Port Botany Long-term Seagrass Monitoring

2019

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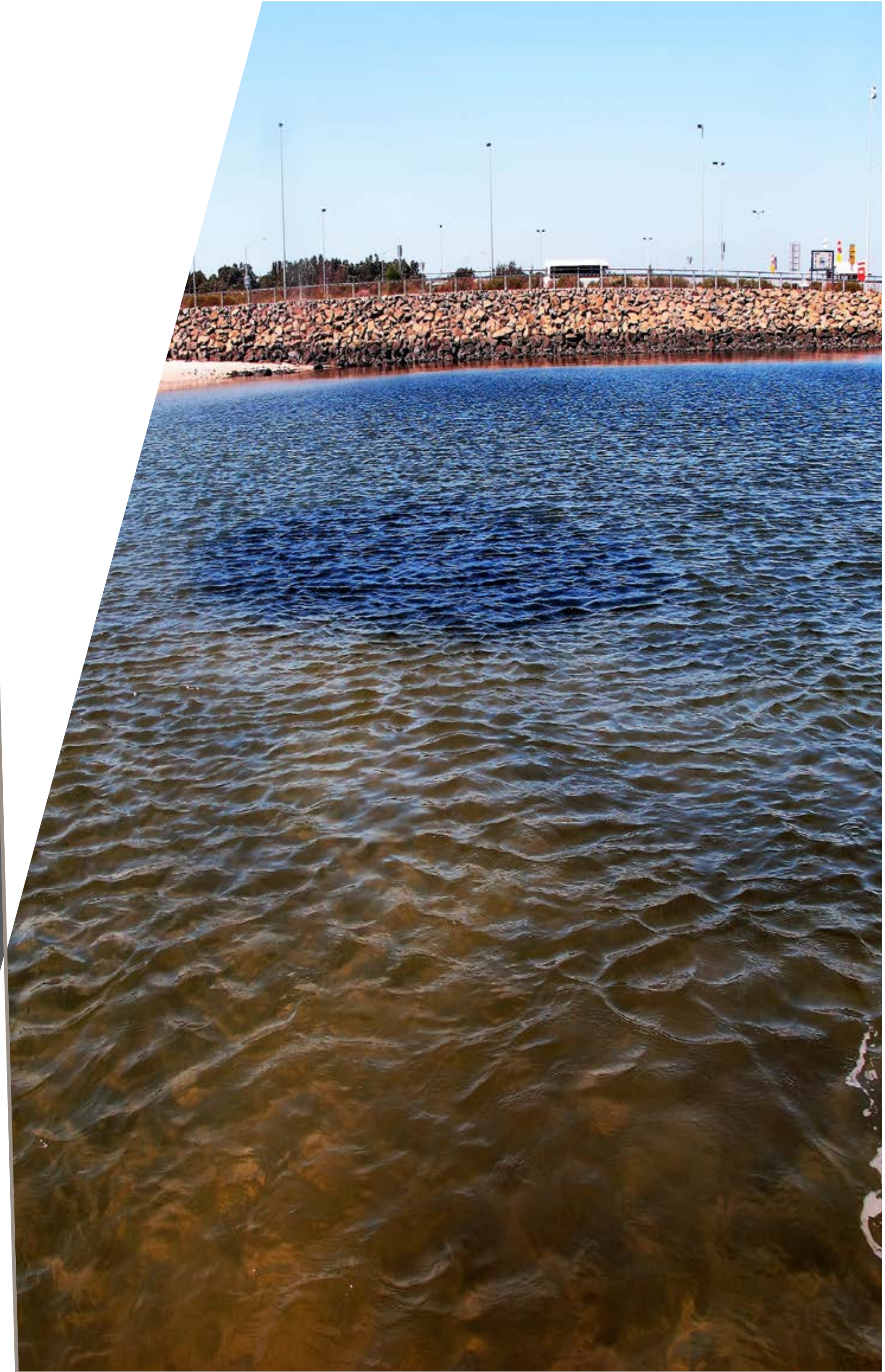

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Executive Summary

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) indicated that approximately 317 m^2 of seagrass (including *Zostera muelleri* subsp. *capricorni*, *Halophila* spp. and *Posidonia australis*) was predicted to 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. 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 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 second of those three additional surveys, which was completed in May 2019. It also incorporates data from the first additional survey (2018), 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 this 2019 survey suggest that the largely positive effect the groyne construction appeared to have had on the distribution and condition of *Halophila* spp., *Z. muelleri* subsp. *capricorni* at the time of the 2018 survey has been at least generally maintained. Key indicators are, however, relatively more difficult to clearly interpret compared to the 2018 survey, with some indicators at some sites suggesting further improvements in seagrass cover and condition, and others suggesting no change or even slight deterioration. The mapped area of seagrass beds decreased in total area by 23.8% between 2018 and 2019 (driven primarily by changes in *Halophila* spp.), but still remained larger than that recorded in 2017. In contrast, seagrass cover (species combined) measured along transects increased by 34% from 2018 to 2019, continuing the observed trend of incline from 2017 onwards. There was no clear overall trend of increase or decrease in the density of *Halophila* spp. shoots or associated leaf lengths from 2018 to 2019, with trajectories of difference varying among the sites sampled. The lack of clear and consistent patterns of change in seagrass from 2018 to 2019 may be indicative of a high level of spatial, and possibly temporal, variability in seagrass cover and condition.

Following the doubling in size between 2017 and 2018, a further doubling in size of the high density patch of *Z. muelleri* subsp. *capricorni* in the south-eastern section of Foreshore Beach between 2018 and 2019 presents strong evidence that this species may be recovering and colonising new areas. Stabilisation of sediments in that particular location, possibly caused by installation of the groynes, may be facilitating this process.

While the total area of *P. australis* at Foreshore Beach has been comparatively small since the start of monitoring, results from the 2019 survey indicate that the apparent decline in one of the two patches of *P. australis* recorded during the 2018 survey has progressed to its complete disappearance. On-site evidence discovered by divers in 2018, including deteriorating frond condition and burial of shoot bases, indicates that the patch has been lost as a consequence of smothering due to sedimentation. In contrast, after substantially decreasing in size between the 2017 and 2018 surveys, the extent and condition of a second patch of *P. australis* has not changed between 2018 and 2019, suggesting it may have stabilised in line with a potential relative stabilisation in patterns of sediment mobilisation, transport and deposition.

Collectively, the findings from the 2018 and 2019 surveys suggest that the addition of groynes at Foreshore Beach may have altered sediment mobilisation, transport and deposition patterns. Consequently, growth and expansion of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. appears to have been facilitated in certain areas (i.e. between and either side of the ends of the groynes, and in the south-eastern corner of Foreshore Beach), while deterioration, and even complete burial of some patches of seagrass is occurring in other areas as a result of localised sedimentation.

The next monitoring survey, planned to take place in Autumn 2020, will provide further evidence of ongoing recolonisation (or otherwise) of *Z. muelleri* subsp. *capricorni* and will assist in understanding trends or potential limitations for long-term establishment and persistence of seagrass in Foreshore Beach.

Note that although the results of any additional informative surveys may change conclusions with respect to the success of the PEHEP there would not implications for compensatory habitat or offsetting.

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	Living on or in the seabed
Infauna	Aquatic animals living within the sediment
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
PAR	Photosynthetically Active Radiation, the portion of the light spectrum that plants utilise to photosynthesize
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')
Secchi (disk) depth	The depth at which a disk with black and white quarters dissapears from sight when lowered into the water. Considered to be a good indicator of the maximum depth at which aquatic plants, particularly seasgrasses can grow.
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.
Target	The aspirational value or magnitude of a nominated indicator

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Appendix A Statistical Analysis

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*; *Halophila* spp.; and *Posidonia australis*) 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 both 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 the effects to the existing seagrass beds attributable to the new groynes (Details provided in **Section 1.3.4**). It was anticipated that a reduction in beach erosion and sediment transport facilitated by the groynes would improve water quality and mitigate sedimentation, thus improving conditions for seagrasses.

1.2 Aims

The key objective of this 2019 survey is to determine the recovery, if any, of seagrasses within Foreshore Beach following the completion 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 nearshore 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 *Zostera* 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, episodic pulses of rainfall and would enter via Floodvale and Springvale Creeks.

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 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 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 groyne structures 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 and now 2019. 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)
2011	During Construction	Not comparable	SPC (2011)

Year	Project Phase	Approximate Area of Seagrass (m^2)	Reference
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)

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 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 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 towed camera system, 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 and 2019 surveys. The following four species grouping categories were used:

> Patchy sparse *Z. capricorni;*

> Patchy sparse *Halophila*;

> Patchy *P. australis;* and

> Continuous sparse *Halophila* and patchy sparse *Z. 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 and 2018 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 (refer to **Figure 4**), 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. 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**). Two new patches, P3A and P3B, along with FP8 mentioned in the previous section, were added during the 2018 survey.

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 – 2018.

> 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 and Autumn 2019);
  - Site (random) – (P1A, P1B, P2A, P2B, P3A, P3B; see **Figure 1** – note that sites P3A and P3B were sampled in 2018 and 2019 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.

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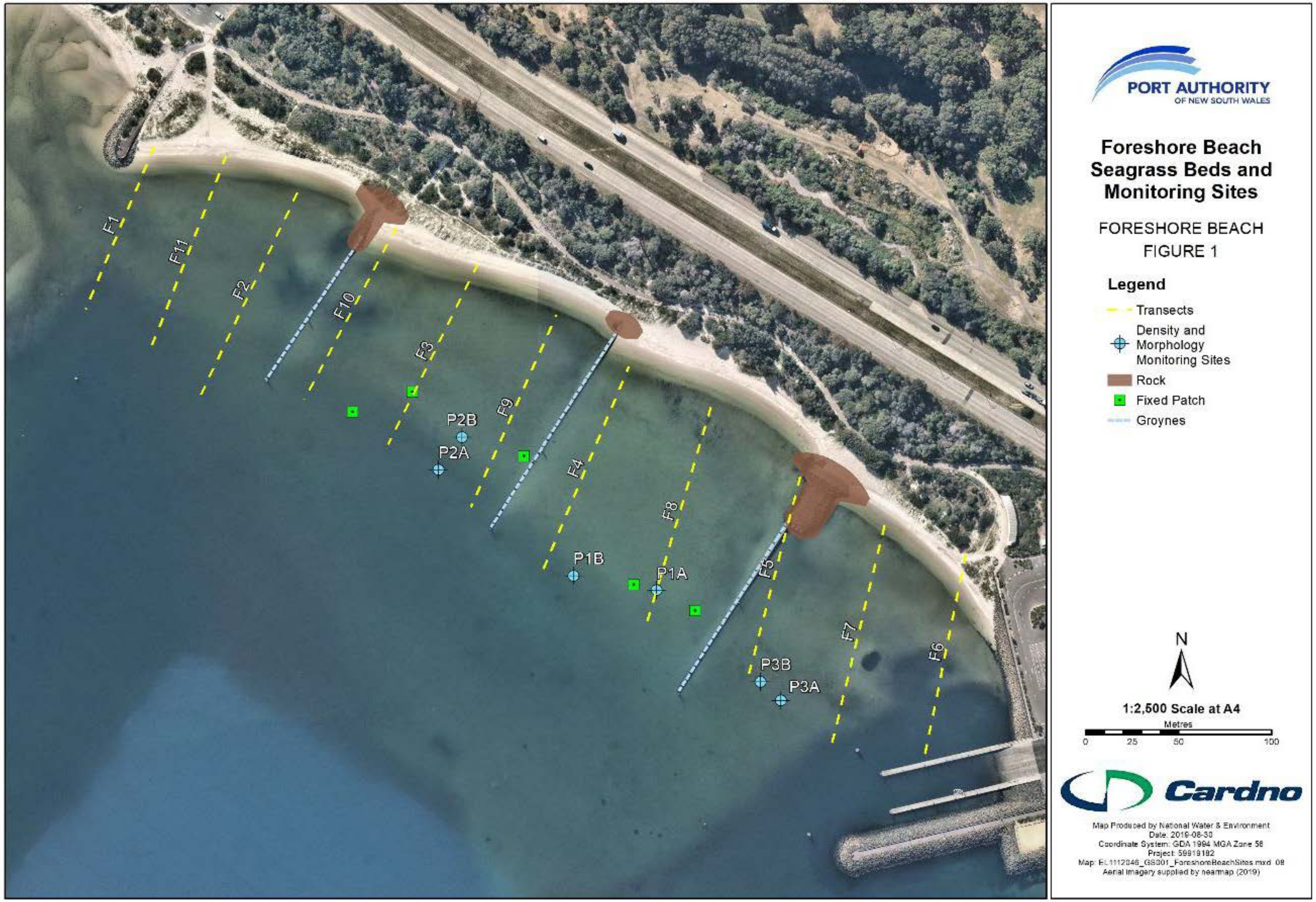

Figure 1 Foreshore Beach transect, fixed patches and morphology monitoring sampling locations

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 mapping (entire area)	Seagrass species Area	Before: 2002, 2006, 2007, 2008 After: 2012, 2013, 2014, 2015, 2017, 2018
	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
	Diver observations (Fixed Patches) x5 Sites (since 2012)	Seagrass species % cover estimates	Before: 2007, 2008 After: 2012, 2013, 2014, 2015, 2017, 2018, 2019
	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

2.3 Sampling Dates

All seagrass data collection (mapping, transects, fixed patches and morphology sites) at Foreshore Beach for the 2019 survey was carried out by Cardno on 13 and 16 May 2019.

3 Results

3.1 Mapping

The most recent survey of seagrasses at Foreshore Beach was completed in May 2019. Total seagrass area in May 2019 was 1,404 m^2, representing an 23.8% decrease from the previous survey (1,843 m^2) done in 2018 (**Figure 2**). All three types of seagrass – *P. australis*, *Z. muelleri* subsp. *capricorni* and *Halophila* spp. – were recorded during the 2019 survey. The overall decrease was almost entirely attributed to a reduction in *Halophila* spp. from 1,798 m^2 in 2018 to 1,317 m^2 in 2019. In contrast, the area of *Z. muelleri* subsp. *capricorni* more than doubled from 38 m^2 in May 2018 to 80 m^2 in 2019; this following the doubling observed between 2017 and 2018 (i.e. 15 to 38 m^2). The total area of *P. australis* remained relatively stable, decreasing only slightly from 8.5 m^2 in 2018 to 7.1 m^2 in 2019 (**Figure 3**).

Trends in total seagrass cover at Foreshore Beach from before port expansion (2002 – 2008) through to the current post-expansion period (2012 – 2019) 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 2018 and May 2019 indicate that the extent of *Halophila* spp. has contracted in existing beds – particularly the two 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 38 to 80 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**). While there has been a slight decline in overall seagrass extent between the 2018 and 2019 surveys (driven by the decrease in *Halophila* spp.), it is notable that the 2019 seagrass extent remains greater than that recorded in 2017 (i.e. 1,024 m^2).

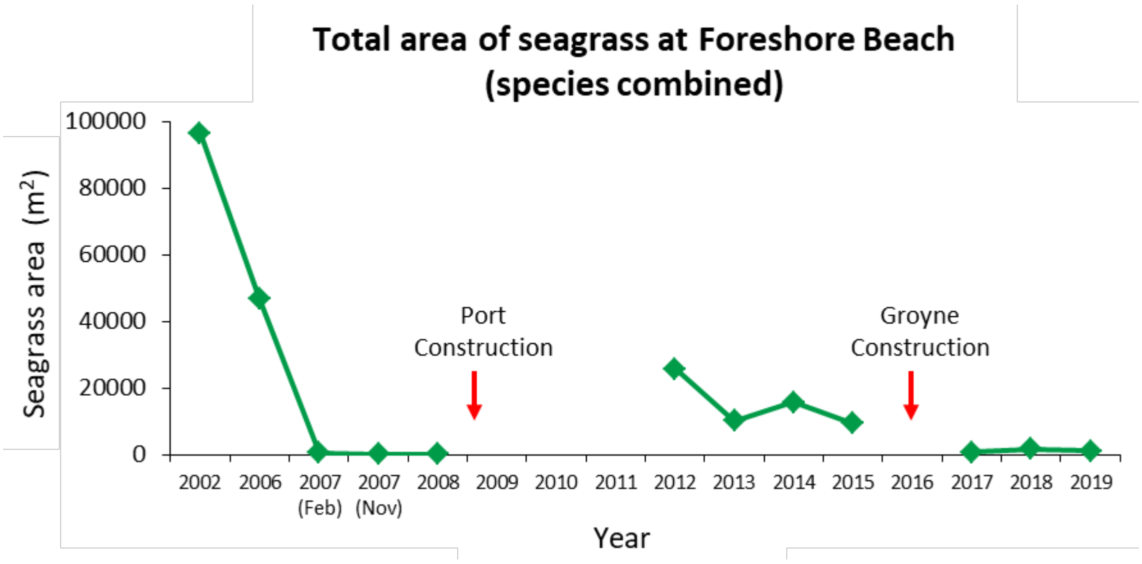

Figure 2 **Total area of seagrasses at Foreshore Beach between 2002 and 2019. NB: comparable quantitative data was not collected during port construction (2009-2011)**

Table 3 Total seagrass area (m²) at Foreshore Beach between 2002 and 2019

*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 (m²)	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)

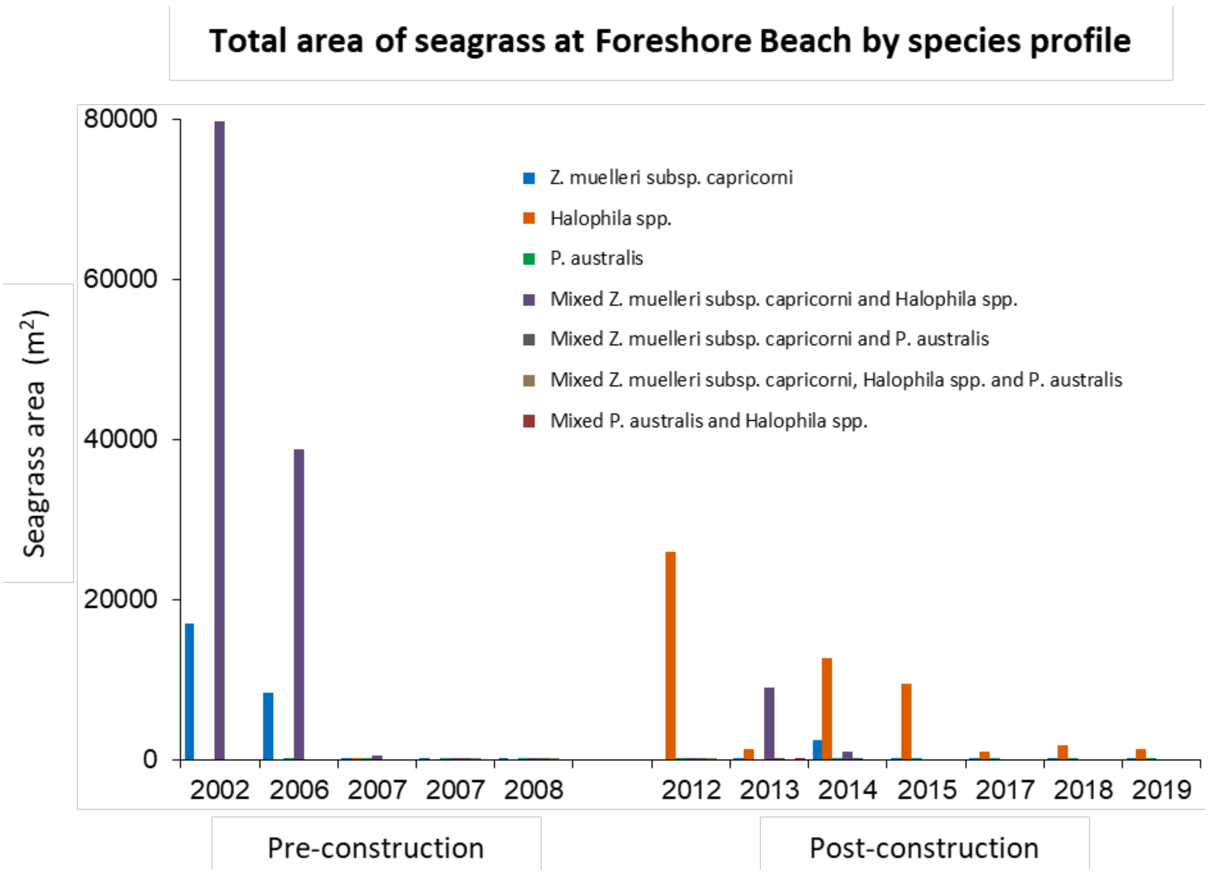

Figure 3 Area of seagrass taxa at Foreshore Beach between 2002 and 2019. Includes data from Foreshore Beach Fixed Patches

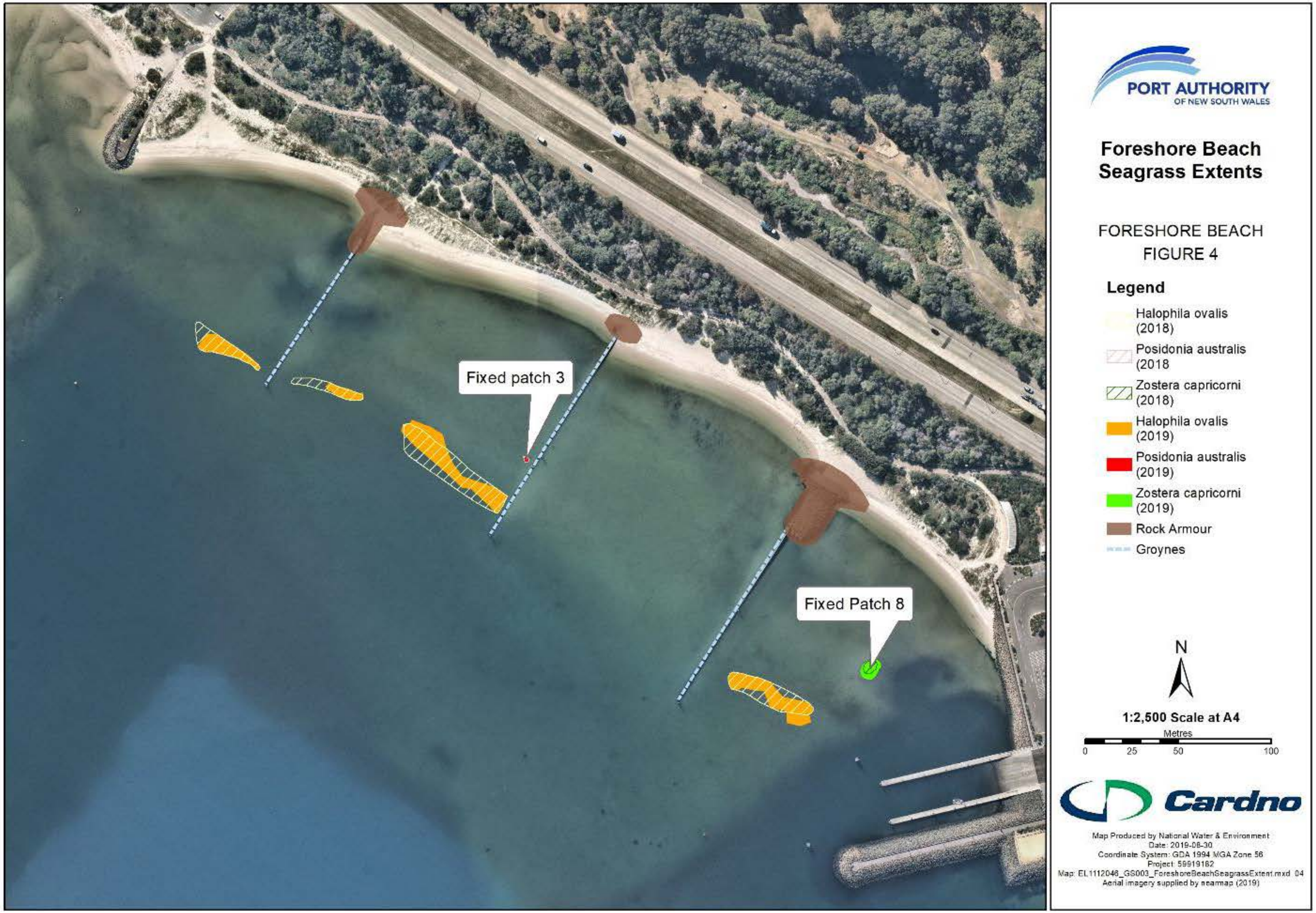

Figure 4 **Seagrass mapped at Foreshore Beach in 2019 compared to 2018**

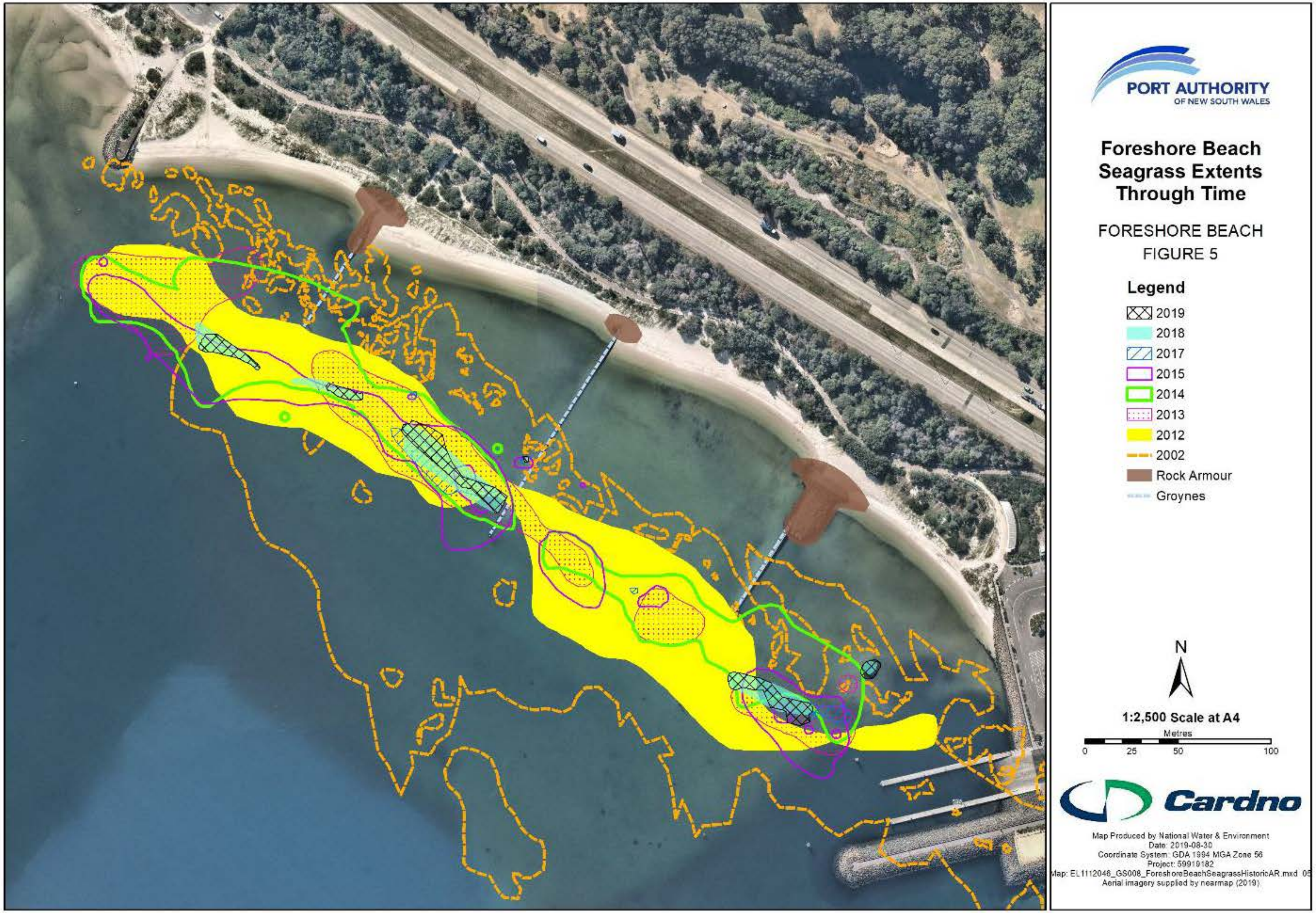

Figure 5 **Seagrass mapped at Foreshore Beach prior to (2002) and after (2012, 2013, 2014, 2015, 2017, 2018 and 2019) port expansion**

3.2 Transects

Only *Halophila* spp. was found along transects in 2019, with the small amounts of *Z. muelleri* subsp. *capricorni* and *P. australis* found in 2018 apparently absent (**Figure 6**). Given this, percent cover estimates for *Halophila* spp. can be also interpreted as percent cover estimates for all seagrass species combined for the purpose of comparison with 2018 data.

Estimates of percent cover of *Halophila* spp. for 1 m measurement points along transects during 2019 ranged from 0 to 20 %, with an overall average of ~0.17% cover per measurement point (*n* = 1,249 measurement points; **Figure 6**). Given that the overall average of percent cover of seagrass (species combined) in transects was ~0.13% in 2018, this represents a net increase in percent cover of seagrass of ~0.04% (i.e. approximately 34% greater coverage) – estimates that also account for the losses of *Z. muelleri* subsp. *capricorni* and *P. australis* in transects from 2018 to 2019.

The overall average percent cover of *Halophila* spp. along transects increased from ~0.12% in 2018 to ~0.17% in 2019, representing a 38% rise in coverage for that species (**Figure 6**). This increase followed the almost ten-fold rise in coverage of *Halophila* spp. from ~0.013% to ~0.12% between the 2017 and 2018 surveys.

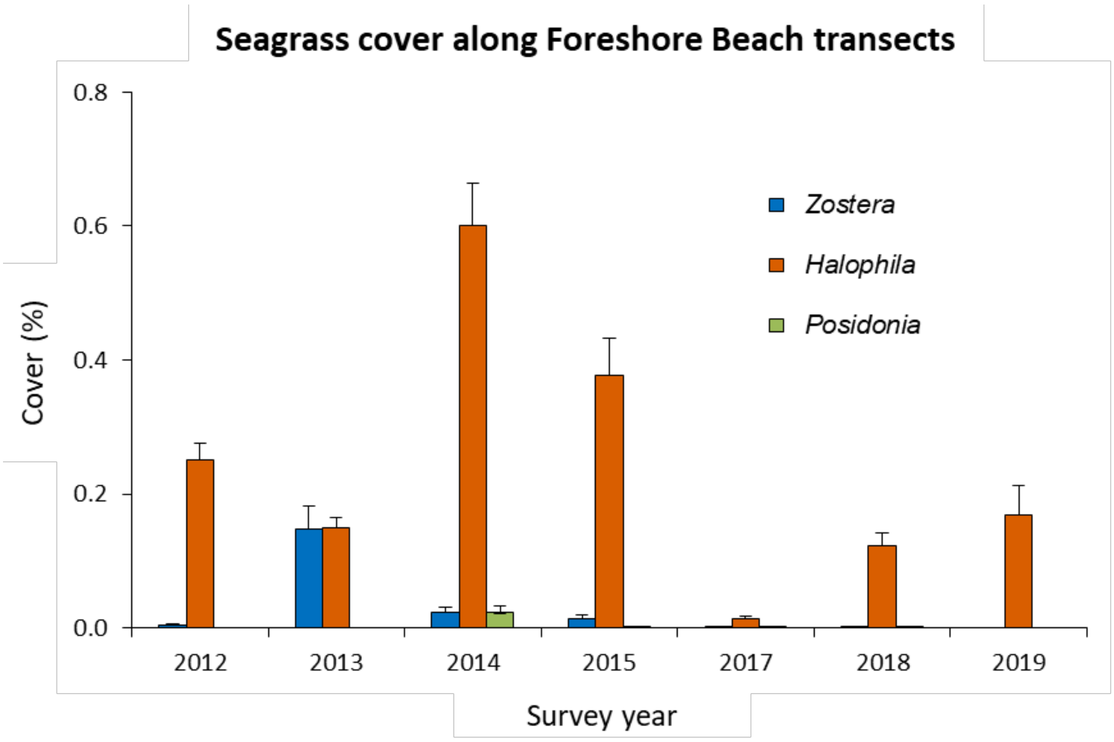

Figure 6 Percent cover (+ SE) of seagrasses recorded along transects at Foreshore Beach in Autumn 2012, 2013, 2014, 2015, 2017, 2018 and 2019.

3.3 Fixed Patches

Seagrass was recorded at only two of the eight patches (Patches 3 and 8) during the 2019 survey, as was the case in 2018. Patch 3 contained a small area of *P. australis* (2 m^2), which remained unchanged in area from 2018. This small patch has persisted since the start of fixed patch surveys in 2008, but did decline substantially from 36 m^2 recorded in 2017 to 2 m^2 in 2018. Patch 8 contained a healthy and dense area of *Z. muelleri* subsp. *capricorni,* that has increased in area from 38 m^2 in 2018 to 80 m^2 in 2019 (**Table 4**, **Plate 1**).

Overall, the collective areal extent of seagrass in fixed patches (i.e. Patches 3 and 8) has increased from 40 m^2 in 2018 to 82 m^2 in 2019. Patches 2, 5 and 7 which were recorded in 2017, were not recorded in 2018 (**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
1	5	20	5	1.5	1.7			
2	4	6	4.4	4	5	1		
3	4	12	17.8	15	19	36	2	2
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
Total	**20**	**48.5**	**28.2**	**27**	**40.6**	**52.6**	**40.0**	**82.0**

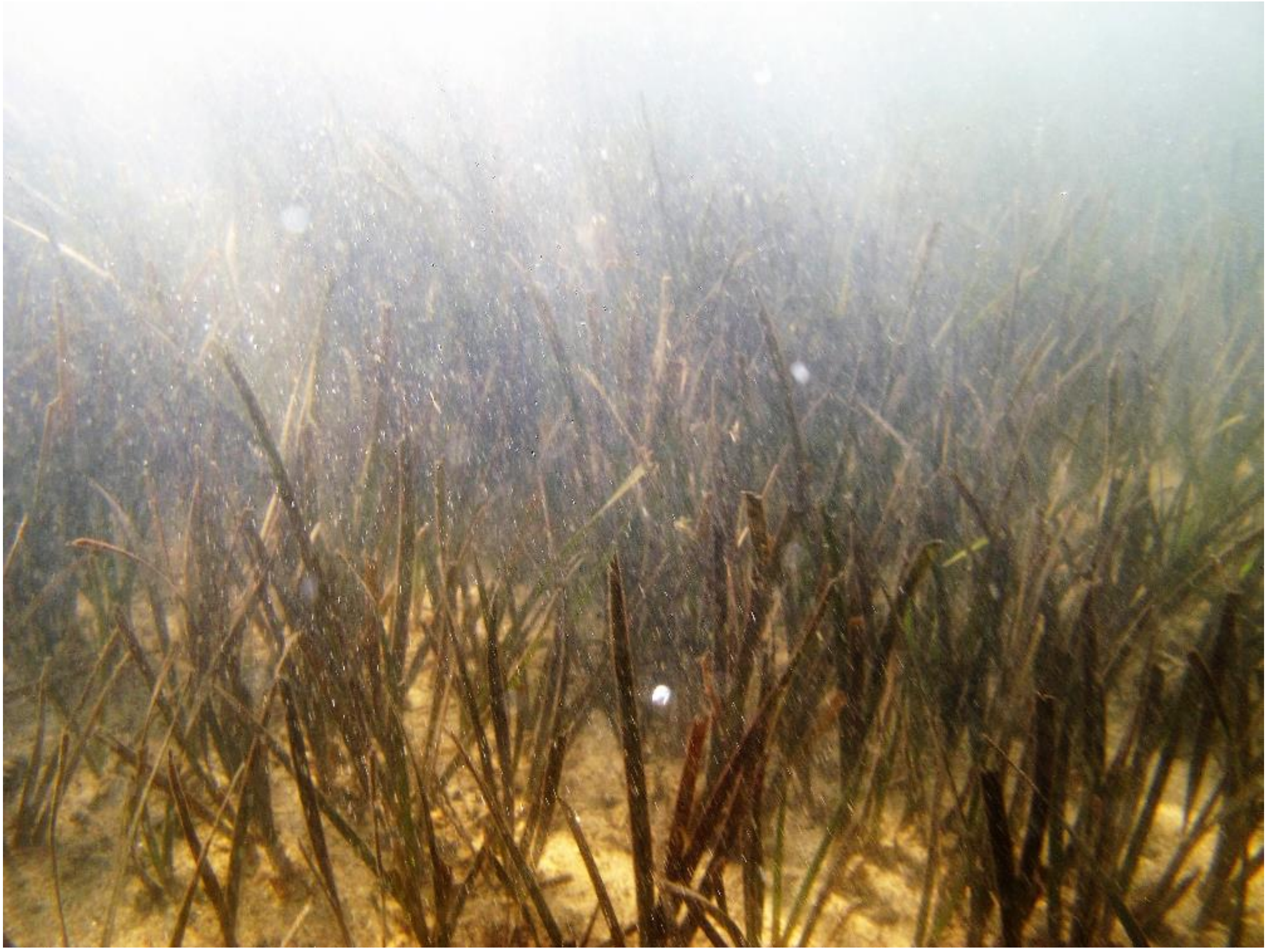

Plate 1. *Z. muelleri* subsp. *capricorni* at Fixed Patch 8 – first detected in 2017 and showed expansions (a doubling of area) between 2017 and 2018, and then again between 2018 and 2019.

3.4 Seagrass Density and Morphology

3.4.1 Shoot Density

The average density of *Halophila* spp. at morphology sites P2A and P2B in 2019 was 10.4 and 11.4 shoots per 0.25 m^2 respectively, compared to 9.4 and 29.0 shoots per 0.25 m^2 recorded in 2018 (**Table 5**, **Figure 7**). At sites P3A and P3B the average *Halophila* spp. shoot density was 9.8 and 42.6 shoots per 0.25 m^2 respectively in 2019, compared to 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 2018 to 2019 at these morphology sites, illustrating a high level of spatial, and possibly temporal, variability in shoot density within established beds.

The average density of *Z. muelleri* subsp. *capricorni* at Fixed Patch 8 (FP8) – the relatively large area (80 m^2) of dense *Z. muelleri* subsp. *capricorni* described in **Section 3.3** (**Plate 1**) – was 233.6 shoots per 0.25 m^2, which was very similar to the density recorded in 2018 (i.e. 236 shoots per 0.25 m^2) (**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.

Statistical analysis of *Halophila* spp. shoot density comparing among surveys 2002 to 2018 for patches P1 (A and B) and P2 (A and B) detected a significant survey x site interaction ($p < 0.001$; **Appendix A**), indicating shoot density was significantly different among surveys for at least some of the morphology sites. Pair-wise comparisons among surveys 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 (**Figure 7**). 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. Finally, shoot densities did not significantly change from 2018 to 2019 at Sites P3A and P3B.

Table 5 **Mean shoot densities (shoots per 0.25 m^2 quadrat, n=5) of seagrass in morphology monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017, 2018 and 2019 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
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			7.8	8.4			
	2018			9.4	29.0	15.6	15.0	
	2019			10.4	11.4	9.8	42.6	
Posidonia	2012		2.0					
	2013							
	2014							
	2015							
	2017							
	2018							
	2019							

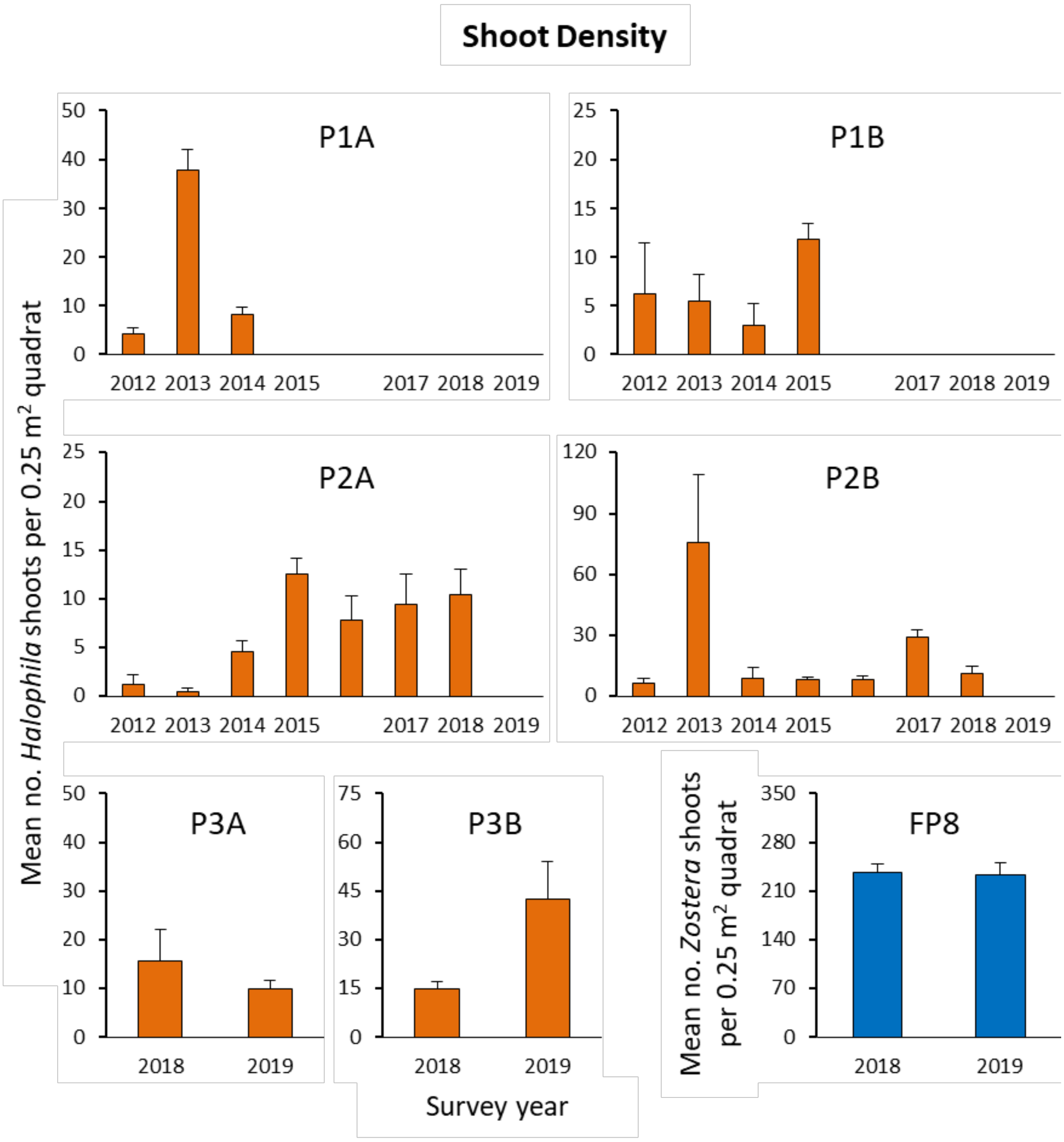

Figure 7 Mean (±SE) shoot densities (0.25 m^2) of *Halophila* spp. (n = 5) sampled in morphology monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017, 2018 and 2019.

3.4.2 Leaf Length

The average leaf length of *Halophila* spp. at morphology sites P2A and P2B in 2019 was 2.8 and 2.3 cm respectively, compared to 2.2 and 2.7 cm long respectively in 2018 (**Table 6**, **Figure 8**). At sites P3A and P3B the average leaf length of *Halophila* spp. was 2.0 and 3.2 cm respectively in 2019, compared to 2.1 and 3.1 cm long in 2018. As was the case for shoot density estimates, there were no clear patterns of change in *Halophila* spp. leaf length from 2018 to 2019 at these morphology sites, with some sites showing a very slight increase in average leaf length and others a slight decrease. It is notable, however, that P2A exhibited the greatest change by a considerable margin, with a 30% increase in average *Halophila* spp. leaf length between the 2018 and 2019 surveys.

The average length of *Z. muelleri* subsp. *capricorni* leaves at Fixed Patch 8 (FP8) – the relatively large area (80 m^2) of dense *Z. muelleri* subsp. *capricorni* described in **Section 3.3** (**Plate 1**) – was 20.7 cm, which was slightly longer than that recorded in 2018 (i.e. 19.2 cm long) (**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 comparisons among surveys found that the leaf lengths recorded for *Halophila* spp. at Site P2A in 2019 were significantly longer than leaf lengths recorded in 2018, but not significantly different from lengths recorded in 2017 (**Figure 8**, **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. A relative lack of leaf length measurements at P2A in 2012 and 2013 (**Table 6**) prevents meaningful interpretation of pair-wise comparisons against the 2019 data.

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**). Finally, leaf lengths recorded for *Halophila* spp. did not significantly change from 2018 to 2019 at Sites P3A and P3B. Collectively, these *Halophila* spp. data are generally suggestive of the likelihood of a return to a pattern of natural annual variability in leaf length in this genus.

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 and 2019 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)
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)	
Posidonia	2012		2.2 (10)					
	2013							
	2014							
	2015							
	2017							
	2018							
	2019							

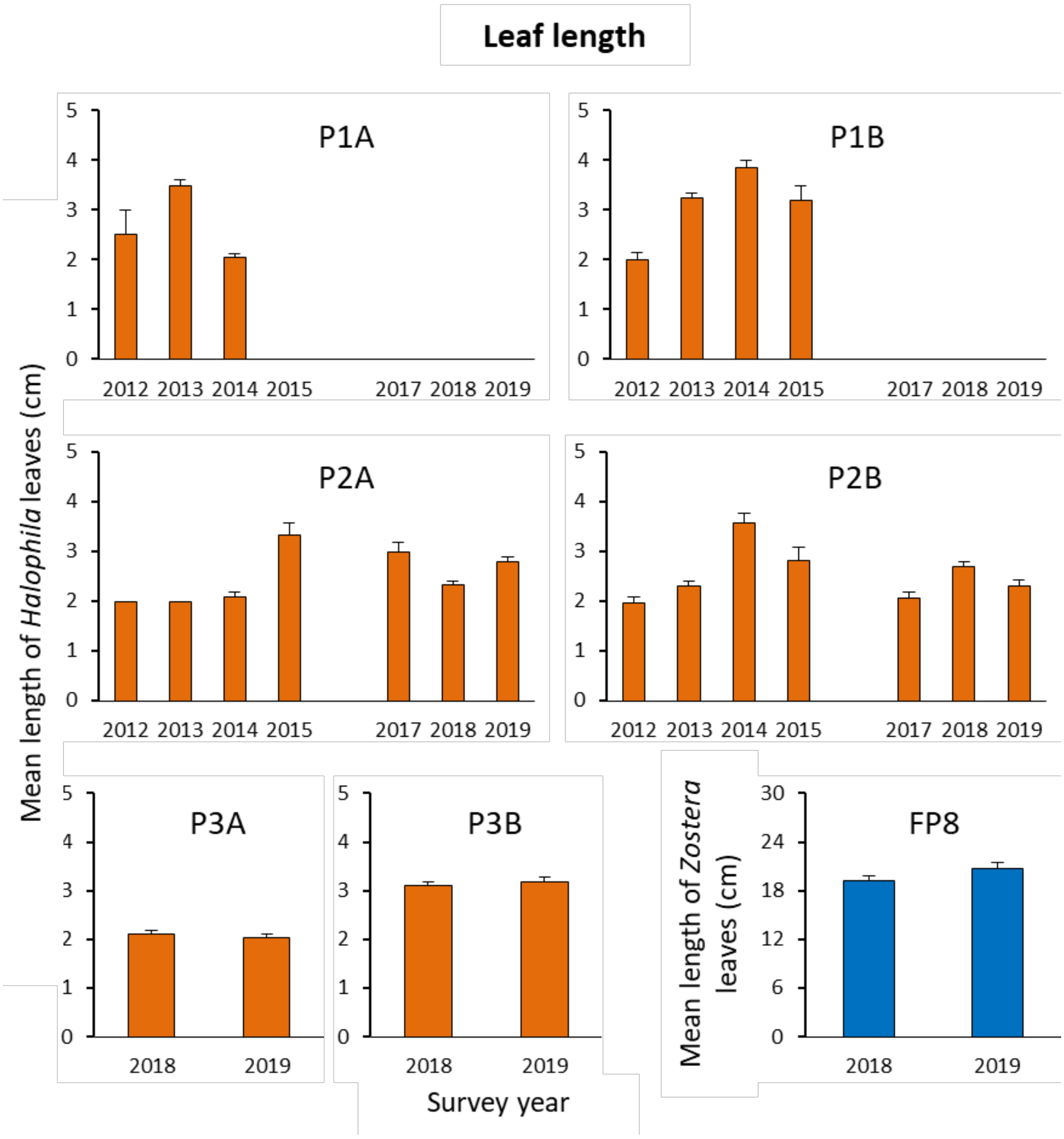

Figure 8 Mean (±SE) leaf length (cm) of *Halophila* spp. sampled at Foreshore Beach morphology monitoring sites during 2012, 2013, 2014, 2015, 2017, 2018 and 2019 (see Table 6 for *n*).

3.4.3 Epiphyte Load

Epiphytes were recorded on all fronds of *Halophila* spp. sampled in the 2019 survey. Patterns in levels of epiphyte loads on *Halophila* spp. varied among the four sites, with two sites characterised by the occurrence of mostly low loads (P2A – 75% low; P3B – 84% low), one by mostly high loads (P2B – 52% high), and P3A showing a relatively more even mixture (46% low, 18% medium and 36% high) (**Table 7**). The data suggest that from the 2018 survey to the 2019 survey the epiphyte load on *Halophila* spp. fronds generally decreased from higher to relatively lower levels at P2A and P3B, while there were no clear patterns for the other two sites.

Epiphytes were recorded on fronds of *Z. muelleri* subsp. *capricorni* sampled in FP8, with 100% of the growth falling within the 'low' level category (**Table 7**). This suggests a very slight decrease in epiphyte load from the 2018 survey (92% low, 8% medium), and a similar load profile to those found during the 2013 and 2015 surveys.

As epiphyte load is a qualitatively sampled variable, and given the inconsistencies in seagrass occurrence through time, it cannot be concluded statistically 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 and 2019 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	‘18	‘19	‘18	‘19
Zostera	L	100		100																				92	100
	M																							8	
	H																								
Halophila	L	46	55				64		39	70	100	26	75			84	81	12	27	34	46	50	84		
	M	50	26		43		28	100	53	26		35	25	100	58	14	12	54	21	48	18	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 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) 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 2017, with cover recorded in 2018 and 2019 remaining generally similar to that estimated in 2017.

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 since 2012, by 2019 all but one had shown no signs of spreading and many had disappeared, leaving one notable patch for each species in 2019. The notable exception to this general lack of expansion has been Fixed Patch 8, the small, elliptical-shaped patch of *Z. muelleri* subsp. *capricorni* located in the south-east of the monitoring area (between groynes F6 and F7), which doubled in size between 2017 and 2018 and again between 2018 and 2019.

In addition to the permanent changes brought about by the expansion of Port Botany, other activities such as beach nourishment and groyne construction may also influence environmental factors important for seagrass growth and survival and hence have an impact on the health and areal extent of seagrass beds. It is understood that artificial beach nourishment has been undertaken twice since completion of port expansion works, while in 2016 three groyne structures were installed across Foreshore Beach to address foreshore erosion and sedimentation issues. It was anticipated that the construction of the groynes would help to stabilise sediments and minimise sediment mobilisation and transport, thus improving water quality via reduced turbidity and minimising smothering of seagrasses by sedimentation.

4.2 Post Groyne Construction

While the first survey following groyne construction, done in 2017, was too soon after the groynes had all been installed to discern any benefit to seagrass from sediment stabilisation facilitated by the groynes, results from the 2018 survey were more encouraging, indicating a general improvement in seagrass cover and condition from levels recorded in 2017. Specifically, the mapped area of seagrass beds increased in total area by 81.2%, while there was also a substantial increase in seagrass cover along transects from the extremely low level recorded in 2017 – primarily attributed to substantial increases in shoot density of *Halophila* spp.

Results from the 2019 survey are relatively more difficult to clearly interpret, with some indicators at some sites suggesting further improvements in seagrass cover and condition, and others suggesting no change or even slight deterioration. The mapped area of seagrass beds decreased in total area by 23.8% between 2018 and 2019 (driven primarily by changes in *Halophila* spp.), but still remained larger than that recorded in 2017. In contrast, seagrass cover (species combined) measured along transects increased by 34% from 2018 to 2019, continuing the observed trend of incline from 2017 onwards. Further, there was no clear overall trend of increase or decrease in the density of *Halophila* spp. shoots or associated leaf lengths from 2018 to 2019, with trajectories of difference varying among the sites sampled. The lack of clear and consistent patterns of change in seagrass from 2018 to 2019 may be indicative of a high level of spatial, and possibly temporal, variability in seagrass cover and condition – a known characteristic of the more ephemeral and pioneering *Halophila* spp.

While overall change in *Halophila* spp. from 2018 to 2019 has been unclear, Fixed Patch 8 – the small, elliptical-shaped patch of *Z. muelleri* subsp. *capricorni* located in the south-east of the monitoring area (between the south-eastern-most groyne and the breakwall) – continued the observed trend of expansion from 2017 onwards, doubling in size again between 2018 and 2019. As noted above, future monitoring of this growing patch of healthy *Z. muelleri* subsp. *capricorni* may yield some optimism regarding ongoing reestablishment of this species in the area.

As was the case for the 2018 survey, results in 2019 did not show any notable changes in epiphyte cover that would be indicative of nutrient enrichment of impaired water quality.

While the total area of *P. australis* at Foreshore Beach has been comparatively small since the start of monitoring, results from the 2019 survey indicate that the apparent decline in one of the two patches of *P. australis* recorded during the 2018 survey has progressed to its complete disappearance. On-site evidence discovered by divers in 2018, including deteriorating frond condition and burial of shoot bases, indicates that the patch has been lost as a consequence of smothering due to sedimentation. In contrast, the extent and condition of the second patch of *P. australis* (Fixed Patch 3 – located close to the northern face of the middle groyne) has not changed between 2018 and 2019, although it is notable that the area of this patch had already decreased substantially between the 2017 and 2018 surveys.

Collectively, these findings suggest that the addition of groynes at Foreshore Beach may have altered sediment mobilisation, transport and deposition patterns. Consequently, growth of *Z. muelleri* subsp. *capricorni and Halophila* appears to have been facilitated in certain areas (i.e. between and either side of the ends of the groynes, and in the south-eastern corner of Foreshore Beach), while deterioration, and even complete burial of patches of seagrass may have occurred in other areas as a result of localised sedimentation. I

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.

5 Conclusions and Recommendations

Pre- and post-construction monitoring of seagrass done over the past 18 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 sedimentation) 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 arrested the erosion and hence the potential for relatively large loads of sediment to be mobilised across the seagrass habitat.

Results of this 2019 survey suggest that the largely positive effect the groyne construction appeared to have had on the distribution and condition of *Halophila* spp., *Z. muelleri* subsp. *capricorni* at the time of the 2018 survey has been at least generally maintained. There was, however, relatively limited clarity compared to the 2018 survey in terms of evidence of further increases or definitive declines in *Halophila* spp. distribution and condition. An apparent decrease in overall areal extent matched with patchy increases and decreases in seagrass cover, shoot density and leaf length at smaller spatial scales. This observation could be a manifestation of the ephemeral nature of that species.

Further expansion (doubling in size) between 2018 and 2019 of the high density patch of *Z. muelleri* subsp. *capricorni* in the south-eastern section of the site, following the doubling in size between 2017 and 2018, presents strong evidence that this species may be recovering and colonising new areas at Foreshore Beach. Stabilisation of sediments in that particular location, possibly caused by installation of the groynes, may be facilitating this process. In contrast, the sole remaining patch of *P. australis* had not changed in size or condition between the 2018 and 2019 surveys, suggesting it may have stabilised in line with a potential relative stabilisation in patterns of sediment mobilisation, transport and deposition.

The next monitoring survey, planned to take place in Autumn 2020, will provide further evidence of ongoing recolonisation of *Z. muelleri* subsp. *capricorni* (or otherwise) and will assist in understanding trends or potential limitations for long-term establishment and persistence of seagrass in Foreshore Beach.

Note that although the results of any additional informative surveys may change conclusions with respect to the success of the PEHEP there would not be implications for compensatory habitat or offsetting.

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2019

APPENDIX A

STATISTICAL ANALYSIS

Appendix A: 2019 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	7
Site	Si	Random	6

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Su	6	9619.6	1603.3	1.4441	0.218	9941
Si	5	6460.9	1292.2	1.1639	0.3573	9940
SuxSi**	16	17764	1110.2	4.3841	0.0001	9910
Res	112	28362	253.24			
Total	139	63710				

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
Autumn 2012, Autumn 2013	7.8587	0.0072	48
Autumn 2012, Autumn 2014	2.1141	0.0917	14
Autumn 2012, Autumn 2015	3.5	0.047	6
Autumn 2012, Autumn 2017	3.5	0.0477	6
Autumn 2013, Autumn 2014	6.7943	0.0071	46
Autumn 2013, Autumn 2015	9.2113	0.0075	12
Autumn 2013, Autumn 2017	9.2113	0.0064	12
Autumn 2014, Autumn 2015	5.6054	0.0096	13
Autumn 2014, Autumn 2017	5.6054	0.0075	13
Autumn 2015, Autumn 2017	Denom is 0		

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	0.13465	0.9354	22
Autumn 2012, Autumn 2014	0.56358	0.8848	6
Autumn 2012, Autumn 2015	1.016	0.3649	30
Autumn 2012, Autumn 2017	1.1793	0.4501	2
Autumn 2013, Autumn 2014	0.68543	0.5423	18
Autumn 2013, Autumn 2015	1.9846	0.1047	24
Autumn 2013, Autumn 2017	1.9511	0.0492	6
Autumn 2014, Autumn 2015	3.2481	0.0304	23

Autumn 2014, Autumn 2017	1.3988	0.4434	2
Autumn 2015, Autumn 2017	7.1286	0.0088	15

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	0.76277	0.7159	4
Autumn 2012, Autumn 2014	2.4042	0.0536	10
Autumn 2012, Autumn 2015	6.2755	0.0079	23
Autumn 2012, Autumn 2017	2.4461	0.0324	16
Autumn 2012, Autumn 2018	2.4952	0.0255	22
Autumn 2012, Autumn 2019	3.2128	**0.0148**	22
Autumn 2013, Autumn 2014	3.8025	0.0079	9
Autumn 2013, Autumn 2015	7.6853	0.0103	15
Autumn 2013, Autumn 2017	2.9025	0.02	14
Autumn 2013, Autumn 2018	2.8432	0.0083	20
Autumn 2013, Autumn 2019	3.6711	**0.0068**	22
Autumn 2014, Autumn 2015	4.3259	0.0177	20
Autumn 2014, Autumn 2017	1.1763	0.3001	16
Autumn 2014, Autumn 2018	1.4525	0.2661	16
Autumn 2014, Autumn 2019	2.0108	0.0811	18
Autumn 2015, Autumn 2017	1.6274	0.151	19
Autumn 2015, Autumn 2018	0.91541	0.3896	21
Autumn 2015, Autumn 2019	0.70931	0.523	18
Autumn 2017, Autumn 2018	0.39752	0.7348	22
Autumn 2017, Autumn 2019	0.70502	0.5348	20
Autumn 2018, Autumn 2019	0.24168	0.8556	22

Within level 'P2B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	2.1068	0.0668	41
Autumn 2012, Autumn 2014	0.50918	0.6826	18
Autumn 2012, Autumn 2015	0.79282	0.4559	16
Autumn 2012, Autumn 2017	0.72929	0.5192	18
Autumn 2012, Autumn 2018	5.324	0.008	38
Autumn 2012, Autumn 2019	1.288	0.2782	23
Autumn 2013, Autumn 2014	2.0065	0.1156	53
Autumn 2013, Autumn 2015	2.0452	0.0997	57
Autumn 2013, Autumn 2017	2.0439	0.0963	87
Autumn 2013, Autumn 2018	1.4151	0.2381	81
Autumn 2013, Autumn 2019	1.9468	0.1174	91
Autumn 2014, Autumn 2015	0.11986	0.9708	24
Autumn 2014, Autumn 2017	0.11664	0.9375	28
Autumn 2014, Autumn 2018	3.3473	0.0228	45
Autumn 2014, Autumn 2019	0.41367	0.7074	33
Autumn 2015, Autumn 2017	1.3463E-8	1	11
Autumn 2015, Autumn 2018	5.6786	0.0087	40

Autumn 2015, Autumn 2019	0.89964	0.5364	16
Autumn 2017, Autumn 2018	5.3987	0.0073	42
Autumn 2017, Autumn 2019	0.84785	0.5314	18
Autumn 2018, Autumn 2019	3.773	**0.0242**	37

Within level 'P3A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2018, Autumn 2019	0.86175	0.4971	34

Within level 'P3B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2018, Autumn 2019	2.3784	0.086	48

Permanova Leaf Length (*Halophila spp.*)

Factors

Name	Abbrev.	Type	Levels
Survey	Su	Random	7
Site	Si	Random	6

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Su	6	37.071	6.1785	0.71009	0.6274	9956
Si	5	72.88	14.576	1.6233	0.2434	9949
SuxSi**	13	119.93	9.2251	9.1166	**0.0001**	9922
Res	878	888.45	1.0119			
Total	902	1158.8				

Pair Wise Leaf Length (*Halophila* spp.)

Within level 'P1A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	2.7307	0.0094	18
Autumn 2012, Autumn 2014	1.7806	0.1153	12
Autumn 2013, Autumn 2014	10.264	0.0001	36

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	7.3763	0.0001	18
Autumn 2012, Autumn 2014	9.0206	0.0001	12
Autumn 2012, Autumn 2015	2.2614	0.0254	521
Autumn 2013, Autumn 2014	3.7575	0.0014	12
Autumn 2013, Autumn 2015	9.3371E-2	0.9165	710
Autumn 2014, Autumn 2015	1.0172	0.3133	524

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	Denom is 0		
Autumn 2012, Autumn 2014	0.35417	1	6
Autumn 2012, Autumn 2015	1.3457	0.2338	53
Autumn 2012, Autumn 2017	1.3122	0.2016	133
Autumn 2012, Autumn 2018	1.2903	0.4143	7
Autumn 2012, Autumn 2019	2.2551	**0.0459**	7
Autumn 2013, Autumn 2014	0.28899	1	5
Autumn 2013, Autumn 2015	1.0984	0.3074	26
Autumn 2013, Autumn 2017	1.0709	0.2937	89
Autumn 2013, Autumn 2018	1.0531	0.515	5
Autumn 2013, Autumn 2019	1.8402	0.113	5
Autumn 2014, Autumn 2015	4.3171	0.0001	797
Autumn 2014, Autumn 2017	3.9516	0.0001	289
Autumn 2014, Autumn 2018	2.2188	0.0338	32
Autumn 2014, Autumn 2019	5.4599	**0.0001**	22
Autumn 2015, Autumn 2017	1.1171	0.269	1737
Autumn 2015, Autumn 2018	3.8864	0.0002	860
Autumn 2015, Autumn 2019	1.9563	0.0539	829
Autumn 2017, Autumn 2018	3.2342	0.0011	284
Autumn 2017, Autumn 2019	0.87122	0.3972	151
Autumn 2018, Autumn 2019	4.0557	**0.0001**	39

Within level 'P2B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	2.4322	0.0223	67
Autumn 2012, Autumn 2014	7.4328	0.0001	32
Autumn 2012, Autumn 2015	2.4972	0.0149	100
Autumn 2012, Autumn 2017	0.61072	0.5612	45
Autumn 2012, Autumn 2018	4.7091	0.0001	26
Autumn 2012, Autumn 2019	2.1176	**0.0409**	50
Autumn 2013, Autumn 2014	6.8062	0.0001	97
Autumn 2013, Autumn 2015	1.7209	0.0905	177
Autumn 2013, Autumn 2017	1.738	0.0948	81
Autumn 2013, Autumn 2018	2.8415	0.0048	82
Autumn 2013, Autumn 2019	1.2888E-2	1	84
Autumn 2014, Autumn 2015	1.7312	0.0921	94
Autumn 2014, Autumn 2017	7.3356	0.0001	59
Autumn 2014, Autumn 2018	4.639	0.0001	27
Autumn 2014, Autumn 2019	6.1806	**0.0001**	59
Autumn 2015, Autumn 2017	2.5876	0.0122	56
Autumn 2015, Autumn 2018	0.59366	0.5787	55
Autumn 2015, Autumn 2019	1.852	0.0764	100
Autumn 2017, Autumn 2018	4.2953	0.0001	54

Autumn 2017, Autumn 2019	1.616	0.1296	53
Autumn 2018, Autumn 2019	2.6055	**0.0127**	50

Within level 'P3A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2018, Autumn 2019	0.75717	0.509	20

Within level 'P3B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2018, Autumn 2019	0.56561	0.63	24