Scar F	Rehabilitation	55.0	56.7
Trench East	Rehabilitation	78.3	65.7
Trench West	Rehabilitation	63.7	60.0
Scar D	Rehabilitation	-	44.0
PBK03	Reference	89.3	68.3
PBK04	Reference	91.3	77.0
PBK07	Reference	97.0	89.7
PBK08	Reference	95.0	84.3
PBR01	Reference	90.4	89.0
PBR02	Reference	97.0	91.7

Table A-5: Mean percentage cover of benthic categories at rehabilitation and reference sites over the course of the monitoring program. Monitoring of benthic cover commenced in monitoring round 1 in October 2023. . Note the February 2024 mean overall value for rehabilitation sites excludes Scar D because restoration at this site commenced just prior to the monitoring event.

		Posidonia		*Zostera*		*Halophila*		Sand	
Site	Site type	Oct 2023	Feb 2024	Oct 2023	Feb 2024	Oct 2023	Feb 2024	Oct 2023	Feb 2024
Overall	Rehabilitation	29.1	30.2	23.2	11.8	9.2	19.8	38.3	38.2
Overall	Reference	73.4	72.9	17.4	8.3	2.5	2.2	6.6	16.7
Scar B	Rehabilitation	26.7	28.0	31.5	20.3	4.4	14.7	37.4	37.0
Scar C	Rehabilitation	33.8	30.4	5.2	7.1	18.3	24.7	42.1	37.8
Scar E	Rehabilitation	20.0	26.3	23.7	17.3	4.4	16.3	51.9	40.0
Scar F	Rehabilitation	26.7	24.7	23.3	19.3	5.0	12.7	45.0	43.3
Trench East	Rehabilitation	29.7	38.0	41.3	6.0	7.3	21.7	21.0	34.3
Trench West	Rehabilitation	33.3	30.7	22.0	6.7	8.3	22.7	36.0	40.0
Scar D	Rehabilitation	-	16.7	-	1.0	-	26.3	-	56.0
PBK03	Reference	69.0	64.7	15.7	2.7	4.7	1.0	10.7	31.7
PBK04	Reference	65.0	64.3	22.0	12.3	4.3	0.3	8.7	23.0
PBK07	Reference	69.7	80.7	25.3	5.0	2.0	4.0	3.0	10.3
PBK08	Reference	75.3	63.7	19.0	18.3	0.7	2.3	5.0	15.7
PBR01	Reference	85.2	80.0	4.4	7.3	0.7	1.7	9.6	11.0
PBR02	Reference	77.7	84.0	16.7	4.0	2.7	3.7	3.0	8.3

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 2 monitoring event in February 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	2.6118E5	151.83	**0.002**
Site(Site type)	11	19413	3.384	**0.002**
Residuals	117	61018		
Total	129	3.5343E5		

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 C, Trench East	0.34701	0.783
Scar C, Trench West	0.38794	0.709
Scar C, Scar E	0.32809	0.796
Scar C, Scar F	9.4932E-2	0.951
Scar C, Scar B	0.29959	0.801
Scar C, Scar D	2.1698	**0.049**
Trench East, Trench West	0.10014	0.967
Trench East, Scar E	Negative	
Trench East, Scar F	0.1365	0.946
Trench East, Scar B	0.68426	0.542
Trench East, Scar D	2.5808	**0.030**
Trench West, Scar E	9.5709E-2	0.965
Trench West, Scar F	0.17063	0.885
Trench West, Scar B	0.58474	0.627
Trench West, Scar D	1.9122	0.088
Scar E, Scar F	0.12661	0.942
Scar E, Scar B	0.61991	0.575
Scar E, Scar D	2.3388	**0.026**
Scar F, Scar B	0.304	0.816
Scar F, Scar D	1.5684	0.154
Scar B, Scar D	2.2049	0.051
Reference sites		
PBK03, PBK04	0.89419	0.393
PBK03, PBR01	4.5529	**0.003**
PBK03, PBR02	4.0956	**0.003**
PBK03, PBK07	1.6823	0.135
PBK03, PBK08	0.86787	0.405
PBK04, PBR01	1.94	0.087
PBK04, PBR02	2.2088	**0.035**
PBK04, PBK07	0.4423	0.664
PBK04, PBK08	0.23432	0.842
PBR01, PBR02	0.71129	0.48
PBR01, PBK07	1.7314	0.103
PBR01, PBK08	2.9766	**0.009**
PBR02, PBK07	2.026	0.067
PBR02, PBK08	3.0098	**0.014**
PBK07, PBK08	0.82239	0.431

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 2 monitoring event in February 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	4808.5	24.032	**0.001**
Site(Site type)	11	2267.6	5.5418	**0.001**
Residuals	117	4352.3		
Total	129	11522		

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 C, Trench East	4.3747	**0.001**
Scar C, Trench West	1.6091	0.129
Scar C, Scar E	1.7113	0.1
Scar C, Scar F	1.1071	0.281
Scar C, Scar B	4.3143	**0.001**
Scar C, Scar D	3.1606	**0.01**
Trench East, Trench West	1.4089	0.195
Trench East, Scar E	2.1804	**0.044**
Trench East, Scar F	3.3339	**0.006**
Trench East, Scar B	0.20033	0.856
Trench East, Scar D	5.5507	**0.001**
Trench West, Scar E	0.29299	0.813
Trench West, Scar F	1.5041	0.147
Trench West, Scar B	1.2808	0.218
Trench West, Scar D	3.0367	**0.004**
Scar E, Scar F	1.8557	0.088
Scar E, Scar B	2.0627	0.063
Scar E, Scar D	3.7052	**0.001**
Scar F, Scar B	3.3594	**0.008**
Scar F, Scar D	1.1004	0.285
Scar B, Scar D	5.5906	**0.001**
Reference sites		
PBK03, PBK04	1.5947	0.135
PBK03, PBR01	3.8213	**0.001**
PBK03, PBR02	2.2884	**0.026**
PBK03, PBK07	4.8108	**0.001**
PBK03, PBK08	4.0035	**0.002**
PBK04, PBR01	1.0058	0.296
PBK04, PBR02	0.36345	0.719
PBK04, PBK07	1.7939	0.09
PBK04, PBK08	1.2882	0.219
PBR01, PBR02	0.69354	0.51
PBR01, PBK07	1.4373	0.161
PBR01, PBK08	0.54437	0.617
PBR02, PBK07	1.6394	0.107
PBR02, PBK08	1.0358	0.312
PBK07, PBK08	0.77162	0.431

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 2 monitoring event in February 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	16.643	9.5398	**0.017**
Site(Site type)	11	19.722	4.041	**0.001**
Residuals	117	51.911		
Total	129	90.623		

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

Groups	t-value	P-value
Rehabilitation sites		
Scar C, Trench East	0.1266	0.923
Scar C, Trench West	1.4013	0.18
Scar C, Scar E	2.9645	**0.015**
Scar C, Scar F	1.2671	0.262
Scar C, Scar B	0.12965	0.919
Scar C, Scar D	0.20449	0.858
Trench East, Trench West	1.5908	0.183
Trench East, Scar E	3.3723	**0.005**
Trench East, Scar F	1.3316	0.253
Trench East, Scar B	8.0694E-9	1
Trench East, Scar D	9.9504E-2	1
Trench West, Scar E	4.5616	**0.003**
Trench West, Scar F	2.279	**0.049**
Trench West, Scar B	1.6466	0.136
Trench West, Scar D	1.29	0.27
Scar E, Scar F	0.94281	0.412
Scar E, Scar B	3.5839	**0.007**
Scar E, Scar D	2.1108	0.055
Scar F, Scar B	1.4012	0.219
Scar F, Scar D	0.84593	0.473
Scar B, Scar D	0.10177	1
Reference sites		
PBK03, PBK04	0.15309	0.945
PBK03, PBR01	2.8711	**0.01**
PBK03, PBR02	3.6848	**0.001**
PBK03, PBK07	3.0547	**0.01**
PBK03, PBK08	2.6566	**0.021**
PBK04, PBR01	2.5156	**0.029**
PBK04, PBR02	3.0393	**0.005**
PBK04, PBK07	2.5608	**0.025**
PBK04, PBK08	2.3181	**0.046**
PBR01, PBR02	0.46108	0.782
PBR01, PBK07	0.30151	0.878
PBR01, PBK08	0.38694	0.78
PBR02, PBK07	1.1275	0.347
PBR02, PBK08	1.0031	0.386
PBK07, PBK08	0.16342	1

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 (LRT) and P-values (Pr(>Chi). **Bold** font indicates a statistically significant result.

	df	AIC	LRT	Pr(>Chi)
Scar B				
Null		266.8022		
Monitoring round	2	254.9651	15.837	**0.0003639**
Scar C				
Null		364.7362		
Monitoring round	2	368.2226	0.5136	0.7735
Scar E				
Null		266.5069		
Monitoring round	2	255.715	14.792	**0.0006137**
Scar F				
Null		123.6319		
Monitoring round	2	127.1632	0.4687	0.7911
Trench East				
Null		241.2404		
Monitoring round	2	237.9146	7.3258	**0.02566**
Trench West				
Null		256.031		
Monitoring round	2	259.9853	0.0457	0.9774

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	Pr(>|z|)
Scar B				
(Intercept) Aug 2023	4.23120	0.09557	44.275	**<2e-16**
Oct 2023	-0.59362	0.13944	-4.257	**2.07E-05**
Feb 2024	-0.46536	0.1383	-3.365	**0.000766**
Scar C				
(Intercept) Aug 2023	3.85439	0.07495	51.426	**<2e-16**
Oct 2023	0.02235	0.10585	0.211	0.833
Feb 2024	-0.05219	0.10635	-0.491	0.624
Scar E				
(Intercept) Aug 2023	4.22537	0.09431	44.805	**<2e-16**
Oct 2023	-0.58779	0.13768	-4.269	**1.96E-05**
Feb 2024	-0.37949	0.13588	-2.793	**0.00522**
Scar F				
(Intercept) Aug 2023	3.8712	0.12639	30.629	**<2e-16**
Oct 2023	-0.12405	0.18028	-0.688	0.491
Feb 2024	-0.05129	0.17936	-0.286	0.775
Trench East				
(Intercept) Aug 2023	3.627	0.09435	38.443	**<2e-16**
Oct 2023	-0.16127	0.13516	-1.193	0.2328
Feb 2024	0.21888	0.13145	1.665	0.0959
Trench West				
(Intercept) Aug 2023	3.8795	0.11096	34.963	**<2e-16**
Oct 2023	-0.03362	0.15715	-0.214	0.831
Feb 2024	-0.01667	0.15703	-0.106	0.915

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	Pr(>|z|)
Scar B				
Oct 2023 - Aug 2023	-0.5936	0.1394	-4.257	**<1e-04**
Feb 2024 - Aug 2023	-0.4654	0.1383	-3.365	**0.00216**
Feb 2024 - Oct 2023	0.1283	0.1425	0.9	0.64022
Scar E				
Oct 2023 - Aug 2023	-0.5878	0.1377	-4.269	**<0.001**
Feb 2024 - Aug 2023	-0.3795	0.1359	-2.793	**0.0144**
Feb 2024 - Oct 2023	0.2083	0.1401	1.487	0.2973
Trench East				
Oct 2023 - Aug 2023	-0.1613	0.1352	-1.193	0.457
Feb 2024 - Aug 2023	0.2189	0.1315	1.665	0.219
Feb 2024 - Oct 2023	0.3801	0.1332	2.854	**0.012**

Table B-10: PERMANOVA table of results, comparing seagrass composition between rehabilitation and reference sites quantified during the round 2 monitoring event in February 2024. **Bold** font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	2305.7	34.8	**0.001**
Residuals	11	728.82		
Total	12	3034.6		

Table B-11: 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 2 monitoring event in February 2024.

Benthic category	Rehabilitation sites mean cover (%)	Reference sites mean cover (%)	Contribution to dissimilarity (%)
Posidonia australis	5.24	8.52	32.73
Halophila sp.	4.42	1.39	30.22
Sand	6.40	3.97	24.30
Zostera sp.	3.11	2.73	12.75