Transport for NSW

Kamay Ferry Wharves project

Seagrass Translocation, Rehabilitation and Monitoring

Seagrass Monitoring Report 1

November 2023

NSW GOVERNMENT

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

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

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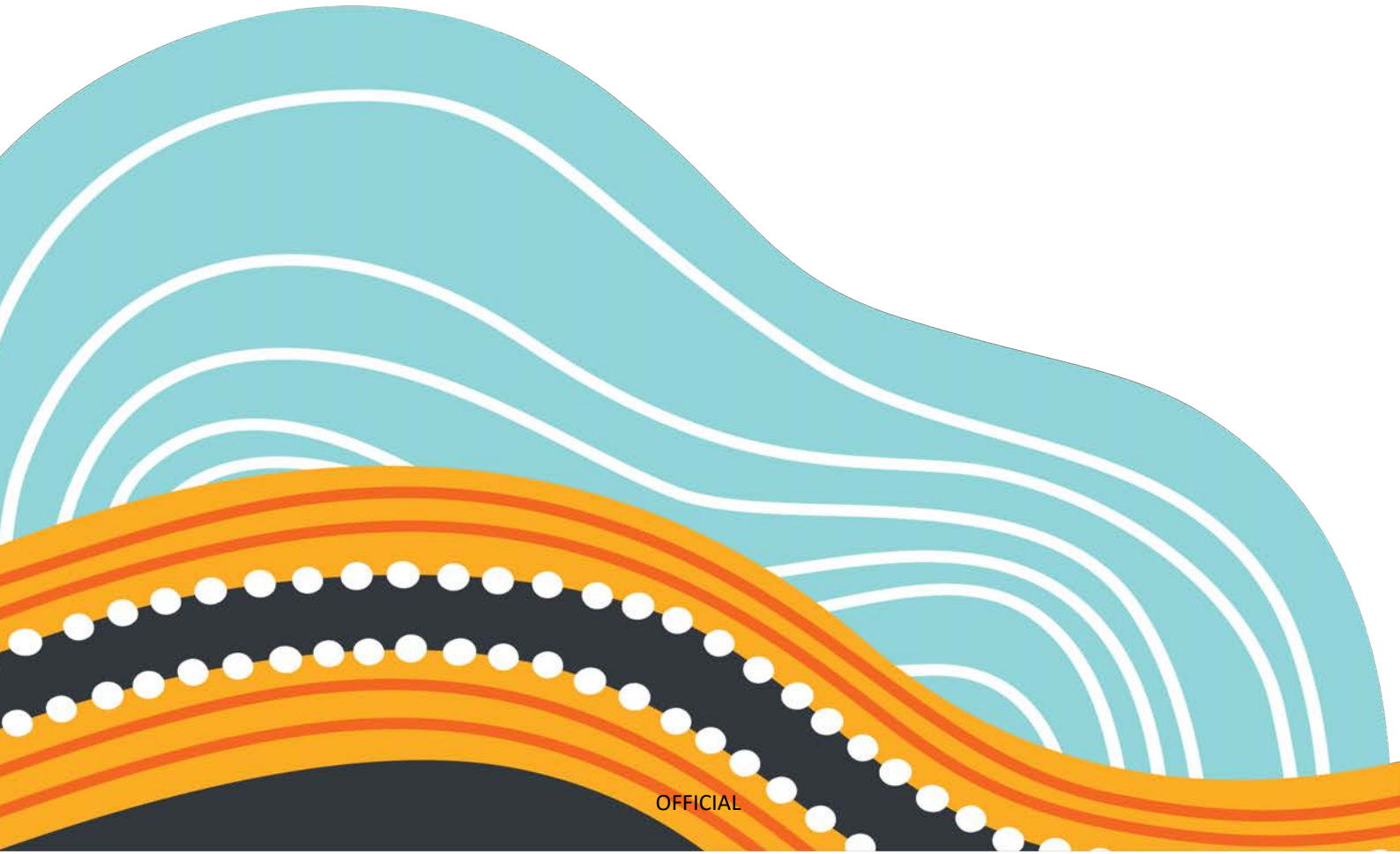

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Terms and acronyms

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
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.
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 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* fragments from the project impact area at Kurnell to nearby rehabilitation sites commenced in mid-June and was completed in early July.

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 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 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 4).

Monitoring reports will be provided to the MBOS Implementation Reference Panel, NSW DPE, 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

An initial round of in-situ mapping and surveys of the six rehabilitation sites that received translocated *Posidonia australis* and six reference sites located within the natural meadow at Kurnell was carried out in late July-early August 2023 following completion of translocation of *Posidonia australis* at Kurnell. The initial surveys provided baseline data about the density and condition of translocated and natural meadows of *Posidonia australis* (UNSW, 2023d).

This report documents the results of the first monitoring event of the ten-year monitoring program. Monitoring was carried out in late October and early November 2023 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. Methods

2.1 Location and timing of monitoring

Surveys were carried out at six 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 2.0-4.0 metres (Figure 2-1).

Surveys were also carried out at six reference sites to enable comparisons between the density, condition and benthic composition of natural *Posidonia australis* meadows and *Posidonia australis* in rehabilitation sites. 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 four days in late October to early November 2023, being about three months following completion of the *Posidonia australis* translocation stage. Monitoring was carried out by experienced marine ecologists from the University of New South Wales (UNSW) using SCUBA.

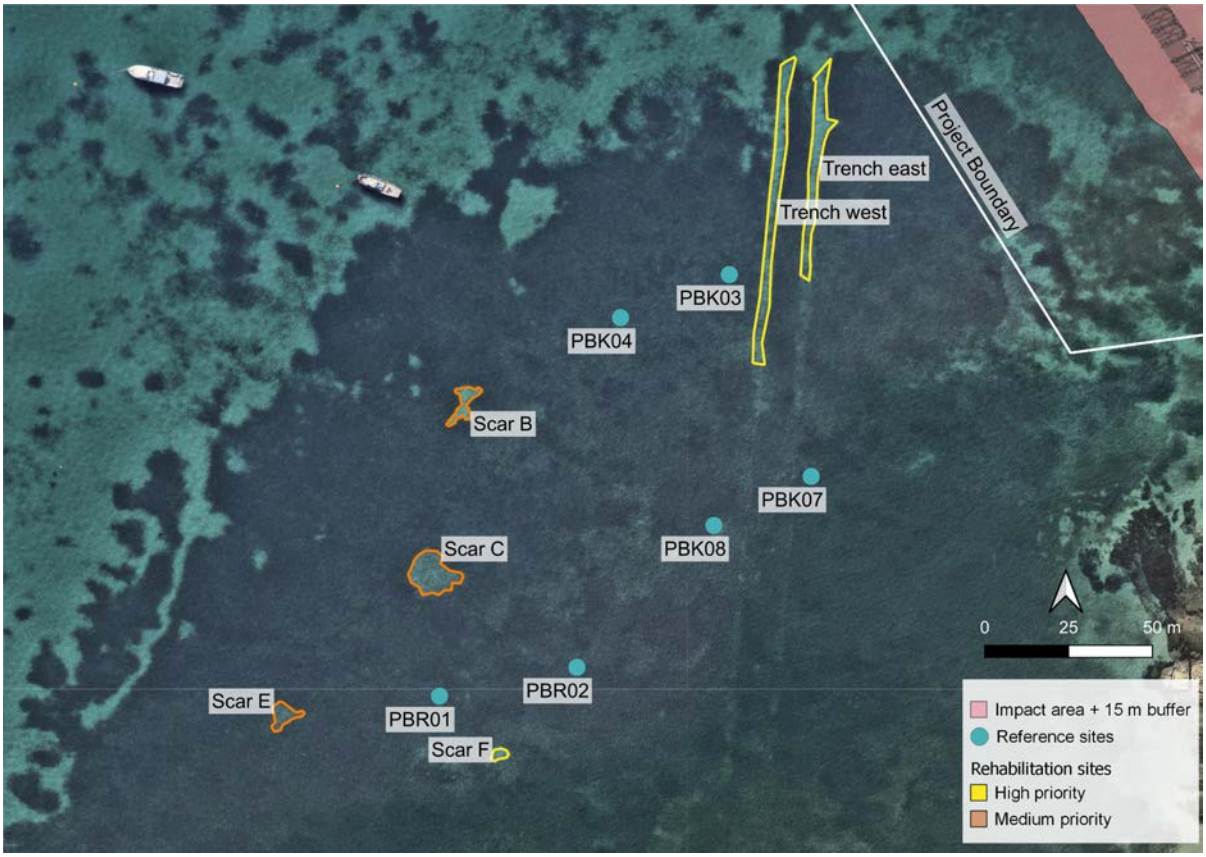

Figure 2-1: Overview of the survey area at Kurnell (Gamay, Botany Bay)

2.2 *Posidonia australis* surveys

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

Monitoring of *Posidonia australis* density and condition (leaf length and epiphyte cover) was carried out at the six rehabilitation and six reference sites. Each site was located in the field 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.

2.2.2 Benthic cover

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

2.3 Mapping rehabilitation sites

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

In-situ mapping was carried out at Trench West and Trench East sites to record the extent of the area restored with *Posidonia australis*. Mapping was carried out at Trench West and Trench East sites only because: (a) these sites had not previously been mapped due to the fragmented distribution of restored areas in these sites, and (b) there had been minimal change (0-4m^2 increase) in the restored area of the other four rehabilitation sites.

The mapping exercise for Trench West and Trench East sites involved divers installing metal reinforcing bars around the perimeters of the restored areas within the sites. Transect tapes were then placed around the marked-out perimeters and divers recorded measurements from the transect tapes in situ. GPS points and distances between restored areas within the sites were also recorded to enable maps to be produced.

2.4 Analysis

2.4.1 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 nested within site type as a random factor. 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. Generalized 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. Analyses and plots were prepared using the packages MASS (Venables and Ripley, 2002) and lmtest (Zeileis and Hothorn, 2002) in the R programming language version 4.3.1 (R Core Team, 2023).

2.4.2 Analysis of benthic cover

Digital photographs of survey quadrats 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 total percentage cover of seagrass and mean percentage cover of each benthic type were calculated for each rehabilitation and reference site and the results were plotted for visual interpretation. A one-factor PERMANOVA was used to test for differences in seagrass 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 seagrass percentage cover data and the PERMANOVA was run with unrestricted permutation of the raw data, Type III sum of squares and 999 permutations.

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

The data collected during the in-situ mapping of Trench East and Trench West sites was reviewed in GIS software. Polygons were produced to depict the approximate area within these rehabilitation sites restored with *Posidonia australis*. Polygons depicting the restored areas of the six rehabilitation sites were overlaid on high-resolution Nearmap imagery of the area captured in May 2023 and maps of the sites were produced for visual interpretation.

The new areas that had been restored with *Posidonia australis* since the initial survey were quantified for each rehabilitation site and the total area for each site and overall restored area were calculated.

2.4.4 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, 2024). 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 HOBO pendant temperature data loggers installed at three rehabilitation sites. Water temperature data recorded at Scar F was selected for analysis because this data logger provided the longest time series of data. 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 10 October 2023 (67 days). A time series plot of the water temperature data was produced.

3. Results

3.1 *Posidonia australis* density and condition

A summary of the overall mean values for *Posidonia australis* shoot density, leaf length and epiphyte cover for the six rehabilitation and reference sites captured during the round 1 monitoring event is provided in Table 3-1. 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 3-3.

The overall mean shoot density of transplanted *Posidonia australis* in the rehabilitation sites was 41 shoots per m^2 (Table 3-1) with a range across sites of about 32-48 shoots per m^2 (Figure 3-1a). In comparison, the reference sites had an overall mean shoot density of 110 shoots per m^2 with a range of about 81-159 shoots per m^2, which equated to about 2.7 times more shoots per square metre than the rehabilitation sites. PERMANOVA confirmed this difference was statistically significant (p=0.004, pseudo-F=29.03; Appendix B, Table B-1). Shoot densities also varied among sites (p=0.001, pseudo-F=6.63; Table B-1). There was little significant variation in shoot densities among the rehabilitation sites (Table B-2). When comparing the reference sites, the shallower sites PBR01 and PBR02 tended to have greater shoot densities than the other reference sites (Table B-2).

Maximum leaf lengths of *Posidonia australis* in rehabilitation sites were about 34 cm on average with little variation between sites (29-36 cm) (Table 3-1, Figure 3-1b). Maximum leaf lengths of *Posidonia australis* in reference sites were greater than those in rehabilitation sites (p=0.001, pseudo-F=74.00; Table B-3), with an overall mean length of 50 cm and leaves frequently measuring >70 cm. Leaf lengths differed among sites (p=0.019, pseudo-F=2.27, Table B-3). Scar F leaf lengths tended to be shorter than other rehabilitation sites (Table B-4), while among the reference sites leaf lengths of *Posidonia australis* at site PBR02 were longer than two other sites (Table B-4).

There was little difference in mean epiphyte cover of *Posidonia australis* in rehabilitation (2.7) and reference sites (3.3) (Table 3-1; p=0.063, pseudo-F=4.80; Table B-5). Epiphyte cover did vary among sites, with most of this variation coming from differences among rehabilitation sites (p=0.001, pseudo-F=5.229, Table B-6). Epiphyte cover of *Posidonia australis* was generally low (<3) across all sites with some exceptions, including rehabilitation sites Trench East and Trench West (Figure 3-1c).

Table 3-1: Summary (mean ± standard error) of *Posidonia australis* characteristics quantified in rehabilitation and reference sites at Kurnell during the round 1 monitoring event (October 2023).

Site type (number of sites)	Shoot density (m^{-2})	Leaf length (cm)	Epiphyte cover (1-5 scale)
Rehabilitation (6)	41 (±2.0)	34 (±0.5)	2.7 (±0.1)
Reference (6)	110 (±5.7)	50 (±1.2)	3.3 (±0.1)

Considering trends in *Posidonia australis* shoot densities at the rehabilitation sites through time, significant changes in shoot density were found at two sites, Scar B (GLM, p=0.0010, Table B-7) and Scar E (GLM, p=0.0004, Table B-7). Shoot densities at these two sites were found to decrease to a similar degree from about 68 to 38 shoots per m^2 between the initial surveys in August 2023 and round 1 monitoring in October 2023 (Figure 3-2a). Shoot densities at the other rehabilitation sites and six reference sites (Figure 3-2b) showed little variation between monitoring rounds.

When comparing *Posidonia australis* shoot densities at the rehabilitation sites to the success criteria, three of the six sites, Scar C, Scar F and Trench West, consistently exceeded through time the long-term (ten-year) success criteria for shoot density of 42 shoots per m^2. Shoot densities recorded during the October 2023 monitoring round for the remaining three sites, Scar B, Scar E and Trench East, exceeded the mid-term (six-year) success criteria of 32 shoots per m^2.

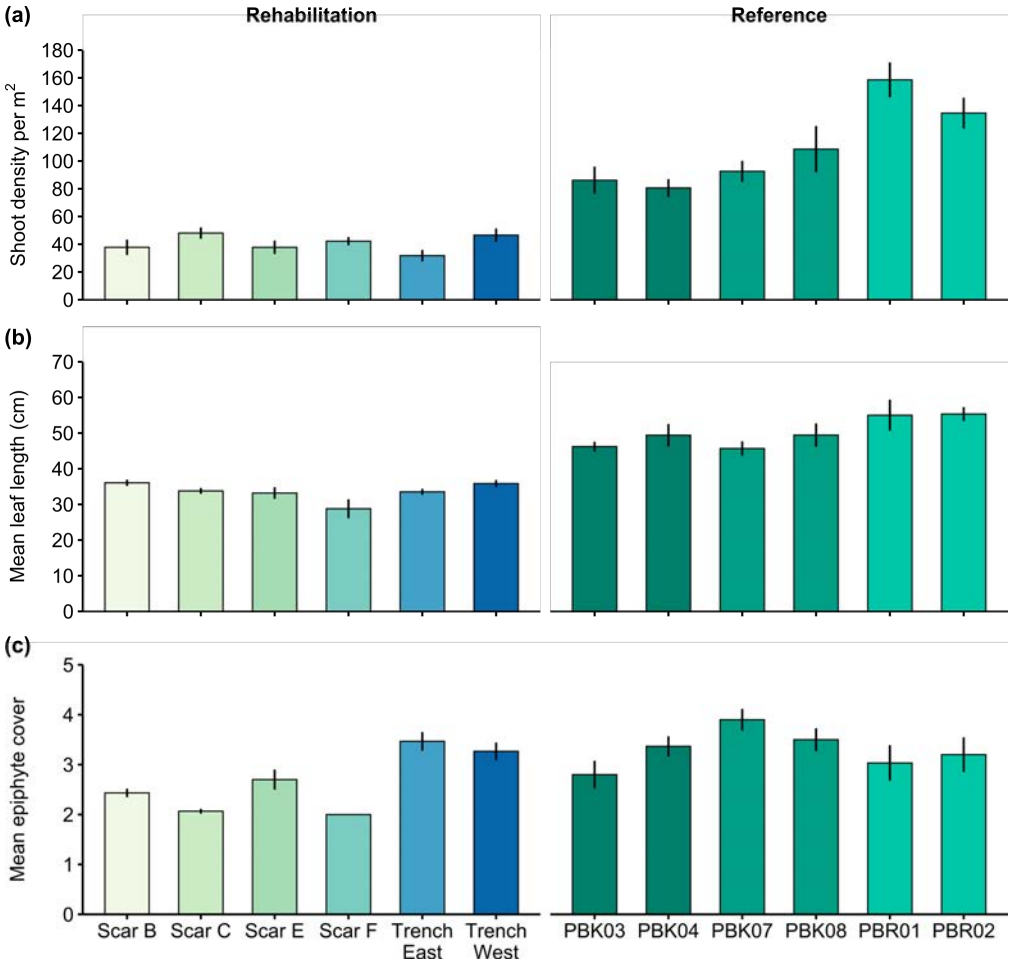

Figure 3-1: *Posidonia australis* characteristics at six rehabilitation and six reference sites at Kurnell captured during the round 1 monitoring event in October 2023: (a) shoot density, (b) leaf length and (c) epiphyte cover. Error bars indicate standard error of the mean.

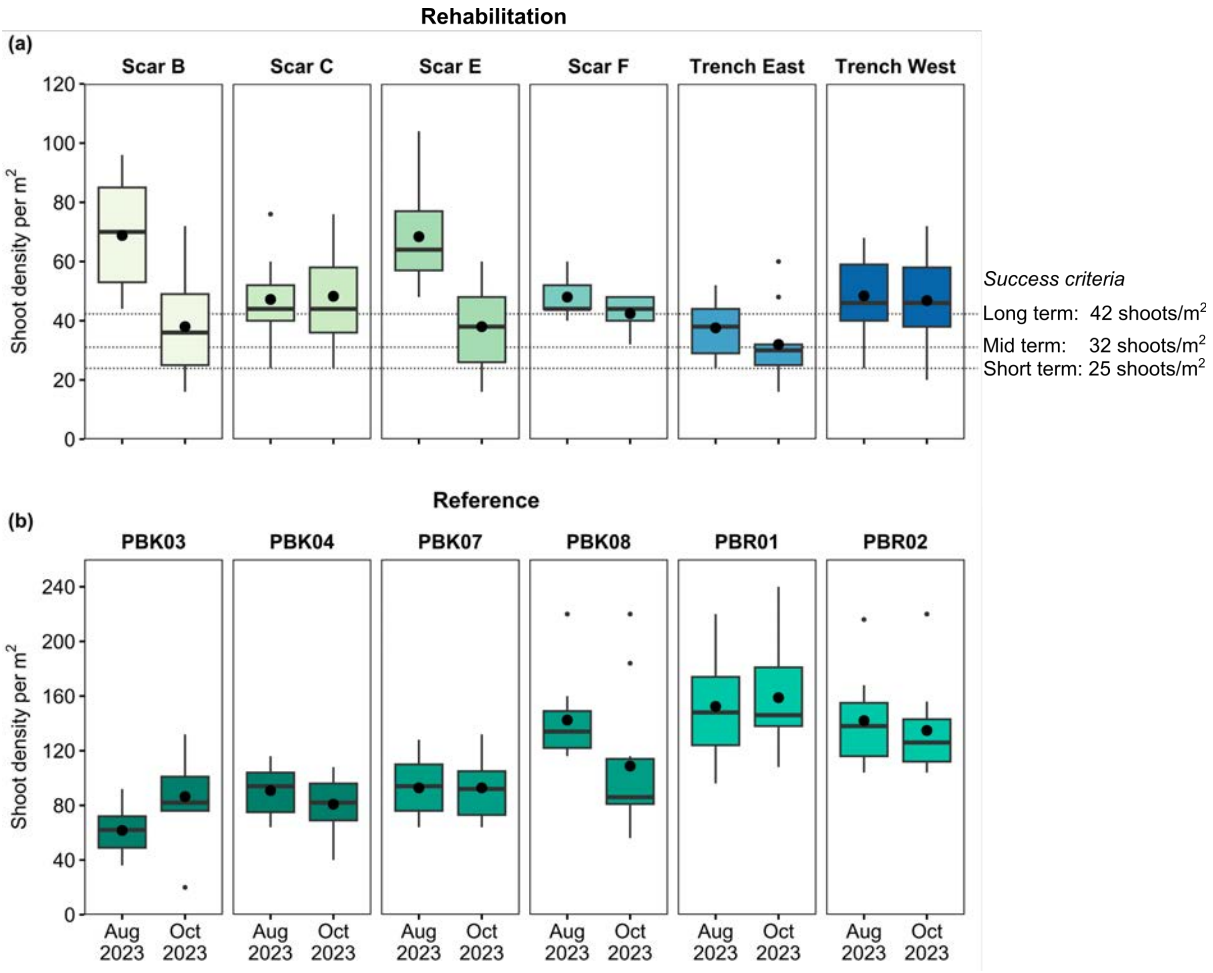

Figure 3-2: Shoot density through time at the (a) six rehabilitation sites in relation to the success criteria and (b) six reference sites.
Each time point represents a monitoring event. The box-whisker represents the median (line), interquartile range (box), range (whiskers) and outliers (dots). Means are represented by large black circles. Note that scales for shoot density differ for rehabilitation (a) and reference (b) site plots.

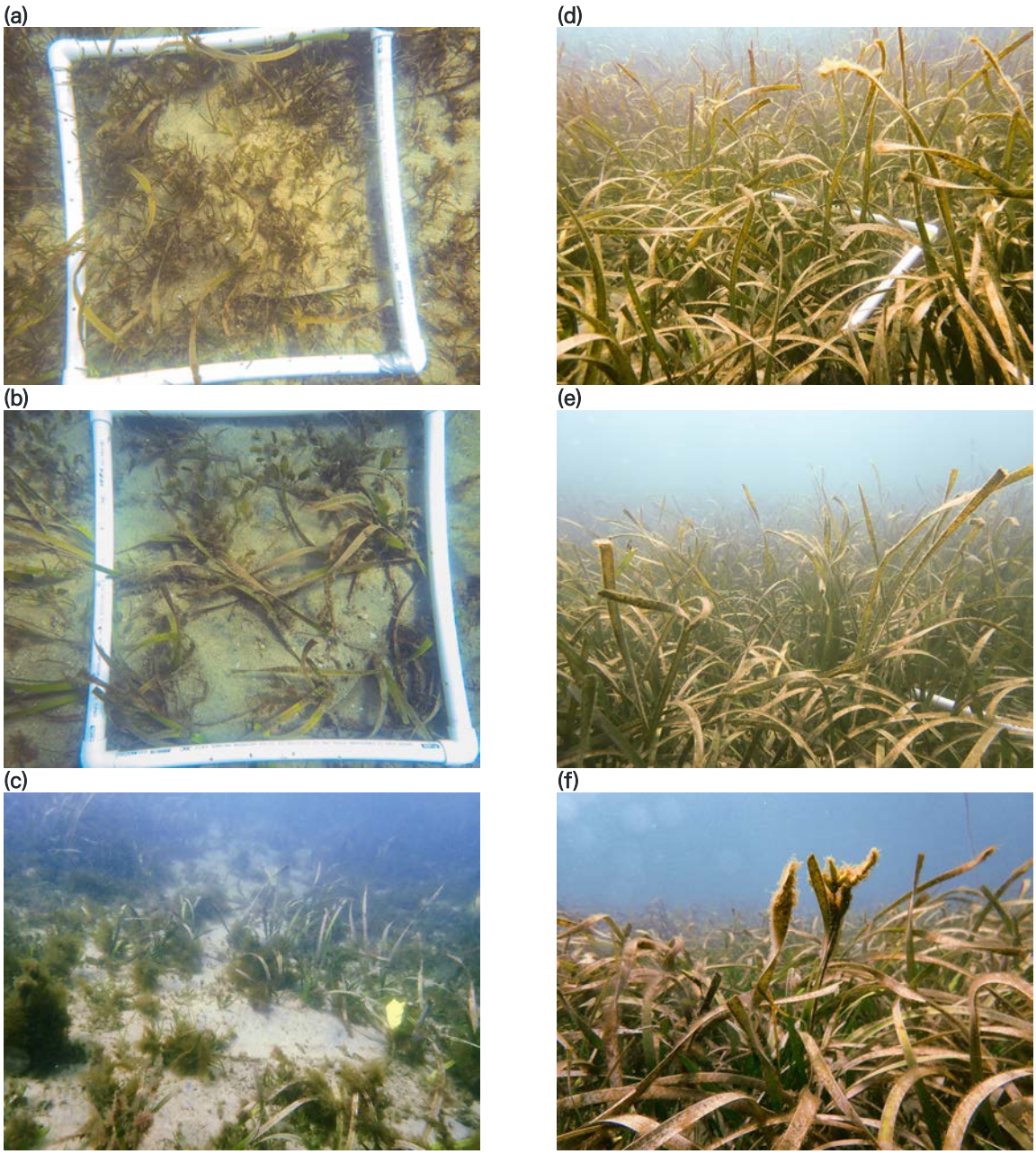

Figure 3-3: Photos of *Posidonia australis* at rehabilitation and reference sites at Kurnell.
Photos showing (a) dense cover of Zostera in a jute mat at Scar F, (b) survey quadrat of translocated *Posidonia australis* in Scar E, (c) epiphytic algae attached to *Posidonia australis* at Trench East, (d and e) dense, long leaf *Posidonia australis* in reference sites and (f) *Posidonia australis* flowers in a reference site.

3.2 Benthic cover in rehabilitation and reference sites

Analysis of the photoquadrats captured during the round 1 monitoring surveys revealed the presence of three seagrass species, *Posidonia australis*, *Zostera sp*. and *Halophila sp*. The overall mean total seagrass cover was lower in rehabilitation sites than reference sites (61% vs 93%, Appendix A, Table A-4). Total seagrass cover ranged from 48-78% in rehabilitation sites and 89-97% in reference sites (Figure 3-4a; Appendix A, Table A-4). Among the rehabilitation sites, Scar E had the lowest and Trench East the highest cover of seagrass.

There were significant differences in the composition of seagrass species between rehabilitation and reference sites (p=0.002, pseudo-F=16.82; Table B-8). *Posidonia australis* tended to dominate the benthos in the reference sites, where it comprised at least 65% of the total benthic cover (Figure 3-4b). In the rehabilitation sites this dominance was generally shared with *Zostera sp*. The exception to this pattern was Scar C where *Halophila sp.* was more prevalent; elsewhere, *Halophila sp*. contributed <9% to the benthic cover composition. Sandy

sediment accounted for almost all the remaining area in the sites. Few observations of other benthic categories were recorded but included brown macroalgae and invertebrates.

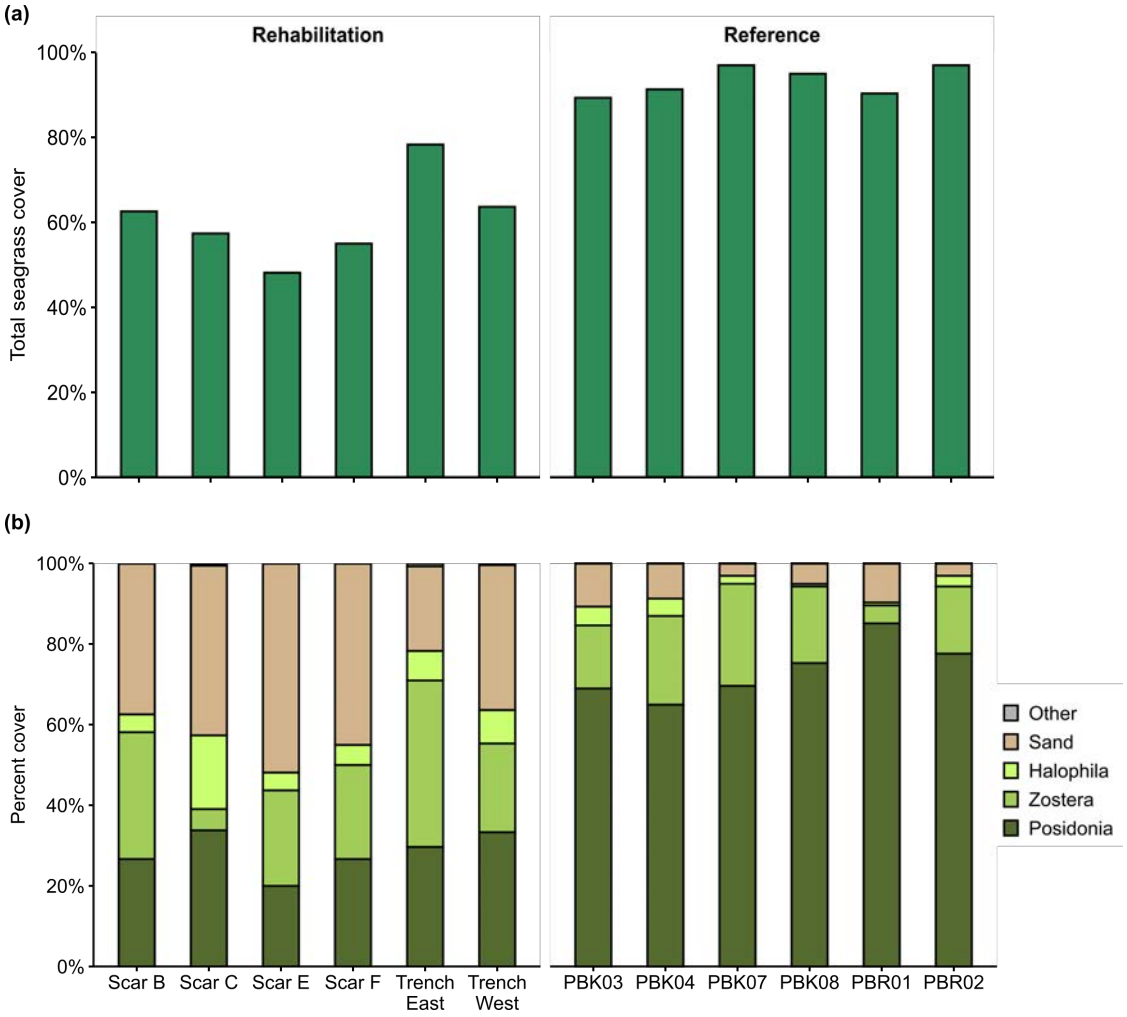

Figure 3-4: Comparison of (a) total seagrass cover and (b) benthic composition at the six rehabilitation and six reference sites at Kurnell captured during the round 1 monitoring event in October 2023.

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

The area of the six sites rehabilitated with *Posidonia australis* is provided in Table 3-2. The total area restored across all six rehabilitation sites was estimated to be 319 m^2, an increase of 17 m^2 during the period between completion of the translocation stage and the round 1 monitoring event, August to October 2023. The increase in restored area was accounted for by: (a) transplanting of naturally detached *Posidonia australis* shoots at three sites (8 m^2) and (b) revised area calculations resulting from the detailed mapping of Trench East and Trench West sites (9 m^2).

Transplanting of naturally detached *Posidonia australis* shoots occurred at three of the six rehabilitation sites (Scar B, Scar E and Scar F) between August and October 2023. The transplanting events increased the area restored at Scar E (4 m^2), Scar B and Scar F (both 2 m^2). Owing to these small increases in area, mapping was not carried out at these sites during monitoring and the values identified in Table 3-2 are based on data recorded by scientific divers during each transplanting event.

Transplanting of naturally detached *Posidonia australis* shoots had not commenced at Trench East or Trench West prior to the round 1 monitoring event in October 2023. The values in Table 3-2 for total area restored for these two sites were revised based on data obtained from the detailed in situ mapping exercise carried out during monitoring round 1. The mapping indicated that the previous estimate (UNSW, 2023d) for area restored at these sites was under-estimated by 2 m^2 at Trench East and 7 m^2 at Trench West.

Polygons representing the approximate areas of the six rehabilitation sites restored with *Posidonia australis* are displayed in Figure 3-5.

Table 3-2: Time series of change in restored *Posidonia australis* area at rehabilitation sites over the entire monitoring period.
Each time point represents a monitoring event.

Site	Restored area (m^2) Aug 2023	Oct 2023	Change since previous
Scar B	48	50	+2
Scar C	152	152	0
Scar E	38	42	+4
Scar F	10	12	+2
Trench East	26	28*	+2
Trench West	28	35*	+7
Total	**302**	**319**	**+17**

*Value revised based on field-based mapping carried out during the round 1 monitoring event in October 2023

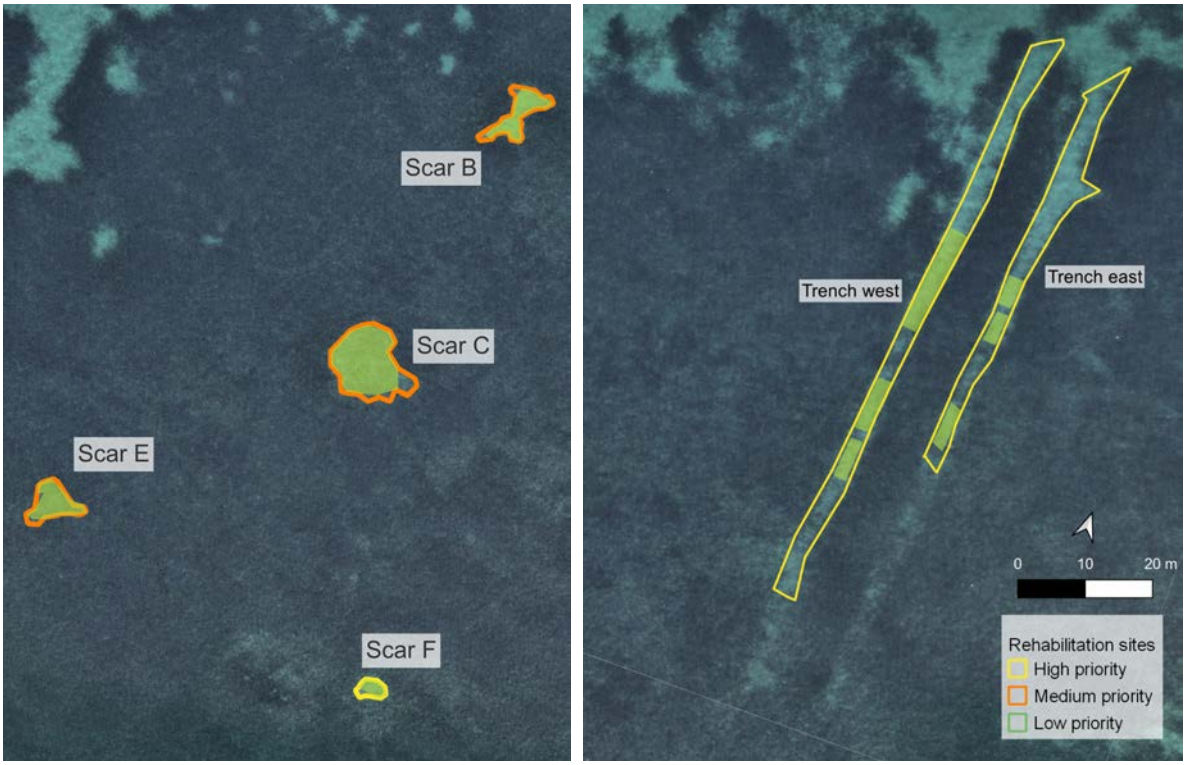

Figure 3-5: Map of Kurnell showing the approximate areas within each of the six medium and high priority rehabilitation sites restored with *Posidonia australis*.

3.4 Botany Bay climate patterns

Monthly rainfall and air temperature data for the Sydney Airport AMO weather station (66037) obtained from BOM (BOM, 2023a; BOM, 2023b) indicated that Botany Bay weather conditions continued to be drier and warmer than the long-term mean over the six months preceding the monitoring event (Figure 3-6a, b). The highest daily precipitation event recorded at Sydney Airport AMO weather station between August and October 2023 was 13.8 mm. September and October 2023 were particularly dry with less than half the long-term mean rainfall occurring during these months, indicative of El Niño conditions (BOM, 2023c). Maximum air temperatures between August and October were 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). Solar exposure is influenced by the position of the sun in the sky and level of cloud cover, and in the Sydney region typically follows a seasonal pattern where it decreases in winter and increases in summer. At a local level, it can be used as a proxy for the amount of light reaching seagrasses. Daily global solar exposure data recorded at the Kurnell AWS (66043) (BOM, 2023d) indicated that solar exposure levels were on average lowest in June (9.8 MJ m^{-2}) and gradually increased over the following months to reach 22.4 MJ m^{-2} in October 2023. Solar exposure at Kurnell AWS has been consistently greater than the long-term mean since June 2023 (Figure 3-6c). Below average rainfall and clear skies are likely to have contributed to this ongoing pattern.

Wind data recorded at Kurnell AWS (BOM, 2023e) indicated that wind conditions were generally calm over the three month period preceding the monitoring event (August-October 2023) (Figure 3-6d). Mean wind speeds ranged from 15-18 km/h and were similar to wind conditions in previous months.

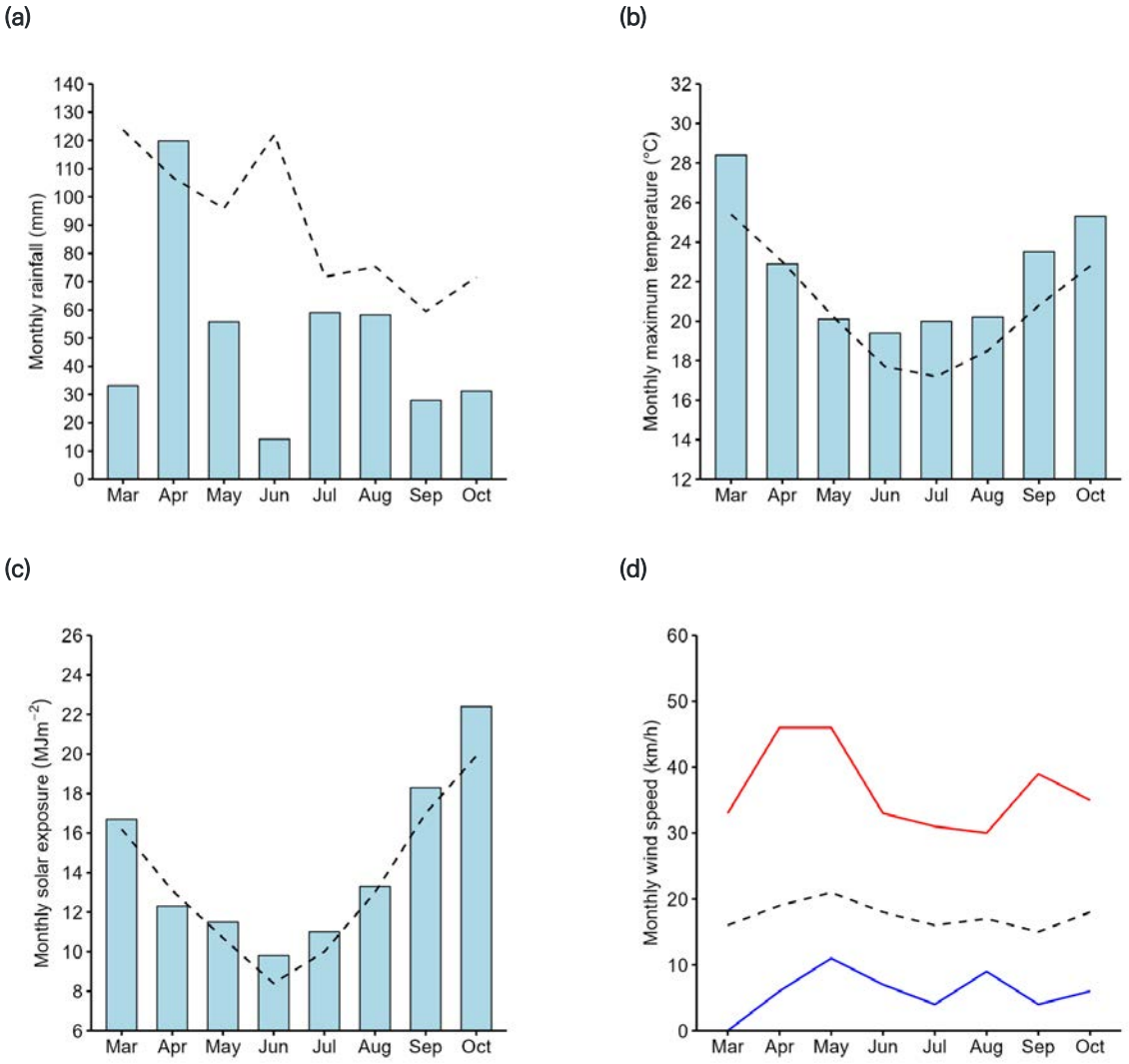

Figure 3-6: Monthly climate data for Botany Bay for May-October 2023 (a) total rainfall, (b) maximum air temperature, (c) mean solar exposure and (d) mean, minimum and maximum wind speed.
Dashed line in a, b and c indicates the long-term mean. Rainfall and air temperature records at Sydney Airport AMO commenced in 1929 and 1939 respectively. Solar exposure monitoring at Kurnell AWS commenced in 2007.

Wave height data retrieved from the Sydney offshore waverider buoy indicated that maximum significant wave heights were below 2 metres for most (80%) and below 1.5 metres for half (51%) of days during August to October (Figure 3-7). There was a gradual increase in maximum daily wave heights during the period. Overall, the wave height conditions were typical of long-term Sydney offshore winter and spring conditions (Manly Hydraulics Laboratory, 2023).

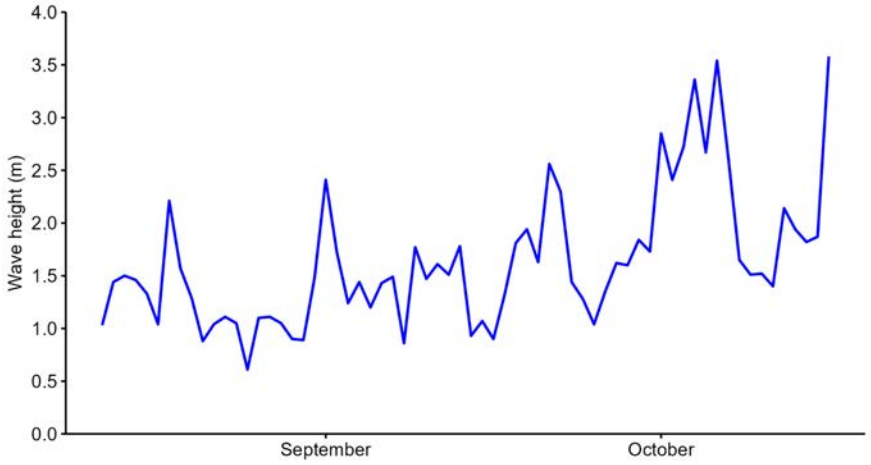

Figure 3-7: Daily maximum significant wave height recorded by the Sydney offshore waverider buoy (SYDDOW) between 12 August and 16 October 2023.
Data was sourced from Australia's Integrated Marine Observing System (IMOS) – IMOS is enabled by the National Collaborative Research Infrastructure strategy (NCRIS). It is operated by a consortium of institutions as an unincorporated joint venture, with the University of Tasmania as Lead Agent.

Water temperature data recorded at rehabilitation site Scar F located in shallow water (about 1.5-2.0 m) demonstrated a gradual warming of about 2°C over the period August-October (Figure 3-8). The mean minimum water temperature for August was 16.3°C (±0.13) with daily mean values as low as 14.3°C, but this had increased to 17.9°C (±0.30) by October. The mean maximum water temperature recorded for the first 10 days of October was 19.5°C (±0.31) which was about 2°C than the August maximum of 17.6°C (±0.13).

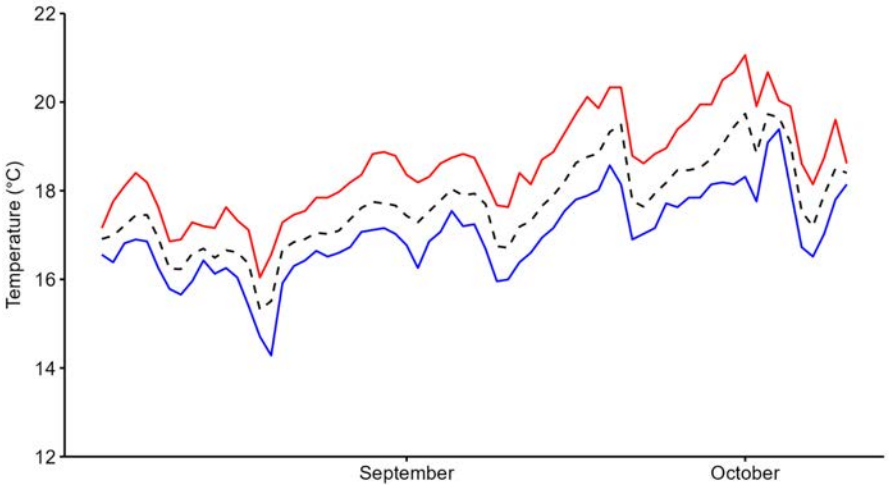

Figure 3-8: Daily mean, maximum and minimum water temperature recorded by a data logger installed at Scar F. Data recorded between 5 August and 10 October 2023. Daily mean, maximum and minimum water temperature are indicated by dashed, red and blue lines respectively.

4. Discussion

4.1 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 success criteria is summarised in Table 4-1.

Table 4-1: *Posidonia australis* offsetting success criteria and measures for the short-term period (two years) 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 beach-cast *Posidonia australis* in rehabilitation sites has increased the area initially restored during the translocation stage. The area restored exceeds the short-term success criteria at this stage.
Long term (10-year) goal: 536m^2	Minimum value:	268m^2	319m^2 **Exceeds target**
Maintain *Posidonia australis* density.	Shoot density of restored *Posidonia australis* (based on 0.25m^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).	Densities of *Posidonia australis* shoots in six rehabilitation sites closely match or exceed the mean overall shoot density (42 shoots/m^2) of the *Posidonia australis* that was translocated from the Kurnell impact area.
Long term (10-year) goal: 42 shoots/m^2	Minimum value:	25 shoots/m^2	41 shoots/m^2 (range 32-48) **Exceeds target**

Monitoring of rehabilitation sites at Kurnell indicates that the short-term offset strategy targets for restored area and shoot density detailed in Table 4-1 were exceeded. The areal extent of restored *Posidonia australis* habitat reported here exceeds the short-term success criteria target of 268m^2 by 51m^2. This represents an increase in restored area of 17m^2 since the initial survey that immediately followed completion of the translocation stage (UNSW, 2023d). The increase in restored area is due to a combination of restoration using naturally detached *Posidonia australis* shoots collected from Botany Bay and improved accuracy of the measurements of the restored areas in Trench East and Trench West sites.

Few large areas of bare substrate remain in the six rehabilitation sites due to rapid colonisation by opportunistic seagrass species *Zostera sp.* and to a lesser extent *Halophila sp.* over the months preceding the monitoring. These species tend to have strong seasonal growth patterns and their distribution is likely to change following the spring-summer period. Ongoing restoration efforts using naturally detached *Posidonia australis* shoots will adapt in response to temporal and spatial changes in the distribution of vegetated and unvegetated areas in rehabilitation sites.

Shoot densities of *Posidonia australis* in all six rehabilitation sites exceed the short-term success criteria goal of 25 shoots per m^2 and at three of six sites also exceed the long-term goal of 42 shoots per m^2. Shoot densities

for the rehabilitation sites quantified from the current round of monitoring were generally lower than the values recorded during the initial round of monitoring in July-August 2023. These differences can be partially explained by more equal sampling in the round 1 monitoring surveys of areas restored with and without jute mats, with the latter tending to be planted less densely and resulting in lower overall shoot densities in some sites. Secondly, some mortality of shoots would be expected to have occurred since the initial surveys in July-August 2023. Further monitoring data is required to inform decision-making relating to targeted supplementary transplanting in sites to achieve the long-term success criteria for shoot densities.

4.2 *Posidonia australis* condition and seagrass composition

Maximum leaf length and epiphyte cover are two attributes that are commonly used as indicators of seagrass condition in monitoring programs. *Posidonia australis* leaves in rehabilitation sites tended to be about 30% shorter than leaves in the surrounding natural meadow. This pattern reflects the fact that leaf lengths of *Posidonia australis* in the patches that were translocated from the impact area to rehabilitation sites at Kurnell were less on average than leaf lengths of reference site *Posidonia australis* (UNSW, 2023c).

An epiphytic algae bloom that was initially observed in the seagrass meadow at Kurnell in November 2022 was again detected affecting some sites during the current monitoring event. The algae was not evenly distributed across the monitoring sites but where it was present, the algae tended to attach to *Posidonia australis* leaves. However, most of the rehabilitation and reference sites were unaffected by the epiphytic algae and had relatively low epiphyte loads, suggesting that based on this attribute the *Posidonia australis* at Kurnell was generally in good condition.

The substantially lower seagrass cover in rehabilitation compared to reference sites was as expected given that the rehabilitation sites were previously predominantly bare sediment. The proportionally lower cover of *Posidonia australis* in rehabilitation relative to reference sites results from transplanting of *Posidonia australis* in these sites at much lower densities than reference site *Posidonia australis* densities. Consequently, rehabilitation sites were also characterised by greater coverage of sandy sediment than reference sites. However, many previously bare areas in the rehabilitation sites have been rapidly colonised by opportunistic seagrass species, particularly *Zostera sp*.

4.3 Environmental conditions and general observations during monitoring

Local climatic conditions since completion of the *Posidonia australis* translocation stage were generally favourable, with few storm or other weather events with the potential to disturb seagrasses in Botany Bay. The ongoing weather pattern of above-average air temperatures and solar exposure, below-average precipitation and mostly benign offshore wave activity provide ideal conditions for seagrass growth. Warmer and dryer conditions are expected to continue through spring and summer under the influence of El Niño and a positive Indian Ocean Dipole (BOM, 2023f).

These conditions are likely to be influencing the persistence of the epiphytic algal bloom affecting some areas of the seagrass meadow at Kurnell. While there was a noticeable decline in the observed density and distribution of the algal bloom during this monitoring event relative to the initial surveys carried out in July-August, the algae remained present to some degree at all sites. Visual monitoring and documenting of the algal bloom will continue.

Flowers and fruits were frequently observed in *Posidonia australis* in reference sites during the surveys. Numbers of flowers were quantified during the surveys with the expectation that the data will provide useful information about reproductive patterns of the Botany Bay population of *Posidonia australis*.

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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
Overall	Rehabilitation	53 (±2.3)	41 (±2.0)
Overall	Reference	114 (±5.6)	110 (±5.7)
Scar B	Rehabilitation	68.8 (± 5.8)	38.0 (±5.6)
Scar E	Rehabilitation	68.4 (± 5.2)	38.0 (±4.9)
Scar C	Rehabilitation	47.2 (± 3.2)	48.3 (±4.1)
Scar F	Rehabilitation	48.0 (± 3.6)	42.4 (±3.0)
Trench West	Rehabilitation	48.4 (± 4.6)	46.8 (±4.8)
Trench East	Rehabilitation	37.6 (± 3.0)	32.0 (±4.1)
PBK07	Reference	92.8 (± 6.8)	92.8 (±7.6)
PBK08	Reference	142.4 (± 9.7)	108.8 (±16.7)
PBK03	Reference	61.6 (± 5.4)	86.4 (±9.8)
PBK04	Reference	90.8 (± 5.8)	80.8 (±6.4)
PBR01	Reference	152.4 (± 12.6)	158.8 (±12.6)
PBR02	Reference	142.0 (± 10.7)	134.8 (±11.1)

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
Overall	Rehabilitation	31 (±0.7)	34 (±0.5)
Overall	Reference	35 (±0.7)	50 (±1.2)
Scar B	Rehabilitation	38.2 (± 1.4)	36.1 (±0.9)
Scar E	Rehabilitation	30.8 (± 1.0)	33.3 (±1.6)
Scar C	Rehabilitation	29.6 (± 0.9)	33.9 (±0.8)
Scar F	Rehabilitation	23.1 (± 1.4)	28.9 (±2.7)
Trench West	Rehabilitation	32.8 (± 1.0)	35.9 (±1.0)
Trench East	Rehabilitation	28.0 (± 1.3)	33.6 (±0.9)
PBK07	Reference	35.2 (± 2.0)	45.8 (±2.0)
PBK08	Reference	35.6 (± 1.5)	49.5 (±3.3)
PBK03	Reference	33.6 (± 1.8)	46.3 (±1.4)
PBK04	Reference	36.3 (± 1.7)	49.5 (±3.2)
PBR01	Reference	31.5 (± 0.9)	55.1 (±4.3)
PBR02	Reference	38.2 (± 1.4)	55.4 (±2.0)

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

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

Table A-4: Mean percentage total seagrass cover and cover of benthic categories at rehabilitation and reference sites during monitoring round 1 (October 2023)

		Percentage cover					
Site	Site type	Total seagrass	Posidonia	Zostera	Halophila	Sand	Other
Overall	Rehabilitation	61.4	29.1	23.2	9.2	38.3	0.3
Overall	Reference	93.4	73.4	17.4	2.5	6.6	0
Scar B	Rehabilitation	62.6	26.7	31.5	4.4	37.4	0.0
Scar E	Rehabilitation	48.1	20.0	23.7	4.4	51.9	0.0
Scar C	Rehabilitation	57.4	33.8	5.2	18.3	42.1	0.5
Scar F	Rehabilitation	55.0	26.7	23.3	5.0	45.0	0.0
Trench West	Rehabilitation	63.7	33.3	22.0	8.3	36.0	0.3
Trench East	Rehabilitation	78.3	29.7	41.3	7.3	21.0	0.7
PBK07	Reference	97.0	69.7	25.3	2.0	3.0	0.0
PBK08	Reference	95.0	75.3	19.0	0.7	5.0	0.0
PBK03	Reference	89.3	69.0	15.7	4.7	10.7	0.0
PBK04	Reference	91.3	65.0	22.0	4.3	8.7	0.0
PBR01	Reference	90.4	85.2	4.4	0.7	9.6	0.0
PBR02	Reference	97.0	77.7	16.7	2.7	3.0	0.0

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 1 monitoring event in October 2023. Table gives degrees of freedom (df), Sum of Squares (SS), pseudo-F, and P-values. ; αţÐ font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	1.3724E5	29.027	**0.004**
Site(Site type)	10	49143	6.6255	**0.001**
Residuals	108	80106		
Total	119	2.7208E5		

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

Groups	t-value	P-value
Rehabilitation sites		
Scar E, Scar B	Negative	
Scar E, Scar F	0.60405	0.557
Scar E, Scar C	1.6084	0.112
Scar E, Trench West	1.2879	0.225
Scar E, Trench East	0.94139	0.378
Scar B, Scar F	0.53137	0.611
Scar B, Scar C	1.5201	0.159
Scar B, Trench West	1.1959	0.26
Scar B, Trench East	0.86522	0.424
Scar F, Scar C	0.79432	0.472
Scar F, Trench West	0.60916	0.573
Scar F, Trench East	1.6531	0.133
Scar C, Trench West	0.23056	0.83
Trench West, Trench East	2.3344	**0.034**
Reference sites		
PBK03, PBK04	0.47801	0.678
PBK03, PBK07	0.517	0.669
PBK03, PBK08	1.1588	0.261
PBK03, PBR02	3.2724	**0.004**
PBK03, PBR01	4.54	**0.002**
PBK04, PBK07	1.2057	0.264
PBK04, PBK08	1.5665	0.15
PBK04, PBR02	4.2094	**0.001**
PBK04, PBR01	5.5137	**0.001**
PBK07, PBK08	0.87352	0.413
PBK07, PBR02	3.1256	**0.009**
PBK07, PBR01	4.4894	**0.001**
PBK08, PBR02	1.2984	0.181
PBK08, PBR01	2.393	**0.03**
PBR02, PBR01	1.4301	0.177

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 1 monitoring event in October 2023. ; αţÐ font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	7889.5	73.999	**0.001**
Site(Site type)	10	1093.5	2.2706	**0.019**
Residuals	108	5201.1		
Total	119	14211		

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

Groups	t-value	P-value
Rehabilitation sites		
Scar E, Scar B	1.5315	0.148
Scar E, Scar F	1.4805	0.158
Scar E, Scar C	0.35695	0.721
Scar E, Trench West	1.3826	0.199
Scar E, Trench East	0.18028	0.876
Scar B, Scar F	3.2652	0.007
Scar B, Scar C	1.788	0.093
Scar B, Trench West	0.14697	0.9
Scar B, Trench East	2.0344	0.058
Scar F, Scar C	2.4156	0.025
Scar F, Trench West	3.0404	0.013
Scar F, Trench East	2.1658	0.043
Scar C, Trench West	1.5631	0.154
Scar C, Trench East	0.21408	0.862
Trench West, Trench East	1.7554	0.095
Reference sites		
PBK03, PBK04	0.93003	0.37
PBK03, PBK07	0.21943	0.854
PBK03, PBK08	0.9137	0.399
PBK03, PBR02	3.8297	0.001
PBK03, PBR01	1.9322	0.056
PBK04, PBK07	0.99599	0.354
PBK04, PBK08	7.3326E-3	1
PBK04, PBR02	1.5954	0.129
PBK04, PBR01	1.042	0.326
PBK07, PBK08	0.98129	0.346
PBK07, PBR02	3.4395	0.001
PBK07, PBR01	1.9481	0.073
PBK08, PBR02	1.5487	0.137
PBK08, PBR01	1.0237	0.306
PBR02, PBR01	6.9911E-2	0.95

Table B-5: Univariate PERMANOVA table of results, comparing *Posidonia australis* epiphyte loads between rehabilitation and reference sites and among sites quantified during the round 1 monitoring event in October 2023. ; αţÐ font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	11.804	4.7964	0.063
Site(Site type)	10	25.531	5.229	**0.001**
Residuals	108	52.733		
Total	119	90.51		

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

Groups	t-value	P-value
Rehabilitation sites		
Scar E, Scar B	1.2153	0.298
Scar E, Scar F	2.4101	**0.049**
Scar E, Scar C	3.6546	**0.003**
Scar E, Trench West	2.1086	**0.047**
Scar E, Trench East	2.7869	**0.016**
Scar B, Scar F	3.4649	**0.008**
Scar B, Scar C	3.9878	**0.002**
Scar B, Trench West	4.2124	**0.002**
Scar B, Trench East	5.007	**0.001**
Scar F, Scar C	0.78335	0.806
Scar F, Trench West	4.944	**0.004**
Scar F, Trench East	5.4351	**0.002**
Scar C, Trench West	7.7211	**0.001**
Scar C, Trench East	8.6149	**0.001**
Trench West, Trench East	0.7746	0.53
Reference sites		
PBK03, PBK04	1.6521	0.141
PBK03, PBK07	3.1229	**0.011**
PBK03, PBK08	1.9451	0.087
PBK03, PBR02	0.89776	0.408
PBK03, PBR01	0.51651	0.649
PBK04, PBK07	1.8014	0.124
PBK04, PBK08	0.43701	0.736
PBK04, PBR02	0.41396	0.721
PBK04, PBR01	0.81409	0.459
PBK07, PBK08	1.268	0.282
PBK07, PBR02	1.7052	0.123
PBK07, PBR01	2.0772	0.066
PBK08, PBR02	0.7193	0.523
PBK08, PBR01	1.1015	0.322
PBR02, PBR01	0.33433	0.775

Table B-7: Results of Generalized Linear Models (GLM) for differences in *Posidonia australis* shoot densities in rehabilitation sites through time. Table gives degrees of freedom (df), Akaike Information Criterion (AIC), Likelihood Ratio Test (LRT) and P-values (Pr(>Chi). ; αţÐ font indicates a statistically significant result.

	df	AIC	LRT	Pr(>Chi)
Scar B				
Null		185.8042		
Monitoring round	1	177.0725	10.732	**0.001053**
Scar C				
Null		244.5654		
Monitoring round	1	246.5195	0.0459	0.8303
Scar E				
Null		183.6128		
Monitoring round	1	173.1876	12.425	**0.0004236**
Scar F				
Null		69.74405		
Monitoring round	1	70.00843	1.7356	0.1877
Trench East				
Null		155.9846		
Monitoring round	1	156.6731	1.311476	0.2521277
Trench West				
Null		167.3609		
Monitoring round	1	169.3013	0.0596	0.8072

Table B-8: PERMANOVA table of results, comparing seagrass composition between rehabilitation and reference sites quantified during the round 1 monitoring event in October 2023. ; αţÐ font indicates a statistically significant result.

Source of variation	df	SS	Pseudo-F	P-value
Site type	1	1239.6	16.821	**0.002**
Residuals	10	736.95		
Total	11	1976.6		