# Port Botany Post Construction Environmental Monitoring

## End of Project Report

EL1112046

Prepared for

Port Authority of New South Wales

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## Executive Summary

Penrhyn Estuary is a small, approximately ~80 ha waterway located adjacent to Port Botany. It holds great ecological importance as it includes saltmarsh, seagrass, mangroves, intertidal flats and it is frequented by migratory shorebirds. When the facilities at Port Botany were expanded there was a need to reclaim ~63 ha of Penrhyn Estuary. Given Penrhyn Estuary's ecological importance, the conditions of consent for development included a plan to enhance the remaining key ecological habitats within the estuary. The Penrhyn Estuary Habitat Enhancement Plan (PEHEP) focused on enhancing intertidal flats, saltmarsh, shorebird and seagrass habitat.

The key objectives of the PEHEP were to:

> Expand the existing shorebird habitat to continue to attract migratory shorebirds and potentially attract more shorebirds;

> Create seagrass habitat;

> Expand the area of saltmarsh habitat; and

> Provide controlled public access and minimise anthropogenic disturbances within the estuary.

Enhancement included a combination of creating and/or expanding areas of these habitats and restoration of some existing degraded habitat. Mangroves, weeds and introduced species were removed. Part of the estuary was re-shaped to accommodate these changes. An extensive area of foredune was levelled to create intertidal feeding and roosting habitat for key species of migratory shorebirds that previously used the estuary, and to potentially attract a greater number of shorebirds. New saltmarsh (an endangered ecological community) and seagrass habitat was created and directly affected *Posidonia australis* (a threatened seagrass) was transplanted to other areas in Botany Bay.

Monitoring plans were prepared to provide an assessment of the success of the PEHEP. These included plans for shorebirds, saltmarsh and seagrass (the focus of the PEHEP); benthos, to measure changes in the food source of shorebirds; and water quality, to verify that there was adequate tidal flushing of Penrhyn Estuary.

Cardno undertook the post-construction phase for the monitoring plans, which included annual interpretive reports of the monitoring results to identify trends in variables monitored, recommendations for further monitoring (including changes in monitoring protocol and reasons), and recommendations for management measures, remedial actions or implementation of contingencies. Post-construction monitoring durations were set based on reasonable timeframes within which success of the habitat enhancement works would be expected to be achieved. Post-construction monitoring has now been completed.

### Key Findings of Post-construction Monitoring

#### *Shorebirds*

The area of shorebird feeding and roosting habitat in Penrhyn Estuary was increased four-fold as part of the PEHEP. The original area of intertidal flats of 3.4 ha was increased to a total of 13.8 ha, which included reshaping of 1.7 ha of the existing area and creation of a new 10.4 ha area. The area of new roosting islands is 0.2 ha.

During the five year period of post-construction monitoring, the Red Knot and Curlew Sandpiper were rarely recorded in Penrhyn Estuary, and seen in only one or two years respectively. The other four key species monitored were present in nearly every post-construction monitoring year. Only the Pacific Golden Plover and Red-necked Stint reached their target counts, and these occasions were only in the first half of the post-construction monitoring period. At that time, peak counts of Double-banded Plover in Penrhyn Estuary also came close to the targets. In the last few years of post-construction monitoring, peak counts of shorebirds were generally declining, and in 2018 were at their lowest ever.

For key species other than Red-necked Stint or Double-banded Plover monitoring showed similar patterns of decline to Penrhyn Estuary in at least one or more sites (within and external to Botany Bay). These results suggest larger scale declines for shorebirds generally from threats that were independent of construction of the new port facilities.

#### *Saltmarsh*

The total area of saltmarsh in Penrhyn Estuary has more than doubled the pre-rehabilitation extent. Monitoring in 2016 indicated that species diversity in saltmarsh remained similar to baseline levels, while abundance and condition generally increased following the rehabilitation works. Importantly, the distribution

and abundance of newly planted saltmarsh vegetation along the northern and southern shorelines of Penrhyn Estuary has continued to grow during post-construction surveys. Areas that received transplanted saltmarsh have maintained saltmarsh cover and diversity. In terms of ecological function, epifaunal assemblages have recolonised areas that were disturbed during the rehabilitation works and have recruited into newly planted areas of saltmarsh. In general, although most targets were met, a few areas did not respond as expected, including areas that were transplanted with saltmarsh vegetation and areas that were cleared of mangroves and weeds.

***Seagrass***

There was a major decline in seagrass area, from approximately 65,821 $m^2$ in 2002 prior to construction works commencing, to 698 $m^2$ in February 2007. The five post–construction monitoring surveys at Foreshore Beach recorded a bed of *Halophila* spp. that extended along the beach; but notably, it was much narrower in width than the original bed of *Zostera muelleri* subsp. *capricorni* and more discontinuous. The extent of *Halophila* spp. in the 2017 survey was at its smallest for the entire period of post-construction monitoring. Erosion at Foreshore Beach during the post-construction period resulted in sedimentation of beds of seagrass and is likely to have been a factor contributing to the observed decline. These impacts were probably exacerbated by beach nourishment works, which occurred twice during post construction, as required, to try to mitigate beach and vegetation erosion. Construction of three groynes at Foreshore Beach in 2016 had arrested erosion and hence the potential for sediment to be mobilised across the seagrass habitat; however only one survey has been done as part of the PEHEP monitoring program after these works were completed, and therefore potential benefit of these groynes to seagrass has not been confirmed.

In post-construction surveys in the Rehabilitation Area (flushing channel and inner estuary), seagrasses appeared to prefer shallow, marginal intertidal habitat over the deeper central area, but any observed colonisation was sporadic and short-lasting. This may have been due to a number of factors including but not limited to: turbidity and associated available light, seabed movement/shifting, and the accumulation of a deep layer of fine, silty sediments over the seabed in deeper areas. The occurrence of *Z. muelleri* subsp. *capricorni* had all but disappeared in 2017.

Overall, the experiment investigating transplanting of *Posidonia australis* from Foreshore Beach to Quibray Bay was successful, particularly for whole or trimmed plants, rather than plants with rhizomes only. The last survey of one of the two main transplant sites in Quibray Bay (in November 2013) recorded decreases in shoot densities of plants, which suggests that bare substrata may not have been the most appropriate site for transplantation.

***Benthos***

In intertidal sand flats, the average abundance of macroinvertebrates (all species) decreased at Penrhyn Estuary and did not reach its post-construction target. However, abundance at both of the Quibray Bay reference sites also decreased. Hence, the significant change was not attributed to construction, and was likely due to factors external to the project. There was a slight increase in biomass of macroinvertebrates in the intertidal sand flats at Penrhyn Estuary after construction, but this was not statistically significant.

In intertidal mud flats there was a general decrease in the abundance of macroinvertebrates both in Penrhyn Estuary and at reference sites. Macroinvertebrate abundances in mud habitat was significantly lower in Penrhyn Estuary after habitat enhancement, but not significantly different to abundances at reference sites. This suggests that enhancement works may have had an effect on macrofaunal abundance in mud habitat. Mean biomass in intertidal mud flats increased in Penrhyn Estuary after habitat enhancement works, while there were decreases at the reference sites. This suggests that habitat enhancement may have had the effect of increasing macroinvertebrate biomass within Penrhyn Estuary in mud flat habitats. This effect did not appear to be statistically significant, most likely because there was high variability among surveys.

***Water Quality***

Comparisons of the trends over three years of the post-construction water quality monitoring results (2013-2015) identified few areas of significant variance in water quality for the physico-chemico parameters measured. Variance in conductivity and pH values was identified for the post-construction data, but this was not of concern given the results were within expected ranges.

Some exceedances of ANZECC (2000) trigger values were recorded, although exceedances of suspended solids were much reduced during 2014 and 2015 compared with 2013. The exceedances of suspended solids concentrations were below levels recorded in pre-construction monitoring at estuary and control sites. Nutrient concentrations in excess of trigger values generally followed periods of significant rainfall and were likely an indication of long recovery times of water quality throughout Botany Bay following these events.

Trends for nutrient concentrations indicated that modelled nutrient concentrations prepared for the port expansion Environmental Impact Study (EIS) were conservative, and predicted concentrations had not been consistently exceeded in post-construction monitoring.

Wet weather monitoring indicated that the flushing rates in Penrhyn Estuary following high catchment outflows were within reasonable timeframes, reinforcing the positive results of the dry weather monitoring.

### Assessment against PEHEP Success Criteria

There were three criteria for determining success or failure of the habitat enhancement works:

> Criteria 1 - Shorebird Usage;

> Criteria 2 - Seagrass Area; and

> Criteria 3 - Saltmarsh Area.

The PEHEP indicated that success or failure of enhancement of seagrass and saltmarsh habitat was to be determined in **2016** and in the case of shorebirds, in late **2018**.

The monitoring outcomes for Penrhyn Estuary have been assessed against the success criteria for shorebirds, seagrass and saltmarsh habitat in **Table ES1**.

Table ES1. Outcomes (in yellow) for the three key components of the habitat enhancement works

| Success Criterion | Impact | | | Comment |
|---|---|---|---|---|
| | Positive | No change | Negative | |
| 1. Shorebird Usage (in Penrhyn Estuary) | Increase in use of the estuary | No change in shorebird usage of the estuary | Reduction in shorebird usage of the estuary | Targets for primary indicators (i.e. counts of key species) not met and declines continuing, but declines for most key species are consistent with patterns observed in reference areas. Secondary indicators (habitat area and quality) show increase in areas of suitable habitat and utilisation of feeding and roosting habitats by shorebirds. |
| 2. Seagrass Area (in the project area) | Increase in cover along Foreshore Beach and the estuary channel | No net loss of seagrass cover/quality along Foreshore Beach and the estuary channel | Reduction in area of seagrass cover along Foreshore Beach and the estuary channel | Trend of decline at Foreshore Beach commenced prior to construction of port facilities so that the meadow was “no longer a functioning seagrass meadow”. |
| 3. Saltmarsh Area and Condition (in Penrhyn Estuary) | Increase in saltmarsh habitat in the estuary | No net loss of saltmarsh area/quality in the estuary | Reduction in area of saltmarsh habitat in Penrhyn Estuary | Area of saltmarsh more than double the previous area, and condition generally improved from baseline and equivalent to reference areas. |

#### *Success Criteria 1 - Shorebird Usage*

The peak shorebird counts were the key indicators for determination of success or failure of enhancement of shorebird habitat. Other (secondary) indicators that monitored habitat quality assisted with interpretation of the level of shorebird usage.

In 2018, peak counts of shorebirds in Penrhyn Estuary were below targets and at the lowest levels seen during post-construction surveys. There had been a trend of declining peak counts during the latter years of post-construction monitoring. Importantly, declines in peak counts of four of the key species monitored were not confined to Penrhyn Estuary, as similar patterns were observed for these species in some, if not all, reference sites in Botany Bay or further afield. For the other two species, Red-necked Stint and Double-banded Plover, broader declines were not noted but given these species were monitored in only one reference location, interpretation is limited. Given trends varied (i.e. stability or declines) among locations for those species where monitoring was done at more than one reference location, it is likely that a only single reference location provides a biased interpretation of overall trends outside of Penrhyn Estuary. Hence, the weight of evidence indicates that migratory shorebirds are generally responding negatively to unknown threats at a larger scale than Penrhyn Estuary, and when reference areas are considered, there has been no change in shorebird usage of the estuary.

The secondary indicators monitored generally suggested there are no problems with the quality of feeding or roosting habitat that could be deterring shorebirds from utilising Penrhyn Estuary. The area of intertidal feeding areas (including saltmarsh) has increased six-fold, roosting habitat has been created and infauna on the flats (i.e. a food source of shorebirds) has reached most of the baseline targets. A significant decrease in abundance in benthos in mud habitat was noted in Penrhyn Estuary after habitat enhancement works but not at reference locations, which suggests the enhancement works may have had an effect. However, this was unlikely to have contributed to the declines in shorebirds given mud flat only makes up a small proportion of the total intertidal feeding area for shorebirds in Penrhyn Estuary. Further, despite low peak counts, shorebirds have been observed actively feeding and roosting in the enhanced habitats of Penrhyn Estuary in all post-construction years.

Notwithstanding the broader declines to key species due to external factors, it is clear that migratory shorebirds do utlilise Penrhyn Estuary to a limited extent for feeding and roosting and as such, it continues to remain an important area to these species as well as for other birds. As such, it will be important to maintain the quality of shorebird habitat in Penrhyn Estuary into the future, particularly as utilisation of the area could improve over time or because the quality of other areas currently available to shorebirds in other parts Botany Bay could potentially decline.

***Success Criteria 2 – Seagrass Area***

*Foreshore Beach*

Comparison of pre- and post-construction monitoring over the past 15 years identified a major decline in seagrass area at Foreshore Beach immediately prior to construction works commencing. Further, there was a gradual decline of the main seagrass meadow at Foreshore Beach, comprised of *Halophila* spp., throughout post-construction monitoring. Importantly, as the worst of the decline commenced prior to construction of the port facilities it is considered that this was likely to be unrelated to the construction works. The observation that *Halophila* spp. had consistently been the dominant seagrass at Foreshore Beach during post-construction surveys also suggests that the process of succession had either been very slow or arrested. Notwithstanding the general decline of the main bed of *Halophila* spp., post-construction monitoring of the small isolated patches of remnant *P. australis* and *Z. muelleri* subsp. *capricorni* at Foreshore Beach has indicated general persistence of these species and, importantly, that post-construction conditions are suitable for these species to survive. In late 2016, the Port Authority of New South Wales constructed three groynes along Foreshore Beach to stabilise sand at the beach. There were encouraging signs in 2017 that the groynes have addressed the ongoing issue of sediment mobilisation, with new, high density patches of *Z. muelleri* subsp. *capricorni* becoming established in the south-eastern parts of the site.

*The Estuary Flushing Channel and Inner Estuary*

Colonisation of the estuary channel by seagrass should have been unaffected by the problems affecting seagrass at Foreshore Beach. However, there were no signs that seagrass was successfully colonising the channel. Although some *Halophila* spp. plants occasionally colonised the channel, they did not persist. This may be due to a number of factors including, but not limited to: poor supply of seed, turbidity and reduced availability of light, seabed movement, and the accumulation of a deep layer of fine, silty sediments over the seabed in deeper areas. The occurrence of *Z. muelleri* subsp. *capricorni* had all but disappeared in 2017.

Patches of *Halophila* spp. and *Z. muelleri* subsp. *capricorni* were recorded in post-construction surveys in the inner estuary with variable occurrence. On each occasion, they were present in isolated, sparse occurrences over short periods of time. Variable colonisation and lack of persistence of seagrass in intertidal areas is normal given the harsh environment.

***Success Criteria 3 – Saltmarsh Area***

Of the three key habitats in Penrhyn Estuary, enhancement of saltmarsh was the most successful and the only one to show a ‘positive’ outcome with respect to the success criteria. Not only has the area of saltmarsh in Penrhyn Estuary doubled compared to that present prior to the habitat enhancement works, but there has also been an improvement in its condition and quality. Activities to reduce weed and mangrove encroachment and manage access (i.e. potential for trampling) have, and will continue to be, important for maintaining its condition. However, it is thought that good water quality has probably also contributed to saltmarsh health.

The modelled pre- and post-enhancement flushing times for the inner estuary (i.e. where the saltmarsh occurs) were expected to increase post-construction, and were in the order of 1.5 to 3 days, compared to less than one day pre-construction. Despite the increased flushing times, it was predicted that water quality would improve. Post-construction monitoring of nutrients and flushing times were in good agreement with

modelled values, confirming water quality (particularly the potential for eutrophication) in the inner estuary has improved.

The positive outcome for saltmarsh provides a benefit to shorebirds, given they forage in this habitat, but it also has broader implications in relation to State and Commonwealth conservation goals. In NSW, *Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions* is listed under the NSW *Biodiversity Conservation Act 2016* as an endangered ecological community (EEC). Further, saltmarsh in Penrhyn Estuary also meets the key diagnostic characteristics and condition thresholds of the ecological community *Subtropical and Temperate Coastal Saltmarsh,* listed as vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act).

Increasing its area locally increases the resilience of this ecological community, and ongoing management of disturbances and potential threats is consistent with recommended activities for assisting this community in its State and Commonwealth listings.

### Need for Offsetting

The monitoring plans were designed to provide information about the performance of the habitat enhancement works and, in the case of a 'negative impact' outcome, whether an offset package for that particular habitat would be required.

As a result of the significant decline in seagrass area and quality prior to commencement of the PEHEP, and the fact that there were only sparse and isolated seagrass patches in the project area at the commencement of post-construction monitoring, advice had been given in the *Alternative Compensatory Habitat Options (ACHO) Package* (SPC 2008), that it was not considered warranted to implement alternate compensatory in the event of failure of the seagrass enhancement works.

The PEHEP has had a positive impact on saltmarsh.

Although some of the data suggests that port operations may be deterring some shorebird species, this was unable to be confirmed. Even if this were the case, it would be very difficult to discriminate as to which aspect of operations were problematic. Notwithstanding this, there is no question regarding the quality of feeding and roosting habitat in Penrhyn Estuary created or enhanced as part of the PEHEP despite broad declines to many species due to external factors, and it is clear that migratory shorebirds continue to utlilise Penrhyn Estuary to a limited extent for feeding and roosting. As such, given that Penrhyn Estuary continues to remain an important area to these species as well as other birds and that we cannot determine unequivocally whether port operations have contributed to declines in utilisation in addition to the effects of the broader declines observed in the East Asian-Australasian Flyway, it is considered that offsetting is not required

### Recommendations

#### Shorebirds

With the completion of the Shorebird Monitoring component of the PEHEP, regular maintenance, and monitoring of conditions, is required to retain the quality of Penrhyn Estuary as habitat for migratory shorebirds. This could involve a Plan of Management (PoM) for Penrhyn Estuary for its future governance. The following recommendations for maintenance would be fit for purpose for inclusion in a PoM to maintain the quality of shorebird habitat at a desirable level.

***Maintenance of habitat quality***

*Roosting islands*

The main roosting island (Big Island) requires that its surface is maintained so that there is no vegetation apart from low profile saltmarsh at its shore. It is recommended that this island is regularly monitored and maintained to ensure it is kept clear of vegetation.

*Saltmarsh habitat*

The low profile saltmarshes of *Sarcocornia quinqueflora* and *Sporobolus virginicus* provide suitable roosting habitat around much of the fringe of Penrhyn Estuary by providing some shelter from strong winds while enabling the birds to look over the top of the vegetation for the approach of impending danger, such as terrestrial or avian predators. Shorebirds may also feed in saltmarsh areas.

Taller saltmarsh plant species such as *Suaeda australis*, and *Juncus kraussii* are a deterrent to shorebirds given they obstruct the view of potential predators. These plants generally grow in the upper intertidal zones which are generally not frequented by shorebirds, however, in Penrhyn Estuary, *Suaeda australis* can

occasionally recruit to the seaward margin of saltmarsh areas, presenting a deterrent. It is recommended that this species is regularly searched for and removed from the seaward margin of saltmarsh areas.

Another tall species that may seed into the saltmarsh is *Casuarina glauca*. It is recommended that this species is also regularly searched for and removed from any of the saltmarsh areas. Further, *Casuarina glauca* stands grow along the landward edge of the saltmarsh, from the eastern side of Springvale Channel, along the fringing saltmarsh to Corner Marsh. It is also around the Bird Hide and surrounds. As the heights of these stands increases it is likely to deter shorebirds from some of the roosting and feeding areas currently utilised. Consideration of how best to manage this potential deterrent is recommended for inclusion in the PoM.

*Tidal flats*

Mangroves may seed into the tidal flats which are feeding areas for shorebirds. As indicated above, tall plants such as mangroves are a deterrent to shorebirds given they obstruct the view of potential predators. It is recommended that mangroves are regularly searched for and removed from the tidal flats.

***Monitoring***

*Deterrents*

1. The maintenance of habitat quality as recommended above would require regular checking of conditions against a benchmark level and the actual maintenance would best be done at times outside of the peak period of occupation of the northern hemisphere migratory shorebirds. Hence, checking against benchmarks and maintenance would best be done annually between July and August, i.e. within the preceding two months prior to the arrival in September of northern hemisphere migratory shorebirds with spot checks for predator activity throughout the peak season (September to April).

**Seagrass**

***Monitoring***

The following, if implemented, would improve understanding of seagrass habitat condition at Foreshore Beach and in the Rehabilitation Area (i.e. estuary channel and inner estuary):

1. Three additional annual surveys to determine whether the high density patches of *Z. muelleri* subsp. *capricorni* in the south-eastern parts of Foreshore Beach that appeared immediately after construction of the three groynes continue to expand and to assess whether seagrass habitat at Foreshore Beach generally improves due to modification of littoral transport along the beach;
2. A survey in the Rehabilitation Area at a time between five and 10 years after the last survey done (2017) to determine long-term trends in seagrass colonisation in the inner Penrhyn Estuary and flushing channel.

Further, given there was some concern about transplanted *P. australis* at one of the transplant sites in Quibray Bay, it would be useful to:

3. Revisit the transplant sites to confirm long-term success or failure of transplanted seagrass

**Saltmarsh**

***Monitoring***

1. In addition to regularly removing tall saltmarsh plants so as to retain a low profile for shorebirds utilising Penrhyn Estuary, it is also recommended that saltmarsh condition is monitored to ensure that the quality of this habitat is maintained and does not deteriorate. Inspections should be conducted by an appropriately qualified expert and with reference to previous Penrhyn Estuary saltmarsh monitoring reporting, with the aim of identifying any noticeable deterioration of the saltmarsh community. Biennial monitoring would be sufficient given it would allow for timely intervention, were it necessary, for the removal of threats that had been identified as having caused a deterioration in the condition of saltmarsh.

## Glossary

| Term or Acronym | Definition |
|---|---|
| Baseline | The value or magnitude of a nominated indicator prior to development or other change |
| Benthic | Living on or in the seabed |
| Benthos | The collection of organisms attached to or resting on the bottom sediments (i.e. epifauna) and those which burrow into the sediments (i.e. infauna) |
| Biomass | The mass of an individual or group of organisms |
| Construction | Refer to the phase of works for construction of the rehabilitated habitat at Penrhyn Estuary |
| Contingencies | Processes developed in the event that adverse effects were identified following implementation of the works |
| EIS | Environmental Impact Study |
| Enhancement | Refers to the alterations to shorebird, seagrass and saltmarsh habitats in Penrhyn Estuary associated with the PEHEP |
| Epifauna | The collection of organisms attached to or resting on the bottom sediments or on saltmarsh plants |
| Eutrophic | Waters rich in phosphates, nitrates, and organic nutrients that promote a proliferation of plant life, especially algae, the decay of which depletes shallow waters of oxygen in summer. |
| Flushing Channel | The entrance channel to Penrhyn Estuary |
| Foredune | The dune ridge that runs parallel to the shore of the estuary |
| Groyne | Structures built on Foreshore Beach to arrest sediment transport |
| Infauna | Aquatic animals living within the sediment |
| Intertidal | The portion of shoreline between low and high tide marks, that is intermittently submerged |
| LAT | Lowest Astronomical Tide |
| Macrofauna, Macrobenthos | Organisms associated with sediment and retained in a sieve of 1.0 mm mesh aperture |
| Macroinvertebrates | Invertebrates animals such a segmented worms, crustaceans and molluscs that are retained in a sieve of 1.0 mm mesh aperture |
| Microchannels | Small channels on intertidal flats |
| Migratory | In this report, refers to shorebirds that that spend only the warmer part of the year in Australia, usually to feed and nest |
| MSMP | Monitoring Services Management Plan |
| Offsetting | Processes to be instigated in the event that the PEHEP was unsuccessful |
| PEHEP | Penrhyn Estuary Habitat Enhancement Plan |
| PAR | Photosynthetically Active Radiation, the portion of the light spectrum that plants utilise to photosynthesize |
| Peak counts | The maximum count of birds on any one occasion during a survey period |
| Physico-chemico parameters | Various measures of water quality |
| Post-construction | Refers to the phase after construction of the rehabilitated habitat at Penrhyn Estuary |
| Pre-construction | Refers to the phase prior to construction of the rehabilitated habitat at Penrhyn Estuary |
| QA/QC | Quality Assurance/ Quality Control |
| Reclamation | Subtidal habitat converted to terrestrial habitat for the expansion of Port Botany |
| Rehabilitation Area | Aquatic habitat created during the expansion of Port Botany that links Penrhyn Estuary with the water of Botany Bay |
| Reference area | An area in another part of Botany Bay or further afield at which data were collected for comparison with data in Penrhyn Estuary |

| | |
|---|---|
| Saltmarsh | Saltmarshes are terrestrial salt tolerant ecosystems dominated by halophytic plant such as grasses, shrubs and herbs. They largely occur in the intertidal zone between land and the sea and are covered by salty or brackish water for at least some of the time. |
| Seagrass | Aquatic flowering plants found mainly in the shallow subtidal and intertidal areas of estuaries and lagoons. For this report, refers to three main species: *Halophila* spp. (including *Halophila ovalis* and *Halophila decipiens*, both known as 'paddleweed'), *Zostera muelleri* subsp. *capricorni* ('eelgrass') and *Posidonia australis* ('strapweed') |
| Shorebird | Any of numerous species of birds that use nearshore habitats such as rocky shores, beaches, intertidal flats, saltmarshes and coastal lagoon to roost, feed or nest. A subset of shorebirds is migratory. |
| Substratum | The seabed type |
| Subtidal | Waters below the low-tide mark |
| Success Criteria | Criteria for shorebird, seagrass and saltmarsh habitat used to determine the success or failure of the PEHEP |
| Target | The aspirational value or magnitude of a nominated indicator |
| Transplanted | Refers to *Posidonia australis* plants moved from Penrhyn estuary to Quibray Bay |
| Turbidity | A measure of the clarity of water |

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# 1 Introduction

## 1.1 Background

### 1.1.1 The Port Botany Expansion Project

Sydney Ports Corporation expanded facilities at Port Botany by creating 1,850 m of additional wharf face, five new shipping berths, berth boxes and a public boat ramp. The project, worth $515 million, was completed in 2011 and reclaimed ~63ha of Botany Bay.

Adjacent to Port Botany is Penrhyn Estuary, a small, approximately ~80 ha waterway located to the north of Brotherson Dock. This estuary is 'artificial' and was created during the reclamation of the Botany foreshore between 1975 and 1978. Notwithstanding this, it holds great ecological importance as it includes saltmarsh (an endangered ecological community), seagrass, mangroves, and intertidal flats, and it is frequented by migratory shorebirds. It also holds local ecological importance given the extent of foreshore development in northern Botany Bay.

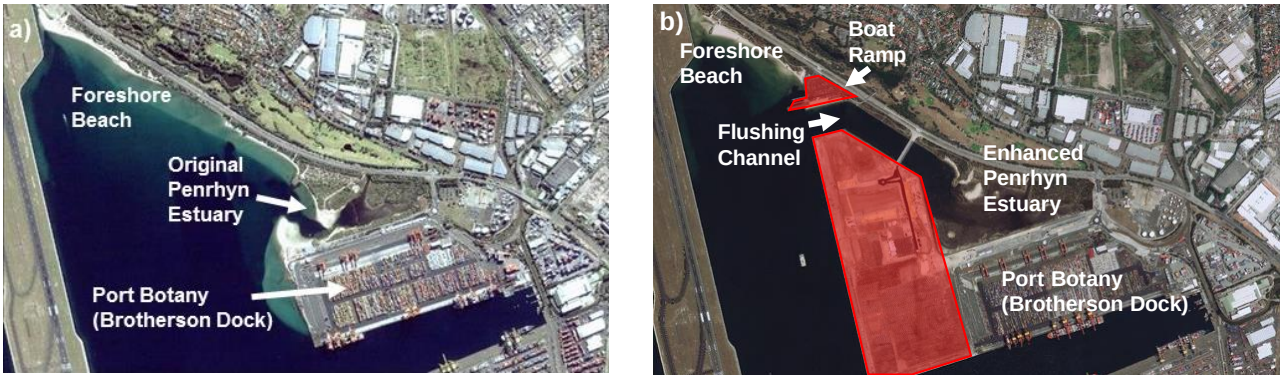


Figure 1-1 (a) Port Botany's Brotherson Dock and Penrhyn Estuary in 2008 prior to expansion of port facilities, and (b) in 2012, 18 months after completion of the new port facilities (in red).

As part of the Port Botany Expansion Project, Penrhyn Estuary was partially enclosed to accommodate the new container terminal (**Figure 1-1**).

### 1.1.2 The Penrhyn Estuary Habitat Enhancement Plan (PEHEP)

Some of Penrhyn Estuary needed to be reclaimed for the port's expansion. Given Penrhyn Estuary's ecological importance, the conditions of consent for the port expansion included a plan to retain and enhance the remaining key ecological habitats within the estuary. The plan, called the Penrhyn Estuary Habitat Enhancement Plan (PEHEP), focused on enhancing intertidal flats, saltmarsh, shorebird and seagrass habitat.

The key objectives of the PEHEP were to:

> Expand the existing shorebird habitat, to continue to attract migratory shorebirds and potentially attract more shorebirds;

> Create seagrass habitat;

> Expand the area of saltmarsh habitat; and

> Provide controlled public access and minimise anthropogenic disturbances within the estuary.

Enhancement included a combination of creating and/or expanding areas of these habitats and restoration of some areas of existing degraded habitat. Mangroves, weeds and introduced species were removed. Part of the estuary was reshaped to accommodate these changes. An extensive area of foredune was levelled to create intertidal feeding and roosting habitat for key species of migratory shorebirds that previously used the estuary, and to potentially attract a greater number of shorebirds. New seagrass habitat was created and directly impacted *Posidonia australis* (a threatened seagrass) was transplanted to other areas in Botany Bay. The layout of habitats in the enhanced estuary is given in **Figure 1-2** and further details of its construction can be found in the document entitled *Penrhyn Estuary Habitat Enhancement Plan* (SPC 2007).

The Penrhyn Estuary habitat enhancement works was designed to provide the following ratios of compensatory habitat to offset the direct impacts associated with the Port Botany expansion:

> Shorebird feeding habitat – approximately four times the previous shorebird feeding habitat;

> Seagrass habitat – approximately seven times the area of seagrass to be lost, which would nearly double the previous area of seagrass in the project area; and

> Saltmarsh habitat – approximately six times the area of saltmarsh to be lost, which would more than double the previous area of saltmarsh in the estuary.

The areas of habitat to be newly created and their levels (relative to Lowest Astronomical Tide, LAT) are given in **Table 1-1**.

Table 1-1 Habitat design features in terms of areas and levels

| Habitat | Design Levels (LAT) | Area of Habitat | | | |
|---|---|---|---|---|---|
| | | Existing Area (ha) | Area Lost (ha) | New Area (ha) | Total Area (ha) |
| Roosting Islands | 2.0 m | 0 | 0 | 0.2 | 0.2 |
| Intertidal Flats | 0.3 to 1.4 m | 3.4 | 1.7 to be reshaped | 10.4 | 13.8 |
| Saltmarsh | 1.4 to 2.0 m | 1.4 | 0.4 | 2.4 | 3.4 |
| Seagrass | -1.0 to 2.0 m | 1.1* | 0.9 | 6.3 | 6.5 |

*There was an additional existing area of 3.6 ha of seagrass outside Penrhyn Estuary, to the west of the new boat ramp.

A key challenge to designing the new saltmarsh, seagrass, intertidal flats and shorebird roosting habitats in the PEHEP was determining appropriate levels (relative to LAT) for the habitats based on comparable sites elsewhere. These design criteria were important to maximising the quality and functionality of the habitats. Within each habitat type a range of elevations were considered to ensure that niches of sufficient size would be available to accommodate future changes in environmental conditions (water quality or sea level). In addition, the sediment type and plants proposed for each habitat were also considered carefully. Walls along the boundary of the new port terminal were constructed to protect the estuary from operational noise, light and movement.

Another key challenge was to address water quality given ambient concentrations of some nutrients (i.e. total phosphorous (TP) and total nitrogen (TN)) in the inner estuary exceeded the ANZECC trigger values (ANZECC 2000) for ecological protection prior to enhancement works, and noting that the port expansion had potential to affect tidal flushing. The reclaimed area partially enclosed Penrhyn Estuary and restricted tidal flows to a new 130 m wide channel, whereas it was previously open to Botany Bay. The PEHEP proposed to treat stormwater and extract groundwater, and numerical modelling was used to determine whether the flushing times achieved for the proposed design would be detrimental to water quality (SPC 2007).

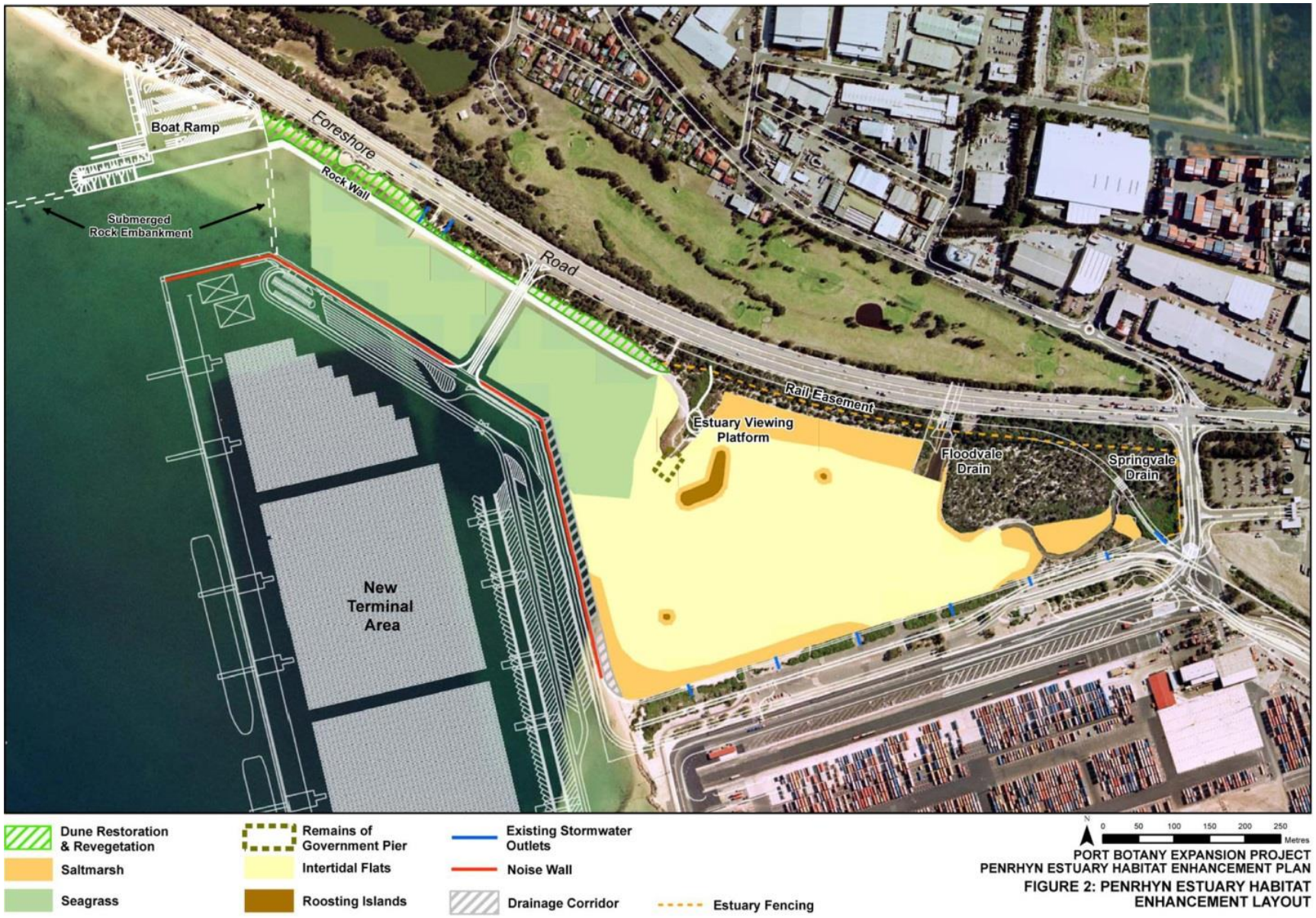


Figure 1-2 Layout of proposed enhanced habitats in Penrhyn Estuary (Source: PEHEP).

#### *1.1.2.2 Monitoring for the PEHEP*

Seven monitoring plans were prepared in consultation with government agencies to provide an assessment of the success of the PEHEP. The objectives for each of the monitoring plans are given below:

> The Shorebird Monitoring Plan aimed to:

- Monitor the numbers and species composition of shorebirds found in Penrhyn Estuary following the habitat enhancement works and assess changes;
- Assess the feeding behaviour of shorebirds in Penrhyn Estuary following habitat enhancement to determine habitat usage patterns;
- Monitor the effect of disturbance in Penrhyn Estuary, pre- and post-expansion, on the behaviour of shorebirds; and
- Monitor disturbance and predation in the estuary, and assess the effectiveness of secure access restriction measures.

> The Benthos Monitoring Plan aimed to:

- Monitor changes in benthic invertebrate communities in existing and new intertidal/shallow subtidal habitats in terms of their impacts on food items for shorebirds;
- Assess changes in benthic communities in different feeding sub-habitats used by shorebirds. Based on results from pre-enhancement surveys that indicated no differences in benthic community assemblages in sub-habitats (microchannels) compared to mud and sand flats, further investigations of sub-habitats was omitted from post-enhancement comparisons; and
- Assess the sustainability of created habitats with respect to their provision of food items for shorebirds.

> The Saltmarsh Monitoring Plan aimed to:

- Monitor new, retained and altered saltmarsh habitats within Penrhyn Estuary and reference locations during and after habitat enhancement; and
- Assess the performance of all saltmarsh habitats with respect to their ability to sustain abundance and diversity through time.

> The Seagrass Monitoring Plan aimed to:

- Map the distribution and measure the ecological characteristics of seagrass along Foreshore Beach and in the Rehabilitation Area; and
- Measure the success of transplanting *Posidonia australis* into Quibray Bay.

> The Water Quality Monitoring Plan aimed to:

- Monitor the flushing of Penrhyn Estuary via monitoring of physico-chemical water quality parameters and assess the potential for eutrophic conditions to form.

> The Sediment Monitoring Plan aimed to:

- Establish baseline surface topography (landform) for future relative comparison;
- Measure any change in surface topography (landform) due to the movement or displacement of sediments through hydrodynamic processes and/or scour and erosion;
- Determine the need to remove/relocate any excess build-up of sediments;
- Determine the need for maintenance replenishment/nourishment due to loss or displacement of sediments;
- Identify potential risks to the sustainability of seagrass and/or saltmarsh areas; and
- Identify the need for alternative remediation actions/works due to unexpected or unwanted changes to the area.

> The Groundwater Monitoring Plan aimed to:

- Measure any change in groundwater levels as a result of the Port Botany Expansion project.

Cardno undertook the post-construction phase for the monitoring plans above apart from the 'Sediment' and 'Groundwater' monitoring, which was done by other consultants. Post-construction monitoring included annual interpretive reports which included analysis of monitoring results to identify trends in variables monitored, recommend further monitoring (including changes in monitoring protocol and reasons) and recommend management measures, remedial actions or contingencies, as required.

Post-construction monitoring durations were set based on reasonable time periods within which success of the habitat enhancement works would be expected to be achieved. Post-construction monitoring for all plans has now been completed (see **Table 1-2)**.

Table 1-2 Years in which post-construction monitoring has been undertaken for each of the programs

| Program | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|
| **Shorebirds** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Benthos** | ✓ | ✓ | ✓ | | | | |
| **Saltmarsh** | ✓ | ✓ | ✓ | | ✓ | | |
| **Seagrass** | ✓ | ✓ | ✓ | ✓ | * | ✓ | |
| **Water Quality** | ✓ | ✓ | ✓ | ✓ | | | |

* Note that additional (unscheduled) seagrass surveys were completed in June, September and December 2016 for Ward Civil & Environmental Engineering Pty Ltd for the *Foreshore Beach Stabilisation Project* and these data were presented as part of the 2017 Seagrass Annual Monitoring report

#### *1.1.2.3 Alternative Compensatory Habitat Options*

It was important that the PEHEP had a suitable means of determining its success or failure. Success of the Penrhyn Estuary habitat enhancement works was to be determined by:

> Shorebird use of the Penrhyn Estuary;

> Area and quality of seagrass in the project area; and

> Area and condition of saltmarsh in Penrhyn Estuary.

These components were chosen as the indicators for success as they were the focus for the works and the main objectives of the habitat enhancement. These three components have been reported against the potential outcomes of a positive, negative or no impact (**Table 1-3**). Whilst the habitat enhancement works were designed to achieve a 'positive impact' outcome, the PEHEP indicated that a 'no impact' outcome would also be considered as a success given it would indicate there had been 'no net loss' in the area or quality of these habitats or their biota.

Table 1-3 Potential outcomes for the three components of the habitat enhancement works

| Impact | Outcome for indicator | | |
|---|---|---|---|
| | **Shorebird use in Penrhyn Estuary** | **Area and quality of seagrass in the project area** | **Area and condition of saltmarsh in Penrhyn Estuary** |
| Positive | Increase in use of the estuary | Increase in cover along Foreshore Beach and the estuary channel | Increase in saltmarsh habitat in the estuary |
| None | No change in shorebird usage of the estuary | No net loss of seagrass cover/quality along Foreshore Beach and the estuary channel | No net loss of saltmarsh area/quality in the estuary |
| Negative | Reduction in shorebird usage of the estuary | Reduction in area of seagrass cover along Foreshore Beach and the estuary channel | Reduction in area of saltmarsh habitat in the estuary |

Failure of one of the habitat components was not necessarily linked to the failure of another habitat component. Therefore, success was assessed separately for each of these criteria. In the case of a 'negative impact' outcome, the PEHEP indicated that offsetting for that habitat would be required, as per Condition B2.32 of the NSW Department of Planning consent for the Port Botany Expansion (DA-494-11-2003-i).

Offsetting would involve additional funding for alternative compensatory habitat as outlined in the document entitled *Port Botany Expansion - Alternative Compensatory Habitat Options (ACHO) Package* (SPC 2008). It is understood that the selection of projects as alternative compensatory habitat would require a detailed feasibility and selection study at the time of trigger, were one to occur.

## 1.2 Aims of this Report

This 'End of 'Project' report summarises the results of the post-construction monitoring and assesses the PEHEP against nominated 'success criteria' that had been chosen to determine whether the key objectives of the PEHEP had been met, or whether contingency measures and compensation plans are required to be implemented.

# 2 Key Findings of Post-construction Monitoring

This section provides a summary of results of the shorebird, benthos, saltmarsh, seagrass and water quality post-construction monitoring programs. The full list of reports produced for each program are given in **Appendix A**. The results of the sediment and groundwater post-construction monitoring programs are reported elsewhere.

## 2.1 Shorebirds

Post-construction shorebird surveys have been conducted since 2012 at Penrhyn Estuary and associated reference sites. These included fortnightly surveys at low and high tide during the off-peak season (April – August) and weekly surveys for the peak season (September – March, i.e. when the northern hemisphere migrants are most likely to be present). Low tide counts were an indicator of shorebirds using feeding habitats at a particular location and high tide counts were an indicator of shorebird utilisation of roosting habitat.

The area of available shorebird feeding and roosting habitat was increased as part of the PEHEP. The existing area of intertidal flats of 3.4 ha was increased four-fold to around 13.8 ha, which included reshaping of 1.7 ha of the existing area and 10.4 ha of new area (see **Table 1-1** in **Section 1.1.2**). Shorebirds were observed foraging on intertidal flats in post-construction surveys. Most of the newly created intertidal area is sand flat but the total area includes some original sand flat and mud flat. Shorebirds also potentially feed in saltmarsh habitat, the area of which has also increased (see **Table 1-1** in **Section 1.1.2)**.

There were no existing roosting islands in Penrhyn Estuary and shorebirds previously roosted in the more elevated areas of intertidal flats. The new roosting islands comprised a total of 0.2 ha of habitat (see **Table 1-1** in **Section 1.1.2**). Shorebirds were observed on roosting islands in post-construction surveys.

During post-construction monitoring, the Red Knot and Curlew Sandpiper were rare in Penrhyn Estuary and were seen in only one and two of the five years of post-construction monitoring, respectively. The other four key species were seen in nearly every post-construction monitoring year. Only the Pacific Golden Plover, Red Knot and Red-necked Stint have at some point been equal to or above the target during or after construction, and only the Pacific Golden Plover for an extended period. At that time, peak counts of Double-banded Plover in Penrhyn Estuary also came close to meeting the target counts. The Pacific Golden Plover and the Red-necked Stint appeared to recover numbers immediately after construction but these species, along with three of the other four, have all gradually declined during the post-construction phase so that many are all in very low numbers at Penrhyn Estuary. In the last few years of post-construction monitoring, peak counts were declining and in 2018 were at their lowest ever.

For key species other than Red-necked Stint or Double-banded Plover, declines can be explained by broader declines to the species either in the East Asian-Australasian Flyway (EAAF) or concurrently at monitored reference locations.

Notwithstanding the broad declines to many of the key shorebird populations and that birds are found throughout the various microhabitats within Penrhyn Estuary, it would appear that the key species are not utilising the rehabilitated habitat generally to expected levels. Further, the diversity of all shorebirds (i.e. species additional to the key species) since construction commenced has ranged between 53 and 70% of baseline levels and although other small shorebirds (in addition to the key species monitored) also visited Penrhyn Estuary occasionally, they were also in small numbers. In addition to the broad decline due to external factors, given declines in Penrhyn Estuary have been gradual and declines of peak counts at high tide appear greater than for low tide it is also possible that there are deterrents in Penrhyn Estuary and that they are potentially having a greater effect on the quality of roosting habitat than on feeding habitat. What is not clear, is whether the effect has been increasing from year to year or whether the deterrent(s) has been at a constant level and the gradual declines to abundance have been a reflection of a gradual response from the birds rather than an instantaneous effect from when the deterrent(s) started. A review of the status of the potential deterrents during the monitoring period suggests there have no obvious changes in the status of the deterrents during the monitoring period that could have potentially affected abundance.

## 2.2 Benthos

Shorebirds feed in intertidal mud and sand flat habitats in Penrhyn Estuary but also near the sparse hard substrata in the inner estuary, which includes small, isolated clumps of oysters, rocks and flotsam.

The benthos monitoring program compared changes in key indicators before and after enhancement at Penrhyn Estuary and at reference locations in other parts of Botany Bay. Sampling was done in mud flat and newly created sand flats for the physical indicators of median grain size (MGS) and percentage fine sediment particles (combined clay and silt fractions) and the biological indicators of invertebrate abundance and biomass. Benthos monitoring was done for three years following completion of the works, and included spring and autumn sampling events each year to provide a seasonal context.

As indicated in **Section 1.1.2**, enhanced habitat included a four-fold increase in the area of intertidal feeding habitat for shorebirds. Most of the newly created intertidal area was sand flat and as such, the post-construction intertidal habitat area had a larger proportion of sand flat prior to construction. The monitoring plan has met its objectives in documenting the changes in benthic invertebrate communities in existing and new intertidal/shallow subtidal habitats and assessing the sustainability of these habitats in terms of their impact on food items for shorebirds.

The composition of invertebrates in soft sediments within Penrhyn Estuary included high proportions of polychaete worms and molluscs. Prior to the habitat enhancement works in Penrhyn Estuary, polychaete worms made up 76% of all invertebrates in sand habitats, but declined to an average of 47% after enhancement, while molluscs increased on average from 16% before enhancement to 49% after enhancement. Variation in the percent contributions of these phyla among surveys appears consistent both before and after habitat enhancement.

In sand habitats, a total of 22,029 individuals from 87 taxa were counted across the nine surveys. The average abundance of macroinvertebrates (species combined) decreased at Penrhyn Estuary and did not reach its post-construction target. However, abundance at both Quibray Bay reference locations also decreased after habitat enhancement. Hence, the significant change in abundance from the before and after phases was not attributed to construction. There was a slight increase in the biomass of macroinvertebrates in sand habitat at Penrhyn Estuary after construction but this was not statistically significant.

In mud habitats, a total of 16,041 individuals from 56 taxa were counted across the nine surveys. While there was a general decrease in abundance in both Penrhyn Estuary and reference locations, invertebrate abundances in mud habitat was significantly lower in Penrhyn Estuary after habitat enhancement, but not at reference locations. This suggests that the habitat enhancement works may have had a negative effect on macrofaunal abundance in mud habitat, despite this habitat being essentially undisturbed by heavy equipment during the construction phase of the project.

Mean biomass of benthos in mud habitat increased in Penrhyn Estuary after habitat enhancement works, while over the same period there were decreases at the Georges River and Woolooware Bay reference locations, respectively. This suggests that habitat enhancement may have resulted in an increase in macroinvertebrate biomass within Penrhyn Estuary in mud flats. This effect did not appear to be statistically significant, likely due to high variability among surveys.

Overall, statistical analysis showed that mean grain size in mud habitats was significantly smaller after habitat enhancement works at Penrhyn Estuary, but remained similar at reference locations suggesting that this was an effect of enhancement works, possibly indicative of mixing within the estuary. The fine sediment content decreased significantly at all three locations within the estuary when comparing samples from before to after enhancement works.

It does not appear that the treatment of sediments with seagrass wrack and mud has had a substantial effect in enhancing the food resources available to shore birds, although any effect it did have may have been masked by tidal exchange and mixing between treated and untreated areas. Importantly, the sediments continue to yield sustainable levels of food items (as measured by biomass) following habitat enhancement.

Assemblages associated with hard substrata were clearly different to those associated with the created soft sediment habitats. They comprised a high proportion of sedentary organisms such as oysters, limpets and anemones, which require a hard attachment surface, and/or mobile gastropod molluscs, which graze on microalgae attached to the rock surface. Following habitat enhancement there have been significant increases in the mean percent contributions of taxa in these assemblages, likely to be a result of the overall increase in hard substrata in the estuary, and particularly in the vicinity of the entrance (flushing) channel. Hard substrata assemblages therefore add to the diversity and biomass of prey items available to shorebirds.

## 2.3 Saltmarsh

Prior to the habitat enhancement works there was 1.4 ha of saltmarsh habitat in the Penrhyn Estuary. One hectare of this was retained and 0.4 ha was removed, with some of the saltmarsh plants being transplanted. An additional 2.4 ha of saltmarsh habitat was created by planting with suitable saltmarsh species (see **Table 1-1** in **Section 1.1.2)**. The main saltmarsh species occurring in Penrhyn Estuary were *Suaeda australis, Sarcornia quinqueflora, Sporobulus virginicus* and *Juncus kraussi*. The new species planted in the estuary aimed to increase the diversity of the community by introducing species that also occurred at other sites in Botany Bay. The new saltmarsh area is primarily (90%) made up of two saltmarsh species: *Sarcocornia quinqueflora* and *S. virginicus*. The tall saltmarsh species, *J. krausii* and *S. australis,* are not favoured shorebird habitat and hence were only planted sparingly.

Saltmarsh was established in the created saltmarsh habitat by planting seedlings grown from locally sourced seeds or pieces. Given a major focus of the PEHEP was to enhance shorebird habitat, mangroves and introduced saltmarsh species (e.g. *Juncus actus*) were removed from the estuary prior to the these works. *Sporobolus* and *Sarcocornia* plants were taken from the 0.4 ha area of saltmarsh to be removed as a result of the expansion project, and transplanted directly into the areas from which mangroves and introduced saltmarsh species had been removed.

The post-rehabilitation area of saltmarsh in Penrhyn Estuary represented more than a two-fold increase from existing saltmarsh area (see **Table 1-1** in **Section 1.1.2**). In 2016, monitoring indicated that species diversity in saltmarsh remained similar to baseline levels, while abundance and condition generally increased following the rehabilitation works. Importantly, the distribution and abundance of newly planted saltmarsh vegetation along the northern and southern shorelines continued to grow during post-construction surveys. Areas that received transplanted saltmarsh maintained their cover and diversity of saltmarsh. In terms of ecological function, epifaunal assemblages recolonised areas that were disturbed during the rehabilitation works and recruited into newly planted areas of saltmarsh. In general, although most targets were met, a few areas did not respond as expected, including areas that were transplanted with saltmarsh vegetation and areas that were cleared of mangroves and weeds.

The decrease in saltmarsh area between 2014 and 2016 was in part due to an area of approximately 380 m² in the south-eastern corner of the estuary which was mapped in 2014, but excluded from 2016 mapping as it comprised of sparse, poor condition saltmarsh. In other parts of the estuary, preliminary findings indicated some new growth and increases in density at the western end of the estuary, as well as changes in the seaward boundary of the new saltmarsh in the southern end of the estuary. The 2016 survey revealed that *S. quinqueflora* was the dominant species of saltmarsh recorded throughout the study area. It was observed to be in good condition.

The 12.8% decrease in saltmarsh extent between 2013 and 2014 was due to the variability of the new growth of plants on the seaward margin of the saltmarsh communities. The loss of saltmarsh habitat between 2012 and 2013 was largely attributed to the removal of around 1,980 m² of saltmarsh in the south-west corner of Penrhyn Estuary as a result of the construction of drainage works.

## 2.4 Seagrass

As part of the Port Botany Expansion Project, extensive dredging and other modifications have altered seagrass habitat in Penrhyn Estuary and along the nearby Foreshore Beach in Botany Bay. Based on mapping undertaken in May 2008, it was expected that ~317 m² of sparse *Zostera muelleri* subsp. *capricorni* and *Halophila ovalis* and some *Posidonia australis* would be directly impacted as part of the port expansion works. Given the conservation value of *P. australis*, a threatened population, it was transplanted to Quibray Bay (a site that already supported *P. australis*) on the southern shore of Botany Bay prior to the commencement of dredging and reclamation. Neither *Z. capricornii* nor *Halophila* were transplanted, as these species were expected to readily colonise newly created suitable seagrass habitat.

The depth of the Penrhyn Estuary flushing channel is between -2.0 m to -1.0 m LAT, with slopes to 0.3 m LAT, providing a total of 6.5 ha of potential seagrass habitat. The channel was expected to provide sufficient depth range for seagrass growth, allowing seagrasses to adjust to changing water quality or sea level rise. Creation of potential seagrass habitat within the estuary channel was achieved through re-shaping, by removing sand in some areas and filling with sand in others. Where seagrass was not present, the habitat was topped with a minimum of 10 cm of sediment with some finer particles to promote colonisation.

Various sampling methods and indicators were used to measure the distribution, composition and condition of seagrasses at Foreshore Beach, the rehabilitated section of Penrhyn Estuary (the Rehabilitation Area) and at Planting Areas and Experimental Sites within Quibray Bay where *P. australis* from Foreshore Beach was transplanted to. Seagrass morphology monitoring sites for measuring indicators of condition were

established at Foreshore Beach in 2012, while additional sites were established in the Rehabilitation Area during 2013. Surveys were done annually, and the fifth and final year of post-construction monitoring of seagrass was completed in March - April 2017.

Comparison of pre- and post-construction monitoring over the past 15 years identified that seagrass distribution and species composition at Foreshore Beach and the Penrhyn Estuary Rehabilitation Area had been highly variable. This was evident from a major decline in seagrass area from approximately 65,821 $m^2$ in 2002 to 698 $m^2$ in February 2007, immediately prior to construction works commencing. Monitoring carried out during the construction works indicated that seagrass condition and distribution remained relatively stable during this period. Importantly, the greatest changes to seagrass at Foreshore Beach over the entire monitoring occurred prior to construction for the port expansion works and these changes were due to factors other than construction for the Port Botany Expansion.

The five post–construction monitoring surveys at Foreshore Beach identified a bed of *Halophila* spp. that extended along the beach but notably, was much narrower in width and more discontinuous than the original bed of *Z. muelleri subsp. capricorni* that originally occurred at this location. The observation that *Halophila* spp. had consistently been the dominant seagrass at Foreshore Beach during post-construction surveys suggests that the process of succession had either been very slow or arrested. The post-construction monitoring indicated that sediment mobilisation and (potentially) reductions to light availability or water circulation may have affected the long-term establishment of large beds of seagrass, particularly *Z. muelleri* subsp. *capricorni* and *P. australis,* at Foreshore Beach.

The extent of *Halophila* spp. in the 2017 survey was at its smallest for the entire period of post-construction monitoring. Erosion at Foreshore Beach during the post-construction period caused sediment to be mobilised onto the beds of seagrass, and this is likely to have been a contributing factor preventing colonisation and/or succession. Construction of three groynes at Foreshore Beach in 2016 arrested the erosion and hence, the potential for sediment to be mobilised across the seagrass habitat. There has only been one formal post-construction survey since the construction of the groynes, and it was not possible at the time to assess the impact of the modified sediment transport pathways on seagrass.

Given data for the Rehabilitated Area (inner estuary and flushing channel) were available for five years of post-construction monitoring, some analysis of the success of mitigation efforts and habitat creation (for seagrass) was possible. The establishment of *Halophila* spp. and the variable occurrence of *Z. muelleri* subsp. *capricorni* in the Rehabilitation Area were first recorded in the 2013 post-construction survey, although patches were isolated and sparse in cover.

In post-construction surveys of the Rehabilitation Area, seagrasses appeared to prefer the shallow, marginal intertidal habitat over the deeper central area, but any observed colonisation was sporadic and short-term. This may have been due to a number of factors including, but not limited to:

> Turbidity and associated reduction in available light;

> Seabed (sediment) movement; and

> The accumulation of a deep layer of fine, silty sediments over the seabed in deeper areas.

*Z. muelleri* subsp. *capricorni* had all but disappeared by 2017.

Overall, the experiment investigating transplanting of *P. australis* from Foreshore Beach to Quibray Bay was successful, particularly for whole or trimmed plants that were transplanted, rather than plants with rhizomes only. However, in one of the two main transplant areas, decreases in shoot densities of plants in the last of the surveys done there (November 2013) suggested areas of bare substrata may not have been the most appropriate sites for transplantation.

## 2.5 Water quality

The PEHEP water quality monitoring program aligned with the pre-construction water quality monitoring such that interpretive analyses were able to be undertaken that compared pre- and post-construction data.

The post-construction dry weather sampling provided reliable data to compare with the following:

> Water quality data conducted prior to the Port Botany Expansion project;

> Modelling predictions carried out to support the EIS; and

> ANZECC (2000) guideline trigger-values.

The wet weather sampling provided reliable data to compare the recovery of Penrhyn Estuary from transient to ambient water quality with the flushing times (measured as e-folding time) for systems considered to be oligotrophic, mesotrophic and eutrophic. That is, the focus of sampling was to reliably capture data that described the change in water quality in the estuary from the peak post-storm concentrations towards normal ambient concentrations.

The results of the water quality monitoring also helped inform and interpret the broader ecological processes in the estuary. Results of the ecological monitoring components of the PEHEP were supported by further analysis of the water quality results as required.

Sampling was done at stations in the estuary channel, Foreshore Beach, and at two sites further afield which acted as controls.

Comparisons of the trends over three years of the post-construction water quality monitoring from 2013-2015 identified few areas of significant variance in water quality for the physico-chemico parameters measured. Variance in conductivity and pH values was identified, but this was not of concern given the results were within expected ranges.

Some exceedances of ANZECC (2000) trigger values were recorded, although exceedances of suspended solids were much reduced during 2014 and 2015 when compared to those recorded in 2013. The exceedances of suspended solid concentrations were below levels recorded in pre-construction monitoring at both estuary and control sites. Nutrient concentrations in excess of trigger values generally followed periods of significant rainfall, and were likely an indication of long recovery times of water quality throughout Botany Bay following these events.

Trends for nutrient concentrations indicated that modelled nutrient concentrations prepared for the port expansion EIS were conservative, and were not consistently exceeded during post-construction monitoring.

The results of the wet weather monitoring indicated that the flushing rates of Penrhyn Estuary following high catchment outflows were within reasonable timeframes, reinforcing the positive results of the dry weather monitoring.

# 3 Assessment against Success Criteria

The PEHEP intended that the success or failure of the habitat enhancement works would be measured against the three key 'success criteria' given below, following five years of post-construction monitoring after completion of the works. This post-construction monitoring has now been completed.

## 3.1 Success Criteria 1 - Shorebird Usage

### 3.1.1 Key Indicators

For shorebirds, success was measured based on peak counts of six key migratory shorebird species using Penrhyn Estuary following the completion of habitat enhancement works, relative to counts collected before the enhancement works (baseline), and considering any changes observed at reference sites

Five of six key species (Bar-tailed Godwit, Pacific Golden Plover, Red-necked Stint, Curlew Sandpiper and Double-banded Plover) were present at Penrhyn Estuary in the 2017-2018 peak period but none of the counts were above the targets (as determined from baseline counts). During post-construction surveys only the Pacific Golden Plover, Red Knot and Red-necked Stint have at some point been equal to or above the target during or after construction, and only the Pacific Golden Plover for an extended period. Counts of five of the six key species have all gradually declined during the post-construction phase, and in the final post-construction survey year (2017-2018) total counts (particularly high tide counts) of the six species were the lowest seen in post-construction monitoring.

For the species other than Red-necked Stint or Double-banded Plover, declines can be explained by broader declines to the species either in the EAAF or concurrently at monitored reference locations.

### 3.1.2 Secondary Indicators

The secondary indicators (to peak counts) measured the quality of the shorebird habitat in Penrhyn Estuary and provided additional information for interpreting the level of use (along with peak counts at reference sites).

*Expansion of intertidal feeding area*

The original area of intertidal flats was 3.4 ha. This was increased by approximately four times to a total of 13.8 ha, which included reshaping of 1.7 ha of the existing intertidal area and creation of 10.4 ha of new area (see **Table 1-1** in **Section 1.1.2)**. Shorebirds have been observed on intertidal flats in post-construction surveys. Most of the newly created intertidal area is sand flat but the total post-construction area includes some original sand flat and mud flat.

*Provision of high tide roosting area*

High tide roosting islands did not originally occur in Penrhyn Estuary, and shorebirds roosted in the more elevated areas of intertidal flats. The area of new roosting islands is 0.2 ha (see **Table 1-1** in **Section 1.1.2**). Shorebirds have been observed on these roosting islands in post-construction surveys.

*Successful colonisation of the expanded intertidal flats with invertebrate food species*

The abundance of macroinvertebrates in the sand flats in Penryhn Estuary decreased and did not reach its post-construction target. However, this significant change in abundance from the pre-rehabilitation and post-rehabilitation phases was not attributed to construction given it occurred in other (reference) areas in Botany Bay as well as in Penrhyn Estuary. There was a slight increase in biomass of macroinvertebrates in sand habitat at Penrhyn Estuary after construction, but this was not statistically significant.

Macroinvertebrate abundance in mud habitat was significantly lower in Penrhyn Estuary after habitat enhancement, but not significantly different at reference locations. This suggests that the habitat enhancement works may have had an effect on macrofaunal abundance in mud habitat despite it being essentially undisturbed by heavy equipment during the works. When compared to pre-enhancement conditions, the changing ratios of the key macroinvertebrate assemblages molluscs (snails and clams), polychaetes (worms) and crustaceans (crabs, yabbies and amphipods) suggests that the sedimentary system had not yet reached equilibrium. However, the variation in estimates of invertebrate abundance through time is either the same as or smaller than that measured prior to construction, which indicates acceptable stability within the benthic ecosystem.

Importantly, the sediments continue to yield sustainable food resources (as measured by biomass), similar to those before enhancement, indicating enhancement of the feeding habitat has generally been successful.

The apparent discrepancies between biomass and abundance can be explained by the presence of more and relatively heavier molluscs, and fewer of the lighter weight polychaete worms, after the habitat enhancement works. Data on feeding preferences of the six key shorebird species monitored are insufficient to determine if this shift in abundance of different prey items has had any effect on shorebird abundance. It is noteworthy that the decrease in abundance has only occurred in mud habitat, which is only a small proportion of the total intertidal flats and feeding area of shorebirds.

*Controlled access to Penrhyn Estuary to reduce disturbance of birds from both humans and potential predators*

As part of the enhancement works, public access to Penrhyn Estuary has been controlled by restricting access through a boardwalk and public lookout, accessible only from the foreshore pedestrian pathway. The entry is via a self-closing gate which is locked at night. Domestic animals are not permitted past the gate and into the estuary. Access from the foreshore and Foreshore Road is prevented by security fencing. This fencing assists in restricting feral animal access. A floating boom across the flushing channel prevents access by boats. There is also a sound barrier between the estuary and the port.

Disturbances from human activity or the presence of foxes and cats in the estuary were monitored during shorebird surveys. Both fox and cat prints were recorded regularly on the flats near the bird hide and around the saltmarsh adjacent to Foreshore Road, and also as far up the estuary as Springvale Creek. Rabbits were frequently seen near the access gates on Foreshore Road, as well as feeding in the saltmarsh adjacent to Foreshore Road. The Port Authority of New South Wales undertakes feral animal control regularly and it is likely that predation has reduced from levels prior to construction.

## 3.2 Success Criteria 2 - Seagrass Area

### 3.2.1 Key Indicators

The success criteria for seagrass following habitat enhancement was via assessment of the cover and quality of seagrass along Foreshore Beach and the flushing channel of Penrhyn Estuary. An appropriate timeframe for colonisation by *Zostera muelleri* subsp. *capricorni* was considered to be within five years of completion of dredging and reclamation works, the works along Foreshore Beach and the Penrhyn Estuary habitat enhancement works.

*Foreshore Beach*

Comparison of pre- and post-construction monitoring over the past 15 years identified a major decline in seagrass area at Foreshore Beach immediately ‘prior’ to construction works commencing. The five post–construction monitoring surveys at Foreshore Beach indicated that a bed of *Halophila* spp. extended along the beach but, notably, it was much narrower in width than the original bed of *Z. muelleri* subsp. *capricorni*, more discontinuous and its condition variable. The distribution of the bed of *Halophila* spp. contracted and narrowed during post-construction surveys. That *Halophila* spp. had consistently been the dominant seagrass at Foreshore Beach during post-construction surveys suggested that the process of succession had either been very slow or arrested. There were signs that sediment mobilisation and possibly reductions to light availability or water circulation may have affected the success of the long-term establishment of large beds of seagrass at Foreshore Beach, particularly *Z. muelleri* subsp. *capricorni* and *P. australis*.

The extent of *Halophila* spp. in the final (2017) survey was at its smallest for the entire period of post-construction monitoring. Erosion at Foreshore Beach during the post-construction period causing sediment to be mobilised onto the beds of seagrass is likely to have been a factor and this was potentially exacerbated by beach nourishment that occurred twice post construction, as required to try and mitigate any beach erosion observed. In 2016, the construction of three groynes at Foreshore Beach arrested the erosion and hence the potential for sediment to be mobilised across the seagrass habitat but given only one survey was done after this time, interpretation of the benefit of these groynes to seagrass was not possible.

*The flushing channel*

In general, post-construction surveys over the past five years have recorded very little *Halophila* spp. or *Z. muelleri* subsp. *capricorni* in shallower areas of the flushing channel (<3 m), and even less seagrass was found in the deeper areas (up to 5 m). Thus, some areas within the flushing channel may be at or beyond a depth that seagrass can permanently colonise because of reduced light availability.

*Halophila* spp. and the occasional patch of *Z. muelleri* subsp. *capricorni* in the flushing channel was first recorded in post-construction surveys in 2013, although patches were isolated and sparse in cover. *Z. muelleri* subsp. *capricorni* had all but disappeared by 2017, and there was very little *Halophila* spp.

## 3.3 Success Criterion 3 – Saltmarsh Area

### 3.3.1 Key Indicators

Success was to be measured by achievement of no net loss in area and condition of saltmarsh in Penrhyn Estuary, relative to baseline (pre-habitat enhancement) levels and in comparison to any changes observed in saltmarsh reference sites in other parts of Botany Bay.

*Area of saltmarsh*

The original area of saltmarsh in Penrhyn Estuary was 1.4 ha and 0.4 ha was reclaimed for the port expansion. A total of 2.4 ha of saltmarsh was created as part of the PEHEP, resulting in a total area after construction of 3.4 ha, more than doubling the pre-construction area of saltmarsh (see **Table 1-1** in **Section 1.1.2**).

After habitat enhancement, the total area of saltmarsh consisted of some pre-existing areas that were either:

> Undisturbed;

> Modified (i.e. had mangroves and/or weeds removed);

> Transplanted (i.e. where saltmarsh plants were moved from the area to be reclaimed); or

> Some new areas (i.e. where additional nursery grown saltmarsh plants were added to).

For the duration of the post-enhancement monitoring, species diversity in all of these saltmarsh areas remained similar to baseline levels. Abundance of most saltmarsh species increased following the rehabilitation works within Penrhyn Estuary, apart from *Sueada australis*. However, abundance of this species was similar to reference areas and only less at Penrhyn Estuary after construction (compared to baseline) due to increased abundance of other species. Importantly, the total abundance (species combined) was greater after construction than the baseline.

*Condition of saltmarsh*

Following the rehabilitation works, saltmarsh vegetation was in better condition with the percentage of vegetation (all saltmarsh species) in poor or dead / near dead condition reducing compared to baseline. The condition of plants was equivalent to those plants in reference areas.

The ecological functioning of many of the saltmarsh areas in the estuary was similar to baseline conditions, with generally similar diversity and abundance of epifaunal assemblages. Diversity and abundance increased throughout the first three post-construction surveys and appeared to stabilise by the fourth survey. This suggests that epifaunal assemblages had recolonised areas that were disturbed during the rehabilitation works and had recruited into newly planted areas of saltmarsh vegetation.

Importantly, monitoring has shown that mangroves were not present within saltmarsh areas in Penrhyn Estuary during the post-construction surveys, suggesting mangrove management had been successful.

# 4 Conclusions and Recommendations

## 4.1 Outcome of Assessments

The post-habitat enhancement works monitoring outcomes for Penrhyn Estuary for shorebird, seagrass and saltmarsh habitat are summarised in **Table 4-1**.

Table 4-1 Outcomes (in yellow) for the three key components of the habitat enhancement works

| Success Criterion | Impact | | | |
|---|---|---|---|---|
| | Positive | No Change | Negative | Comment |
| 1. Shorebird use in Penrhyn Estuary | Increase in shorebird usage of the estuary | No change in shorebird usage of the estuary | Reduction in shorebird usage of the estuary | Targets for key species not met and declines continuing, but declines for most key species are consistent with patterns observed in reference areas. Secondary indicators show increase in areas of suitable habitat and utilisation of feeding and roosting habitats by shorebirds. |
| 2. Area and quality of seagrass in the project area | Increase in seagrass cover/quality along Foreshore Beach and the estuary channel | No net loss of seagrass cover/quality along Foreshore Beach and the estuary channel | Reduction in seagrass cover/quality along Foreshore Beach and the estuary channel | Trend of decline at Foreshore Beach commenced prior to construction of port facilities so that the meadow was “no longer a functioning seagrass meadow”. |
| 3. Area and condition of saltmarsh in Penrhyn Estuary | Increase in area/quality of saltmarsh habitat in the estuary | No net loss of saltmarsh area/quality in the estuary | Reduction in area/quality of saltmarsh habitat in Penrhyn Estuary | Area of saltmarsh more than double the previous area. Condition generally improved from baseline and equivalent to reference areas. |

### 4.1.1 Shorebird Habitat

Peak shorebird counts were adopted as the key indicator for success or failure of enhancement of shorebird habitat. Other (secondary) indicators of habitat quality were measured to help with interpretation of the level of shorebird usage.

In 2018, peak counts of shorebirds in Penrhyn Estuary were below targets and at the lowest levels seen during any post-construction survey. There had been a trend of declining peak counts during the latter years of post-construction monitoring. Importantly, declines in peak counts of the key species monitored were not confined to Penrhyn Estuary and similar patterns were observed in some, if not all, reference sites in Botany Bay or further afield for four of the six key species. For the other two species, Red-necked Stint and Double-banded Plover, broader declines were not noted but given these species were monitored in only one reference location, interpretation is limited. Given trends varied (i.e. stability or declines) among locations for those species where monitoring was done at more than one reference location, it is likely that a only single reference location provides a biased interpretation of overall trends outside of Penrhyn Estuary. Hence, the weight of evidence indicates that migratory shorebirds are generally responding negatively to unknown threats at a larger scale than Penrhyn Estuary, and when reference areas are considered, there has been no change in shorebird usage of the estuary.

The secondary indicators monitored have not suggested that there are any problems with the quality of feeding or roosting habitat that could be deterring shorebirds from using Penrhyn Estuary. The intertidal feeding areas have increased six-fold (including saltmarsh), roosting habitat has been created, and infauna on the flats (i.e. a food source of shorebirds) had reached most of the baseline targets. Although a significant decrease in abundance of benthos in mud habitat was noted in Penrhyn Estuary after the habitat enhancement, but not at reference locations, there was also a corresponding increase in biomass of benthos. This change was considered unlikely to have contributed to the declines in shorebirds given mud flat makes up only a small proportion of the total intertidal feeding area for shorebirds in Penrhyn Estuary.

Further, despite low peak counts, shorebirds have been noted actively feeding and roosting in the enhanced habitats of Penrhyn Estuary in each of the post-construction surveys conducted.

Notwithstanding the broader declines to key species due to external factors, it is clear that migratory shorebirds do utlilise Penrhyn Estuary to a limited extent for feeding and roosting and as such, it continues to remain an important area to these species as well as other birds. As such, it will be important to maintain the quality of shorebird habitat in Penrhyn Estuary into the future, particularly as utilisation of the area could improve over time or because the quality of other areas currently available to shorebirds in other parts Botany Bay could potentially decline. Recommendations are given in **Section 4.3** regarding ongoing maintenance.

### 4.1.2 Seagrass

*Foreshore Beach*

Seagrass was the only habitat where there had not been a 'no net loss' outcome. Indeed, a gradual decline of the main *Halophila* spp. seagrass meadow at Foreshore Beach was measured throughout the five years of post-construction monitoring. Importantly, as the decline commenced prior to construction of the port facilities, the net decline over the post-construction monitoring period is considered unrelated to the construction works. At the time the PEHEP was written, burial of seagrass by sand being transported along Foreshore Beach was thought to be the major driver. The observation that *Halophila* spp. had consistently been the dominant seagrass at Foreshore Beach during post-construction surveys suggests that the process of succession had either been very slow or arrested. In late 2016, the Port Authority of New South Wales constructed three groynes along Foreshore Beach to stabilise sand at the beach, and this may have implications for trends in seagrass cover and condition.

Notwithstanding the general decline of the main bed of *Halophila* spp., post-construction monitoring of the small isolated patches of remnant *P. australis* and *Z. muelleri* subsp. *capricorni* at Foreshore Beach has indicated general persistence of these species and importantly, that post-construction conditions are suitable for these species to survive. Further, an encouraging sign that the groynes have addressed the ongoing issue of sediment mobilisation was the observation in 2017 of new, high density patches of *Z. muelleri* subsp. *capricorni* in the south-eastern parts of the site.

*The Estuary Channel and Inner Estuary*

The colonisation of the estuary channel by seagrass should not have been affected by the same issues affecting seagrass at Foreshore Beach. However, seagrass has not successfully colonised the flushing channel. Although some *Halophila* spp. plants were on occasion present, they did not persist. This may be due to a number of factors including, but not limited to:

> Poor supply of seed;

> Turbidity and associated reductions in available light; and/or

> Seabed instability and the accumulation of a deep layer of fine, silty sediments over the seabed in deeper areas.

*Z. muelleri* subsp. *capricorni* had all but disappeared in 2017.

Patches of *Halophila* spp. and *Z. muelleri* subsp. *capricorni* were recorded in post-construction surveys in the inner estuary, with variable occurrence in post-construction surveys, but on each occasion, they were isolated and sparse in cover and short-lasting. Variable colonisation and lack of persistence of seagrass in intertidal areas is normal given the harsh environment.

### 4.1.3 Saltmarsh

Of the three key habitats in Penrhyn Estuary, enhancement of saltmarsh was the most successful and the only one to show a positive outcome with respect to the relevant success criteria. Not only had the area of saltmarsh in Penrhyn Estuary doubled compared to the pre-enhancement area, but there had also been an improvement in its condition and quality. Ongoing management of weeds, mangrove encroachment and public access (i.e. potential for trampling) will continue to be an important factor for maintaining its condition and quality (see **Section 4.4**). These management initiatives, along with improved water quality, has probably contributed to the positive outcomes for saltmarsh.

The modelled pre- and post-enhancement estuarine flushing times indicated that flushing times for the inner estuary (i.e. where the saltmarsh occurs) would increase post-construction from less than one day pre-construction to 1.5 to 3 days post-construction. Post-construction monitoring of nutrients and flushing time

were in good agreement with modelled values, confirming water quality in the inner estuary had improved and the potential for eutrophication reduced.

The positive outcome for saltmarsh provides a benefit to shorebirds given they forage in this habitat, but it also has broader implications in relation to State and Commonwealth conservation goals. In NSW *Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions* is listed under the *Biodiversity Conservation Act 2016* as an endangered ecological community (EEC). Further, the saltmarsh in Penrhyn Estuary also meets the key diagnostic characteristics and condition thresholds of the ecological community of *Subtropical and Temperate Coastal Saltmarsh,* listed as vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) (http://www.environment.gov.au/cgi-bin/sprat/public/publicshowcommunity.pl?id=118&status=Vulnerable).

Increasing the area of saltmarsh locally increases the resilience of this community. The ongoing management of disturbance and threatening processes (see **Section 4.4**) is consistent with recommended activities for assisting the recovery of this community, as per the State (http://www.environment.nsw.gov.au/threatenedSpeciesApp/profile.aspx?id=10866) and Commonwealth listings (http://www.environment.gov.au/biodiversity/threatened/communities/pubs/118-conservation-advice.pdf).

## 4.2 Need for Contingencies or Offsetting

The PEHEP monitoring plans were designed to provide information about the performance of the habitat enhancement works and to identify the need for contingency measures or, in the case of a 'negative impact' outcome, whether an offset package for that particular habitat would be required.

### 4.2.1 Contingencies

As part of the development of the PEHEP, contingency measures were developed in the event that adverse effects were identified following implementation of the works (see Section 7 of the PEHEP). Given the results, two contingency measures require consideration.

***Shorebird Contingency Measure – Port Operations:*** *Should port operations have adverse impacts on the shorebird use of the estuary, operational changes or further mitigation measures would be implemented to address the causes of the adverse impact e.g. additional shielding of lights, modification of certain activities etc. The precise measures to be implemented would be subject to the cause of the adverse impact and would be identified as part of the Shorebird Monitoring Plan.*

As indicated above, there is insufficient information to determine unequivocally whether the PEHEP has been successful or not for shorebirds. The weight of evidence, however, indicates that migratory shorebirds are generally responding negatively to unknown threats at a larger scale than Penrhyn Estuary, and when reference areas are considered, it can be concluded that there has been no change in shorebird usage of the estuary.

Although disturbance from port operations could be an additional contributor to the observed decline in peak counts in Penrhyn Estuary (see **Section 4.1.1.2**), it is not clear if any changes to port operations would improve shorebird utilisation of the estuary. Hence, it is unlikely that this contingency measure would be effective and as such, it is not recommended.

***Seagrass Contingency Measure – High Turbidity Levels:*** *The contingency measure to address high levels of turbidity would depend on the cause of the problem. If it is as a result of high sediment loads from the catchment, a stormwater quality improvement device or sedimentation pond at the outlet of Floodvale or Springvale Drain could be installed to reduce the sediment load entering the Estuary. If the turbidity is a result of high velocities in the Estuary, then erosion protection measures, as outlined for erosion of intertidal flats above could be implemented.*

High turbidity may potentially have contributed to the lack of colonisation of seagrass in the flushing channel (see **Section 4.1.1.2**). However, given there are potential for other contributing factors, it is unlikely that this contingency measure would be effective. Hence, it is not recommended.

### 4.2.2 Offsetting

#### *4.2.2.1 Shorebirds*

Although some of the data suggests that port operations may be deterring some shorebird species, this was unable to be confirmed. Even if this were the case, it would be very difficult to discriminate as to which aspects of operations were problematic. Notwithstanding this, there is no question regarding the quality of feeding and roosting habitat in Penrhyn Estuary created or enhanced as part of the PEHEP despite broad

declines to many species due to external factors, and it is clear that migratory shorebirds continue to utlilise Penrhyn Estuary to a limited extent for feeding and roosting. As such, given that Penrhyn Estuary continues to remain an important area to these species as well as other birds and that we cannot determine unequivocally whether port operations have contributed to declines in utilisation in addition to the effects of the broader declines observed in the East Asian-Australasian Flyway it is considered that offsetting is not required.

##### *4.2.2.2 Seagrass*

As a result of the significant decline in seagrass area and quality prior to commencement of the PEHEP, and the fact that there were only sparse and isolated seagrass patches in the project area at the commencement of post-construction monitoring, advice had been given in the *Alternative Compensatory Habitat Options (ACHO) Package* (SPC 2008), that it was not considered warranted to implement alternate compensatory habitat options in the event of failure of the seagrass enhancement works.

##### *4.2.2.3 Saltmarsh*

The PEHEP has had a positive impact on saltmarsh and hence offsetting is not required.

## 4.3 Recommendations

### 4.3.1 Shorebirds

With the completion of the Shorebird Monitoring component of the PEHEP, regular maintenance, and monitoring of conditions, is required to retain the quality of Penrhyn Estuary as habitat for migratory shorebirds. This could involve a Plan of Management (PoM) for Penrhyn Estuary for its future governance. The following recommendations for maintenance would be fit for purpose for inclusion in a PoM to maintain the quality of shorebird habitat at a desirable level.

**Maintenance of habitat quality**

*Roosting islands*

The main roosting island (Big Island) requires that its surface is maintained so that there is no vegetation apart from low profile saltmarsh at its shore. It is recommended that this island is regularly monitored and maintained to ensure it is kept clear of vegetation.

*Saltmarsh habitat*

The low profile saltmarshes of *Sarcocornia quinqueflora* and *Sporobolus virginicus* provide suitable roosting habitat around much of the fringe of Penrhyn Estuary by providing some shelter from strong winds while enabling the birds to look over the top of the vegetation for the approach of impending danger, such as terrestrial or avian predators. Shorebirds may also feed in saltmarsh areas.

Taller saltmarsh plant species such as *Suaeda australis*, and *Juncus kraussii* are a deterrent to shorebirds given they obstruct the view of potential predators. These plants generally grow in the upper intertidal zones which are generally not frequented by shorebirds, however, in Penrhyn Estuary, *Suaeda australis* can occasionally recruit to the seaward margin of saltmarsh areas, presenting a deterrent. It is recommended that this species is regularly searched for and removed from the seaward margin of saltmarsh areas.

Another tall species that may seed into the saltmarsh is *Casuarina glauca*. It is recommended that this species is also regularly searched for and removed from any of the saltmarsh areas. Further, *Casuarina glauca* stands grow along the landward edge of the saltmarsh, from the eastern side of Springvale Channel, along the fringing saltmarsh to Corner Marsh. It is also around the Bird Hide and surrounds. As the heights of these stands increases it is likely to deter shorebirds from some of the roosting and feeding areas currently utilised. Consideration of how best to manage this potential deterrent is recommended for inclusion in the PoM.

*Tidal flats*

Mangroves may seed into the tidal flats which are feeding areas for shorebirds. As indicated above, tall plants such as mangroves are a deterrent to shorebirds given they obstruct the view of potential predators. It is recommended that mangroves are regularly searched for and removed from the tidal flats.

**Monitoring**

*Deterrents*

1. The maintenance of habitat quality as recommended above would require regular checking of conditions against a benchmark level and the actual maintenance would best be done at times outside of the peak period of occupation of the northern hemisphere migratory shorebirds. Hence, checking against benchmarks and maintenance would best be done annually between July and August, i.e. within the preceding two months prior to the arrival in September of northern hemisphere migratory shorebirds with spot checks for predator activity throughout the peak season (September to April).

### 4.3.2 Seagrass

**Monitoring**

The following, if implemented, would improve understanding of seagrass habitat condition at Foreshore Beach and in the Rehabilitation Area (i.e. the estuary channel and inner estuary):

1. Three additional annual surveys to determine whether the high density patches of *Z. muelleri* subsp. *capricorni* in the south-eastern parts of Foreshore Beach that appeared immediately after construction of the three groynes continue to expand and to assess whether seagrass habitat at Foreshore Beach generally improves due to modification of littoral transport along the beach;
2. A survey in the Rehabilitation Area at a time between five and 10 years after the last survey done (2017) to determine long-term trends in seagrass colonisation in the inner Penrhyn Estuary and flushing channel.

Further, given there was some concern about transplanted *P. australis* at one of the transplant sites in Quibray Bay, it would be useful to:

3. Revisit the transplant sites to confirm long-term success or failure of transplanted seagrass.

### 4.3.3 Saltmarsh

**Monitoring**

1. In addition to regularly removing tall saltmarsh plants so as to retain a low profile for shorebirds utilising Penrhyn Estuary, it is also recommended that saltmarsh condition is monitored to ensure that the quality of this habitat is maintained and does not deteriorate. Inspections should be conducted by an appropriately qualified expert and with reference to previous Penrhyn Estuary saltmarsh monitoring reporting, with the aim of identifying any noticeable deterioration of the saltmarsh community. Biennial monitoring would be sufficient given it would allow for timely intervention, were it necessary, for the removal of threats that had been identified as having caused a deterioration in the condition of saltmarsh.

# 5 Acknowledgements

Cardno staff undertook post-construction monitoring for the seagrass, saltmarsh, benthos and water quality components of the PEHEP, including all field investigations and reporting. Avifauna Research & Services Pty Ltd undertook field investigations and reporting for the shorebird monitoring component.

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End of Project Report

# APPENDIX A

## LIST OF PROJECT REPORTS

**Consolidated Annual Reports**

Cardno Pty Ltd (2013a). Port Botany Post Construction Environmental Monitoring - Annual Report 2013, Report prepared for Sydney Ports Corporation.

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