

Port Botany Long-term Seagrass Monitoring

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Executive Summary

As part of the Port Botany Expansion Project, 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 m² 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 in accordance with a 'Penrhyn Estuary Habitat Enhancement Plan' (PEHEP). This involved measuring changes in their distribution and condition.

Post-construction monitoring surveys at Foreshore Beach, however, showed a decline in distribution of seagrass, which was partly attributed to sediment mobilised from beach erosion and/or potentially reductions to light availability or water circulation.

In late 2016 three groynes were constructed along Foreshore Beach for protection against beach erosion and sediment transport to the north and offshore of Foreshore Beach. Surveys completed by Cardno before, during and after groyne construction showed the loss of a small patch of *Z. muelleri* subsp. *capricorni* was likely attributed to a combination of indirect, construction-related effects (from impaired water quality and sedimentation) as well as 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 for the Port Botany Expansion. The 2017 survey also showed a slight increase in the extent of *Z. muelleri* subsp. *capricorni*. This included the appearance of a new, small patch of *Z. muelleri* subsp. *capricorni* at the south-eastern end of Foreshore Beach. The establishment of this patch may have been a result of improved conditions related to groyne construction, particularly stabilisation of sediment. It was therefore recommended that three additional surveys should be completed to assess long-term trends in seagrass beds, and potentially more improved conditions, following construction of the groynes.

This document provides results of the first survey which was completed in May 2018. It also incorporates data from previous investigations carried out as part of PEHEP monitoring to provide a long-term context. This report therefore 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.

Results of the latest 2018 survey are encouraging in that key indicators show a general improvement in seagrass cover and condition since the 2017 survey. Since 2017 mapped area of seagrass beds has increased by 81.2% and there was a 97.4% increase in average seagrass cover in transects. These increases were mostly attributed to *Halophila* spp. although the area of *Z. muelleri* subsp. *capricorni* also more than doubled. The shoot density of both *Halophila* spp. and *Z. muelleri* subsp. *capricorni* also increased substantially and more than doubled for *Halophila* spp. Results did not show any notable changes in epiphyte cover that would be indicative of nutrient enrichment or impaired water quality.

The total area of *P. australis* at Foreshore Beach has been comparatively small since the start of monitoring, however, the latest 2018 survey has shown a notable decline in one of two remaining patches which is located adjacent to the middle groyne. Divers found only some fronds of *P. australis* around the middle groyne patch and shoot bases were ~10 cm below the sand, indicating that some of this patch has been lost due to sediment accumulation and subsequent smothering.

These findings suggest that the addition of groynes at Foreshore Beach may have altered conditions such that the growth of *Z. muelleri* subsp. *capricorni* and *Halophila* has been facilitated in certain areas (i.e. between and either side of the ends of the groynes and the south-eastern corner of Foreshore Beach) but that in areas of sediment accumulation very close to the groynes there may have been a burial effect.

The overall increase in the total area of seagrass (since 2017) combined with an increase in the new, high density patch of *Z. muelleri* subsp. *capricorni* in the south-eastern part of the site (initially identified in 2017)

presents a possibility that seagrass beds may be recovering and colonising new areas at Foreshore Beach following the stabilisation of sediments from the installation of the groynes. Two further monitoring surveys are planned to take place in Autumn 2019 and 2020. The results of these surveys will assist in understanding trends or potential limitations for long-term establishment and persistence of seagrass in this area.

Note that although the results of any additional informative surveys may change conclusions with respect to the success of the PEHEP they would not have 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
PEHEP	Penrhyn Estuary Habitat Enhancement 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: <i>Halophila</i> spp. (including <i>Halophila ovalis</i> and <i>Halophila decipiens</i> , both known as 'paddleweed'), <i>Zostera muelleri</i> subsp. <i>capricorni</i> ('eelgrass') and <i>Posidonia australis</i> ('strapweed')
Secchi (disk) depth	The depth at which a disk with black and white quarters disappears from sight when lowered into the water. Considered to be a good indicator of the maximum depth at which aquatic plants, particularly seagrasses 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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1 Introduction

1.1 Background

As part of the Port Botany Expansion Project, Sydney Ports Corporation (now Port Authority of New South Wales) has rehabilitated Penrhyn Estuary, located adjacent to the port expansion. Penrhyn Estuary is a small waterway of approximately 30 ha located to the north of Brotherson Dock, which was artificially created during the reclamation of the Botany foreshore between 1975 and 1978. Since its creation, it has been utilised by a diverse group of migratory birds. The primary purpose of the 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 to potentially attract a greater number of shorebirds upon completion. The eastern stretch of Foreshore Beach, adjacent to the estuary was also modified due to construction of a public boat and through creation of entrance flushing channel for Penrhyn Estuary. It was anticipated that the redesigned entrance channel to Penrhyn Estuary 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 construction, monitoring works for the PEHEP carried out in May 2008 indicated that approximately 317 m² of seagrass (including *Zostera muelleri* subsp. *capricorni* (synonymous to *Z. capricorni*), *Halophila* spp. and *Posidonia australis*) would be lost through land reclamation, boat ramp construction and dredging works associated with the port expansion (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. The Seagrass Monitoring Plan for the PEHEP (Cardno (NSW/ACT) Pty Ltd (Cardno) 2014a) therefore investigated the success of this transplantation over time. The remaining seagrass beds, and the potential seagrass habitat in the newly created flushing channel, were monitored during the construction and five year post-construction phases of the project in accordance with the PEHEP by measuring changes in distribution and condition. As part of the PEHEP, seagrass was monitored in both these areas 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, it was not considered warranted in the PEHEP's Alternative Compensatory Habitat Options (ACHO) Package (SPC 2008) to implement alternate compensatory habitat in the event of failure of the seagrass enhancement works. That is, there was no requirement for offsetting. Monitoring for the PEHEP has now been completed, however, the addition of three new groynes along Foreshore Beach in late 2016 has warranted additional monitoring to determine the effects of this (Details provided in **Section 1.3.4**). It was anticipated that in minimising beach erosion and sediment transport, water quality would improve and sedimentation be reduced, thus improving conditions for seagrasses.

1.2 Aims

The key objective of this 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 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 also baffle water currents, causing them to release their sediment loads, thus maintaining water quality (Smith and Pollard 1999) and help prevent erosion by stabilising sediments and assisting in the cycling of nutrients (Smith *et al.* 1997). Loss of seagrass can result in the destabilisation of sediments, removal of potential nursery habitats for fish and invertebrates and a decrease in primary productivity of estuaries. Many organisms also benefit from the organic matter released by the slow bacterial and fungal breakdown of seagrass detritus.

A number of fish and invertebrate species important to commercial and recreational fisheries have been recorded from 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 prawns (*Melicertus plebejus*), blue swimmer (*Portunus pelagicus*) and other crabs, octopi, cuttlefish, squid and shrimp. Overall, the seagrass beds off Foreshore Beach have shown consistently greater abundances of commercially important species, but fewer species than other sites in the 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. *Halophila* spp. (including *H. ovalis* and *H. decipiens*, both known as 'paddleweed' and hereafter referred to as *Halophila* spp.), are 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 and are generally considered pioneering species prior to the colonisation of *Z. muelleri* subsp. *capricorni* followed by *P. australis*.

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 leaf length and width may vary considerably depending on conditions. *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 and more mature leaves may be brown in colour and commonly covered in epiphytes (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 and turbidity and nutrient inputs which in turn may result in increased growth of phytoplankton macroalgae and epiphytes, leading to shading. Inputs of suspended sediment loads and nutrients are often related to seasonal episodic pulses of rainfall and would enter Penrhyn Estuary 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 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 of seagrass, recovery of 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 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 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 documenting seagrass distribution and condition have been carried out 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. During this period, considerable changes in the extent of the seagrass beds along the entire northern shore of Botany Bay were observed. This was largely attributed to two expansions of the airport and the development of port facilities although 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 relation to 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 also made comparisons to NSW Fisheries seagrass mapping based on 1995 aerial imagery (Watford and Williams 1998) for the same area. Results showed an increase in total seagrass cover from 74,752 m² in 1995 (Watford and Williams 1998) to 96,715 m² in 2002 (The Ecology Lab). In addition to an actual increase in seagrass cover, these 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 were also not included in the Watford and Williams (1998) mapping (estimated to be 2000 m²). Overall, the 2002 mapping showed that *Z. muelleri* subsp. *capricorni* was the most abundant species of seagrass present which varied from sparse to dense patches and was also mixed with *Halophila* spp. and the green alga *Caulerpa* spp. in places. *P. australis* was found in small clumps at the seaward edge of the main bed of *Z. muelleri* subsp. *capricorni* but was not recorded in the earlier 1995 study.

Prior to dredging and construction activities commencing, 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 survey method involved the placement of 200 m long fixed transects (14 in total) along the length of Foreshore Beach. The total area covered by seagrasses at Foreshore Beach in 2006 was calculated to be 47,100 m² and comprised predominantly of *Z. muelleri* subsp. *capricorni*, mixed *Z. muelleri* subsp. *capricorni* and *Halophila* spp. and small patches of *P. australis* (approximately 14 m²). Within Penrhyn Estuary, variable amounts of short *Z. muelleri* subsp. *capricorni* were recorded on mud flats and among mangrove pneumatophores during five surveys from July 2005 to June 2007 (The Ecology Lab 2007).

The total area of seagrass cover along Foreshore Beach in February 2007 was calculated to be only 698 m², comprised predominantly of mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. (423 m²), followed by monospecific beds of *Z. muelleri* subsp. *capricorni* (192 m²), *P. australis* (45 m²), *Halophila* spp. (27 m²) and mixed patches of all three species (11 m²). This extensive reduction in seagrass cover between 2006 and February 2007 was attributed to burial by sand from erosion along Foreshore Beach, although the cause of increased erosion was not speculated upon. The total area of seagrass cover reported in November 2007 was 365 m² comprised of mixed beds of *Z. muelleri* subsp. *capricorni* and *Halophila* spp. (217 m²), *Z. muelleri* subsp. *capricorni* (93 m²), *P. australis* (43 m²), mixed patches of *Z. muelleri* subsp. *capricorni* and *P. australis* (8 m²) and mixed patches of all three species (approximately 4 m²). The total area of seagrass cover reported in May 2008 was 352 m² comprised of mixed beds of *Z. muelleri* subsps. *capricorni* and *Halophila* spp. (221 m²), *Z. muelleri* subsp. *capricorni* (86 m²), *P. australis* (36 m²), mixed patches of *Z. muelleri* subsp. *capricorni* and *P. australis* (5 m²) and mixed patches of all three species (approximately 4

m²). Following the final pre-construction survey in May 2008, the total area of seagrass estimated to be directly impacted by the dredging and reclamation works was 317 m². This included mixed beds of *Z. muelleri* subsp. *capricorni*, *Halophila* spp. and *P. australis* (207 m²), *Z. muelleri* subsp. *capricorni* (84 m²) and *P. australis* (26 m²).

During construction works, NGH Environmental on behalf of Boulderstone Jan De Nul and Sydney Ports Corporation undertook weekly monitoring of seagrass at 10 Sites along Foreshore Beach using an underwater viewing tube 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 at most of the sites was generally stable and/or increasing initially for *Z. muelleri* subsp. *capricorni* and *Halophila* spp. By the end of 2011, seagrass cover remained stable or was in decline although no physical disturbance to the retained seagrass patches was observed. Epiphytic growth was apparent at all sampling sites over the course of the sampling program which was attributed to high nutrient levels within Port Botany.

In 2016, unscheduled surveys were commissioned by Ward Civil Pty Ltd (Ward Civil) on behalf of the Port Authority of NSW to monitor seagrass during pre-construction, construction and post-construction phases of construction of three groyne structures along Foreshore Beach. The groynes were installed to protect the beach against erosion and sediment transport to the north of Foreshore Beach and offshore (Cardno 2016c). The surveys, done in June 2016 (pre-construction), September 2016 (construction) and December 2016 (post-construction) determined that there was little change to patch sizes during the construction of the groynes and 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, loss of a small patch of *P. australis* and a 56% decline in patch size of another small patch were noted and attributed to poor water quality and sedimentation from the construction of the groynes as well as natural erosion still occurring prior to the installation of the groynes.

Post- construction monitoring of Foreshore Beach and the Rehabilitated Area of Penrhyn Estuary has been carried out by Cardno in March/April 2012, 2013, 2014, 2015 and 2017. Data from these studies are included for comparisons of seagrass distribution at Foreshore Beach through time.

Table 1 Summary of 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 <i>et al.</i> (2006)
2007 (February)	Pre-Construction	1,375	Roberts <i>et al.</i> (2007)
2007 (November)	Pre-Construction	680	Roberts <i>et al.</i> (2008)
2008	Pre-Construction	651	Roberts <i>et al.</i> (2008)
2009	During Construction	Not comparable	SPC (2009)
2010	During Construction	Not comparable	SPC (2010)
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)

Year	Project Phase	Approximate Area of Seagrass (m ²)	Reference
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 m² of *P. australis* would be directly impacted by works associated with the Port Botany Expansion (Roberts *et al.* 2008). Given its conservation value and the species' slow recovery rate, it was identified within the PEHEP that this area of seagrass would be relocated and transplanted to Quibray Bay.

Past seagrass transplantation experiments within Botany Bay, however, have 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 and 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 were selected where there was 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) was 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 during transplantation (Roberts and Murray 2009).

The 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 m² being transplanted, although a number of 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 in July 2008.

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 m² and Planting Area 2 covered an area of approximately 90 m². Densities at the time of planting were 10 and 15 plants per m² in Planting Areas 1 and 2 respectively. Three additional sites (Experimental Sites 1-3) were also established to test and evaluate different transplanting methods. The experimental treatments 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 after 14 months following transplantation, the seagrasses within the Planting Areas had successfully established, with average shoot densities of approximately 9 and 14 plants per square metre in Planting Areas 1 and 2 respectively. Over two years on from transplantation (by October 2010), average shoot densities had increased substantially with estimated densities of 37 and 43 shoots per square metre recorded in Planting Areas 1 and 2 respectively (Roberts and Murray 2010).

Within the experimental plots, the 'whole' treatments recorded the greatest increase in shoot density and 'trimmed' treatments had the greatest increase in leaf length. In October 2010, there had been an increase in the leaf length of plants within all treatments compared to that recorded in the previous survey in September 2009 (Roberts and Murray 2010).

Monitoring of seagrass transplantation 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 included 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 were modified from that originally specified in the PEHEP Seagrass Monitoring Plan due to a significant reduction in seagrass cover between 2006 and 2008 surveys carried out by Roberts *et al.* (2006, 2007 and 2008). The methodology outlined in this report is therefore consistent with these earlier pre-enhancement 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 a towed camera system and the total area (m²) and species composition of each seagrass patch calculated using GIS software. Comparisons were made through time to assess the changes in total seagrass cover. Data were compared for surveys carried out before construction (2003 – 2008) and after construction as part of the PEHEP (2012 to 2018). The total percent cover for different species groups was also compared for years 2012, 2013, 2014, 2015, 2017 and 2018. The following species classifications 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 extending up to 200 m perpendicular to Foreshore Beach. Locations of transects at Foreshore Beach are indicated in **Figure 1**.

Roberts *et al.* (2006, 2007 and 2008) measured percent cover of seagrass along six of these transects prior to construction, however, data were not available to allow statistical comparison with post-construction surveys, therefore only those data from 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 fixed patches numbered 1, 2, 3, 5 and 6, 7 and 8 (**Figure 4**), consistent with 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 post-construction seagrass was only found at five of the fixed patches. Percentage cover was compared at these fixed patches for times before and after construction. New fixed Patch 8 is now being used for morphology monitoring as well 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 *Halophila* spp. mixed with some *Z. muelleri* subsp. *capricorni* at Foreshore Beach. These patches were selected during the first post-construction survey (March 2012) as 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 were added during the 2018 survey as well as Fixed Patch 8, mentioned in the previous section.

Within each site, five 0.25 m² quadrats were placed randomly 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 a measure of seagrass density.

- > Leaf length - The length 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 - 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 high epiphytic load may be indicative of high nutrient levels within the water column.

- > The invasive alga *Caulerpa taxifolia* was noted if present.

2.1.6 Data Analysis

- > Total areas of seagrass at Foreshore Beach is presented in tables and maps through time for the years 2003 – 2018.
- > Percent cover of total seagrass and seagrass species along transects were presented as means, standard errors and ranges for each transect.
- > Data collected at the seagrass morphology monitoring sites on density and leaf length for *Halophila* spp. were 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). The statistical design was as follows:
 - Survey (random) – (March 2012, March 2013, March 2014, March 2015, March 2017 and March 2018); and
 - Site (random) – (P1A, P2A, P1B and P2B; see **Figure 1** – note that site P3A and P3B was not included in this analysis as only one survey has been undertaken at this site and no temporal comparison can be made).
 - Quadrats (1-5) were used as replicates.

Epiphyte load was not analysed statistically but presented as percentages of total observations categorised in the high, medium and low ranges or none if no epiphytes were observed.

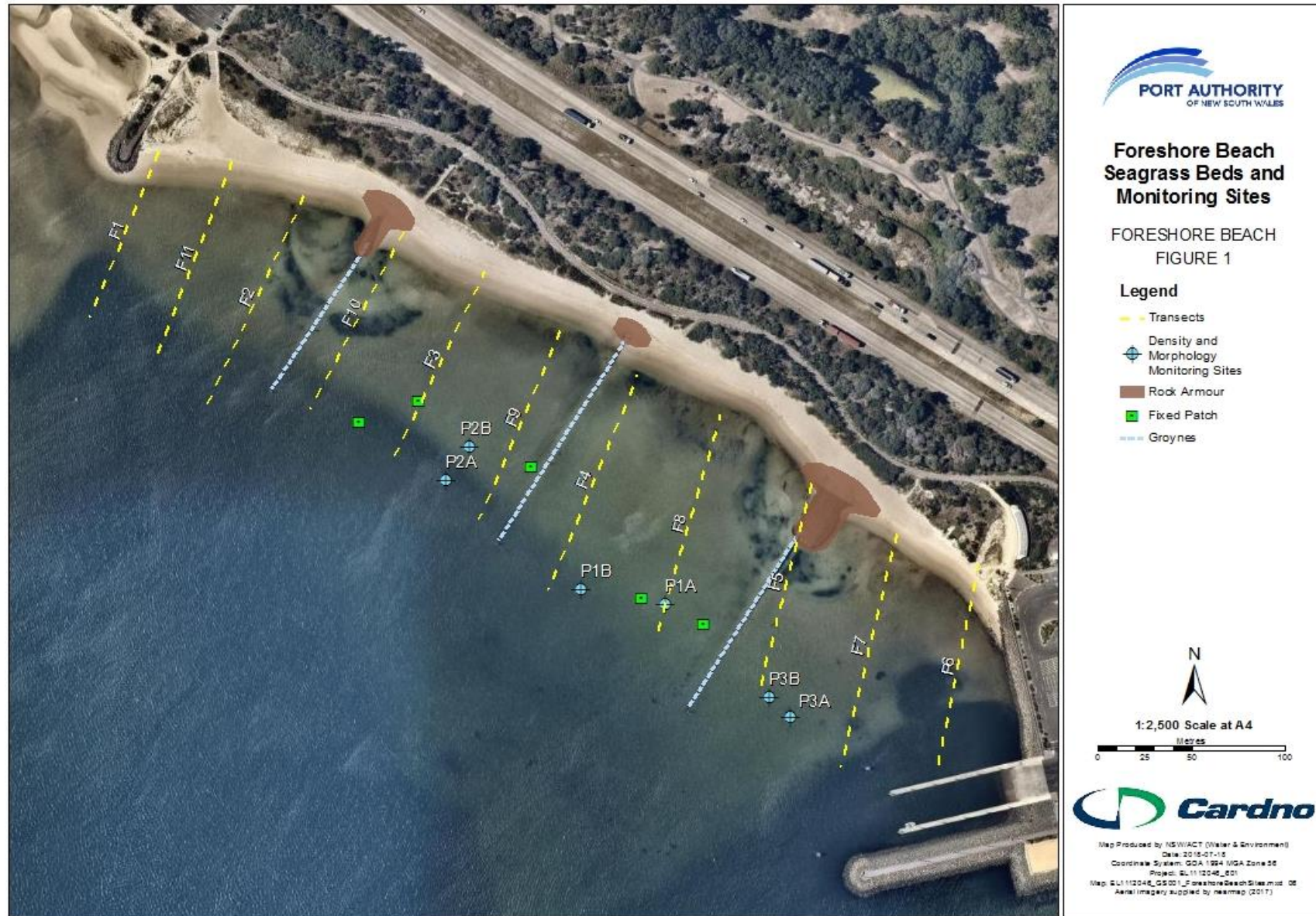


Figure 1 Foreshore Beach transect, fixed patches and morphology monitoring sampling locations

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 mapping (entire area)	Seagrass species % cover (Mapping data available for 2002, 2012 , 2013, 2014, 2015 and 2017 only)	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
	Diver observations (Fixed Patches) x5 Sites (since 2012)	Seagrass species % cover estimates	Before: 2007, 2008 After: 2012, 2013, 2014, 2015, 2017, 2018
	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

2.3 Sampling Dates

All seagrass data collection (mapping, transects, fixed patches and morphology sites) at Foreshore Beach was carried out by Cardno on 22 and 23 May 2018.

3 Results

3.1 Mapping

The most recent survey of seagrasses at Foreshore Beach was completed in May 2018. Total seagrass area in May 2018 was 1,843 m² representing an 81.2 % increase from the previous survey (1,017 m²) in 2017 (**Figure 2**). All three types of seagrass *P. australis*, *Z. muelleri* subsp. *capricorni* and *Halophila* spp. were recorded in the 2018 survey and the overall increase was mainly attributed to an increase of 832 m² in *Halophila* spp. The area of *Z. muelleri* subsp. *capricorni* also more than doubled, from 15 m² in March 2017 to 37 m² in May 2018. The area of *P. australis*, however, declined from 37 m² in March 2017 to 8.5 m² (**Figure 3**).

Trends in total seagrass cover at Foreshore Beach from before port expansion (2002 – 2008) and post-expansion (2012 – 2018) are illustrated in **Figure 2** and summarised in **Table 3**. Trends in seagrass cover (m²) at Foreshore Beach for this timeframe by species is also shown in **Figure 3**.

Maps of seagrass distribution between March 2017 and May 2018 show that the extent of *Halophila* spp. has expanded in existing beds and that new beds have appeared either side of the northernmost groyne. While some very small patches of *Z. muelleri* subsp. *capricorni* have disappeared in 2018, a new healthy and dense patch (approximately 38 m²) has appeared at the southern end of Foreshore Beach between the southernmost groyne and the northern breakwater of the boat ramp (**Figure 4**). The overall seagrass extent in 2018 does, however, remains substantially reduced in comparison with the 2002 pre-expansion survey and the 2012 post-expansion surveys (**Figure 5**). It is noted that a significant decline in seagrass extent occurred between 2002 and 2007 prior to any port expansion works and was not therefore attributed to any port expansion works. Following port expansion works, total seagrass cover increased in 2012 but has steadily declined overall. The 2018 survey represents the first increase in overall seagrass cover at Foreshore Beach since 2014.

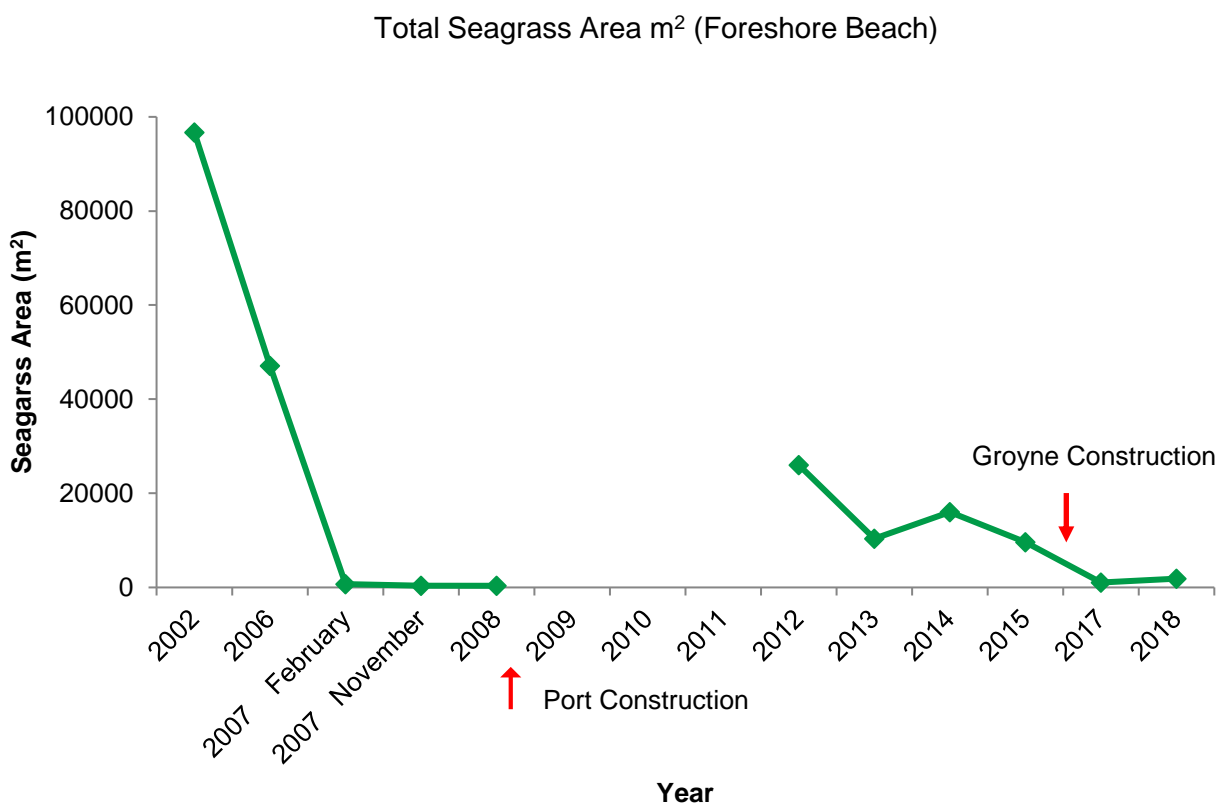


Figure 2 Total area of seagrasses at Foreshore Beach between 2002 and 2018. NB: comparable quantitative data was not collected during port construction (2009-2011)

Table 3 Total seagrass area (m²) at Foreshore beach between 2002 and 2018

*Figures in parentheses include the areas of Foreshore Beach within the construction footprint and 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 <i>et al.</i> (2006)
2007 (February)	Pre-Construction	698	Roberts <i>et al.</i> (2007)
2007 (November)	Pre-Construction	365	Roberts <i>et al.</i> (2008)
2008 (May)	Pre-Construction	352	Roberts <i>et al.</i> (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)

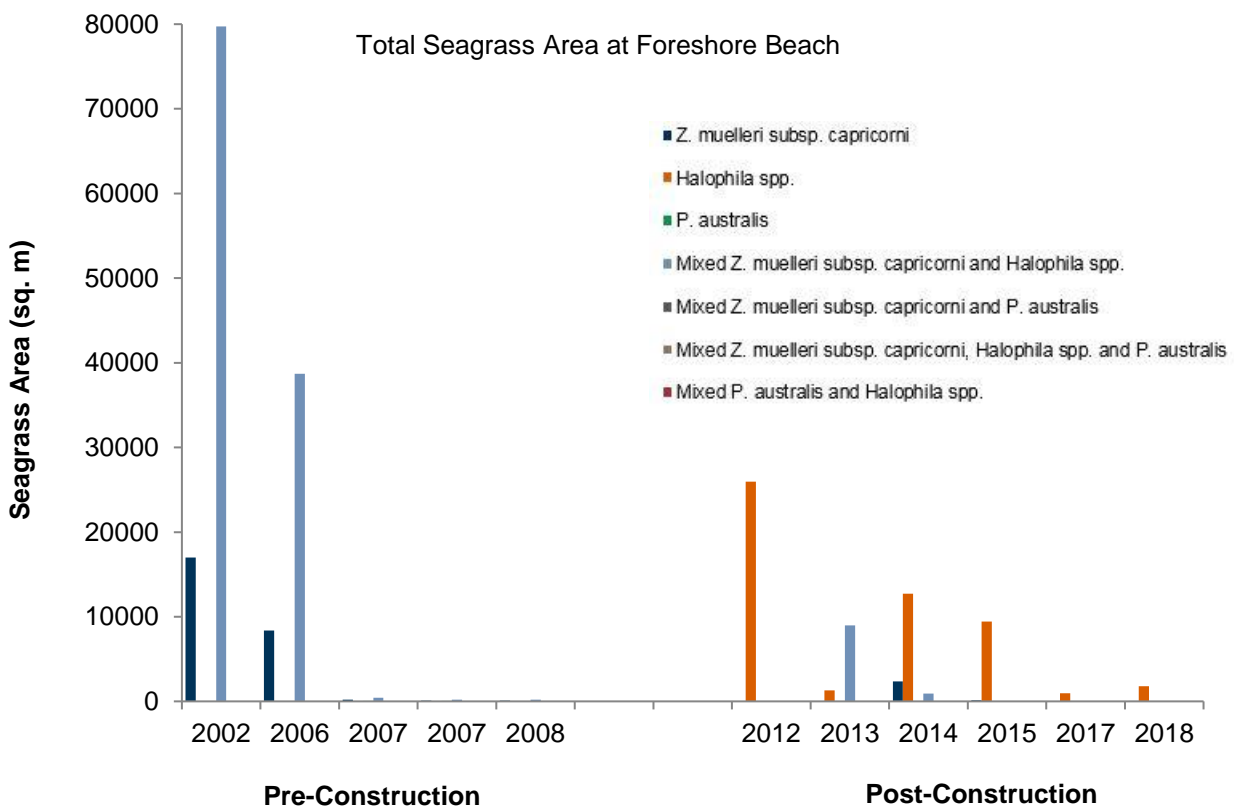


Figure 3 Area of seagrass taxa at Foreshore Beach between 2002 and 2018. Includes data from Foreshore Beach Fixed Patches

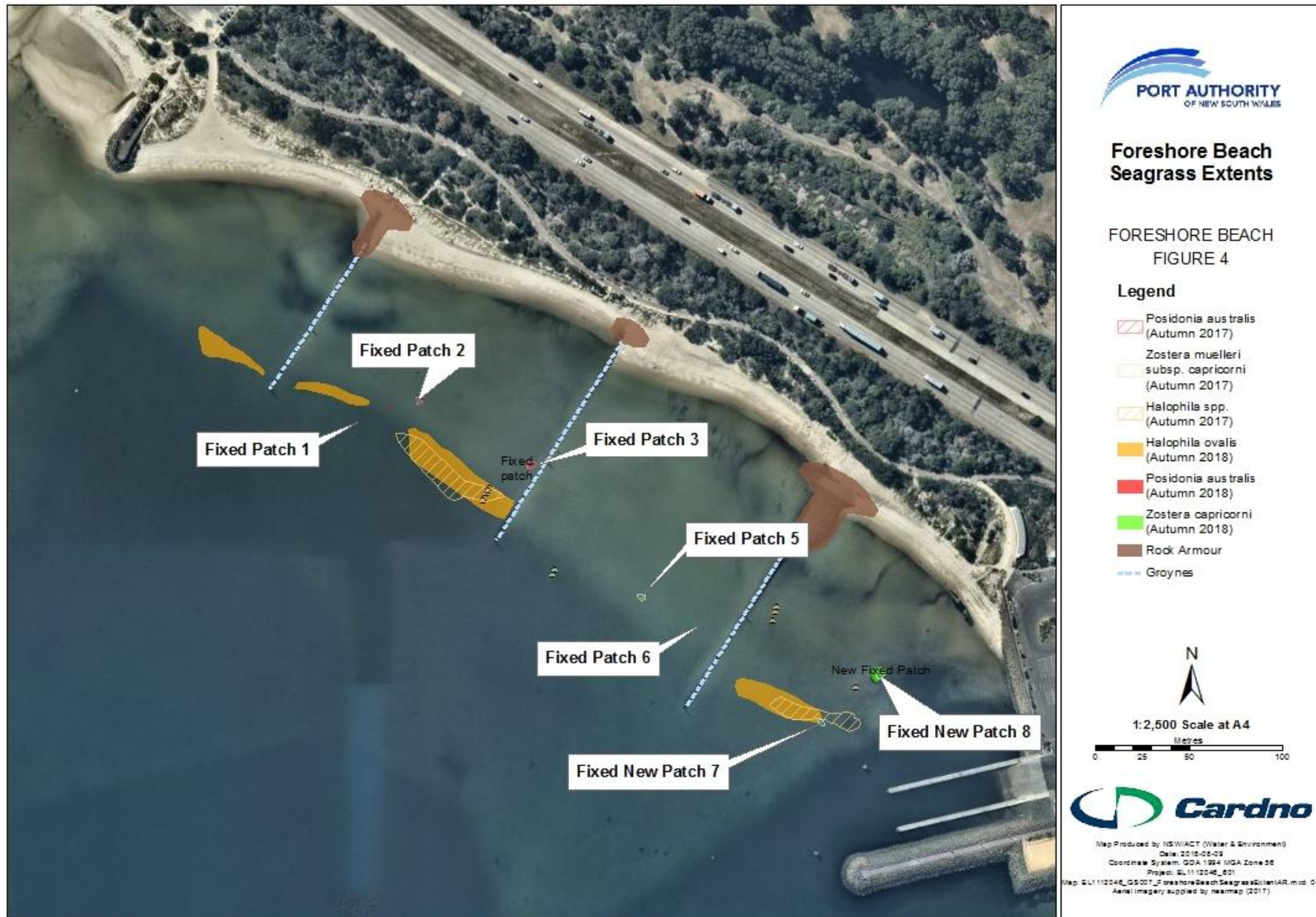


Figure 4 Seagrass mapped at Foreshore Beach in 2018 compared to 2017

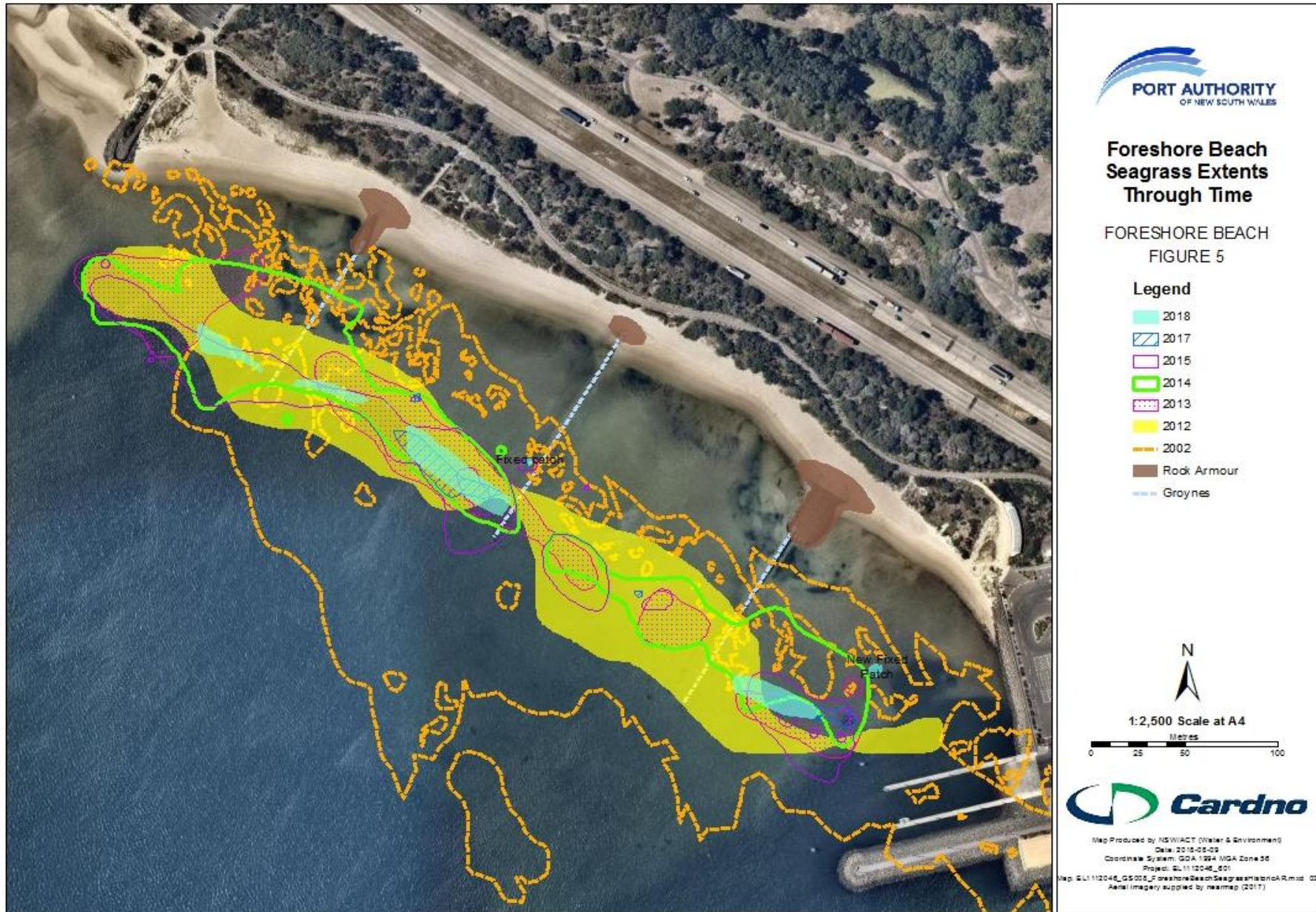


Figure 5 Seagrass mapped at Foreshore Beach prior to (2002) and after (2012, 2013, 2014, 2015, 2017 and 2018) port expansion

3.2 Transects

Percent cover of seagrass along transects during 2018 ranged between 0 - 50 % with an average of 0.2 % cover across three species. This represents a 97.4 % increase in average percent cover across all three species in from 2017 to 2018. Similar to 2015, only one occurrence of *P. australis* was recorded along transects in 2018 and this was in very low cover < 1% in a single quadrat.

For *Z. muelleri* subsp. *capricorni*, average percent cover of seagrass along each transect increased from 0.001 % in 2017 to 0.005 % in 2018. *P. australis* increased in percent cover from 0.001 % to 0.008 % cover. Most notable was the 40 fold increase in percent cover of *Halophila* spp. from an average of only 0.013 % in 2017 to 0.564 % in 2018 (**Figure 6**).

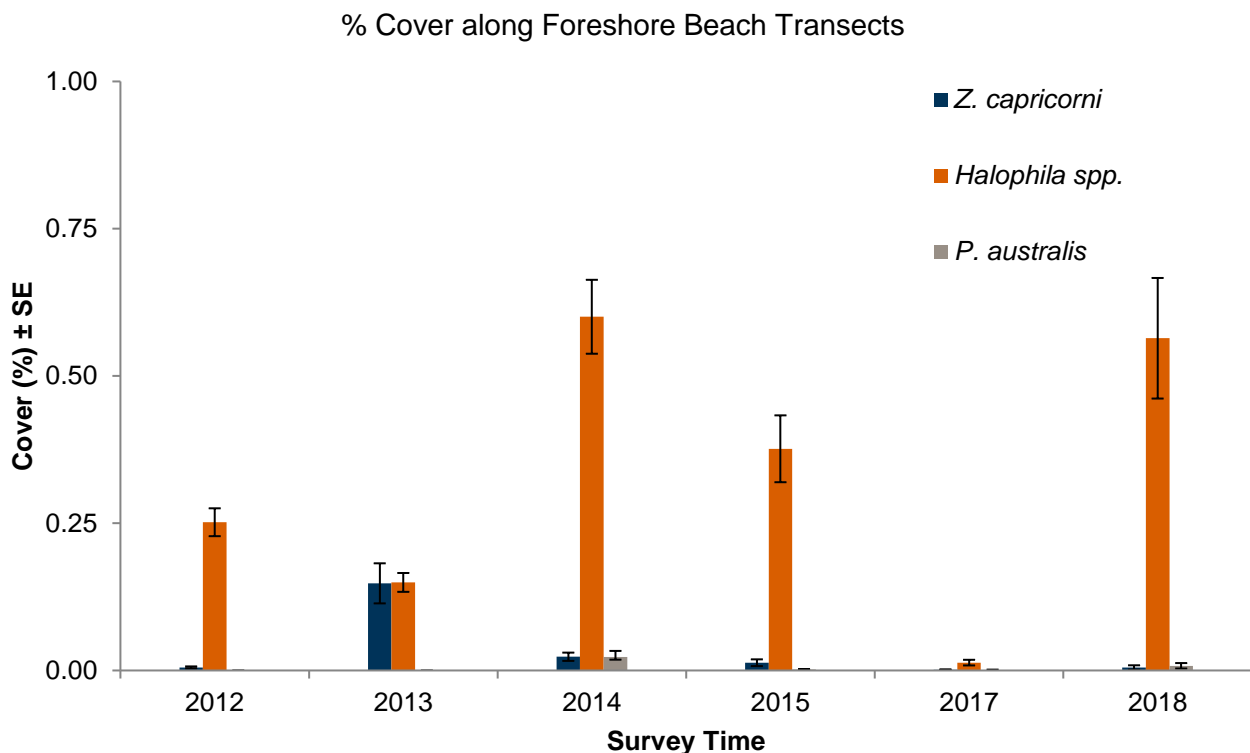


Figure 6 Percent cover (\pm SE) of seagrasses recorded along transects at Foreshore Beach in Autumn 2012, 2013, 2014, 2015, 2017 and 2018

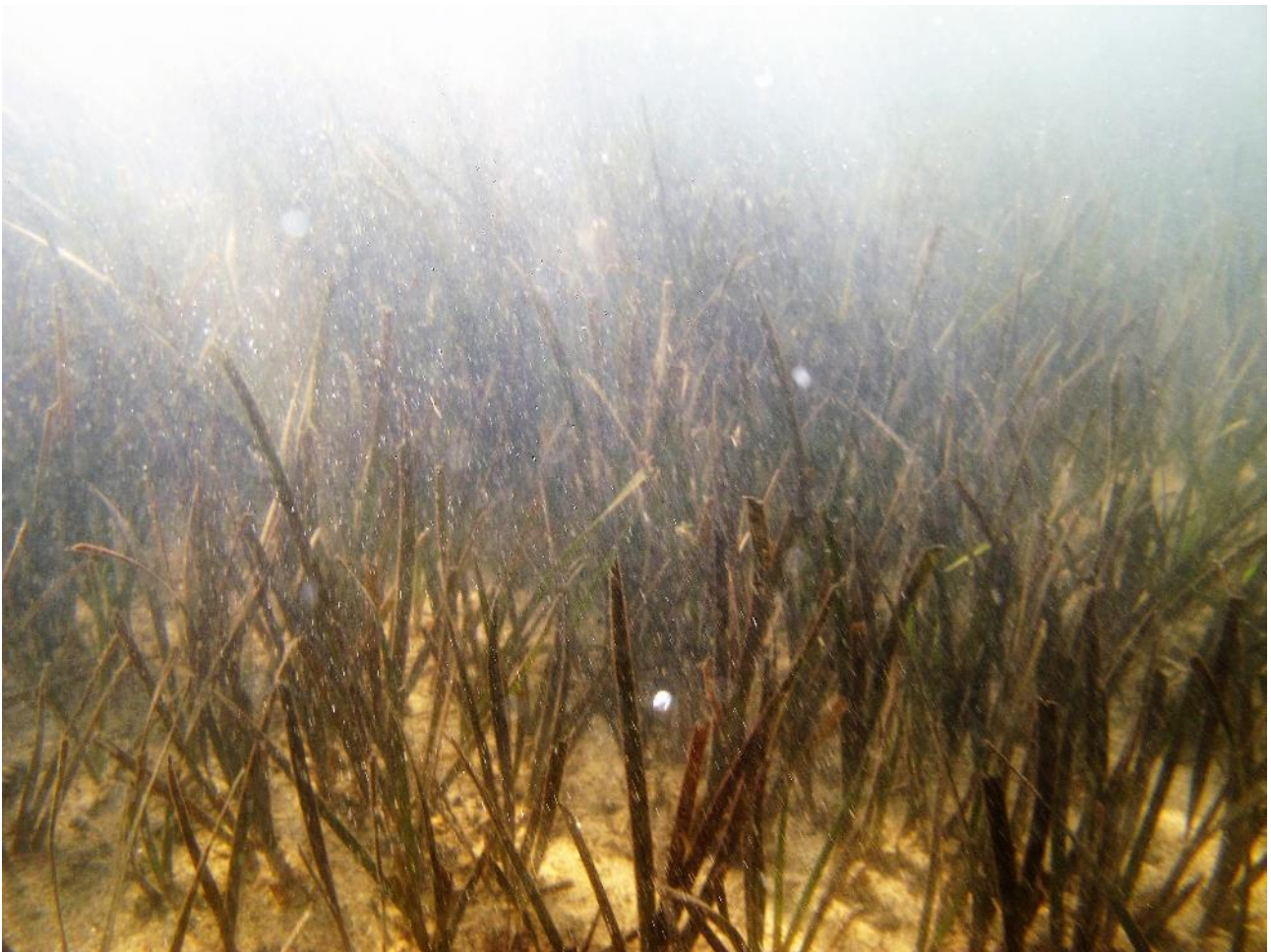
3.3 Fixed Patches

Seagrass was recorded at only two of the eight patches (Patch 3 and 8) during the 2018 survey. Patch 3 contained a small area of *P. australis* which has persisted since the start of fixed patch surveys in 2008, but has declined substantially from 36 m² recorded in 2017 to 2 m² in 2018. Patch 8 contained a healthy and dense area of *Z. muelleri* subsp. *capricorni*, which has increased in area from 11.4 m² in 2017 to 38 m² in 2018 (**Table 4**, **Plate 1**).

Overall, however, area of seagrass in fixed patches has declined from 52.6 m² in 2017, to 40 m² in 2018. 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 and last recorded in patch 4 in 2012.

Table 4 Seagrass area estimates of fixed patches along Foreshore Beach since 2008

Patch	Seagrass Area (m ²)							
	Year	2008	2012	2013	2014	2015	2017	2018
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
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
Total		20	48.5	28.2	27	40.6	52.6	40.0

**Plate 1. *Z. muelleri* subsp. *capricorni* at the new patch 8 first detected in 2017 and which has grown 2018**

3.4 Seagrass Density and Morphology

3.4.1 Shoot Density

At the morphology monitoring sites, the average density of *Halophila* spp. was approximately 19.2 shoots per 0.25 m² at P2 (A and B) compared with 8 shoots per 0.25 m² sampled in 2017. As for 2017, no shoots were recorded at morphology patch P1 (A and B). Because of the appearance of new patches of seagrass, new morphology sites have been established. These have been named P3A and P3B and Patch 8. Patch 8 is a relatively large area (38 m²) of dense *Z. muelleri* subsp. *capricorni* (as described in **Section 3.3, Plate 1**), that has previously been sampled as a fixed patch and will continue to be monitored as per the methodology for fixed patches. However, given that it is a larger, quite dense area, this will also be suitable for post-groyne construction morphology monitoring. Only *Halophila* spp. was detected in the new P3 patch with a mean shoot density of 15.3 shoots per 0.25 m² including P3A and P3B. *P. australis* has not been found in any of the morphology patches since 2012 (**Table 5, Figure 7**).

Statistical analysis of *Halophila* spp. shoot density for surveys 2002 to 2018 at patches P1 (A and B) and P2 (A and B) detected a significant survey x site interaction ($p = <0.001$) indicating shoot density in some sites were significantly different among surveys (**Appendix A**). Shoot density of *Halophila* spp. was notably greater in 2018 than in 2012 and 2013 at Site P2A and also greater in 2018 than in 2012, 2014, 2015 and 2017 at site P2B.

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 and 2018 surveys

Species	2012				2013				2014				2015				2017				2018						
Site	P1 A	P1 B	P2 A	P2 B	P1A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P1 A	P1B	P2A	P2 B	P1 A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P3A	P3 B	8
<i>Z. muelleri</i> subsp. <i>capricorni</i>				0.8	7.0								8.8														236
<i>Halophila</i> spp.	4.2	6.2	1.2	6.2	37.8	5.4	0.4	76	8.2	3	4.6	9		11.8	12.6	8.4				7.8	8.4			9.4	29	15.6	15
<i>P. australis</i>	2.0																										

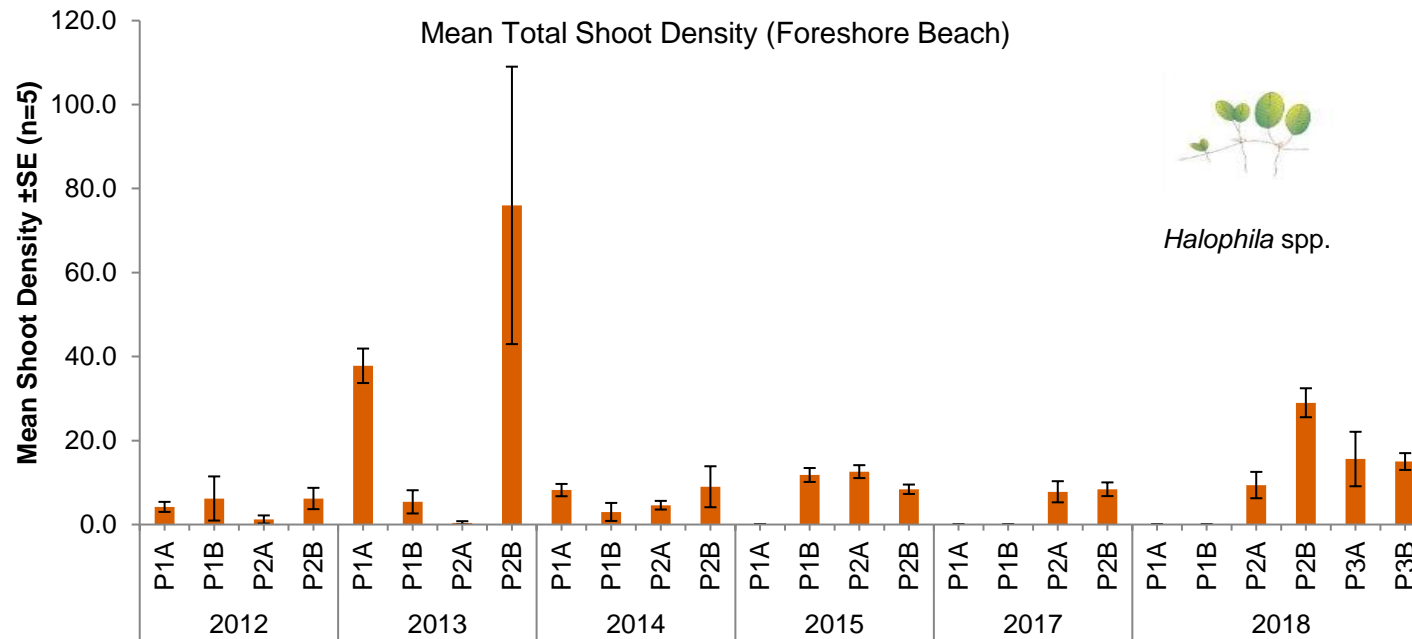


Figure 7 Mean (\pm SE) shoot densities (0.25 m²) of *Halophila* spp. (n=5) sampled in morphology monitoring sites at Foreshore Beach during 2012, 2013, 2014, 2015, 2017 and 2018

3.4.2 Leaf Length

Average leaf length of *Halophila* spp. ranged from 2.1 to 3.1 cm during the 2018 survey which was similar to the average leaf length in 2017. As for 2017, no seagrass was detected in patches P1 (A and B) in 2018 however, as discussed in **Section 3.4.1**, leaf length was measured in new patches P3 (A and B) and Patch 8 where mean leaf lengths at P3 (A and B) were 2.1 cm and 3.1 cm respectively (**Table 6**). Mean leaf length of *Z. muelleri* subsp. *capricorni* (recorded in Patch 8 only) was 19.2 cm which was comparably longer than any *Z. muelleri* subsp. *capricorni* recorded in previous surveys since 2012 (**Table 6**).

Statistical analysis of *Halophila* spp. leaf length detected a significant survey x site interaction ($p < 0.001$) indicating that significant differences existed between times for some sites (**Appendix A**). Notable differences included greater leaf lengths of *Halophila* spp. at P2A in 2018 compared with 2012, 2013 and 2014 but no difference compared to 2017. At Patch P2B leaf length of *Halophila* spp. in 2018 was significantly greater than in 2012, 2013, and 2017 but less than in 2014 and 2015 (**Figure 8, Appendix A**).

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

Species	2012				2013				2014				2015				2017				2018				8									
Site Code	P1A	P1B	P2A	P2B	P1A	P1B	P2A	P2B	P1A	P1B	P2A	P2B	P1A	P1B	P2A	P2B	P1A	P1B	P2A	P2B	P1A	P1B	P2A	P2B	P3A	P3B								
<i>Z. capricorni</i> (n)				3.5 4	1.0 20								4.8 29														19.2							
<i>Halophila</i> (n)	2.5 8	2.0 14	2.0 3	2.0 30	3.5 46	3.2 21	2.0 2	2.3 38	2.0 47	3.9 14	2.1 38	3.6 24		3.2 50	3.3 50	2.8 50											3.0 41	2.1 43			2.3 46	2.7 50	2.1 50	3.1 50
<i>P. australis</i> (n)		2.2 10																																

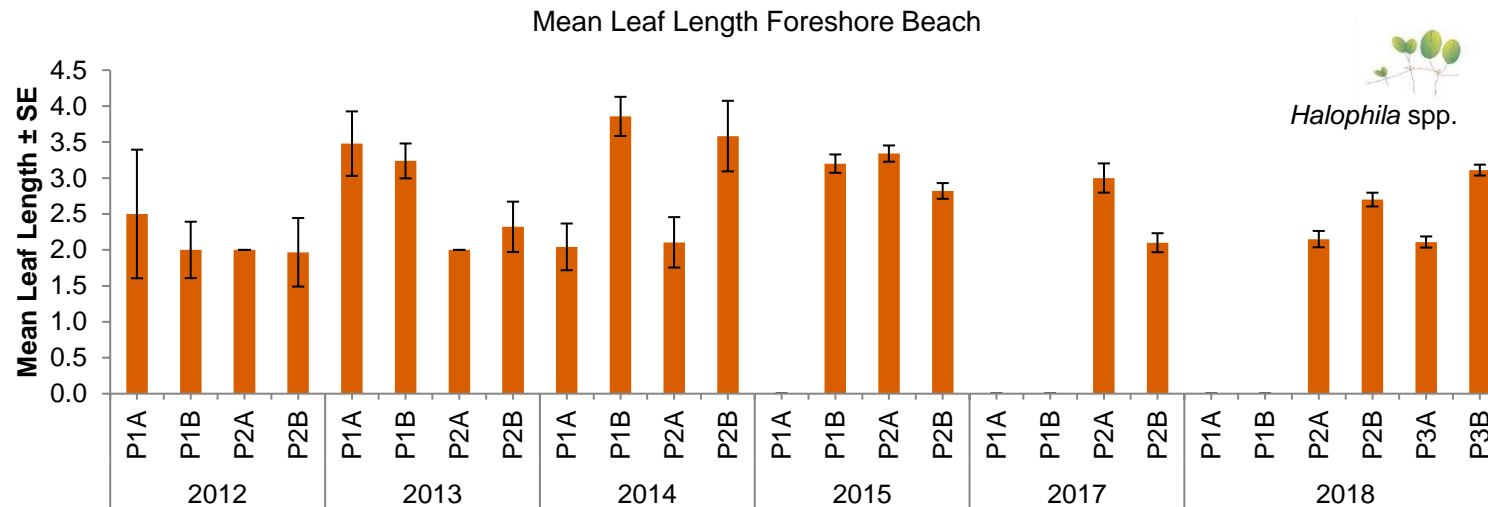


Figure 8 Mean (±SE) leaf length (cm) of *Halophila* spp. sampled at Foreshore Beach morphology monitoring sites during 2012, 2013, 2014, 2015, 2017 and 2018 (see Table 6 for n) Epiphytes

3.4.3 Epiphyte Load

Epiphytes were recorded on all fronds of *Halophila* spp. sampled in the 2018 survey. Epiphyte loads were generally in the moderate range across all sites sampled, varying between 32% and 54% occurrence although high occurrence levels were recorded on 39% of all fronds at site P3A (**Table 7**). Results also indicate a general increase in epiphyte load between 2017 and 2018 surveys at comparable sites which had *Halophila* spp. present in both years. Epiphytes were recorded on fronds of *Z. muelleri* subsp. *capricorni* sampled in Patch 8, although 44% occurred within the 'low' category. Previous surveys where *Z. muelleri* subsp. *capricorni* was present (2013 and 2015) had 100% occurrence of epiphytes in the low category. As this 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 in 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 and 2018 surveys

Species	Epiphyte Load	2013				2014				2015				2017				2018				8		
		% Occurrence		% Occurrence		% Occurrence		% Occurrence		% Occurrence		% Occurrence		% Occurrence		% Occurrence								
Site Code		P1 A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P1 A	P1 B	P2 A	P2 B	P3 A	P3 B	
<i>Z. muelleri</i> subsp. <i>capricorni</i>	L	100								100														44
	M																							4
	H																							0
<i>Halophila</i> spp.	L	46				55		39		64	70	84		100	81					26	12	34	50	
	M	50	43	100	100	26		53	58	28	26	14			12					35	54	48	32	
	H	4	57			19	100	8	42	8	4	2			7					39	34	18	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 all but disappeared prior to the commencement of Port Botany Expansion works has not showed signs of returning to similar 2002 levels over the total monitoring period. 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 beach at that time - although this has not been substantiated.

The first monitoring survey carried out following the completion of port expansion works in 2012 did show an overall increase in seagrass area since the May 2008 pre- expansion works, although this was approximately a third of the cover recorded in 2002. Since 2012, annual monitoring surveys have shown an overall gradual decline through to 2017, with the 2018 survey indicating the first sign of increase since 2014.

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. (in surveys prior to port expansion works), to one characterised by the more ephemeral and pioneering *Halophila* spp. post port expansion. Some small areas of *Z. muelleri* subsp. *capricorni* and *P. australis* have persisted over the course of the study, but have generally shown little increase up until 2018.

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 impact on the environmental factors important for seagrass growth and survival. It is understood that artificial beach nourishment has been undertaken twice post construction, and 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 minimise sediment transport and help stabilise sediments, thus improving water quality and minimising smothering of seagrasses by sediments

4.2 Post Groyne Construction

The first survey after groyne construction, done in 2017, suggested that any benefit from sediment stabilisation on seagrasses was limited, however, given this was completed only 3 months later, this was likely insufficient time for any positive impacts to be detected. Results of the latest 2018 survey are, however, encouraging in that key indicators show a general improvement in seagrass cover and condition since the 2017 survey. Since 2017 mapped area of seagrass beds has increased by 81.2% and there was a 97.4% increase in average seagrass cover in transects. These increases were mostly attributed to *Halophila* spp. although the area of *Z. muelleri* subsp. *capricorni* also more than doubled due to the spread of patch in the south-east that first appeared in 2017. The shoot density of both *Halophila* spp. and *Z. muelleri* subsp. *capricorni* also increased substantially and more than doubled for *Halophila* spp. Results did not show any notable changes in epiphyte cover that would be indicative of nutrient enrichment of impaired water quality.

The total area of *P. australis* at Foreshore Beach has been comparatively small since the start of monitoring, however, the latest 2018 survey has shown a notable decline in one of two remaining patches which is located adjacent to the middle groyne. Divers found only some fronds of *P. australis* around the middle groyne patch and the shoot bases were ~10 cms below the sand, indicating that some of this patch has been lost due to sediment accumulation and subsequent smothering.

These findings suggest that the addition of groynes at Foreshore Beach may have altered conditions such that the growth of *Z. muelleri* subsp. *capricorni* and *Halophila* has been facilitated in certain areas (i.e. between and either side of the ends of the groynes and the south-eastern corner of Foreshore Beach), but that in areas of sediment accumulation very close to the groynes this may have had a burial effect.

The invasive alga *C. taxifolia* has been recorded previously in areas surveyed at Foreshore Beach but not in post-construction surveys to date. The absence of *C. taxifolia* from the study area is favourable for the recovery of seagrass, as *C. taxifolia* is highly competitive and its absence removes further challenges to

successful recolonisation. As the presence of *C. taxifolia* may vary temporally (NSW DPI 2011), it still has potential to establish at Foreshore Beach.

5 Conclusions and Recommendations

Results of pre- and post-construction monitoring over the past 15 years at Foreshore Beach have identified great variability in seagrass distribution and density and changes to species composition. Importantly, the greatest changes to seagrass at Foreshore Beach occurred prior to construction for the Port Botany Expansion, indicating changes were due to other factors. Although monitoring data for the PEHEP was collected in a consistent and quality controlled manner from 2012 to 2017, there have been some external factors that have confounded interpretation of trends in seagrass distribution and condition at Foreshore Beach. Prior to 2016, erosion at Foreshore Beach exacerbated by beach nourishment probably mobilised sediment onto the beds of seagrass. However it is noted that this beach nourishment was 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 sediment to be mobilised across the seagrass habitat. Results of the latest 2018 survey suggest that groyne construction has largely had a positive effect on the distribution and condition of *Halophila* spp. and *Z. muelleri* subsp. *capricorni* but that sediment accumulated to the north-eastern side of the middle groyne may have resulted in the smothering of *P. australis* which is already limited in its distribution at Foreshore Beach.

An increase in the new, high density patch of *Z. muelleri* subsp. *capricorni* in the south-eastern section of the site (initially identified in 2017) presents a possibility that seagrass beds may be recovering and colonising new areas at Foreshore Beach following the stabilisation of sediments from the installation of the groynes. Two further monitoring surveys are planned to take place in Autumn 2019 and 2020. The results of these surveys will assist in understanding trends or potential limitations for long-term establishment and persistence of seagrass in this area.

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

Given the decrease in condition of *P. australis* in the last remaining patch at Foreshore Beach, several options were considered to minimise further losses. This included the possibility of transplanting remaining plants elsewhere in Foreshore Beach, constructing a barrier around the plants and / or regular removal of accumulated sediment. It was, however, concluded that uprooting and transplantation could lead to mortality and that leaving plants in-situ would be preferable given their apparent resilience. Cardno's coastal process engineers were also consulted in regard to the use of barriers or removal of accumulated sediments as alternative safeguards, however, these options were not considered to be feasible or effective in the dynamic coastal environment.

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APPENDIX A
STATISTICAL ANALYSIS

Appendix A: 2018 Statistical Analysis

PERMANOVA tests and Pairwise comparisons. RED = Redundant term. Significant difference $p < 0.05$ in bold.

Permanova Shoot Density (*Halophila* spp.)

Factors

Name	Abbrev.	Type	Levels
Survey	Su	Random	6
Site	Si	Random	4

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Su	5	9841.1	1968.2	1.7161	0.152	9943
Si	3	5374.6	1791.5	1.562	0.2042	9948
SuxSi**	13	14910	1146.9	4.133	0.0002	9899
Res	88	24421	277.51			
Total	109	54951				

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	0.009	48
Autumn 2012, Autumn 2014	2.1141	0.0882	14
Autumn 2012, Autumn 2015	3.5	0.0451	6
Autumn 2012, Autumn 2017	3.5	0.0465	6
Autumn 2013, Autumn 2014	6.7943	0.0081	46
Autumn 2013, Autumn 2015	9.2113	0.0091	12
Autumn 2013, Autumn 2017	9.2113	0.0063	12
Autumn 2014, Autumn 2015	5.6054	0.0072	13
Autumn 2014, Autumn 2017	5.6054	0.0079	13
Autumn 2015, Autumn 2017	Denominator is 0		

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	0.13465	0.9312	22
Autumn 2012, Autumn 2014	0.56358	0.8849	6
Autumn 2012, Autumn 2015	1.016	0.3607	30
Autumn 2012, Autumn 2017	1.1793	0.4431	2
Autumn 2013, Autumn 2014	0.68543	0.5402	18
Autumn 2013, Autumn 2015	1.9846	0.1053	24
Autumn 2013, Autumn 2017	1.9511	0.0461	6
Autumn 2014, Autumn 2015	3.2481	0.0332	23
Autumn 2014, Autumn 2017	1.3988	0.4432	2
Autumn 2015, Autumn 2017	7.1286	0.008	15

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	0.76277	0.7158	4
Autumn 2012, Autumn 2014	2.4042	0.0558	10

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Autumn 2012, Autumn 2015	6.2755	0.0081	23
Autumn 2012, Autumn 2017	2.4461	0.0334	16
Autumn 2012, Autumn 2018	2.4952	0.0244	22
Autumn 2013, Autumn 2014	3.8025	0.0077	9
Autumn 2013, Autumn 2015	7.6853	0.0087	15
Autumn 2013, Autumn 2017	2.9025	0.0172	14
Autumn 2013, Autumn 2018	2.8432	0.0065	20
Autumn 2014, Autumn 2015	4.3259	0.0191	20
Autumn 2014, Autumn 2017	1.1763	0.3039	16
Autumn 2014, Autumn 2018	1.4525	0.2668	16
Autumn 2015, Autumn 2017	1.6274	0.1455	19
Autumn 2015, Autumn 2018	0.91541	0.386	21
Autumn 2017, Autumn 2018	0.39752	0.7277	22

Within level 'P2B' of factor 'Site'

Groups	t	P (perm)	Unique perms
Autumn 2012, Autumn 2013	2.1068	0.0739	41
Autumn 2012, Autumn 2014	0.50918	0.6788	18
Autumn 2012, Autumn 2015	0.79282	0.4635	16
Autumn 2012, Autumn 2017	0.72929	0.5276	18
Autumn 2012, Autumn 2018	5.324	0.0074	38
Autumn 2013, Autumn 2014	2.0065	0.1131	53
Autumn 2013, Autumn 2015	2.0452	0.1057	57
Autumn 2013, Autumn 2017	2.0439	0.0982	87
Autumn 2013, Autumn 2018	1.4151	0.2439	81
Autumn 2014, Autumn 2015	0.11986	0.9664	24
Autumn 2014, Autumn 2017	0.11664	0.9367	28
Autumn 2014, Autumn 2018	3.3473	0.0232	45
Autumn 2015, Autumn 2017	1.3463E-8	1	11
Autumn 2015, Autumn 2018	5.6786	0.0097	40
Autumn 2017, Autumn 2018	5.3987	0.0081	42

Permanova Leaf Length (*Halophila* spp.)

Factors

Name	Abbrev.	Type	Levels
Survey	Su	Random	6
Site	Si	Random	4

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P (perm)	Unique perms
Su	5	3313.6	662.71	3.6703	0.0312	9966
Si	3	362.71	120.9	0.6696	0.6002	9967
SuxSi**	13	2347.3	180.56	116.14	0.0001	9925
Res	1078	1675.9	1.5547			
Total	1099	7708.1				

Pair Wise Leaf Length (*Halophila* spp.)

Within level 'P1A' of factor 'Site'

Groups	t	P (perm)	Unique perms
Autumn 2012, Autumn 2013	12.063	0.0001	36
Autumn 2012, Autumn 2014	8.5363	0.0001	22
Autumn 2012, Autumn 2015	2.6458	0.005	6
Autumn 2012, Autumn 2017	2.6458	0.0052	6
Autumn 2013, Autumn 2014	6.4105	0.0001	22
Autumn 2013, Autumn 2015	18.169	0.0001	38

Autumn 2013, Autumn 2017	18.169	0.0001	35
Autumn 2014, Autumn 2015	20.411	0.0001	21
Autumn 2014, Autumn 2017	20.411	0.0001	20
Autumn 2015, Autumn 2017	Denominator is 0		

Within level 'P1B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	2.9862	0.0037	26
Autumn 2012, Autumn 2014	1.8292	0.0843	27
Autumn 2012, Autumn 2015	20.942	0.0001	69
Autumn 2012, Autumn 2017	4.1636	0.0001	14
Autumn 2013, Autumn 2014	0.82067	0.4485	33
Autumn 2013, Autumn 2015	16.287	0.0001	65
Autumn 2013, Autumn 2017	5.8698	0.0001	27
Autumn 2014, Autumn 2015	16.521	0.0001	69
Autumn 2014, Autumn 2017	4.3122	0.0001	12
Autumn 2015, Autumn 2017	24.56	0.0001	75

Within level 'P2A' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	0.4547	1	3
Autumn 2012, Autumn 2014	9.3581	0.0001	21
Autumn 2012, Autumn 2015	30.312	0.0001	75
Autumn 2012, Autumn 2017	9.5958	0.0001	269
Autumn 2012, May 2018	15.807	0.0001	44
Autumn 2013, Autumn 2014	9.9064	0.0001	22
Autumn 2013, Autumn 2015	30.797	0.0001	75
Autumn 2013, Autumn 2017	9.8831	0.0001	262
Autumn 2013, May 2018	16.889	0.0001	44
Autumn 2014, Autumn 2015	22.234	0.0001	65
Autumn 2014, Autumn 2017	3.1295	0.003	231
Autumn 2014, May 2018	3.0605	0.0028	35
Autumn 2015, Autumn 2017	16.255	0.0001	492
Autumn 2015, May 2018	21.453	0.0001	112
Autumn 2017, May 2018	1.193	0.246	202

Within level 'P2B' of factor 'Site'

Groups	t	P(perm)	Unique perms
Autumn 2012, Autumn 2013	2.6495	0.0101	79
Autumn 2012, Autumn 2014	1.7273	0.1023	30
Autumn 2012, Autumn 2015	17.629	0.0001	59
Autumn 2012, Autumn 2017	2.8583	0.0066	41
Autumn 2012, May 2018	8.3145	0.0001	21
Autumn 2013, Autumn 2014	0.14066	0.8949	104
Autumn 2013, Autumn 2015	15.795	0.0001	190
Autumn 2013, Autumn 2017	7.6124E-2	0.9654	72
Autumn 2013, May 2018	5.1114	0.0001	71
Autumn 2014, Autumn 2015	13.098	0.0001	60
Autumn 2014, Autumn 2017	0.1964	0.8682	59
Autumn 2014, May 2018	3.4081	0.0015	29
Autumn 2015, Autumn 2017	16.104	0.0001	107
Autumn 2015, May 2018	13.944	0.0001	49
Autumn 2017, May 2018	5.4013	0.0001	36