Port Botany Long-term Seagrass Monitoring

August 2020

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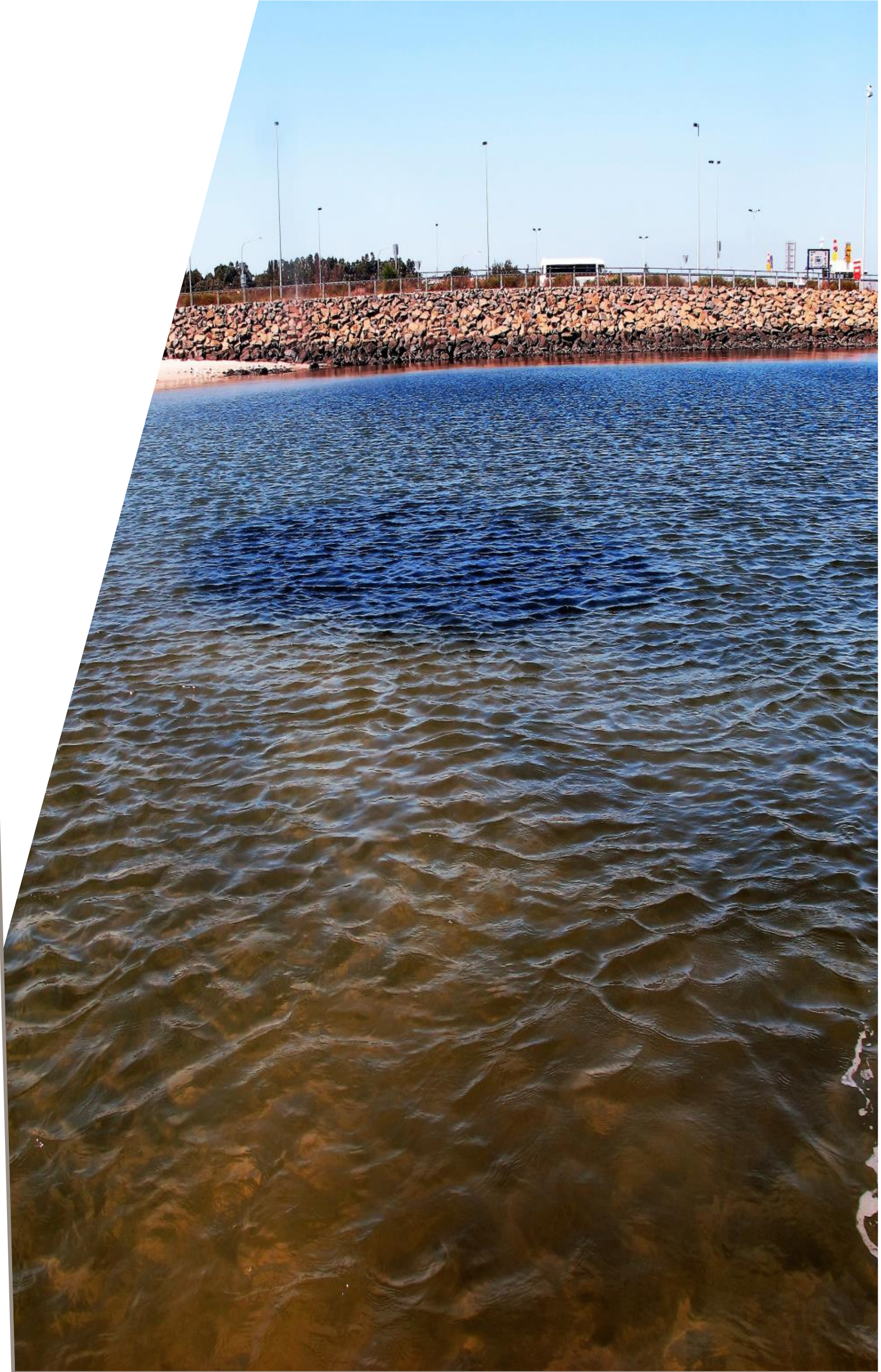

Prepared for Port Authority of New South Wales

17 August 2020

Document Information

Prepared for	Port Authority of New South Wales
Project Name	Port Botany Long-term Seagrass Monitoring
File Reference	59918182_PortBotanySeagrass2020_Rev0.docx
Job Reference	59918182
Date	17 August 2020

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Document Control

Version	Date	Author	Author Initials	Reviewer	Reviewer Initials
Rev A	17/06/2020	Jake Ludlow	JL	Dr Craig Blount	CB
Rev 0	17/08/2020	Dr Craig Blount	CB	Belinda Crichton	BC

Executive Summary

As part of the Port Botany Expansion Project (PBEP), extensive dredging and reclamation altered the availability of seagrass habitat in Penrhyn Estuary and parts of Foreshore Beach in Botany Bay. Prior to construction, monitoring works carried out in May 2008 (Roberts *et al*. 2008) predicted that approximately 317 m^2 of seagrass (including three species: *Zostera muelleri* subsp. *capricorni* [eelgrass], *Halophila* spp. [paddleweed] and *Posidonia australis* [strapweed]) would be lost through land reclamation, boat ramp construction and dredging works associated with the port expansion. The remaining seagrass beds, and a newly created area in the flushing channel of Penrhyn Estuary with potential to be colonised, were monitored during the construction and post-construction phase of the PBEP in accordance with a 'Penrhyn Estuary Habitat Enhancement Plan' (PEHEP). This monitoring involved annual measurement of changes to the distribution and condition of seagrasses in those areas.

Post-construction monitoring surveys at Foreshore Beach showed a decline in the distribution of seagrass that was partly attributed to smothering by sediment mobilised from beach erosion and/or potential reductions to light availability or water circulation. The overall composition of seagrass at Foreshore Beach has gone from one characterised predominantly by *Z. muelleri* subsp. *capricorni* and mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. prior to port expansion works to one characterised by the more ephemeral and pioneering *Halophila* spp. since completion of port expansion works. Perhaps the most important observation was that the most substantial changes (by far) to the seagrass beds at Foreshore Beach occurred prior to commencement of construction for the Port Botany Expansion, indicating that those changes, detected prior to 2009, can only be attributed to factors other than the construction works.

In late 2016 three groynes were constructed along Foreshore Beach to protect the beach against erosion and sediment transport to the north of Foreshore Beach and offshore. Surveys completed by Cardno before, during and immediately after groyne construction showed the loss of a small patch of *Z. muelleri* subsp. *capricorni* was attributed to the widespread decline of this species at Foreshore Beach, while loss of a small patch of *P. australis* was likely attributed to a combination of indirect, construction-related effects (i.e. impaired water quality and sedimentation), and natural erosive processes.

Following completion of the final post-construction survey for the PEHEP in 2017, it was concluded that overall seagrass distribution and species composition within Foreshore Beach had been highly variable, but that these changes were due to factors other than construction works done as part of the Port Botany Expansion. The 2017 survey also showed a slight increase in the extent of *Z. muelleri* subsp. *capricorni*, including the appearance of a new, small patch at the south-eastern end of Foreshore Beach. It was supposed that the establishment of this patch may have been a result of improved conditions related to groyne construction, particularly stabilisation of sediment, so three additional annual surveys were recommended to continue monitoring of long-term trends in seagrass beds following groyne construction.

This document provides results from the final survey of the three additional surveys, which was completed in April 2020. It also incorporates data from the first two additional surveys, along with data from previous investigations carried out as part of PEHEP monitoring, to provide a long-term context. The scope of this report concentrates on seagrass within Foreshore Beach only and does not extend to neighbouring Penrhyn Estuary, rehabilitation areas or other locations where seagrass was previously monitored as part of PEHEP.

Results of the 2020 survey suggested mixed localised changes to the distribution of *Halophila* spp., *Z. muelleri* subsp. *capricorni* and *P. australis*. Whereas previous surveys indicated limited understanding of long-term trends in *Halophila* spp. distribution and condition after construction of the groynes, the 2020 survey highlighted a definitive decline of seagrass area in some parts of Foreshore Beach but a substantial recovery in other parts.

Since construction of the groynes was completed in late 2016, the beds of *Halophila* spp. between the groynes have gradually narrowed and have disappeared in some places. The total area of *P. australis* at Foreshore Beach has been comparatively small since 2016 but the 2020 survey noted complete disappearance of the last remaining patch located close to the northern face of the middle groyne. Since 2017, frond condition in this patch has been deteriorating, shoot density and extent has been reducing and the shoot bases have been observed to be buried under at least 10 cms of sediment. Along with the general long-term trend of declining seagrass at Foreshore Beach, accreting sediment has probably contributed to the cause of the disappearance.

Although seagrass has disappeared from Foreshore Beach in many places, conditions appear to have improved for seagrass in the area between the southernmost groyne and the boat ramp. There, the patch of *Halophila* spp. essentially doubled in extent between 2019 and 2020, expanded seaward and shoot density increased significantly at one of the two sampling sites within the patch. A low epiphyte load on fronds of *Halophila* spp. was indicative of new growth in 2020. Further, the small, elliptical-shaped patch of high density *Z. muelleri* subsp. *capricorni*, is also within this area. In this patch there has been a trend of rapid expansion with a tenfold increase in extent since 2017. These findings suggest the rate of accretion of sediment in this area (due to the groynes) has stabilised and that the environment supports seagrass recolonisation. It is particularly encouraging to see continued expansion, since 2017, of the high density patch of *Z. muelleri* subsp. *capricorni* in this area. This presents strong evidence that the groynes have stabilised sediments in that part of Foreshore Beach and bodes well for recolonisation of seagrass in other areas off Foreshore Beach once benthic sediment stabilises there.

It is recommended that:

1. Further monitoring of the growing patch of healthy *Z. muelleri* subsp. *capricorni* and the patch of *Halophila* spp. between the southernmost groyne and the boat ramp is done to track trends or potential limitations for long-term establishment and persistence of seagrass at Foreshore Beach.
2. Discussions with NSW Department of Primary Industries (Fisheries) are undertaken to get approval to transplant a few small clumps from the fringe of the growing patch of healthy *Z. muelleri* subsp. *capricorni* to other areas between the southernmost groyne and the boat ramp to fast track recolonisation of seagrass in this area. Removing a few very small clumps of seagrass would not have adverse impacts to the donor bed of seagrass and will reduce the risk of *Z. muelleri* subsp. *capricorni* disappearing completely at Foreshore Beach by establishing more patches. It is possible that the spread of the growing patch of healthy *Z. muelleri* subsp. *capricorni*, or seed from it, will be the only natural means available to recover the species at Foreshore Beach. There have been few observations of natural recruitment of *Z. muelleri* subsp. *capricorni* to the area over the last few years (i.e. from seeds or seedlings that were dispersed into the area or had existed in a seed bank within the sediment). It may be that construction of the third runway and the expansion of the port has restricted potential recruitment to Foreshore Beach from seeds or seedlings transported in currents from other parts of Botany Bay.
3. The rate of accretion is monitored between the groynes within the parts of Foreshore Beach where seagrass has disappeared and compared with the rate in the area between the southernmost groyne and the boat ramp. This could be done by measuring the level of the seabed against permanent marks on the sheet piles of groynes, annually. When the rate of accretion becomes similar to that measured in the area between the southernmost groyne and the boat ramp, it is recommended that NSW DPIE (Fisheries) are consulted for approval for additional transplanting to these areas of a few small clumps from the growing patch *Z. muelleri* subsp. *capricorni* to augment recovery of this species throughout Foreshore Beach. This action would be dependent on the success of Recommendation (2) above.
4. Finally, given beach nourishment in recent years has potentially contributed to declines of seagrass, or its recolonisation, in some areas at Foreshore Beach, future use of beach nourishment should be reviewed. To minimise the risk to long-term recovery of seagrass at Foreshore Beach, beach nourishment should be undertaken less often than it has been done in recent years. If practicable, it should be avoided in the area of beach between the southernmost groyne and the boat ramp where *Z. muelleri* subsp. *capricorni* is recolonising rapidly. Where situations in the future require it to be done in other parts of the beach consideration should be given to minimising the volume of sand used as far as practicable.

Foreshore Beach offers a unique opportunity to augment recovery of seagrass beds once stressor(s) have been removed and where natural recruitment is greatly limited. Recommendations 2-3 would not only fast-track recovery at Foreshore Beach but would add valuable scientific knowledge about how effective transplanting could be in other similar situations. The Port Authority of New South Wales may want to consider a research partnership with a university to implement Recommendations 2-3 to maximise learnings from the project and to ensure that findings are passed on to the broader community.

Glossary

Term or Acronym	Definition
Baseline	The value or magnitude of a nominated indicator prior to development or other change. Target values for key indicators were based on baseline values pre-construction.
Benthic	On or in the seabed
Intertidal	The portion of shoreline between low and high tide marks, that is intermittently submerged
MSMP	Monitoring Services Management Plan
PBEP	Port Botany Expansion Project
PEHEP	Penrhyn Estuary Habitat Enhancment Plan
QA/QC	Quality Assurance/ Quality Control
Rehabilitation Area	Aquatic habitat created during the expansion of Port Botany that links Penrhyn Estuary with the water of Botany Bay
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')
Subtidal	Waters below the low-tide mark
Supralittoral zone	The area of beach above the spring high tide line that is regularly splashed, but not submerged by ocean water. Seawater penetrates these elevated areas only during storms with high tides.

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Appendices

1 Introduction

1.1 Background

As part of the Port Botany Expansion Project (PBEP), Sydney Ports Corporation (now Port Authority of New South Wales) has been rehabilitating Penrhyn Estuary, located adjacent to the port expansion. A small waterway of approximately 30 ha located to the north of Brotherson Dock. Penrhyn Estuary was artificially created during the reclamation of the Botany foreshore between 1975 and 1978, and since its creation it has been utilised by a diverse group of migratory birds. The primary purpose of the more recent rehabilitation works was to enhance the existing intertidal habitat and to expand the estuary as a long-term habitat for migratory shorebirds. This involved the removal of mangroves, weeds and introduced species, the enhancement of existing saltmarsh, and the creation of new saltmarsh habitat. An extensive area of foredune was also levelled to create intertidal feeding and roosting habitat for key species of migratory shorebirds that currently use the estuary and, upon completion, to potentially attract a greater number of shorebirds to the area. The eastern stretch of Foreshore Beach, adjacent to Penrhyn Estuary, was also modified as part of construction of a public boat ramp and through creation of an entrance flushing channel for the estuary. It was anticipated that this redesigned entrance channel would be suitable for colonisation of seagrass. The design, methodology and ongoing maintenance for Penrhyn Estuary are outlined within the Penrhyn Estuary Habitat Enhancement Plan (PEHEP) (Sydney Ports Corporation 2007).

Prior to commencement of PBEP construction works, monitoring for the PEHEP carried out in May 2008 indicated that approximately 317 m^2 of seagrass (including *Zostera muelleri* subsp. *capricorni* – synonymous to *Z. capricorni* [eelgrass]; *Halophila* spp. [paddle weed]; and *Posidonia australis* [strapweed]) would be lost through the land reclamation, boat ramp construction and dredging works (Roberts *et al*. 2008). The population of *P. australis* within Botany Bay is listed under the NSW *Fisheries Management Act 1994* (FM Act) as endangered. As such, beds of *P. australis* that were within the dredging footprint were removed and transplanted to Quibray Bay as part of the PEHEP, with the Seagrass Monitoring Plan for the PEHEP (Cardno (NSW/ACT) Pty Ltd (Cardno) 2014a) investigating the success of this transplantation over time. The remaining seagrass beds and the potential seagrass habitat in the newly created flushing channel were each monitored during the construction and five year post-construction phases of the PBEP in accordance with the PEHEP by measuring changes in distribution and condition. During the post-construction phase those areas were also monitored for colonisation by seagrass (Cardno 2012, 2013, 2014, 2015a, 2017).

As a result of the significant pre-construction decline in seagrass area and quality, and the fact that there only remains sparse and isolated seagrass patches in the project area, the PEHEP's Alternative Compensatory Habitat Options (ACHO) Package (SPC 2008) did not consider it warranted to implement a plan for provision of alternative compensatory habitat in the event of failure of the seagrass enhancement works. That is, there was no requirement for offsetting.

While seagrass monitoring for the PEHEP has now been completed, the addition of three new groynes along Foreshore Beach in late 2016 has warranted additional monitoring to determine potential effects of these to seagrass (details provided in **Section 1.3.4**). It was anticipated that the groynes would reduce erosion and sediment transport along the beach which would in turn improve water quality and mitigate sedimentation, thus improving conditions for seagrasses.

1.2 Aims

The key objective of the 2020 survey was to determine whether seagrasses at Foreshore Beach were recovering following the construction of three groynes in late 2016. This was assessed by:

> Mapping the extent of seagrass habitat along Foreshore Beach and recording distribution, species present, density, morphology and presence of epiphytes compared with previous surveys; and

> Undertaking statistical analyses of changes in density and leaf length of seagrass along Foreshore Beach through time.

1.3 Review of Existing Information

1.3.1 Ecological Function of Seagrasses

Seagrass is a functional grouping of marine flowering plants mostly found in soft sediment in nearshore coastal and estuarine environments (Butler and Jernakoff 1999). The ecological functions of seagrasses include a significant contribution to the productivity of marine ecosystems, stabilising sediments, and providing food and habitat for fish and invertebrates, including juveniles of recreational and commercial importance (Smith and Pollard 1999). Seagrasses baffle water currents, causing them to release their suspended sediment loads, thus maintaining water quality (Smith and Pollard 1999). They also help to prevent erosion by stabilising benthic sediments and assisting in the cycling of nutrients (Smith *et al*.1997). Many organisms benefit from the organic matter released by the slow bacterial and fungal breakdown of the seagrass detritus shed by healthy seagrass beds. Conversely, loss of seagrass plants can result in the destabilisation of benthic sediments, the removal of potential nursery habitats for fish and invertebrates, and a decrease in overall primary productivity of estuaries.

A number of fish and invertebrate species important to commercial and recreational fisheries have been recorded in association with seagrass beds in the northern section of Botany Bay, including sand whiting (*Sillago ciliata*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), luderick (*Girella tricuspidata*), sand mullet (*Myxus elongatus*), yellow-finned leatherjacket (*Meuschenia trachylepis*), king prawn (*Melicertus plebejus*), blue swimmer (*Portunus pelagicus*) and other crabs, and various species of octopus, cuttlefish, squid and shrimp. Overall, the seagrass beds off Foreshore Beach have shown consistently greater densities of commercially important species, but fewer species than other sites in Botany Bay (The Ecology Lab 2003).

1.3.2 Seagrasses in Botany Bay

Three types of seagrass, *Halophila* spp., *Z. muelleri* subsp. *capricorni*, and *P. australis*, have been recorded at Foreshore Beach and Penrhyn Estuary. The *Halophila* genus, represented locally by *H. ovalis* and *H. decipiens* (both known as 'paddleweed') and hereafter collectively referred to as *Halophila* spp., is a member of the family Hydrocharitaceae and has small thin ovate leaves with stalk like petioles. *Halophila* spp. can establish and grow rapidly, with high rhizome turn-over. It is generally considered a pioneering seagrass prior to the successional colonisation of *Z. muelleri* subsp. *capricorni*, then *P. australis* (where conditions permit).

Z. muelleri subsp. *capricorni* (also known as 'eelgrass') is the most common species of the family Zosteraceae found in NSW. It generally has narrow, slender leaves with a blunt apex, although the typical lengths and widths of seagrass leaves associated with *Z. muelleri* subsp. *capricorni* beds are highly spatially variable within and among NSW estuaries (Otway and Macbeth 1998), and ultimately dependent on local conditions in terms of interactions among a range of physical factors including water depth, wave action, sediment profile and seasonal climatology (see **Section 1.3.3**). *Z. muelleri* subsp. *capricorni* exhibits fast leaf growth during spring and summer months and generally has a dieback period during winter when leaf growth is slow (West 2000).

P. australis (also known as 'strapweed') is one of eight species of the family Posidoniaceae that occur in Australia. *P. australis* is the largest of the NSW seagrasses and has tough, strap-like leaves that can reach up to 60 cm in length and are typically between 10-20 mm wide. New leaves are often bright green, while more mature leaves may be brown in colour and commonly covered in epiphytes (i.e. small algae and encrusting invertebrates which attach themselves to the leaf surface). Leaves are produced throughout the year, but growth is slower during winter months.

1.3.3 Factors affecting the Growth and Distribution of Seagrasses

A range of physical factors affect the distribution and abundance of seagrass, including light, turbidity, sedimentation, nutrient levels, temperature, salinity, current and wave action and water depth (Connell and Gillanders 2007). Light availability is considered one of the most important environmental variables controlling the distribution and abundance of seagrass, although light requirements vary among species. The main factors affecting light availability are increases in suspended sediments, nutrient inputs and turbidity, which in turn may result in increased growth of phytoplankton macroalgae and epiphytes, leading to shading. Inputs of suspended sediment loads and nutrients into Penrhyn Estuary are often related to seasonal or episodic pulses of rainfall and would enter via Floodvale and Springvale Creeks. Loads and nutrients to Foreshore Beach would enter via the Mill Stream, directly to its west.

Seagrass responses to disturbances and environmental conditions can lead to considerable variability in growth forms for any one particular seagrass species. For example, short stunted growth can occur in most seagrasses subjected to environmental stress (Butler and Jernakoff 1999). Smaller seagrasses (e.g. *Halophila* spp.) have smaller rhizomes which may persist after frond damage for weeks to months while larger seagrasses such as *P. australis* have deeper rooted rhizomes which persist for months to years. Depending on the species, recovery of seagrass beds from disturbances can be slow. Seedlings of *P. australis* take 2–3 years before producing rhizomes (which help anchor plants) and are thought to be particularly vulnerable to physical disturbance and smothering during this time.

Intact stands of *P. australis* have the ability to grow quite rapidly, however if the growing tips of the rhizomes are damaged the plants cease to establish lateral rhizome runners and may be very slow to recover. For example, it may take up to 50 years to close a gap of 1 m following damage to these tips (NSW DPI 2012). For this reason and due to substantial reductions in its abundance, the population of *P. australis* occurring in Port Botany was listed as endangered under the FM Act. Studies done within Botany Bay have also indicated that *Z. muelleri* subsp. *capricorni* may take several years to recolonise following its loss (Larkum and West 1980).

1.3.4 Seagrass Studies Relating to the Port Botany Expansion

A number of studies have been done to document seagrass distribution and condition in the northern part of Botany Bay, including Foreshore Beach and Penrhyn Estuary. Historically, the earliest estimates of seagrass distribution in the northern part of Botany Bay (including Cooks River to Frenchman's Bay) were based on aerial photographs from the 1930s up until the late 1970s. Considerable changes in the extent of the seagrass beds along the entire northern shore of Botany Bay during this period were observed. These changes were largely attributed to two expansions of the Sydney (Kingsford Smith) Airport and the development of port facilities, although observed differences between 1930 and 1961 indicate that natural variability in the area was high prior to any significant development (The Ecology Lab 2003).

A summary of seagrass studies undertaken at Foreshore Beach and Penrhyn Estuary in association with the Port Botany Expansion from 2002 to date are presented in **Table 1**. The first of these investigations was carried out by The Ecology Lab in April/July 2002 as part of baseline investigations for the Port of Botany Expansion Environmental Impact Statement (The Ecology Lab 2003). This study compared data collected in 2002 to NSW Department of Planning, Industry and Environment (DPIE) (Fisheries) seagrass mapping data for the same area based on 1995 aerial imagery (Watford and Williams 1998). Results showed an increase in total seagrass cover from 74,752 m^2 in 1995 (Watford and Williams 1998) to 96,715 m^2 in 2002 (The Ecology Lab 2003). In addition to an actual increase in seagrass cover, the changes were also attributed to possible differences in the quality and scale of the NSW Fisheries aerial photographs. Very sparse areas of seagrasses occurring along the eastern edge of the parallel runway estimated to collectively cover 2000 m^2 were also not included in the Watford and Williams (1998) mapping. Overall, the 2002 study showed that *Z. muelleri* subsp. *capricorni* was the most abundant species of seagrass present, varying from sparse to dense patches, and also mixed with *Halophila* spp. and green algae (*Caulerpa* spp.) in places. While *P. australis* was found in small clumps at the seaward edge of the main bed of *Z. muelleri* subsp. *capricorni*, it was not recorded during the earlier 1995 study.

Prior to the commencement of PBEP dredging and construction activities, Roberts *et al.* (2006, 2007 and 2008) carried out further mapping of Foreshore Beach to provide a baseline for future monitoring and help inform proposed transplant experiments. The surveying method involved the placement of 200 m long fixed transects (14 in total), oriented perpendicular to the shore, along the length of Foreshore Beach. The total area covered by seagrasses at Foreshore Beach in 2006 was estimated by this study to be 47,100 m^2, comprising *Z. muelleri* subsp. *capricorni*, mixed *Z. muelleri* subsp. *capricorni* and *Halophila* spp., and small patches of *P. australis* (approximately 14 m^2). Within Penrhyn Estuary, variable amounts of short *Z. muelleri* subsp. *capricorni* were recorded on mud flats and among mangrove pneumatophores during five surveys completed between July 2005 and June 2007 (The Ecology Lab 2007).

The total area of seagrass cover along Foreshore Beach in February 2007 was calculated to be only 698 m^2 and found to be predominantly comprised of mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. (423 m^2), with monospecific beds of *Z. muelleri* subsp. *capricorni* (192 m^2), *P. australis* (45 m^2), *Halophila* spp. (27 m^2) and mixed patches of all three species (11 m^2) also present. This extensive reduction in seagrass cover between 2006 and February 2007 was attributed to burial by sand mobilised by erosion along Foreshore Beach, although the cause of increased erosion was not speculated upon.

In November 2007 the total area of seagrass cover reported was 365 m^2 and comprised mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. (217 m^2), *Z. muelleri* subsp. *capricorni* (93 m^2), *P. australis* (43 m^2), mixed patches of *Z. muelleri* subsp. *capricorni* and *P. australis* (8 m^2), and mixed patches of all three species (approximately 4 m^2). Similarly, the total area of seagrass cover reported in May 2008 was 352 m^2, comprising mixed beds of *Z. muelleri* subsps. *capricorni* and *Halophila* spp. (221 m^2), *Z. muelleri* subsp. *capricorni* (86 m^2), *P. australis* (36 m^2), mixed patches of *Z. muelleri* subsp. *capricorni* and *P. australis* (5 m^2), and mixed patches of all three species (approximately 4 m^2). Following that final pre-construction survey completed in May 2008, the total area of seagrass estimated to be directly impacted by the dredging and reclamation works was 317 m^2. This area included mixed beds of *Z. muelleri* subsp. *capricorni*, *Halophila* spp. and *P. australis* (207 m^2), and monospecific beds of *Z. muelleri* subsp. *capricorni* (84 m^2) and *P. australis* (26 m^2).

During PBEP construction works (2009–2011), NGH Environmental, on behalf of Baulderstone Jan De Nul and Sydney Ports Corporation, undertook weekly monitoring of seagrass at 10 Sites along Foreshore Beach using an underwater viewing tube deployed from a boat. Monthly surveys were also carried out by divers. Monitoring locations were selected on the basis of earlier studies. Results of 2009 sampling indicated that the area of seagrass cover (*Z. muelleri* subsp. *capricorni* and *Halophila* spp.) at most of the sites was initially generally stable and/or increasing. By the end of 2011 seagrass cover had remained stable or was in decline, although no physical disturbance to the seagrass patches that remained was observed. Epiphytic growth was apparent at all sampling sites over the course of that sampling program, and was attributed to high nutrient levels within Port Botany.

Following the completion of PBEP construction works, post- construction seagrass monitoring of Foreshore Beach and the Rehabilitated Area of Penrhyn Estuary was carried out by Cardno in March/April 2012, 2013, 2014 and, for the final time in 2015. In 2016, unscheduled seagrass surveys were commissioned by Ward Civil Pty Ltd (Ward Civil), on behalf of the Port Authority of NSW, to continue monitoring seagrass off Foreshore Beach during pre-construction, construction and post-construction phases of a project to construct three groynes along the beach. The groynes were installed to protect the beach against erosion and sediment transport to the north of Foreshore Beach and offshore (Cardno 2016c). Those surveys, done in June 2016 (pre-construction), September 2016 (construction) and December 2016 (post-construction), ultimately determined that there was little change to patch sizes during the construction of the groynes, and that the loss of a small patch of *Z. muelleri* subsp. *capricorni* (Patch 5) after June 2016 was attributed to the widespread decline of this species at Foreshore Beach. Notwithstanding this, the loss of one small patch of *P. australis* and 56% decline in size of another were noted and attributed to poor water quality and sedimentation related to the construction combined with natural erosion still occurring prior to completion of the groynes. Further surveys to monitor Foreshore Beach seagrass since groyne construction have been completed in 2017, 2018, 2019 and now 2020. Relevant data from each of the aforementioned surveys done since 2012 are included in this report for appropriate comparison of seagrass distribution at Foreshore Beach through time.

Table 1 Summary of past seagrass studies of Foreshore Beach and Penrhyn Estuary, Port Botany

Year	Project Phase	Approximate Area of Seagrass (m^2)	Reference
1995	Pre-Construction	74,752	Watford and Williams (1998)
2003	Pre-Construction	94,715	The Ecology Lab (2003)
2006	Pre-Construction	47,100	Roberts *et al*. (2006)
2007 (February)	Pre-Construction	1,375	Roberts *et al*. (2007)
2007 (November)	Pre-Construction	680	Roberts *et al*. (2008)
2008	Pre-Construction	651	Roberts *et al*. (2008)
2009	During Construction	Not comparable	SPC (2009)
2010	During Construction	Not comparable	SPC (2010)

Year	Project Phase	Approximate Area of Seagrass (m^2)	Reference
2011	During Construction	Not comparable	SPC (2011)
2012	Post-Construction	26,000	Cardno (2012)
2013	Post-Construction	12,789	Cardno (2013)
2014	Post- Construction	16,406	Cardno (2014)
2015	Post-Construction	11,238	Cardno (2015a)
2016	Post-Construction	1,274 (Foreshore Beach only)	Cardno (2016a)
2016	Post-Construction	1,271 (Foreshore Beach only)	Cardno (2016b)
2016	Post-Construction	1,507 (Foreshore Beach only)	Cardno (2016c)
2017	Post-Construction	1,017 (Foreshore Beach only)	Cardno (2017)
2018	Post-Construction	1,843 (Foreshore Beach only)	Cardno (2018)
2019	Post-Construction	1,404 (Foreshore Beach only)	Cardno (2019)

1.3.5 Transplantation Experiments

Seagrass mapping carried out prior to enhancement works indicated that approximately 26 m^2 of existing *P. australis* would be directly impacted by works associated with the PBEP (Roberts *et al.* 2008). Given its conservation value and slow recovery rate, it was identified within the PEHEP that this area of *P. australis* would be relocated and transplanted to Quibray Bay.

Past seagrass transplantation experiments within Botany Bay have, however, had limited success. One of the greatest causes of failure has been attributed to poor decisions regarding the location of recipient sites (Sainty and Roberts 2004). Recipient sites at Quibray Bay were therefore carefully selected, in consultation with NSW DPIE (Fisheries), to be where conditions were considered to be optimal for transplantation success. Quibray Bay (at the southern end of Botany Bay) contains significant beds of *P. australis*, is sheltered from wave action and receives sufficient sunlight. Sites selected were characterised by either bare substratum adjacent to existing beds of *P. australis* or large bare patches within the existing beds.

The timing of transplantation was considered to be optimal when water temperatures were low and water clarity (light penetration) good. This was based on the assumption that less energy would be expended on growth and/or reproduction and could be conserved for repairing any damage and stress caused by transplantation (Roberts and Murray 2009).

In July 2008 seagrass in the impact area was removed by excavating the sediment down to the roots (below 1 m) using a hand held water pump. As excavations took place, a greater area of seagrass was exposed from beneath the sand, resulting in a total area of 132 m^2 being transplanted, although a number of those plants were lost in the transplantation. Overall, a total of 1771 individual plants were harvested and transplanted to Quibray Bay over a period of 18 days.

Two areas (Planting Area 1 and Planting Area 2) were chosen to receive the bulk of the transplanted seagrasses. Planting Area 1 covered an area of approximately 16 m^2 and Planting Area 2 covered an area of approximately 90 m^2. Densities at the time of transplanting were 10 and 15 plants per m^2 in Planting Areas 1 and 2 respectively. Three additional sites (Experimental Sites 1-3) were also established to test and evaluate different transplanting methods. Experimental treatments investigated included:

1. Whole (rhizomes + whole shoots);
2. Trimmed (rhizomes + shoots trimmed to 2 cm);
3. Rhizomes (rhizomes – no shoots);
4. Seagrass Control (existing *P. australis* at recipient site); and
5. Bare Control (bare sediment).

Locations and sampling methodology are outlined in further detail in the Port Botany Post Construction Environmental Monitoring Seagrass Annual Report 2013 (Cardno 2013).

Initial results indicated that by 14 months following transplantation the seagrasses within the Planting Areas had successfully established, with average shoot densities at Planting Areas 1 and 2 estimated at approximately 9 and 14 plants per square metre respectively. Over two years on from transplantation (by October 2010), average shoot densities had increased substantially, with densities of 37 and 43 shoots per square metre estimated for Planting Areas 1 and 2 respectively (Roberts and Murray 2010).

In the case of the Experimental Sites, the 'Whole' treatment recorded the greatest increase in shoot density, while the 'Trimmed' treatment had the greatest increase in leaf length. By the October 2010 survey there had been increases in the leaf length of plants from lengths recorded in the previous survey (September 2009) for all five treatments (Roberts and Murray 2010). Monitoring of seagrass transplantation Planting Areas and Experiment Sites was completed by 2013 and detailed results are provided in the Port Botany Post Construction Environmental Monitoring Seagrass Annual Report 2013 (Cardno 2013).

2 Methods

2.1 Sampling Design

2.1.1 Study Area

The extent of Foreshore Beach sampling was generally bounded by the area between the new boat ramp and the mouth of the Mill Stream (**Figure 1**). It is noted that the methods used to monitor seagrass at Foreshore Beach between 2009 and 2011 were temporarily modified from that originally specified in the PEHEP Seagrass Monitoring Plan due to a significant reduction in seagrass cover detected during surveys done between 2006 and 2008 by Roberts *et al.* (2006, 2007 and 2008). The methodology outlined in this report is therefore consistent with those earlier pre-construction surveys.

2.1.2 Mapping

The distribution and areal cover of each seagrass patch in existing seagrass beds at Foreshore Beach was mapped by divers and via the use of a remotely operated vehicle (ROV), with the total area (m^2) and species composition of each seagrass patch calculated using GIS software. Data for surveys carried out before construction (2003 – 2008) and after construction as part of the PEHEP (2012 to 2017) were compared to assess the changes in total seagrass cover. The total percent cover for selected species groupings was also compared across the 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys. The following four species grouping categories were used:

> Patchy sparse *Z. muelleri* subsp. *capricorni;*

> Patchy sparse *Halophila*;

> Patchy *P. australis;* and

> Continuous sparse *Halophila* and patchy sparse *Z. muelleri* subsp. *capricorni.*

2.1.3 Transects

Distribution and percent cover of seagrass at Foreshore Beach was mapped by divers along 11 transects spaced 50 m apart and extending up to 200 m perpendicular to Foreshore Beach (**Figure 1**). While Roberts *et al*. (2006, 2007 and 2008) measured percent cover of seagrass along six of these transects prior to construction, data were not available to allow statistical comparison with post-construction surveys so only those data from the 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys have been presented.

2.1.4 Fixed Patches

In addition to mapping and transects, percent cover was estimated by divers at a selection of fixed patches numbered 1, 2, 3, 5 and 6, 7 and 8, consistent with some of those surveyed during pre-construction surveys. These patches were originally established as control patches and were among an initial total of 44 fixed patches surveyed since the 2007 pre-construction survey. However, following the completion of construction works seagrass was only found at five fixed patches, so these fixed patches were used to investigate potential changes in percentage cover estimates for times before and after construction (refer to **Figure 4 Table 3Figure 4**). New Fixed Patch 8 (FP8) is now also being used for morphology monitoring as it represents a healthy, large patch of *Z. muelleri* subsp. *capricorni.*

2.1.5 Morphology Monitoring Sites

To determine seagrass condition, seagrass morphology data were collected from two additional patches of mixed-species seagrass (*Halophila* spp. with some *Z. muelleri* subsp. *capricorni*) at Foreshore Beach. These patches were selected during the first post-construction survey (March 2012) on the basis that they were the largest at the time. Two monitoring sites were randomly selected within each patch, and labelled P1A, P2A, P1B and P2B (**Figure 1**). In 2018, two new patches, P3A and P3B, along with FP8 mentioned in the previous section, were added to the group of patches where morphology was measured.

Within each morphology monitoring site, five 0.25 m^2 quadrats were placed in random positions by divers and used to measure the following indicators:

> Shoot density – The total number of shoots within each of the five quadrats was recorded to provide an estimate of seagrass density.

- Leaf length – The lengths of up to 10 (depending on density) randomly selected leaves within each of the five quadrats was recorded to provide an indicator of growth, which can vary widely depending on the habitat in which seagrass grows.
- Epiphyte load – An indication of epiphyte load was recorded by divers on 10 randomly selected leaves within each of the five quadrats using a four-point classification scale:
  - L=Low;
  - M=Medium;
  - H=High; and
  - N=None.

  The amount of epiphytic growth on the leaves is considered an indicator of seagrass health. Excessive epiphytic growth can reduce the amount of light available for growth and a high epiphytic load may be indicative of high nutrient levels within the water column.
- The presence or absence of the invasive alga *Caulerpa taxifolia* was noted.

2.1.6 Data Analysis

- Estimates of the total extent of areas of seagrass at Foreshore Beach are presented in tables and maps for each of the years 2003 – 2020.
- Estimates of percent cover of total seagrass and for seagrass species were presented as means, standard errors and ranges for each transect.
- Density and leaf length measurements for *Halophila* spp. collected at the seagrass morphology monitoring sites were statistically analysed using permutational analysis of variance (PERMANOVA+). After calculating a Euclidean distance matrix of all possible pairs of samples of the variable of interest, the underlying distribution of the data was determined by repeated randomisation of the samples in the matrix, enabling exact tests for all levels of the experimental design (Anderson *et al.* 2008). Statistically significant terms in the main analysis were further analysed using the relevant multiple pair-wise tests to identify statistically significant differences among surveys. The design applied for the main analysis included the following terms:
  - Survey (random) – (Autumn 2012, Autumn 2013, Autumn 2014, Autumn 2015, Autumn 2017, Autumn 2018, Autumn 2019 and Autumn 2020);
  - Site (random) – (P1A, P1B, P2A, P2B, P3A, P3B; see **Figure 1** – note that sites P3A and P3B were sampled in 2019 and 2020 only); and
  - Survey x Site – (Interaction term); with
  - Quadrats (1-5) used as replicates for shoot density (n = 5), or
  - Leaf length measurements (up to 10 per quadrat) used as replicates for leaf length (n = up to 50).
- Epiphyte load was not analysed statistically but presented as percentages of total observations categorised as high, medium and low epiphyte load, or none if no epiphytes were observed.

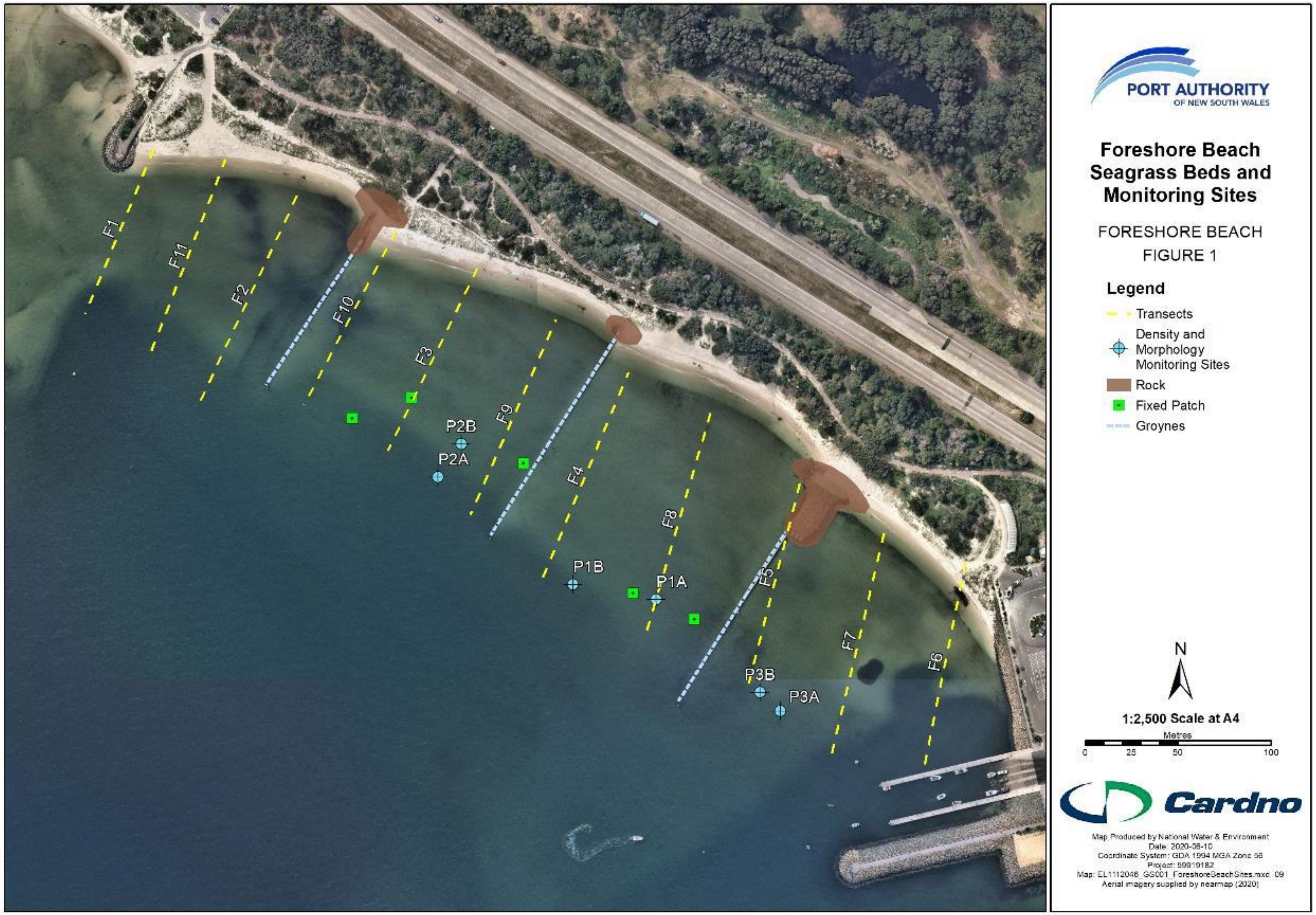

Figure 1 **Foreshore Beach transect, fixed patches and morphology monitoring sampling locations**

2.2 Summary of Sampling

Table 2 Summary of seagrass sampling methods, indicators and period/year of data analysed

Location	Sampling Method	Indicator	Period/Years
Foreshore Beach	Diver / ROV mapping (entire area)	Seagrass species Area	Before: 2002, 2006, 2007, 2008 After: 2012, 2013, 2014, 2015, 2017, 2018, 2019, 2020
	Diver transects survey x11 transects Visual estimates recorded every meter along transect	Seagrass species % cover	Before: Data not available After: 2012, 2013, 2014, 2015, 2017, 2018, 2019, 2020
	Diver observations (Fixed Patches) x5 Sites (since 2012)	Seagrass species % cover estimates	Before: 2007, 2008 After: 2012, 2013, 2014, 2015, 2017, 2018, 2019, 2020
	Diver survey (Morphology Monitoring Sites) x6 patches, x5 quadrats per patch	Shoot density Leaf length (x10 reps) Epiphyte load	After: 2012, 2013, 2014, 2015, 2017, 2018, 2019, 2020

2.3 Sampling Dates

All seagrass data collection (mapping, transects, fixed patches and morphology sites) at Foreshore Beach for the 2020 survey was carried out by Cardno on 28 and 29 April 2020.

3 Results

3.1 Mapping

The most recent survey of seagrasses at Foreshore Beach was completed in April 2020. Total seagrass in April 2020 was 788 m^2 representing a 43.9% decrease from the previous survey (1,404 m^2) done in 2019 (**Figure 2**). Only two types of seagrass - *Z. muelleri* subsp. *capricorni* and *Halophila* spp – were recorded during the 2020 survey. The overall decrease was almost entirely attributed to the reduction in *Halophila* spp. from 1,317 m^2 in 2019 to 656 m^2 in 2020 representing a 50.2% decrease. In contrast, the area of *Z. muelleri* subsp. *capricorni* increased from 80 m^2 in May 2019 to 132 m^2 in 2020 representing a 65% increase; this followed successive doublings in area observed between 2017 and 2018 (i.e. 15 to 38 m^2) and from 2018 to 2019 (i.e. 38 to 80 m^2). *P. australis* was not recorded during the 2020 survey, thus representing a 100% decrease (**Figure 3**).

Trends in total seagrass cover at Foreshore Beach from before port expansion (2002 – 2008) through to the current post-expansion period (2012 – 2020) are illustrated in **Figure 2** and summarised in **Table 3**. Trends in seagrass cover (m^2) by species for this timeframe at Foreshore Beach are shown in **Figure 3**.

Maps of seagrass distribution between May 2019 and April 2020 indicate that the extent of *Halophila* spp. has contracted to exclusively the southernmost groyne from previously also existing in other beds adjacent to the northernmost groyne. The notably healthy and dense patch of *Z. muelleri* subsp. *capricorni* at the southern end of Foreshore Beach between the southernmost groyne and the northern breakwater of the boat ramp has clearly expanded, increasing from 80 to 132 m^2 (Fixed Patch 8 – **Figure 4**).

Irrespective of the recent variability in overall seagrass extent, it remains substantially reduced in comparison to the 2002 pre-expansion survey and the 2012 post-expansion surveys (**Figure 2**, **Figure 3**, **Figure 5** and **Table 3**). It is also noted, however, that the most substantial decline in seagrass extent occurred between 2002 and 2007, prior to any port expansion works and was not, therefore, attributable to any port expansion works. Following completion of the port expansion works, total seagrass cover increased to levels recorded in 2012, then steadily declined overall to the extent recorded in 2017 (**Figure 2**).

The 2020 survey yielded the lowest seagrass extent (i.e. 788 m^2) since groyne construction in 2017 (i.e. 1, 024 m^2), with the majority of the decline driven by the decrease in *Halophila* spp. (largely by P2A and P2B) as well as the loss of *P. australis* (Patch 3).

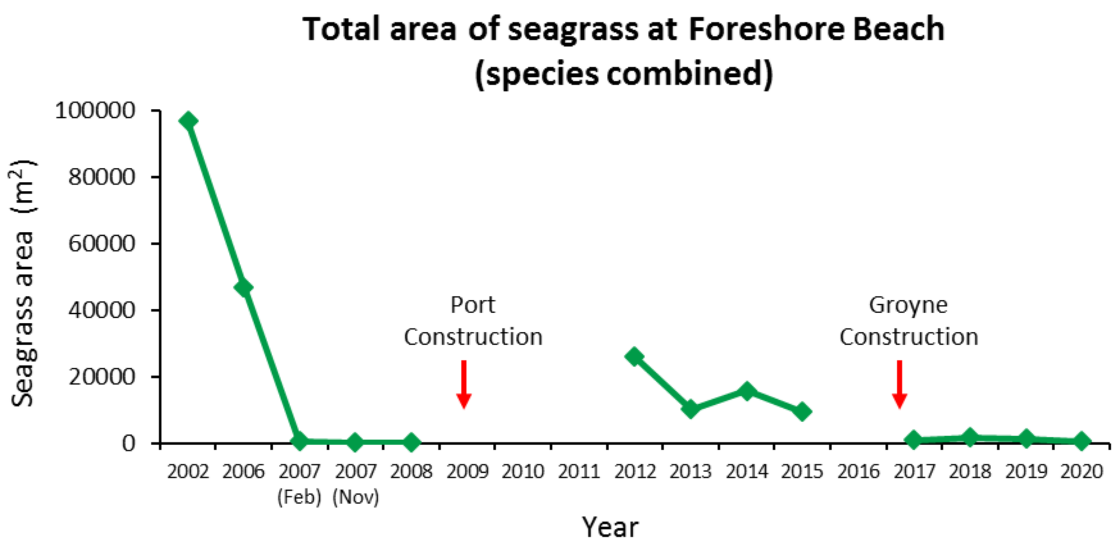

Figure 2 **Total area of seagrasses at Foreshore Beach between 2002 and 2020. NB: comparable quantitative data was not collected during port construction (2009-2011)**

Table 3 Total seagrass area (m^2) at Foreshore Beach between 2002 and 2020

*Figures in parentheses include the combined areas of seagrass at Foreshore Beach within the construction footprint and in Penrhyn Estuary.

Year	Phase	Approximate Area of Seagrass (m^2)	Reference
2002 (April/July)	Pre-Construction	65,821 (94,715)*	The Ecology Lab (2003)
2006 (June)	Pre-Construction	42,100 (47,100)*	Roberts *et al*. (2006)
2007 (February)	Pre-Construction	698	Roberts *et al*. (2007)
2007 (November)	Pre-Construction	365	Roberts *et al*. (2008)
2008 (May)	Pre-Construction	352	Roberts *et al*. (2008)
2012 (March)	Post-Construction	26,000 (Sparse coverage)	Cardno (2012)
2013 (March)	Post-Construction	10,323 (Sparse coverage)	Cardno (2013)
2014 (March)	Post-Construction	15,987 (Sparse coverage)	Cardno (2014)
2015 (March)	Post-Construction	9,589 (Sparse coverage)	Cardno (2015a)
2017 (March)	Post-Construction	1,017 (Sparse coverage)	Cardno (2017)
2018 (May)	Post-Construction	1,843 (Sparse coverage)	Cardno (2018)
2019 (May)	Post-Construction	1,404 (Sparse coverage)	Cardno (2019)
2020 (April)	Post-Construction	788 (Sparse coverage)	This report

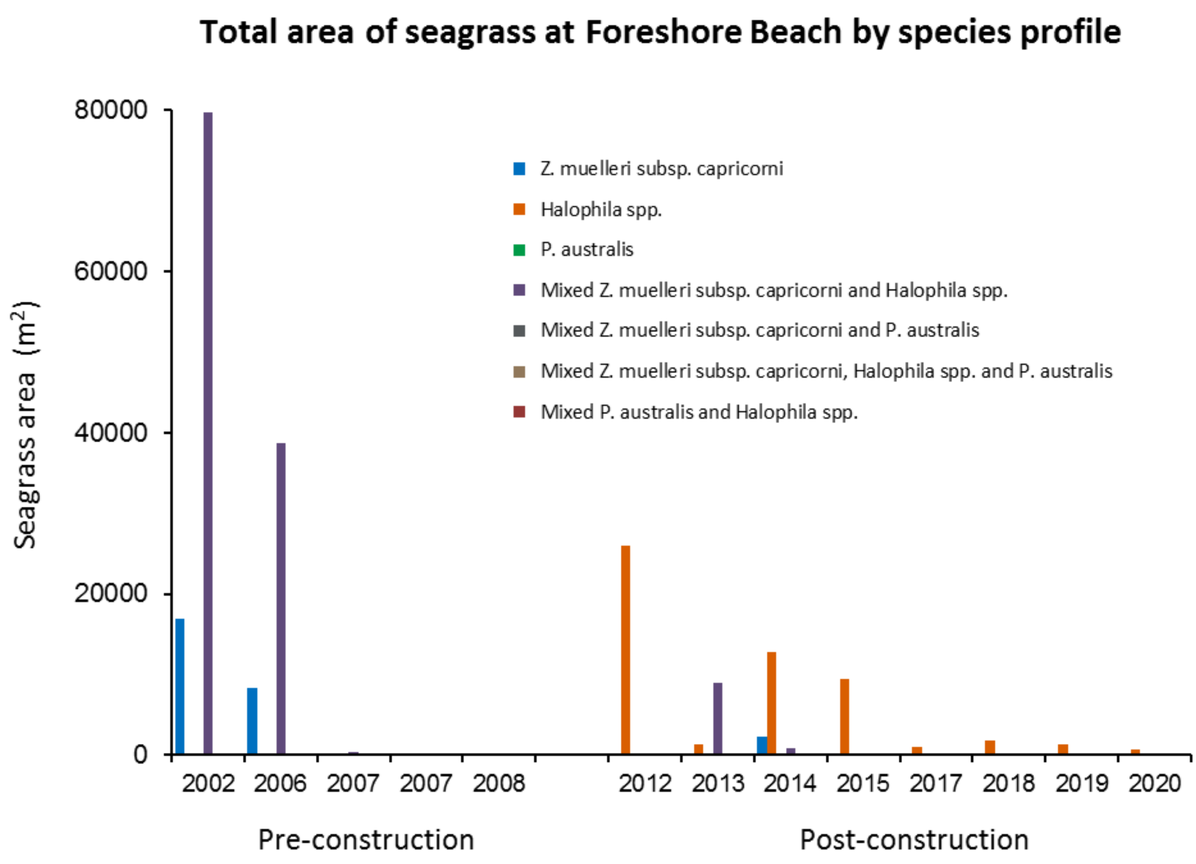

Figure 3 Area of seagrass taxa at Foreshore Beach between 2002 and 2020. Includes data from Foreshore Beach Fixed Patches

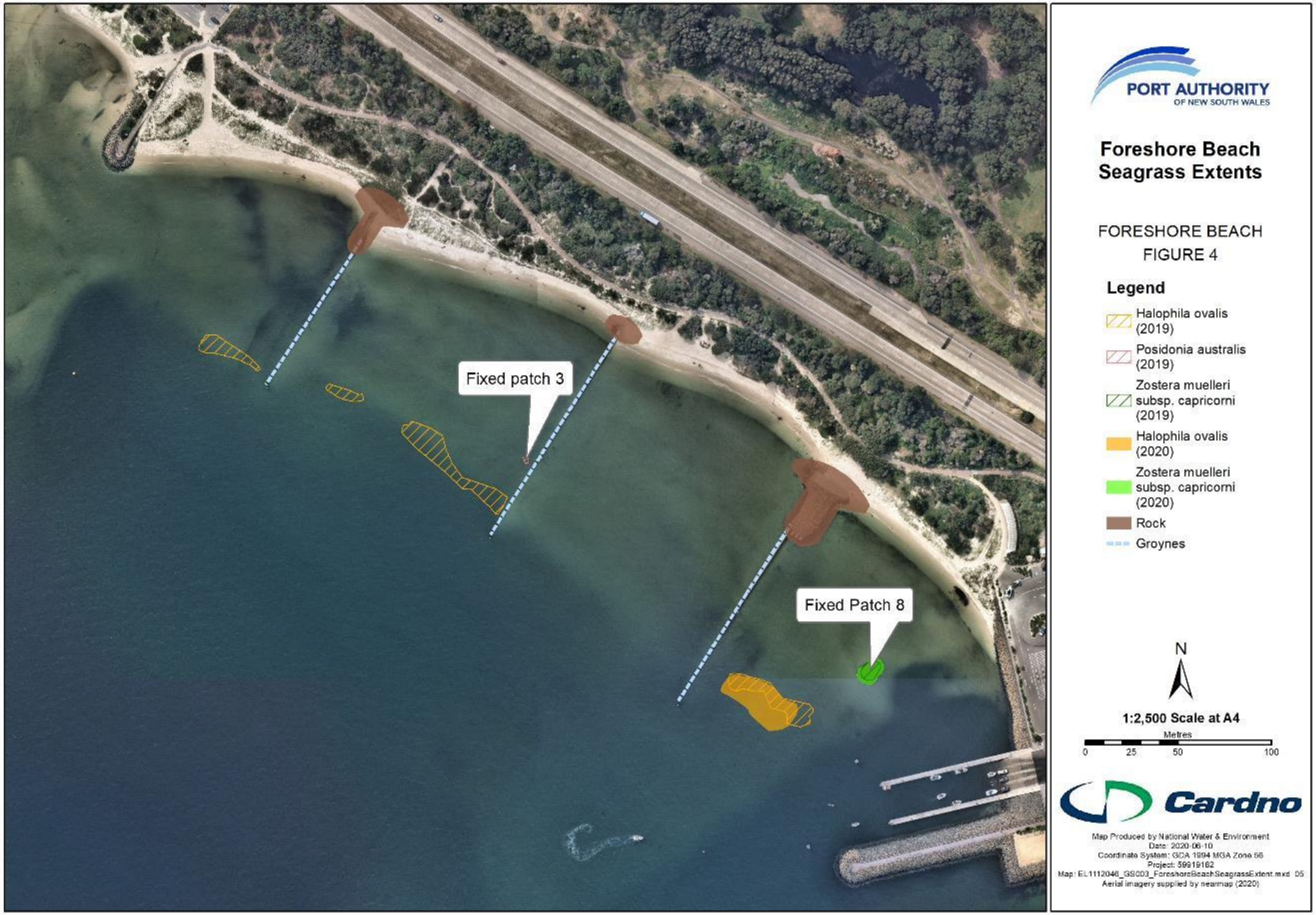

Figure 4 Seagrass mapped at Foreshore Beach in 2020 compared to 2019

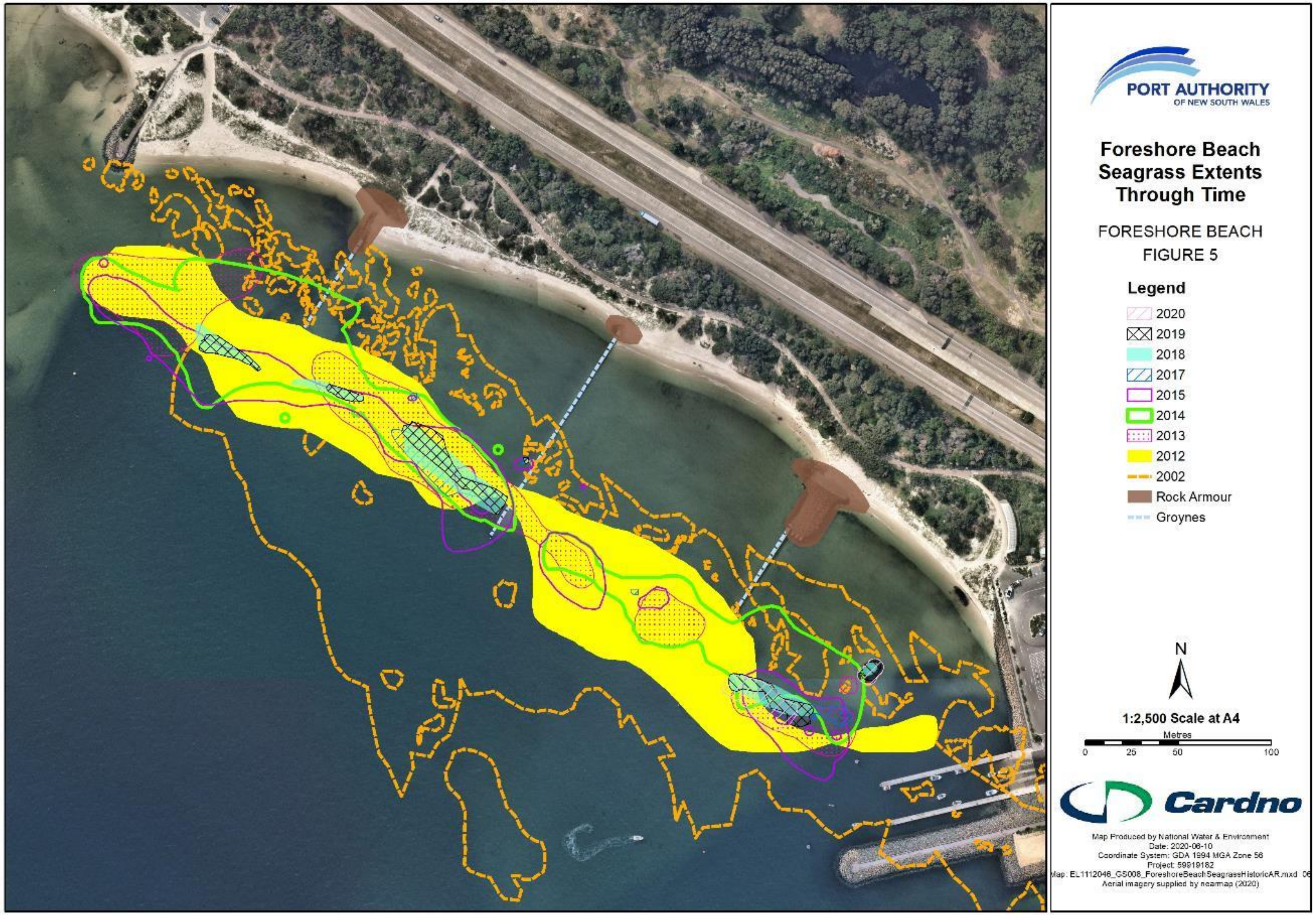

Figure 5 **Seagrass mapped at Foreshore Beach prior to (2002) and after (2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020) port expansion**

3.2 Transects

Only *Halophila* spp. was found along transects in 2020. Therefore, percent cover estimates for *Halophila* spp. have been only interpreted for the purpose of comparison with 2019 data.

Estimates of percent cover of *Halophila* spp. for 1 m measurement points along transects during 2020 ranged from 0 to 10%, with an overall average of ~0.08% cover per measurement point (*n* = 1,315 measurement points; **Figure 6**). Given that the overall average of percent cover of *Halophila* spp. in transects was ~0.17% in 2019, this represents a net decrease in percent cover of *Halophila* spp. of ~0.08% (i.e. approximately -54% lesser coverage) in transects from 2019 to 2020.

The overall average percent cover of *Halophila* spp. along transects decreased from ~0.17% in 2019 to ~0.08%, representing a 54% reduction in coverage (**Figure 6**). This decrease contrasted to the increasing trend in *Halophila* spp. coverage from 2017 to 2019 which saw an almost ten-fold rise in coverage in *Halophila* spp. from ~0.013% to ~0.12% between the 2017 and 2018 surveys.

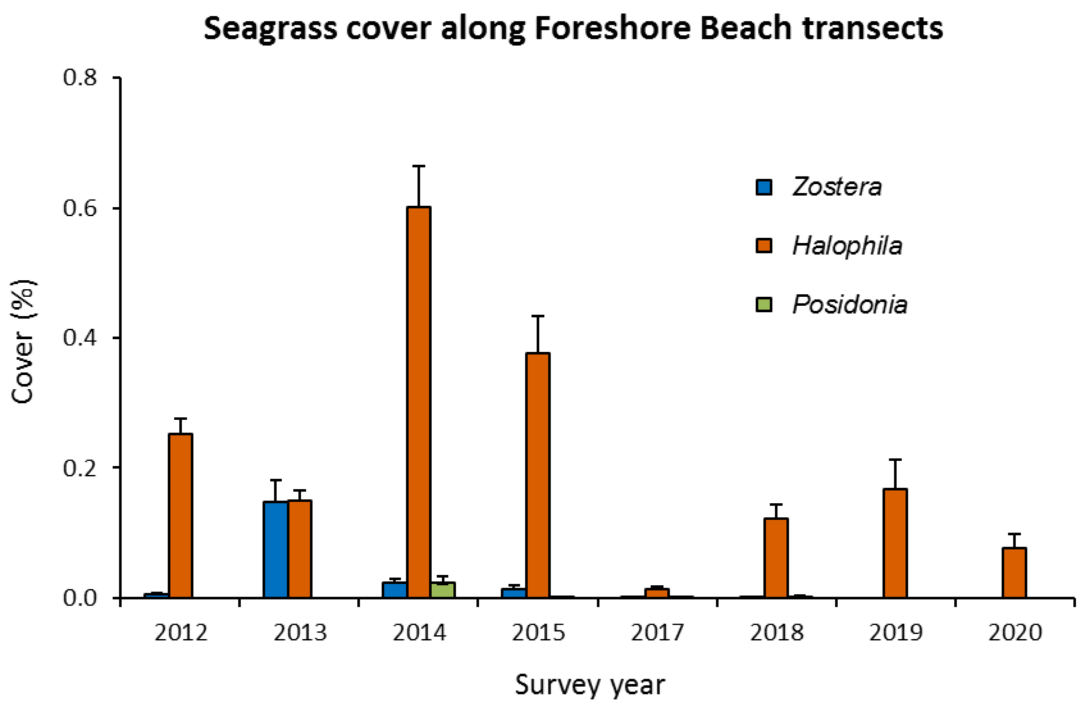

Figure 6 Percent cover (+ SE) of seagrasses recorded along transects at Foreshore Beach in Autumn 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020.

3.3 Fixed Patches

Seagrass was recorded at only one of eight patches (Patch 8) during the 2020 survey. Patch 3 containing a small area of *P. australis* (7 m^2) in the 2019 survey was not recorded in 2020. This small patch persisted since the start of fixed patch surveys in 2008, but did decline substantially from 36 m^2 recorded in 2017 to 7 m^2 in 2019. Patch 8 contained a healthy and dense area of *Z. muelleri* subsp. *capricorni,* that has increased in area from 80 m^2 in 2019 to 132 m^2 in 2020 (**Table 4**, **Plate 1**).

Overall, the collective areal extent of seagrass in fixed patches in the 2020 survey (i.e. Patch 8) has increased from 87 m^2 in 2019 to 132 m^2 in 2020. However, increases were driven solely by *Z. muelleri* subsp. *capricorni* (Patch 8) as *P. australis* (Patch 3) was not recorded in the 2020 survey. Patches 2, 5 and 7 which were recorded in 2017, were not recorded in years thereafter (**Table 4**). Seagrass was last recorded in Fixed Patches 1 and 6 in 2015, in Patch 4 in 2012, and in Patches 2, 5 and 7 in 2017.

Table 4 Seagrass area estimates for Fixed Patches along Foreshore Beach since 2008

Patch	Seagrass Area (m^2)								
Year	2008	2012	2013	2014	2015	2017	2018	2019	2020
1	5	20	5	1.5	1.7				
2	4	6	4.4	4	5	1			
3	4	12	17.8	15	19	36	8	7	
4	4	0.5							
5	2	9		5	14	4			
6	1	1	1	1.5	0.9				
7						0.25			
8						11.4	38	80	132
Total	**20**	**48.5**	**28.2**	**27**	**40.6**	**52.6**	**40**	**82**	**132**

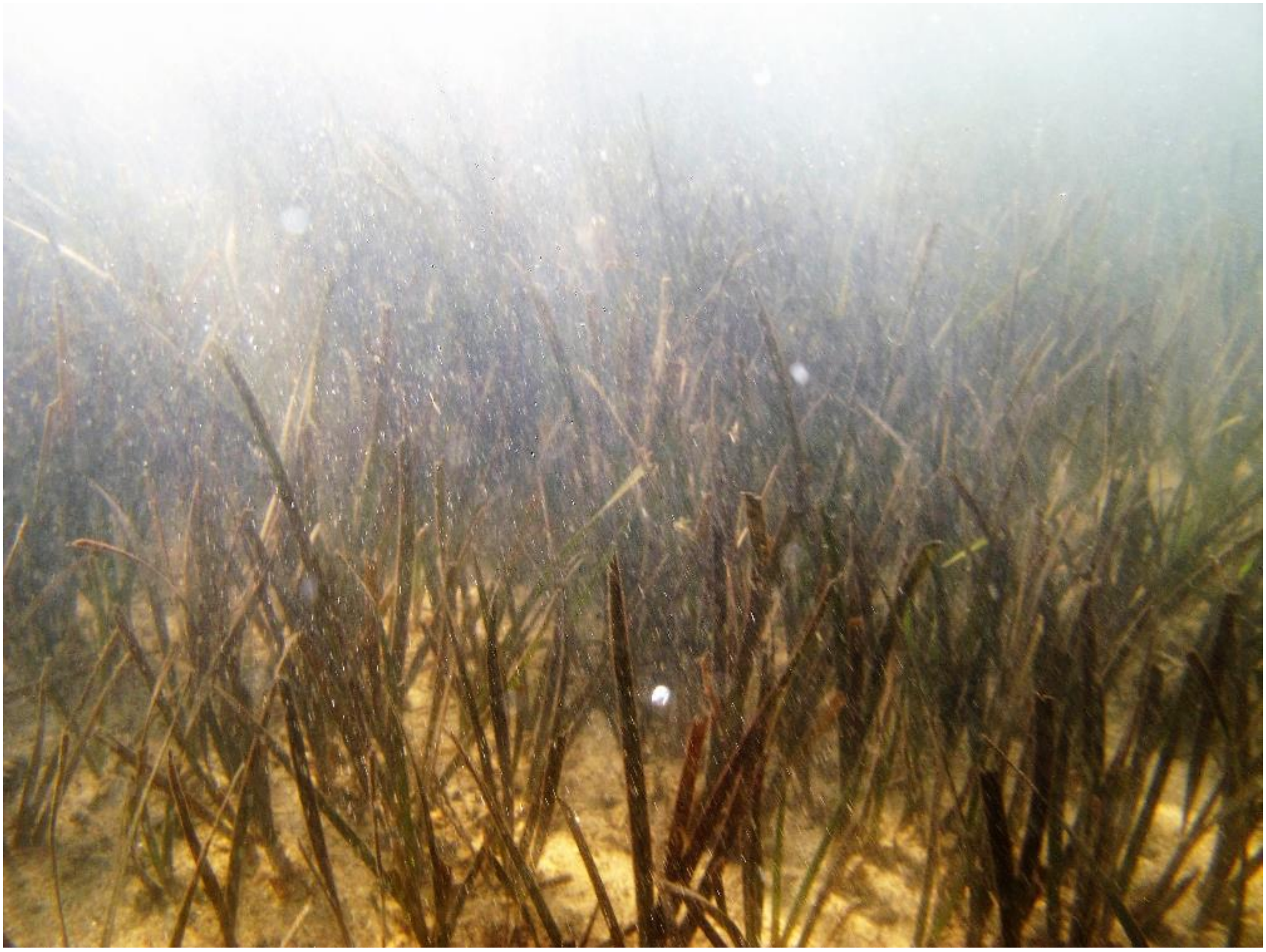

Plate 1. *Z. muelleri* subsp. *capricorni* at Fixed Patch 8 – first detected in 2017 and showed expansions (a doubling of area) between both 2017 and 2018 and 2018 and 2019, with further increase by 65% from 2019 to 2020.

3.4 Seagrass Density and Morphology

3.4.1 Shoot Density

Halophila spp. was not recorded at morphology sites, P1A, P1B, P2A and P2B in 2020 and has not been recorded at P2A or P2B since 2018. Average shoot densities recorded in 2018 at P2A and P2B were 10.4 and 11.4 cm respectively per 0.25 m^2 (**Table 5**, **Figure 7**).

At sites P3A and P3B the average *Halophila* spp. shoot density was 22.8 and 18.0 shoots per 0.25 m^2 respectively in 2020, compared to 9.8 and 42.6 shoots per 0.25 m^2 in 2019 and 15.6 and 15.0 shoots per 0.25 m^2 in 2018. Despite substantial variability in measurements, there were no clear patterns of change in *Halophila* spp. density from 2019 to 2020 at these morphology sites, illustrating a high level of spatial, and possibly temporal, variability in shoot density within established beds.

Statistical analysis of *Halophila* spp. shoot density comparing among surveys 2012 to 2020 detected significant survey x site interaction ($p < 0.0001$; **Appendix A**), indicating shoot density was significantly different among surveys for at least some of the morphology sites. Most differences were attributed to patches that were not recorded in the 2020 survey. That is, pair-wise comparisons found that at Site P2A, shoot density of *Halophila* spp. in 2019 was not significantly different from 2018, 2017, 2015 and 2014 densities, but was significantly greater than densities recorded in 2013 and 2012 (**Table 5**). In contrast, at Site P2B the shoot density of *Halophila* spp. in 2019 was not significantly different from those recorded in 2012, 2013, 2014, 2015 and 2017, but was significantly lower than that recorded in 2018. Of the two sites that were sampled in 2020 (P3A and P3B), shoot density at P3A increased significantly from 2019 to 2020. The average density of *Z. muelleri* subsp. *capricorni* at Fixed Patch 8 (FP8) – the relatively large area (132 m^2) of dense *Z. muelleri* subsp. *capricorni* described in **Section 3.3** (**Plate 1**) – was 254.4 shoots per 0.25 m^2, which has increased from densities recorded in 2019 and 2018 of 233.6 and 236 shoots per 0.25m^2 respectively (**Table 5**, **Figure 7**). In contrast, *P. australis* has not been found in any of the morphology patches since 2012, while no seagrass shoots of any species have been found at morphology patches P1A and P1B since 2015.

Table 5 Mean shoot densities (shoots per 0.25 m² quadrat, n=5) of seagrass in morphology monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys

Species	Year	Site						
		P1A	P1B	P2A	P2B	P3A	P3B	FP8
Zostera	2012				0.8			
	2013	7.0						
	2014							
	2015	8.8						
	2017							
	2018							236.0
	2019							233.6
	2020							254.4
Halophila	2012	4.2	6.2	1.2	6.2			
	2013	37.8	5.4	0.4	76.0			
	2014	8.2	3.0	4.6	9.0			
	2015		11.8	12.6	8.4			
	2017			9.4	29.0	15.6	15.0	
	2018			10.4	11.4	15.6	15	
	2019					9.8	42.6	
	2020					22.8	18	
Posidonia	2012		2.0					
	2013							
	2014							
	2015							
	2017							
	2018							
	2019							
	2020							

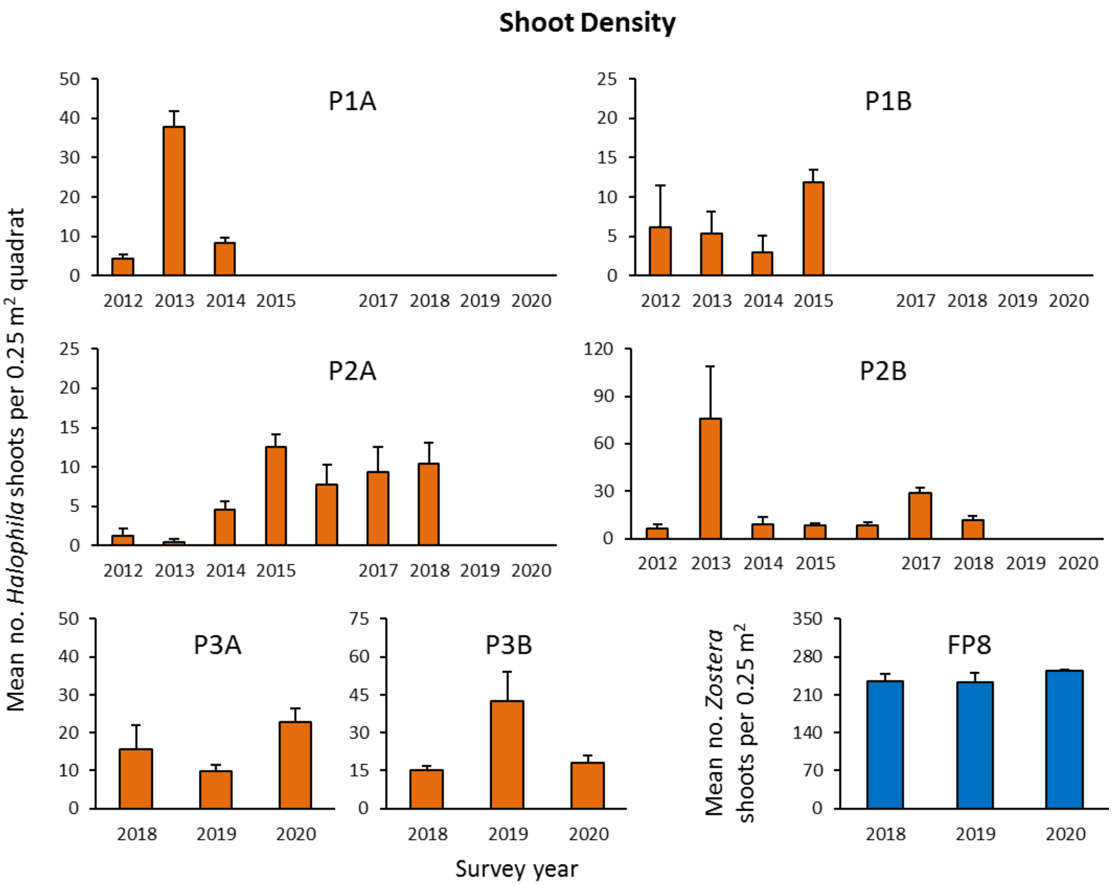

Figure 7 **Mean (±SE) shoot densities (0.25 m^2) of *Halophila* spp. (n = 5) sampled in morphology monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys.**

3.4.2 Leaf Length

No *Halophila* spp. was identified at morphology sites P2A and P2B in 2020, where previous average leaf length of *Halophila* spp. in respective morphology sites in 2019 was 2.8 and 2.3 cm. The average leaf length of *Halophila* spp. at morphology sites P3A and P3B in 2020 was 2.5 and 2.3 cm respectively, compared to 2.0 and 3.2 cm respectively in 2019 (**Table 6**, **Figure 8**).

As was the case for shoot density estimates, there were no clear patterns of change in *Halophila* spp. leaf length from 2018 to 2020 at these morphology sites, with some sites showing a very slight increase in average leaf length and others a slight decrease. At P3A and P3B, the only sites where *Halophila* spp. was present in 2020, there was a 20% increase in average leaf length between the 2019 and 2020 surveys at P3A and a 28% decrease in average leaf length at P3B.

The average length of *Z. muelleri* subsp. *capricorni* leaves at Fixed Patch 8 (FP8) – the relatively large area (132 m^2) of dense *Z. muelleri* subsp. *capricorni* described in **Section 3.3** (**Plate 1**) – was 22.5 cm, which was slightly longer than that recorded in previous years 2018 and 2019 (i.e. 19.2 and 20.7 cm respectively) (**Table 6**, **Figure 8**). *P. australis* has not been found in any of the morphology patches since 2012, while no seagrass of any species has been found at morphology patches P1A and P1B since 2015.

As was the case for shoot densities, statistical analysis of *Halophila* spp. leaf length detected a significant survey x site interaction ($p < 0.001$; **Appendix A**), indicating leaf length was significantly different among surveys for at least some of the morphology sites.

Subsequent pair-wise comparison among surveys found that leaf lengths recorded for *Halophila* spp. at some sites in some years were significantly longer than leaf lengths at other sites in other years (**Appendix A**). Leaf lengths at Site P2A in 2019 were significantly longer than leaf lengths recorded in 2018, but not significantly different from lengths recorded in 2017 (**Table 6**, **Appendix A**). Compared to lengths recorded prior to 2016, the 2019 leaf lengths at Site P2A were not significantly different from those recorded in 2015, but significantly longer than those recorded in 2014.

In contrast to Site P2A, pair-wise comparisons for Site P2B found that the leaf lengths recorded for *Halophila* spp. in 2019 were significantly shorter than leaf lengths recorded in 2018 and 2014, not significantly different from lengths recorded in 2017, 2015 and 2013, and significantly longer than lengths recorded in 2012 (**Figure 8**, **Appendix A**).

In terms of the sites sampled in 2020, leaf lengths at Site P3A in 2020 were significantly longer than leaf lengths recorded in 2018 and 2019. In contrast, Site P3B recorded significant shorter leaf lengths in 2020 compared to the 2018 and 2019 surveys (**Figure 8**, **Appendix A**).

Table 6 Mean leaf length (cm) of seagrasses sampled (including *n* in parentheses) within monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys.

Species	Year	Site						
		P1A	P1B	P2A	P2B	P3A	P3B	FP8
Zostera	2012				3.5 (4)			
	2013	1.0 (20)						
	2014							
	2015	4.8 (29)						
	2017							
	2018							19.2 (50)
	2019							233.6 (50)
	2020							22.46 (50)
Halophila	2012	2.5 (8)	2.0 (14)	2.0 (3)	2.0 (30)			
	2013	3.5 (46)	3.2 (21)	2.0 (2)	2.3 (38)			
	2014	2.0 (47)	3.9 (14)	2.1 (38)	3.6 (24)			
	2015		3.2 (50)	3.3 (50)	2.8 (50)			
	2017			3.0 (41)	2.1 (43)			
	2018			2.3 (46)	2.7 (50)	2.1 (50)	3.1 (50)	
	2019			2.8 (40)	2.3 (48)	2.0 (50)	3.2 (50)	
	2020					2.4 (50)	2.3 (50)	
Posidonia	2012		2.2 (10)					
	2013							
	2014							
	2015							
	2017							
	2018							
	2019							
	2020							

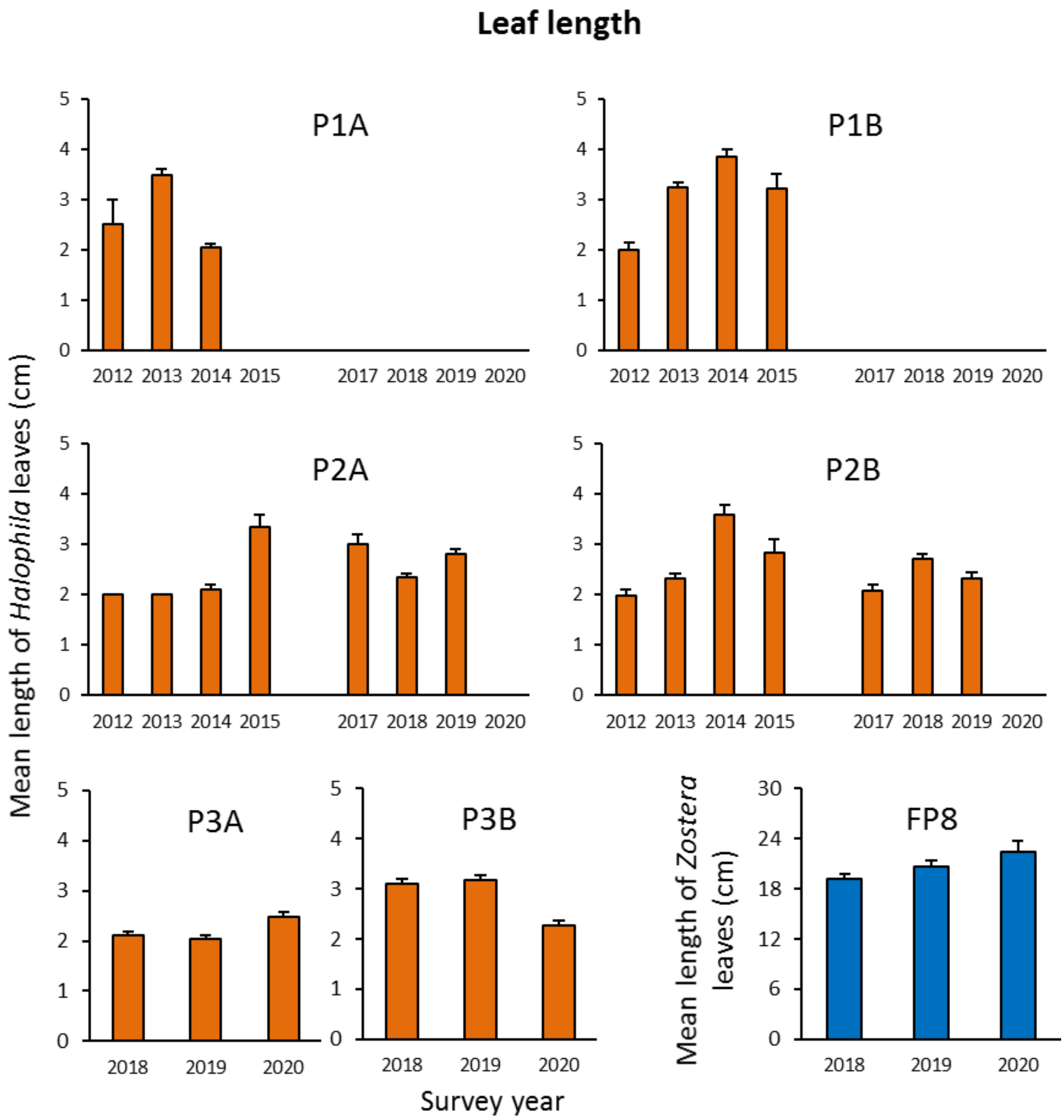

Figure 8 Mean (±SE) leaf length (cm) of *Halophila* spp. and *Zostera* spp. (FP8) sampled at Foreshore Beach morphology monitoring sites during 2012, 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys (see Table 6 for *n*).

3.4.3 Epiphyte Load

Epiphytes were recorded on all fronds of *Halophila* spp. sampled in the 2020 survey. Patterns in levels of epiphyte loads on *Halophila* spp. varied among the sites P3A and P3B characterised by the occurrence of mostly low loads (P3A – 78% low; P3A – 12% medium; P3B – 100% low) (**Table 7**). Comparison between the 2019 survey and 2020 survey suggests the epiphyte load on *Halophila* spp. fronds has generally remained the same at P3A and P3B.

Patterns in levels of epiphyte loads on *Halophila* spp. varied among the sites and among years. In most years, sites were generally characterised by the occurrence of mostly low or medium loads but there were nearly always also a small percentage of fronds with high loads (**Table 7**). Epiphyte loads on the only (P3A and P3B) remaining patches of on *Halophila* spp. generally decreased from higher to relatively lower levels from 2018 to 2020 and in the most recent survey were 84% low and 12% medium at P3A and 100% low at P3B.

Low epiphyte loads were recorded on fronds of *Z. muelleri* subsp. *capricorni* sampled at FP8 in the 2020 survey, with 100% of the growth falling within the 'low' level category (**Table 7**). These low loads were consistent with the previous 2018 and 2019 surveys.

As epiphyte load is a qualitative measure, and given the inconsistencies in seagrass occurrence through time, it is difficult to conclude whether there has been any overall increase or decrease in epiphyte loads associated with seagrasses at Foreshore Beach. The levels recorded do not, however, indicate any obvious form of 'enrichment' and would be considered within a normal range for Foreshore Beach based on the long term observations.

Table 7 Percent occurrence of epiphytic load categories (L = Low, M = Medium, H = High) on seagrass at Foreshore Beach in 2013, 2014, 2015, 2017, 2018, 2019 and 2020 surveys

Species	Epiphyte load	Site (% occurrence per survey year)																										
		P1A			P1B			P2A						P2B						P3A			P3B			FP8		
Survey year:		'13	'14	'15	'13	'14	'15	'13	'14	'15	'17	'18	'19	'13	'14	'15	'17	'18	'19	'18	'19	'20	'18	'19	'20	'18	'19	'20
Zostera	L	100		100																						92	100	100
	M																									8		
	H																											
Halophila	L	46	55				64		39	70	100	26	75			84	81	12	27	34	46	78	50	84	100			
	M	50	26		43		28	100	53	26		35	25	100	58	14	12	54	21	48	18	12	32	16				
	H	4	19		57	100	8		8	4		39			42	2	7	34	52	18	36		18					

4 Interpretation

4.1 Long term Trends

Seagrass beds along Foreshore Beach have undergone great change since the start of monitoring in 2002. The large bed of predominantly *Z. muelleri* subsp. *capricorni* that had all but disappeared prior to the commencement of Port Botany Expansion works in 2009 has, to date, not showed signs of returning to areal extents similar to those recorded in 2002. It is important to note, however, that this extensive reduction occurred prior to the port expansion works and was, therefore, attributed to other factors such as erosion and consequent sedimentation/smothering of seagrass close to the Foreshore Beach at that time, although this hypothesis has not been substantiated. In any case, the observed rapid expansion over the past two years of one small patch of *Z. muelleri* subsp. *capricorni* located in the south-east of the monitoring area provides for some optimism regarding further spread of this species in coming years.

The first monitoring survey following the completion of port expansion works, carried out in 2012, did show a substantial increase in overall seagrass cover (species combined and predominantly *Halophila* spp.) since the last pre-expansion-works survey (May 2008), although this 2012 areal extent was still only approximately a third of that estimated in 2002. Annual monitoring surveys done since 2012 showed a gradual decline in overall seagrass cover through to 2016. Cover then fluctuated between about 1, 000 and 2,000 m^2 between 2016 to 2019 before declining further to 788 m^2 in 2020. Changes since the groynes were completed are discussed in more detail in the next section.

The overall composition of seagrass at Foreshore Beach has also gone from one characterised predominantly by *Z. muelleri* subsp. *capricorni* and mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. prior to port expansion works to one characterised by the more ephemeral and pioneering *Halophila* spp. since completion of port expansion works.

While some of the very small areas of *Z. muelleri* subsp. *capricorni* and *P. australis* had persisted beyond 2012, only a single small patch of *Z. muelleri* subsp. *capricorni* was present in 2020 and there was no *P. australis* (see also **Section 4.2**).

4.2 Post Groyne Construction

In addition to the long-term decline in seagrass at Foreshore Beach (see above), other activities such as beach nourishment and groyne construction have potentially affected seagrass growth and survival. It is understood that beach nourishment has been undertaken twice since completion of port expansion works. After a beach has been nourished it is expected that some of the deposited sand would be mobilised into offshore subtidal areas. This process is likely to have affected seagrass at Foreshore Beach. The groynes were constructed as a permanent solution to beach erosion at Foreshore Beach but stabilisation usually takes some time to occur after establishment of groynes and after an initial process of accretion. Observations by divers indicate that it is likely that accretion was occurring between some of the groynes up until 2020, and may still be ongoing. At some point, however, it is expected that there will be no accretion of sediment in subtidal areas between the groynes.

Since construction of the groynes was completed in late 2016, the beds of *Halophila* spp. between the groynes have gradually narrowed and have disappeared in many places. The total area of *P. australis* at Foreshore Beach has been comparatively small since 2016 but the 2020 survey noted complete disappearance of the last remaining patch (Fixed Patch 3 – located close to the northern face of the middle groyne). Since 2017, frond condition in this patch has been deteriorating, shoot density and extent has been reducing and the shoot bases have been observed to be buried under up to 10 cms of sediment. Along with the general long-term trend of declining seagrass at Foreshore Beach, accreting sediment has probably contributed to the cause of the disappearance.

Although seagrass has disappeared from Foreshore Beach in many places, conditions appear to have improved for seagrass in the area between the southernmost groyne and the boat ramp. There, the patch of *Halophila* spp. essentially doubled in extent between 2019 and 2020, expanded seaward and shoot density increased significantly at one of the two sampling sites within the patch. A low epiphyte load on fronds of *Halophila* spp. was indicative of new growth in 2020. Fixed Patch 8, the small, elliptical-shaped patch of high density *Z. muelleri* subsp. *capricorni*, is also within this area. In this patch there has been a trend of rapid expansion with a tenfold increase in extent since 2017. These findings suggest the rate of accretion of sediment in this area (due to the groynes) has stabilised and that the environment supports seagrass recolonisation.

5 Conclusions and Recommendations

Pre- and post-construction monitoring of seagrass done over the past 19 years at Foreshore Beach has detected changes to species composition, along with great spatial and temporal variability in the distribution and condition of seagrass of the species present. Perhaps the most important observation was that the most substantial changes (by far) to the seagrass beds at Foreshore Beach occurred prior to commencement of construction for the Port Botany Expansion, indicating that those changes, detected prior to 2009, can only be attributed to factors other than the construction works.

Although monitoring data for the PEHEP were collected in a consistent and quality-controlled manner from the 2012 survey onwards, there have been some factors that have arisen that have confounded interpretation of long-term trends in seagrass distribution and condition at Foreshore Beach. Prior to 2016, erosion at Foreshore Beach, further exacerbated by subsequent beach nourishment, probably facilitated a higher than normal level of mobilisation of sediment, resulting in substantial deposition of sediment (or accretion) onto the seagrass beds. It is noted, however, that these beach nourishment works were required due to faster than predicted erosion in the supralittoral zone. Construction of three groynes at Foreshore Beach in late 2016 has reduced the erosion and hence the potential for relatively large loads of sediment to be mobilised across the seagrass habitat but there has also been accretion to the subtidal benthic habitat.

Whereas previous surveys indicated limited understanding of long-term trends in *Halophila* spp. distribution and condition after construction of the groynes, the 2020 survey highlighted a definitive decline of seagrass area in some parts of Foreshore Beach but a substantial recovery in other parts. However, the 2020 survey also indicated mixed localised effects on the distribution of *Halophila* spp, *Z. muelleri* subsp. *capricorni* and *P. australis*. Although seagrass has disappeared in much of Foreshore Beach, it appears to be expanding between the southernmost groyne and the boat ramp, suggesting the rate of accretion of sediment in this area has stabilised and that the environment supports seagrass recolonisation. It is particularly encouraging to see continued expansion, since 2017, of the high density patch of *Z. muelleri* subsp. *capricorni* in this area. This presents strong evidence that the groynes have stabilised sediments in that part of Foreshore Beach and bodes well for recolonisation of seagrass in other areas off Foreshore Beach once benthic sediment has also stabilised there.

The invasive alga *C. taxifolia* has been recorded previously in areas surveyed at Foreshore Beach but not in post-construction surveys to date. The current absence of *C. taxifolia* from the area is favourable in terms of prospects for ongoing recovery of seagrass, as *C. taxifolia* is highly competitive and its presence would present further challenges to successful recolonisation. However, as the presence of *C. taxifolia* may vary temporally (NSW DPI 2011), it still has potential to establish at Foreshore Beach. This factor, along with the issue of sedimentation patterns noted above, highlights the difficulties involved in rehabilitation of such sensitive habitats and the importance of ongoing monitoring.

It is recommended that:

1. Further monitoring of the growing patch of healthy *Z. muelleri* subsp. *capricorni* and the patch of *Halophila* spp. between the southernmost groyne and the boat ramp is done to track trends or potential limitations for long-term establishment and persistence of seagrass at Foreshore Beach.
2. Discussions with NSW DPI (Fisheries) are undertaken to get approval to transplant a few small clumps from the fringe of the growing patch of healthy *Z. muelleri* subsp. *capricorni* to other areas between the southernmost groyne and the boat ramp to fast track recolonisation of seagrass in this area. Removing a few very small clumps of seagrass would not have adverse impacts to the donor bed of seagrass and will reduce the risk of *Z. muelleri* subsp. *capricorni* disappearing completely at Foreshore Beach by establishing more patches. It is possible that the spread of the growing patch of healthy *Z. muelleri* subsp. *capricorni*, or seed from it, will be the only natural means available to recover the species at Foreshore Beach. There have been few observations of natural recruitment of *Z. muelleri* subsp. *capricorni* to the area over the last few years (i.e. from seeds or seedlings that were dispersed into the area or had existed in a seed bank within the sediment). It may be that construction of the third runway and the expansion of the port has restricted potential recruitment to Foreshore Beach from seeds or seedlings transported in currents from other parts of Botany Bay.

3. The rate of accretion is monitored between the groynes within the parts of Foreshore Beach where seagrass has disappeared and compared with the rate in the area between the southernmost groyne and the boat ramp. This could be done by measuring the level of the seabed against permanent marks on the sheet piles of groynes, annually. When the rate of accretion becomes similar to that measured in the area between the southernmost groyne and the boat ramp, it is recommended that NSW DPIE (Fisheries) are consulted for approval for additional transplanting to these areas of a few small clumps from the growing patch *Z. muelleri* subsp. *capricorni* to augment recovery of this species throughout Foreshore Beach. This action would be dependent on the success of Recommendation (2) above.
4. Finally, given beach nourishment in recent years has potentially contributed to declines of seagrass, or its recolonisation, in some areas at Foreshore Beach, future use of beach nourishment should be reviewed. To minimise the risk to long-term recovery of seagrass at Foreshore Beach, beach nourishment should be undertaken less often than it has been done in recent years. If practicable, it should be avoided in the area of beach between the southernmost groyne and the boat ramp where *Z. muelleri* subsp. *capricorni* is recolonising rapidly. Where situations in the future require it to be done in other parts of the beach consideration should be given to minimising the volume of sand used as far as practicable.

Foreshore Beach offers a unique opportunity to augment recovery of seagrass beds once stressor(s) have been removed and where natural recruitment is greatly limited. Recommendations 2-3 would not only fast-track recovery at Foreshore Beach but would add valuable scientific knowledge about how effective transplanting could be in other similar situations. The Port Authority of New South Wales may want to consider a research partnership with a university to implement Recommendations 2-3 to maximise learnings from the project and to ensure that findings are passed on to the broader community.

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August 2020

APPENDIX A

STATISTICAL ANALYSIS

Appendix A: 2020 Statistical Analysis

PERMANOVA tests and Pairwise comparisons. RED = Redundant term. Significant differences ($p < 0.05$) concerning the 2019 survey vs. other surveys in bold.

Permanova Shoot Density (*Halophila* spp.)

Factors

Name	Abbrev.	Type	Levels
Survey	Su	Random	8
Site	Si	Random	6

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Su	7	9620.4	1374.3	1.2635	0.3023	9945
Si	5	5790.5	1158.1	1.0647	0.4152	9953
SuxSi**	17	18492	1087.7	4.5154	0.0001	9905
Res	120	28907	240.89			
Total	149	64871				

Pair Wise Shoot Density (*Halophila* spp.)

Term 'SuxSi' for pairs of levels of factor 'Survey'

Within level 'P1A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	7.8587	0.0097	48	0.0001
Autumn 2012, Autumn 2014	2.1141	0.0863	14	0.0661
Autumn 2012, Autumn 2015	3.5	0.051	6	0.008
Autumn 2012, Autumn 2017	3.5	0.0483	6	0.009
Autumn 2013, Autumn 2014	6.7943	0.0088	46	0.0002
Autumn 2013, Autumn 2015	9.2113	0.007	12	0.0001
Autumn 2013, Autumn 2017	9.2113	0.0079	12	0.0001
Autumn 2014, Autumn 2015	5.6054	0.0085	13	0.0008
Autumn 2014, Autumn 2017	5.6054	0.007	13	0.0009
Autumn 2015, Autumn 2017	Denominator is 0			

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	0.13465	0.9366	22	0.8995
Autumn 2012, Autumn 2014	0.56358	0.884	6	0.5955
Autumn 2012, Autumn 2015	1.016	0.3696	30	0.3382
Autumn 2012, Autumn 2017	1.1793	0.4441	2	0.2698
Autumn 2013, Autumn 2014	0.68543	0.5571	18	0.5128
Autumn 2013, Autumn 2015	1.9846	0.1034	24	0.0791
Autumn 2013, Autumn 2017	1.9511	0.0476	6	0.0881
Autumn 2014, Autumn 2015	3.2481	0.0302	23	0.0116
Autumn 2014, Autumn 2017	1.3988	0.4401	2	0.1993

Autumn 2015, Autumn 2017	7.1286	0.0087	15	0.0002

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	0.76277	0.728	4	0.4575
Autumn 2012, Autumn 2014	2.4042	0.0544	10	0.0425
Autumn 2012, Autumn 2015	6.2755	0.0082	23	0.0002
Autumn 2012, Autumn 2017	2.4461	0.0318	16	0.0366
Autumn 2012, Autumn 2018	2.4952	0.0229	22	0.0374
Autumn 2012, Autumn 2019	3.2128	0.0173	22	0.0129
Autumn 2013, Autumn 2014	3.8025	0.0088	9	0.0046
Autumn 2013, Autumn 2015	7.6853	0.0106	15	0.0001
Autumn 2013, Autumn 2017	2.9025	0.0168	14	0.0218
Autumn 2013, Autumn 2018	2.8432	0.0078	20	0.02
Autumn 2013, Autumn 2019	3.6711	0.0084	22	0.0051
Autumn 2014, Autumn 2015	4.3259	0.0171	20	0.0021
Autumn 2014, Autumn 2017	1.1763	0.2985	16	0.2763
Autumn 2014, Autumn 2018	1.4525	0.2715	16	0.1886
Autumn 2014, Autumn 2019	2.0108	0.0833	18	0.0762
Autumn 2015, Autumn 2017	1.6274	0.1554	19	0.1401
Autumn 2015, Autumn 2018	0.91541	0.3941	21	0.386
Autumn 2015, Autumn 2019	0.70931	0.5215	18	0.5008
Autumn 2017, Autumn 2018	0.39752	0.7291	22	0.6976
Autumn 2017, Autumn 2019	0.70502	0.5365	20	0.502
Autumn 2018, Autumn 2019	0.24168	0.8591	22	0.8132

Within level 'P2B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	2.1068	0.0705	41	0.0697
Autumn 2012, Autumn 2014	0.50918	0.6791	18	0.631
Autumn 2012, Autumn 2015	0.79282	0.467	16	0.4487
Autumn 2012, Autumn 2017	0.72929	0.5226	18	0.4869
Autumn 2012, Autumn 2018	5.324	0.0071	38	0.0008
Autumn 2012, Autumn 2019	1.288	0.2792	23	0.2356
Autumn 2013, Autumn 2014	2.0065	0.1191	53	0.0789
Autumn 2013, Autumn 2015	2.0452	0.1022	57	0.0683
Autumn 2013, Autumn 2017	2.0439	0.0921	87	0.0714
Autumn 2013, Autumn 2018	1.4151	0.2517	81	0.1977
Autumn 2013, Autumn 2019	1.9468	0.1126	91	0.0824
Autumn 2014, Autumn 2015	0.11986	0.9682	24	0.9112
Autumn 2014, Autumn 2017	0.11664	0.9361	28	0.9064
Autumn 2014, Autumn 2018	3.3473	0.0253	45	0.0114
Autumn 2014, Autumn 2019	0.41367	0.7146	33	0.693
Autumn 2015, Autumn 2017	1.3463E-8	1	11	1
Autumn 2015, Autumn 2018	5.6786	0.0092	40	0.0007
Autumn 2015, Autumn 2019	0.89964	0.5365	16	0.4002

Autumn 2017, Autumn 2018	5.3987	0.0081	42	0.0011
Autumn 2017, Autumn 2019	0.84785	0.5395	18	0.4187
Autumn 2018, Autumn 2019	3.773	0.0256	37	0.0049

Within level 'P3A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2018, Autumn 2019	0.86175	0.4951	34	0.4144
Autumn 2018, Autumn 2020	0.94868	0.3828	42	0.3748
Autumn 2019, Autumn 2020	2.9998	0.0208	31	0.0151

Within level 'P3B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2018, Autumn 2019	2.3784	0.0858	48	0.0427
Autumn 2018, Autumn 2020	0.75713	0.4937	23	0.4734
Autumn 2019, Autumn 2020	2.0618	0.1135	63	0.075

Permanova Leaf Length (*Halophila spp.*)

Factors

Name	*Abbrev.*	*Type*	*Levels*
Survey	*Su*	*Random*	*8*
Site	*Si*	*Random*	*6*

PERMANOVA table of results

Source	*df*	*SS*	*MS*	*Pseudo-F*	*P(perm)*	*Unique perms*
Su	*7*	*40.469*	*5.7812*	*0.55955*	*0.7472*	*4990*
Si	*5*	*46.412*	*9.2824*	*0.94775*	*0.4554*	*4993*
*SuxSi***	*14*	*146.51*	*10.465*	*10.912*	*0.0002*	*4979*
Res	*973*	*933.11*	*0.959*			
Total	*999*	*1212.5*				

Pair Wise Leaf Length (*Halophila* spp.)

Within level 'P1A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	2.7307	0.011	18	0.0082
Autumn 2012, Autumn 2014	1.7806	0.1148	13	0.0894
Autumn 2013, Autumn 2014	10.264	0.0002	36	0.0002

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	7.3763	0.0002	16	0.0002
Autumn 2012, Autumn 2014	9.0206	0.0002	11	0.0002
Autumn 2012, Autumn 2015	2.2614	0.0282	450	0.0304
Autumn 2013, Autumn 2014	3.7575	0.0026	12	0.0006

Autumn 2013, Autumn 2015	9.3371E-2	0.913	621	0.925
Autumn 2014, Autumn 2015	1.0172	0.3196	472	0.3184

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	Denominator is 0			
Autumn 2012, Autumn 2014	0.35417	1	6	0.7272
Autumn 2012, Autumn 2015	1.3457	0.2198	53	0.186
Autumn 2012, Autumn 2017	1.3122	0.2072	128	0.1864
Autumn 2012, May 2018	1.2903	0.4168	7	0.2034
Autumn 2012, May 2019	2.2551	0.0518	7	0.0318
Autumn 2013, Autumn 2014	0.28899	1	5	0.7734
Autumn 2013, Autumn 2015	1.0984	0.3114	26	0.2692
Autumn 2013, Autumn 2017	1.0709	0.2874	89	0.292
Autumn 2013, May 2018	1.0531	0.5022	5	0.3036
Autumn 2013, May 2019	1.8402	0.1194	5	0.0744
Autumn 2014, Autumn 2015	4.3171	0.0004	683	0.0004
Autumn 2014, Autumn 2017	3.9516	0.0004	276	0.0002
Autumn 2014, May 2018	2.2188	0.031	30	0.0272
Autumn 2014, May 2019	5.4599	0.0004	24	0.0002
Autumn 2015, Autumn 2017	1.1171	0.2688	1505	0.274
Autumn 2015, May 2018	3.8864	0.0002	734	0.0006
Autumn 2015, May 2019	1.9563	0.0602	706	0.055
Autumn 2017, May 2018	3.2342	0.0012	264	0.0014
Autumn 2017, May 2019	0.87122	0.4112	144	0.389
May 2018, May 2019	4.0557	0.0004	38	0.0002

Within level 'P2B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
Autumn 2012, Autumn 2013	2.4322	0.0188	66	0.018
Autumn 2012, Autumn 2014	7.4328	0.0002	28	0.0002
Autumn 2012, Autumn 2015	2.4972	0.0164	89	0.016
Autumn 2012, Autumn 2017	0.61072	0.5552	40	0.5486
Autumn 2012, May 2018	4.7091	0.0002	25	0.0002
Autumn 2012, May 2019	2.1176	0.0416	41	0.0388
Autumn 2013, Autumn 2014	6.8062	0.0002	89	0.0002
Autumn 2013, Autumn 2015	1.7209	0.0982	175	0.089
Autumn 2013, Autumn 2017	1.738	0.0924	74	0.0922
Autumn 2013, May 2018	2.8415	0.0056	78	0.0058
Autumn 2013, May 2019	1.2888E-2	1	80	0.9914
Autumn 2014, Autumn 2015	1.7312	0.08	89	0.0898
Autumn 2014, Autumn 2017	7.3356	0.0002	57	0.0002
Autumn 2014, May 2018	4.639	0.0002	25	0.0002
Autumn 2014, May 2019	6.1806	0.0002	54	0.0002
Autumn 2015, Autumn 2017	2.5876	0.0142	51	0.013
Autumn 2015, May 2018	0.59366	0.572	48	0.5622
Autumn 2015, May 2019	1.852	0.0726	97	0.062

Autumn 2017, May 2018	4.2953	0.0002	51	0.0002
Autumn 2017, May 2019	1.616	0.1294	47	0.1156
May 2018, May 2019	2.6055	0.0122	51	0.0118

Within level 'P3A' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
May 2018, May 2019	0.75717	0.5174	22	0.4404
May 2018, April 2020	2.8386	0.0052	24	0.006
May 2019, April 2020	3.5358	0.0008	24	0.0008

Within level 'P3B' of factor 'Site'

Groups	t	P(perm)	Unique perms	P(MC)
May 2018, May 2019	0.56561	0.6358	21	0.5682
May 2018, April 2020	7.0694	0.0002	130	0.0002
May 2019, April 2020	6.7478	0.0002	146	0.0002