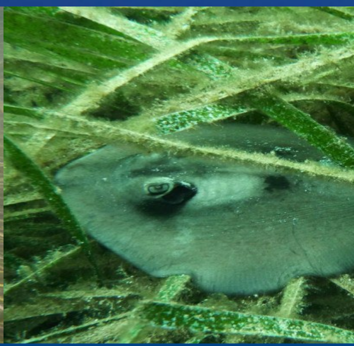
Edith Cowan University
Centre for Marine Ecosystems Research

Keep Watch Seagrass Monitoring 2022 Report for GeoCatch

Kathryn McMahon and Ankje Frouws





Keep Watch Seagrass Monitoring, 2022. Report to GeoCatch

Kathryn McMahon and Ankje Frouws

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Keep Watch Seagrass Monitoring

Annual Report 2022

Investigator: Kathryn McMahon and Ankje Frouws

A project funded by GeoCatch and Water Corporation with in-kind support from the Department of Biodiversity, Conservation and Attractions.

June 2022

1 Executive Summary

1.1 Introduction

This report summarises eleven years of data (Feb 2012 - Feb 2022) from the Keep Watch Seagrass Monitoring Program in Geographe Bay. The program was developed in 2011 in collaboration with GeoCatch, Edith Cowan University (ECU), Department of Water and Environmental Regulation, Department of Biodiversity, Conservation and Attractions, and the South West Catchment Council and reviewed in 2021. Since 2016 annual seagrass monitoring has been carried out by ECU with in-kind support from the Department of Biodiversity, Conservation and Attractions and funding from the Water Corporation.

The Keep Watch seagrass monitoring program was initiated due to concerns for the health of seagrass meadows in Geographe Bay from predicted increases in catchment nutrients. The aim of the program is to monitor near shore seagrass meadows annually to detect any change in seagrass health. Seagrass shoot density of the dominant seagrass species *Posidonia sinuosa* is monitored at seven sites across Geographe Bay as an indicator of seagrass health. Observations of algal epiphyte cover and seagrass leaf nutrient content and nitrogen isotope signals are also measured to help interpret any changes.

Three management triggers have been established for Geographe Bay to detect changes in shoot density outside normal annual variation. Comparison of shoot densities with temperate seagrass meadows in other areas in Western Australia are also used as a comparison to assess inter-annual and site variations.

1.2 Key findings 2022

Key finding 1

Seagrass meadows in Geographe Bay remain healthy with seagrass shoot densities high at all sites. Shoot densities increased at all sites, except Forrest Beach, from 2021. Highest shoot densitists were recorded at Dunsbrough and Buayanup with lowest at the Vasse Diversion and Port Geographe sites. All sites recorded shoot densities above the maximum average shoot densities for similar seagrass meadows in Shoalwater and Jurian Bay. No managagement triggers were breached in 2022.

Key finding 2

The ephiphyte cover remained consistent with previous years with variations between sites with cover ranging from very low to high. The dominant epiphyte types remains microalgal accumulations which are not the type commonly associated with nutrient enrichment. There were no obvious impacts to seagrass condition from epiphyte cover.

Key finding 3

Nutrient content of seagrasses in Geographe Bay continues to be low with signs of higher exposure at Capel compared to other sites. This was confirmed by both seagrass and macroalgal tissue nutrient content. The main sources of nitrogen for seagrass at most sites is likely to be from fixation of atmospheric nitrogen and/or agricultural fertilisers. The higher nitrogen isotope signal at Capel suggests that nitrogen derived from animal wastes, septic tanks or from natural vegetation is also a main source. There is no evidence that nitrogen derived from treated sewerage is a major source of nitrogen for Geographe Bay seagrasses.

1.3 Recommendations

These recommendations are based on the findings from the 2022 Keep Watch monitoring survey.

Recommendation 1

Continue monitoring seagrass health based on the Keep Watch Monitoring protocol including the quality control in the field and laboratory. This program is the only approach in place at present assessing potential impacts in the marine environment, linking the land to the sea.

Recommendation 2

Continue monitoring one species of macroalgae at Capel and at least one 1-2 others sites. Unlike the seagrass samples, macroalgae indicators suggest higher phosphorus exposure at Capel compared to other sites.

2 Introduction

This document is produced for GeoCatch by Kathryn McMahon and Ankje Frouws from Edith Cowan University. It reports on the Keep Watch seagrass monitoring survey that was undertaken in February 2022 and compares to data from the 2012-2021 surveys. The objective for the Keep Watch program is to undertake long-term, cost-effective seagrass monitoring for Geographe Bay to monitor the effects of water quality, particularly catchment nutrients on seagrass distribution and health.

This year the program was funded through collaborative sponsorship from the Water Corporation and in-kind support from the Department of Biodiversity, Conservation and Attractions (DBCA). The aim of this program is to assess seagrass health by examining changes over time. There are three triggers that have been developed to assess change (see 3.1.3 for summary of triggers). This report includes data on two seagrass species (*Posidonia sinuosa* and *Amphibolis antactica*) but the program mostly focuses on *P. sinuosa* shoot density and leaf tissue nutrients (C, N, P and N isotopes) from seven sites with leaf tissue nutrient data for *A. antarctica* seagrass from three sites. Based on the 10 year review workshop held in Busselton on 17th November 2021 this year samples of macroalgae have also been collected at Capel and Dunsborough for nutrient and isotope analysis. This is to explore the potential for incorporating algae into the monitoring program as there were concerns raised in the review that macroalgae cover was increasing at Capel. All raw data is included in the appendix to this report, and has been submitted to GeoCatch as a digital file.

3 Methods for Keep Watch – Seagrass health monitoring program

3.1 Seagrass monitoring

3.1.1 Field program

The "Keep Watch" annual seagrass monitoring program is based on the methods recommended by McMahon (2012) and reviewed and modified in 2021. Eight seagrass sites were monitored, seven for *P. sinuosa* health (Dunsborough to Forrest Beach) and four for *A. antarctica* nutrient content (Table 1, Figure 1). These were chosen to cover the spatial range of *P. sinuosa* meadows in Geographe Bay, and areas associated with a variety of catchments with different known surface water nutrient inputs. They range from 4-5 m depth. All sites, except for Capel have *P. sinuosa* meadows. Sampling occurred from 21st to the 24th February 2022. At Capel (8) there are high relief rocky reefs surrounded by bare sand. On the reef there are patches of *A. antarctica* seagrass that were collected for nutrient analysis in 2m depth. *A. antarctica* was collected at Vasse Diversion Drain (3) and Forrest Beach (7) sites as a comparison to Capel (8). This year due to the reduced abundance of *Amphibolis* at Busselton Jetty (4) from the dieback of *A. antarctica* in 2017 and no subsequent recovery, no samples were collected here.

Table 1: Details for eight Keep Watch sites, seven in *Posidonia sinuosa* meadows (1-7) and one in rocky reef with *Amphibolis antarctica* patches (8) in Geographe Bay. Coordinates are decimal degrees based on the WGS84 grid system. The replicate number was reduced this year due to removal of some data due to quality control issues.

Site Name & #	Coordinates	Depth (m)	Date	Seagrass species assessed	Macroalgal species assessed
1. Dunsborough	S 33.61654°, E 115.12865°	4	22/2/2022	Ps	Padina, Dictyota
2. Buayanup	S 33.65233°, E 115.24840°	4	22/2/2022	Ps	
3. Vasse Diversion Drain	S 33.64746°, E 115.32379°	4.5	22/2/2022	Ps, Aa	
4. Busselton Jetty	S 33.63896°, E 115.34315°	4.5	21/2/2022	Ps	
5. Port Geographe	S 33.62846°, E 115.38240°	4.5	21/2/2022	Ps	
6. Vasse-Wonnerup	S 33.60188°, E 115.42345°	5	22/2/2022	Ps	
7. Forrest Beach	S 33.57295°, E 115.44908°	5	23/2/2022	Ps, Aa	
8. Capel	S 33.51394°, E 115.51508°	2	21/2/2022	Aa	Padina, Dictyota

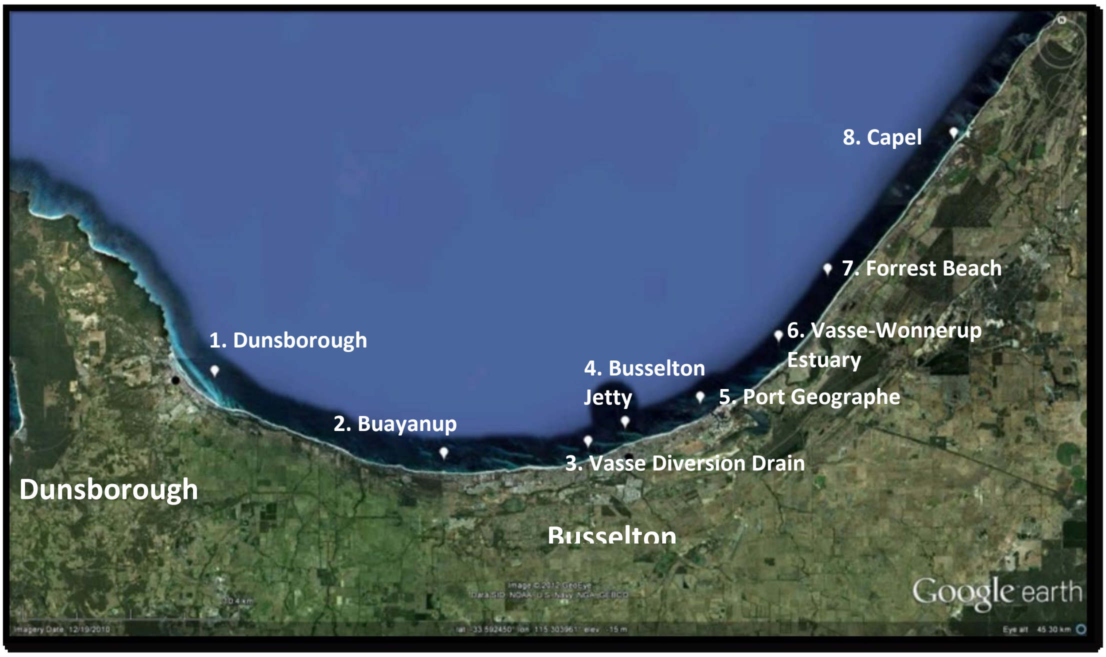


***Figure 1**: Map of Geographe Bay, showing the location of the 8 seagrass sampling sites (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach and 8. Capel).*

Each seagrass site was located at least 30 m from the edge of the meadow and the center of the 50 m diameter site marked with a permanent star picket with a plastic cap (Figure 2). A site label was attached to the star picket. The exact locations were determined with a differential GPS (using the WSG 84 grid system), on the water surface, directly above the permanent marker.

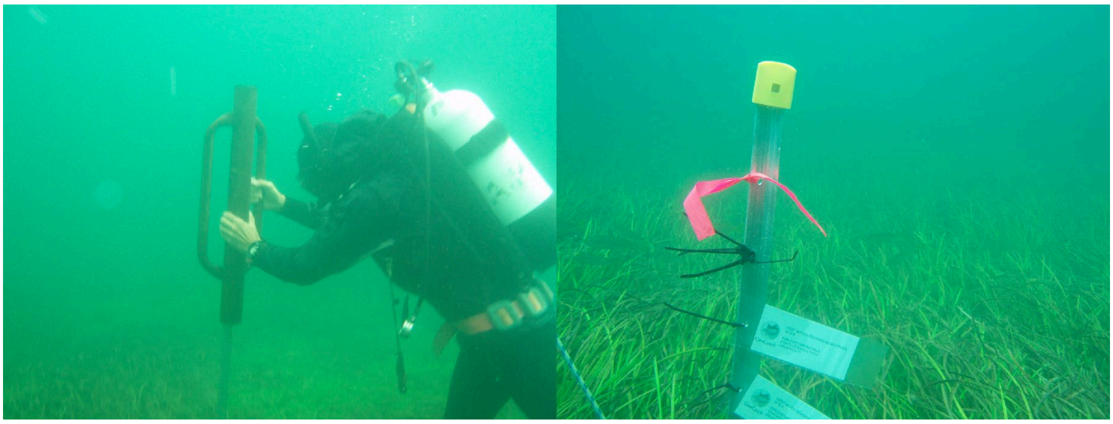


Figure 2: *Left: Banging in permanent marker with pole driver. Right: Star picket with cap and plastic coated site label, indicating center of 50 m diameter Keep Watch seagrass site.*

At each site *P. sinuosa* shoot density was counted in 30 0.2 x 0.2 m quadrats. Only shoots that originated in the quadrat were counted. Seedlings of *P. sinuosa* were also counted; these were identified by the small size of the leaves and the seed that was still attached to the seedling. As it is predicted that there can be high mortality of seedlings, these counts were not included in the shoot density assessment. The position of each quadrat was located randomly using a transect tape swum out on a pre-determined bearing using a compass and the quadrat placed at the pre-determined distance along the transect (Figure 3, See Appendix 1 for the bearing and distance along each transect that the quadrats were positioned). If there was a patch of a different species of seagrass such as *Amphibolis antarctica* or *A. griffithii*, or a blow-out without seagrass, then the quadrat was moved to the next closest point along the transect in the *P. sinuosa* meadow. The quadrats were stabilised by securing to the sediment with tent pegs, to ensure they did not move during counting.

Figure 3*: Left: Determining bearing of transect with compass. Right: Counting P. sinuosa shoots in a quadrat.*

A quality assurance check was carried with all divers before official counts began. Each counter counted a quadrat twice, and this was done with three different quadrats. This was repeated until there was less than a 5% error with counting, i.e. a maximum difference of 1-3 shoots. Then official counting began.

In addition, a photograph of the seagrass meadow and a video in a circle around the star-picket, 5 m distance away from the star-picket was also taken at each site. As well as the cover of algal epiphytes recorded as Very Low, Low, Moderate, High, Very High (See photo-guide for visual representation of these classifications, Figure 4), and the dominant or co-dominant type of algal epiphytes at each site were recorded from observations of the seagrass leaves, based on the following categories: Filamentous algae; Encrusting algae; Microalgal accumulations; and Other epiphytic algae (any type of algae that is not as above such as erect, branched, foliose, leathery or jointed calcareous). A photograph of the dominant epiphytic algae was also taken.

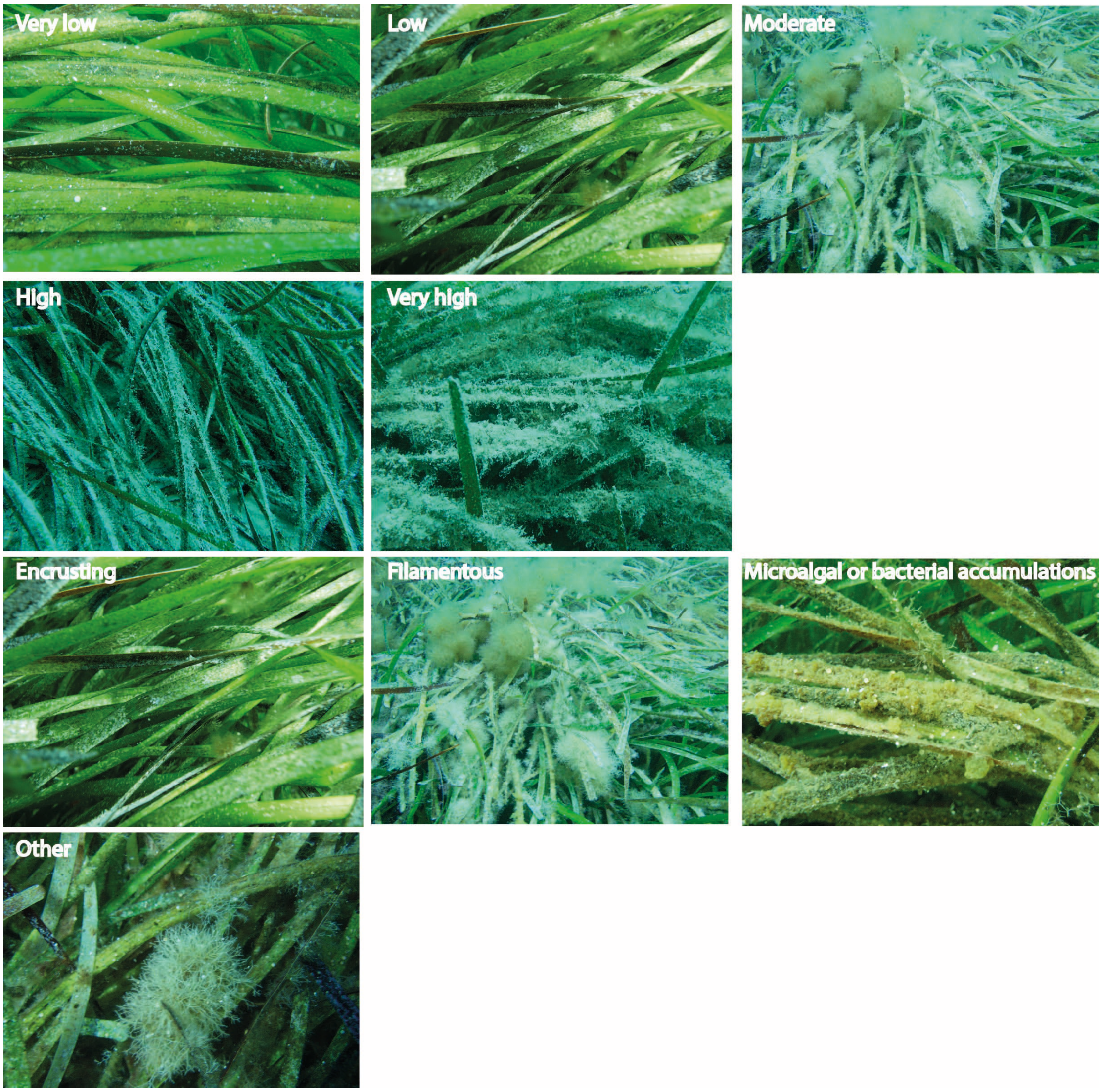


Figure 4: *Classification of epiphytic algal cover and type.*

Finally, the following points were noted: if other seagrass species were present at the site; if there were any bare patches of sand within the meadow, and if there was rhizome in the sand, indicating a loss of shoots from the area. Movement of sand bars through the seagrass meadow is common in this area, so it is likely that these will be noted; and any signs of anchor damage in the meadow.

Also three samples of *P. sinuosa* seagrass shoots were collected for TN, TP and TC as well as nitrogen stable isotope analysis after the counting was completed. Each sample was collected randomly in the meadow, just outside the 50 m diameter of the site and consisted of 5 shoots. These were placed in separate plastic bags and frozen until processed. Three samples of *A. antarctica* stems and leaves were collected at Capel, Forrest Beach, Busselton Jetty and Vasse Diversion sites for the same type of nutrient analysis. A range of algal samples were collected at Capel, and then samples of the sample species or morphotype were collected if possible at Dunsborough and Forrest Beach. Unfortunately, no similar samples were observed at Forrect Beach so no collections occurred. There were two species that overlapped at each site, *Padina* and a dichotomously branching brown algae, *Dictyota*. Both these species were processed.

At each site the Secchi disk depth (m) was recorded from the boat, and temperature was only recorded at a subset of sites due to malfunctioning of the water quality probe. In addition temperature loggers were collected and re-installed at the seven *Posidonia* sites to collect local temperature data. These are provided in-kind from ECU.

Field work was carried out by Kathryn McMahon (KM) and Rob Czarnik (RC) from ECU with Sahira Bell (SB), Eden Baxter (EB) and Ian Anderson (IA) from Department of Biodiversity, Conservation and Attractions. Samples were processed and data analysed by Ankje Frouws. This year the boat was hired from O2 Marine as the Department of Biodiversity, Conservation and Attractions currently does not have a boat appropriate for diving activities. The monitoring program was funded through sponsorship by Water Corporation and in-kind support of Department of Biodiversity, Conservation and Attractions staff.

3.1.2 Laboratory processing

In the laboratory the three seagrass shoot samples were measured for total length and width, just above the sheath. Then all algal epiphytes from both the seagrass and algal samples were removed by gently scraping, and the leaves placed in the oven at 60°C for 24 hours or until dry, then ground into a fine powder with a Ball Mill grinder. This material was then analysed for total C, N and $\delta^{15}N$ (external error of analysis 1 standard deviation) at ECU using a continuous flow Thermo Scientific™ EA IsoLink™ IRMS system consisting of a Flash IRMS Elemental Analyzer, Delta V Advantage IRMS and Conflow IV Univeral Interface. Total phosphorus (<0.05 $mg.P.g^{-1}$) was analysed at ECU by acid digest followed by ICP-OES, the same method that has previously been used.

As presented in 2021, the laboratory that performed the C, N and $\delta^{15}N$ analysis changed in 2020 from UWA to ECU and there was a slight offset between ECU and UWA laboratories. This offset has been applied again this year to the C and N data. In this report the 2020 to 2022 data was modified as follows N% [$y=1.063x - 0.5653$], δN [$y=1.0725x - 0.55824$], δC [$y=0.9846x - 2.1902$] and C% [$y=0.4568x + 24.225$] where x is the ECU laboratory result for each respective variable.

3.1.3 Trigger assessment

To assess change over time, and to keep watch on the health of the seagrass, three triggers proposed by McMahon (2012) and agreed upon by GeoCatch were used. If these thresholds are triggered it indicates a potential issue with seagrass health at a particular site that warrants further investigation. These trigger values are for shoot density. All other information collected i.e. seagrass nutrient concentration, water quality and algal cover are complimentary information to help interpret any changes observed in the seagrass shoot density. The trigger value will be triggered as follows:

Trigger 1:

If there is a > 50% reduction in shoot density at a particular site compared to the previous year (Need 2 years of data to assess this, always compare the current year with the previous year).

Trigger 2:

If there is > 20% reduction in shoot density at a particular site compared to the previous year, two years in a row (Need 3 years of data to assess this).

Trigger 3:

If there is a significant trend of a reduction in shoot density at a particular site over all time periods, as determined by trend analysis (Makesens Mann-Kendall trend statistic, need at least 5 years of data to assess this).

4 Results

4.1 Shoot density

Shoot density varied from a site average of 1031-1567 shoots m^{-2} across the seven sites (Figure 5). Dunsborough (1567 shoots m^{-2}) and Buayanup (1465 shoots m^{-2}) continue to have the highest shoot density with Vasse Diversion (1031 shoots m^{-2}) and Port Geographe (1045 shoots m^{-2}) the lowest.The remaining sites ranged between 1118-1232 shoots m^{-2}. All raw data is in Appendix 2.

Last year five of the seven sites declined by 8-29%, with two, Vasse Diversion and Forrest Beach declining by more than 20%. This year the pattern was reversed with five of the sites increasing in shoot density from 1-18%. Both sites that had the greatest decline from 2020-2021 had the largest increase this year compared to last year (11-18%). Since the first year of monitoring there has been net increase at all sites (2-30%) with the exception of Forrest Beach where a 7% decline has occurred.

Compared to other seagrass meadows in the state, all monitoring sites in Geographe Bay are well above the minimum average site shoot density. For the first year, all sites are also above the maximum shoot density (Figure 5, Data Courtesy of DBCA from equivalent monitoring programs in the the Shoalwater Bay and Jurien Bay Marine Parks). This is a reflection that there is a trend of shoot density decline in regions further north.

P. sinuosa average shoot length ranged from a minimum of 44 cm at Port Geographe to a maximum of 68cm at Vasse Diversion and a range in average width of 5.27-8.00 mm (Appendix 3).

***Table 2**: Change assessment based on Trigger 1 and 2. There is a concern with seagrass health when there is a 50% decline in shoot density from one year to the next (Trigger 1) or when there is more than a 20% decline two years in a row. A negative number indicates a decline in shoot density and orange shading is a decline of more than 20%.*

	% change in shoot density										
Site Name & #	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**20-21**	**21-22**	**12-22**
1. Dunsborough	3	-18	7	9	-3	-10	5	8	11	-7	2
2. Buayanup	11	-24	20	-7	2	-5	15	-11	6	11	11
3. Vasse Diversion	6	-8	0	-15	19	12	8	17	-23	11	20
4. Busselton Jetty	0	22	-4	1	-1	-5	23	-6	-8	9	30
5. Port Geographe	17	-7	12	-6	-23	41	28	-19	-8	-10	7
6. Vasse-Wonnerup	19	13	-4	-3	4	-5	13	-3	-14	1	19
7. Forrest Beach	16	-23	2	5	-3	8	0	11	-29	18	-7

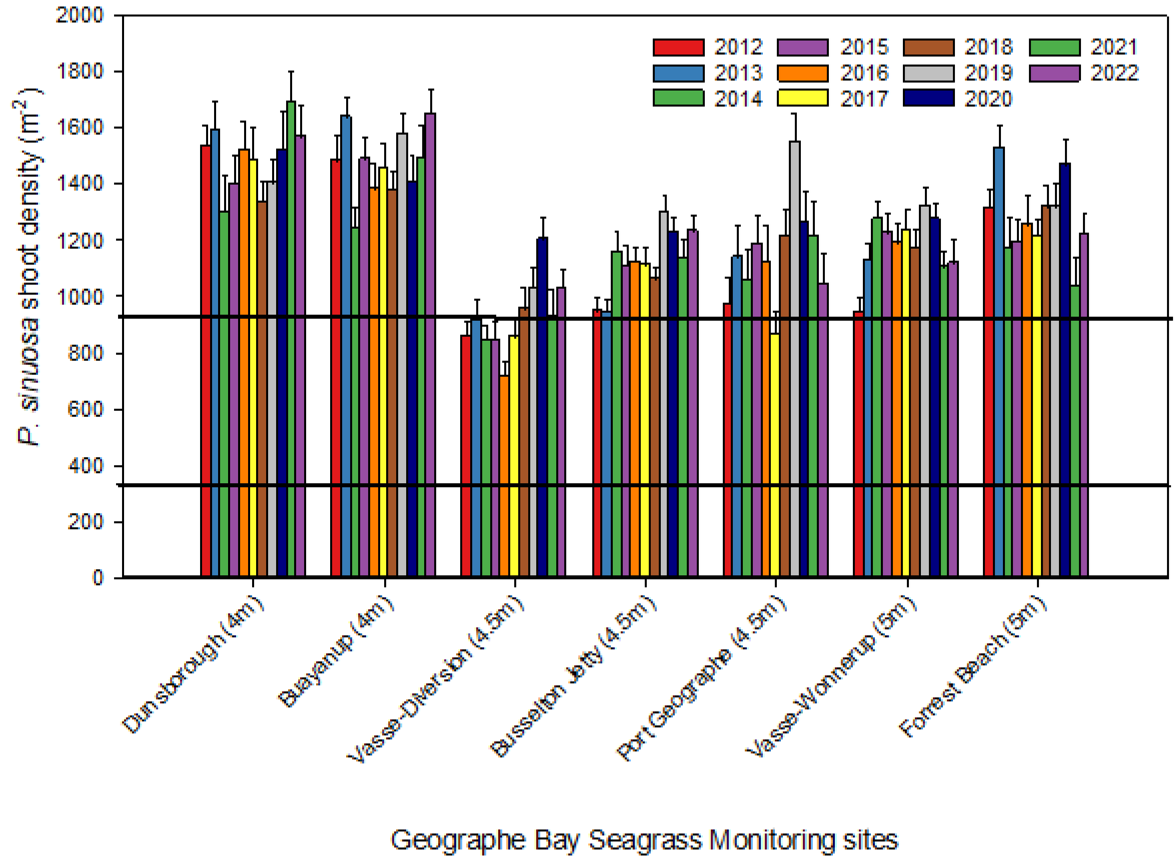


***Figure 5**: Shoot density (average m^{-2} ± se) at the seven Keep Watch seagrass monitoring sites with* P. sinuosa *meadows in January or February 2012-2022. Black lines indicate the minimum and maximum site averages from the reference sites at 3-5 m in Shoalwater Bay and Jurien Bay Marine Parks from 2022 (data courtesy of DBCA, 2022).*

4.2 Trigger assessment

4.2.1 Trigger 1

As a decline of 50% was not detected at any of the seven sites, this threshold was not triggered (Table 2, % change 2021-2022).

4.2.2 Trigger 2

As there were no declines of 20% or more over two consecutive years this threshold was not triggered (Table 2, % change 2020-2021 & 2021-2022).

4.2.3 Trigger 3

This threshold was not triggered as no sites showed a significant decline over time. Interestingly, two of the seven sites, Vasse Diversion and Busselton Jetty showed a significant, positive, linear trend over the eleven years, indicating increases in shoot density over this time period (Table 3).

***Table 3**: Mann-Kendall Trend statistic to assess if there has been a significant decline over time in shoot density from 2012-2022.*

Site Name & #	Significance ($p<0.05$)	Overall slope	R^2
1. Dunsborough	ns	+ve	7%
2. Buayanup	ns	+ve	5%
3. Vasse Diversion	significant	+ve	37%
4. Busselton Jetty	significant	+ve	55%
5. Port Geographe	ns	+ve	10%
6. Vasse-Wonnerup	ns	+ve	7%
7. Forrest Beach	ns	-ve	5%

4.3 Epiphytes

This year epiphyte cover remained relatively stable at the central sites (Buayanup to Port Geographe), it increased from low to moderate cover at Dunsborough and decreased by one cover category at Vasse Wonnerup and Forrest Beach. (Table 4). The levels and spatial patterns are very similar to what has been observed since 2020. The type of epiphyte cover was very consistent amongst the five central sites, with microalgae being dominant. At Dunsborough fine branching brown algae such as *Dictyota* was the dominat type and at Forrest Beach it was encrusting algae. Other epiphytes observed were forams (Figure 6, Table 4). These are not the species of epiphyte expected to dominate with nutrient enrichment.

Table 4: *Algal epiphyte cover at the Keep Watch seagrass monitoring sites, 2012-2022. Algal cover categories were Very low, Low, Moderate, High and Very High. Algal types were F=filamentous, E= encrusting, M=microalgal aggregations and O=other. If the category is capitalised it means it is dominant, lowercase indicates present but not dominant.*

Site	**Algal cover**										
	-12	**-13**	**-14**	**-15**	**-16**	**-17**	**-18**	**-19**	**-20**	**-21**	**-22**
1. Dunsborough	M	L	M	M	L	L	M	M	M	L	M
2. Buayanup	M	L	M	M	H	H	M	VL	H	H	H
3. Vasse Diversion Drain	L	M	H	H	H	H	H	L	H	H	H
4. Busselton Jetty	L	L	H	H	M	M	M	L	H	H	H
5. Port Geographe	L	VL	L	L	M	M	M	L	M	M	M
6. Vasse-Wonnerup	L	VL	L	M	L	L	L	VL	L	M	L
7. Forrest Beach	L	VL	L	L	L	VL	L	VL	L	L	VL
	Algal Type										
	-12	**-13**	**-14**	**-15**	**-16**	**-17**	**-18**	**-19**	**-20**	**-21**	**-22**
1. Dunsborough	O,f,m	F,O	O	O,m	O	O,e,m	O,m	O,m	O,m	O	O,m
2. Buayanup	M,o	E,O	M,o	M,o	M , o	M,e,o	M,o	O,m	M,o,e	M,o	M
3. Vasse Diversion Drain	M,o	E,O	M,o	M,o	M , o	M,o	M,o	O,m	M,o,e,f	M	M,o
4. Busselton Jetty	M,o	O	M	M,f	O,e,m	M,o,e	O,M	O,m	O,m,e,f	M	M,o
5. Port Geographe	E, o	E,M	M,e	M,f	O, f	M,o,e	O,M	M	M,o	M,o	M,o
6. Vasse-Wonnerup	E, o, m	E,O	M,f	O	E,o,m	E,m	O,M	O	O,e	M	M
7. Forrest Beach	E, M,o	F,E	M,f	O,e	E,o	E,o	O,e	O	E,m,o	O	E,m

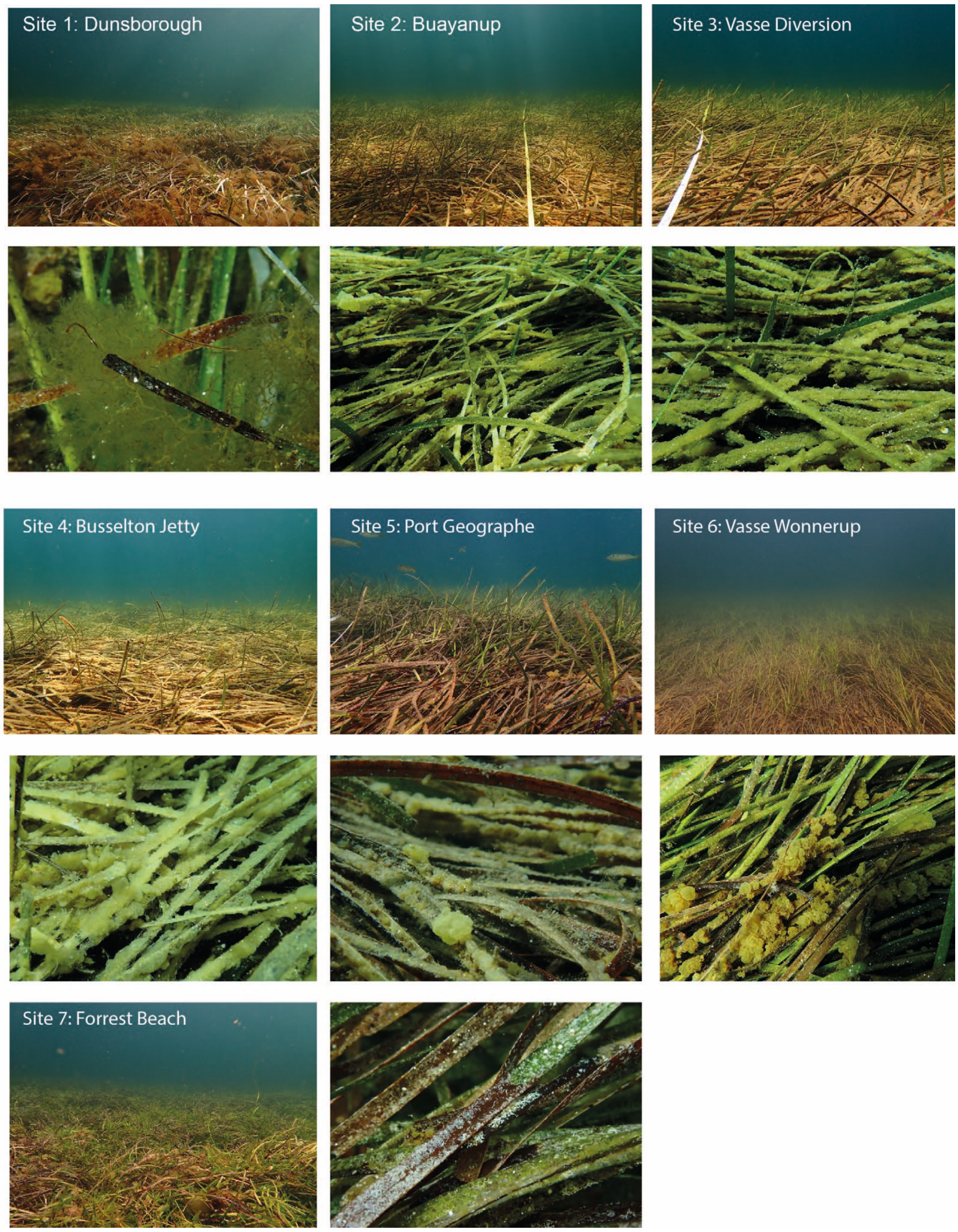


***Figure 6**: Pictures of seagrass meadow and the dominant algal epiphytes at each* P. sinuosa *site. (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach)*

4.4 Other observations

A. antarctica was observed at all sites except Buayanup and Vasse Wonnerup and *A. griffithii* was also growing at Forrest Beach and Capel. Seedlings were only observed at Busselton Jetty this year. No anchor damage was observed at any site and blowouts remain at the Dunsborough site, most likely from water movement. Bare or sparse patches were noted at Vasse Diversion Drain, Busselton Jetty and Port Geographe indicating historical and some small scale recent shoot loss.

4.5 Nutrient content

The nitrogen content of *P. sinuosa* leaves ranged from 0.5-0.9% N dry weight (DW), very similar to the range observed in 2021 (Figure 7). Once again, the nitrogen content of *A. antarctica* leaves was slightly higher, ranging from 0.5-1.2% N DW, and the highest concentration was at Capel (2.0-2.3x higher than the other sites).

The phosphorus content of *P. sinuosa* leaves in 2022 ranged from 0.12-0.15% P DW (Figure 7). All sites were slightly less than last year on average and at some sites there was a high variability between samples. For *A. antarctica* leaves, the phosphorus content ranged was lower than last year from 0.07-0.08% DW (Figure 8). There was little variation among sites, but there was more variability at Capel. All raw data is in Appendix 5.

The nitrogen and phosphorus concentrations continue to be in the range that has been observed in Geographe Bay in the past and these levels are not considered high (Table 5).

***Table 5**: Comparison of shoot tissue nutrient concentrations and δ^{15}N values of P. sinuosa and A. antarctica leaves in Geographe Bay. Data are expressed as averages of all sites from the study with the range of observations in brackets, min-max.*

Date collected	**Study**	***P. sinuosa***			***A. antarctica***		
		TN (% DW)	**TP (% DW)**	δ^{15}N	**TN (% DW)**	**TP (% DW)**	δ^{15}N
1994/95 Apr, Jan	(McMahon & Walk 2008) Geographe Bay	0.8 Jan 1.032 Apr	0.13	-	-	-	-
1994 Apr, Jul, Sep	(McMahon 1994) Geographe Bay	1.26 (0.06-1.66)	0.18 (0.9-0.28)	3.30 (2.61-5.24)	0.95 (0.79-1.14)	0.10 (0.07-0.14)	2.52 (0.8-4.18)
2008 Aug	(Oldham et al. 2010) Geographe Bay	1.43 (1.30-1.56)	-	3.66 (3.30-4.36)	0.97 (0.9-1.16)	-	4.51 (4.01-4.8)
Autumn	(Paling & McComb 2000) Shoalwater Bay	1.8	-	-	0.6	-	-
Summer 2003	(Collier et al. 2008) Cockburn Sound	1.2-1.4	-	-			
Autumn 2008	(Hyndes et al. 2012) Warnbro Sound	-	-	4			

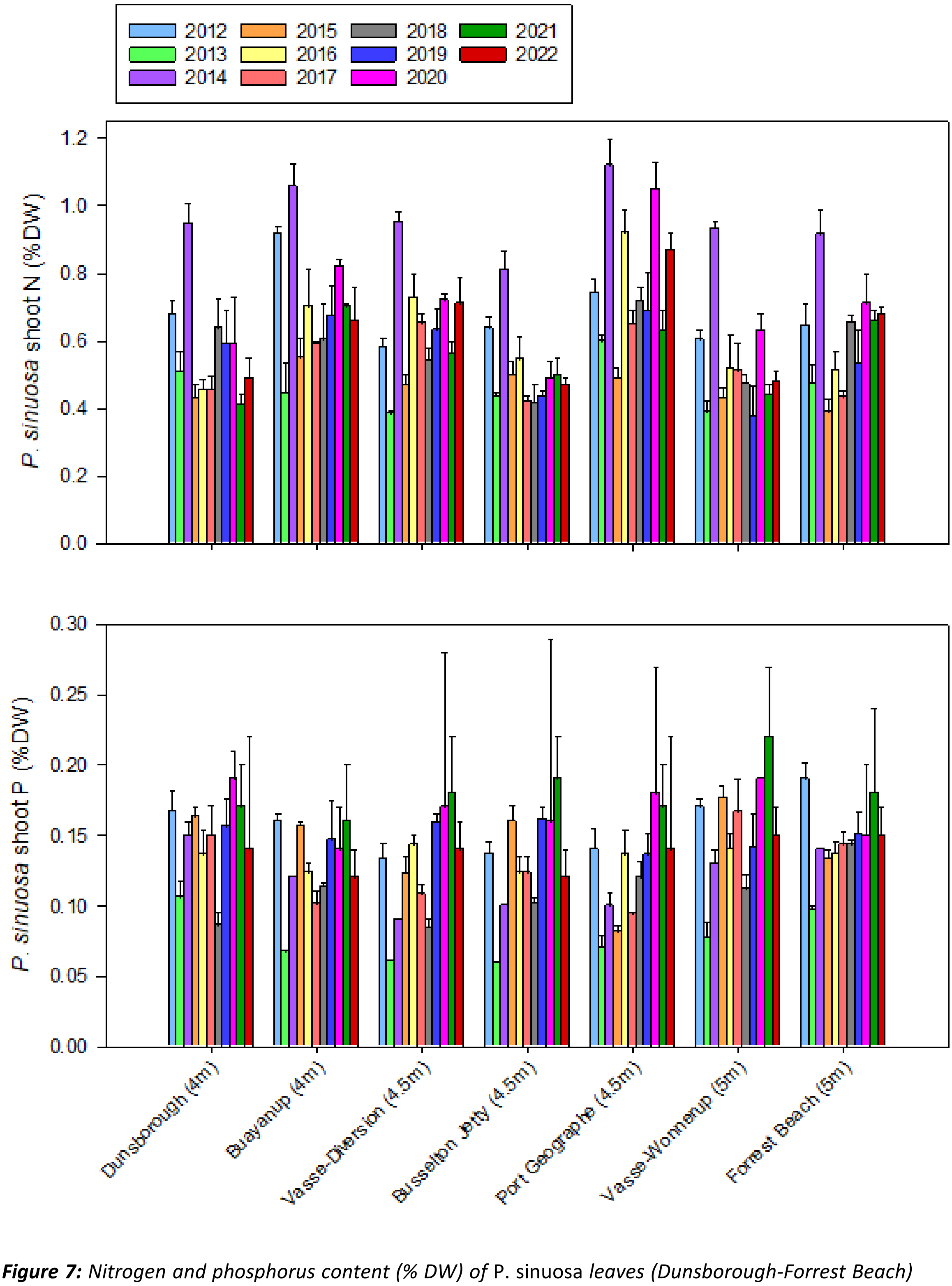
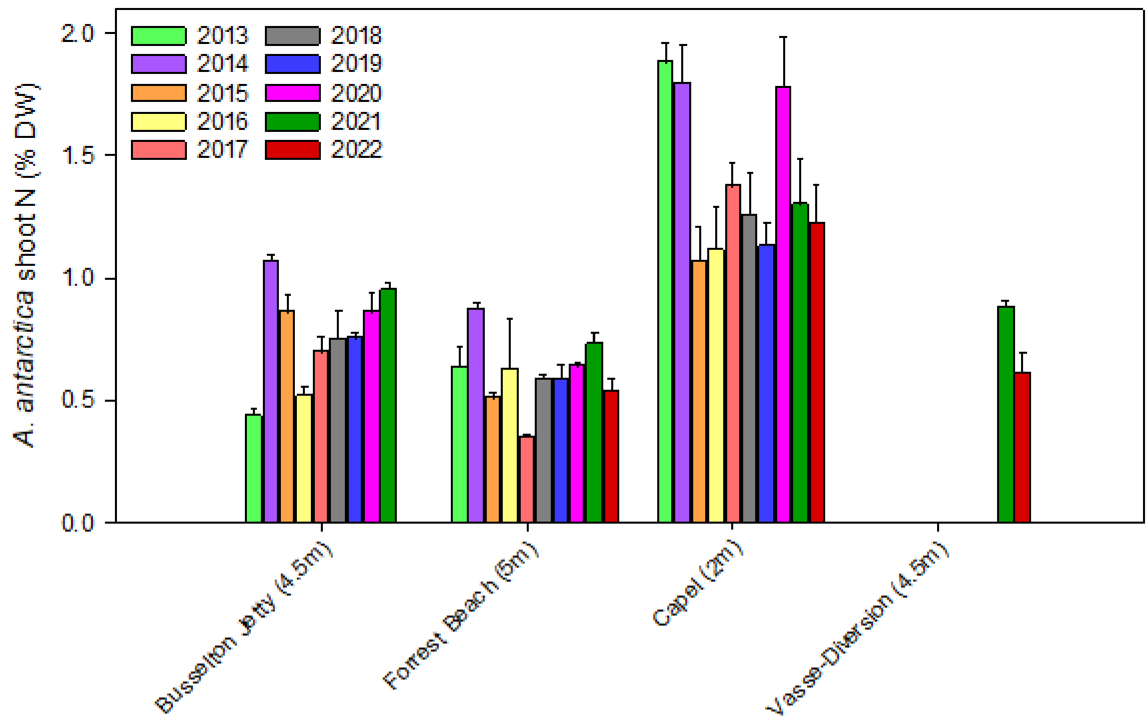


Figure 7: *Nitrogen and phosphorus content (% DW) of* P. sinuosa *leaves (Dunsborough-Forrest Beach) at the Keep Watch seagrass monitoring sites in 2012-2022.*



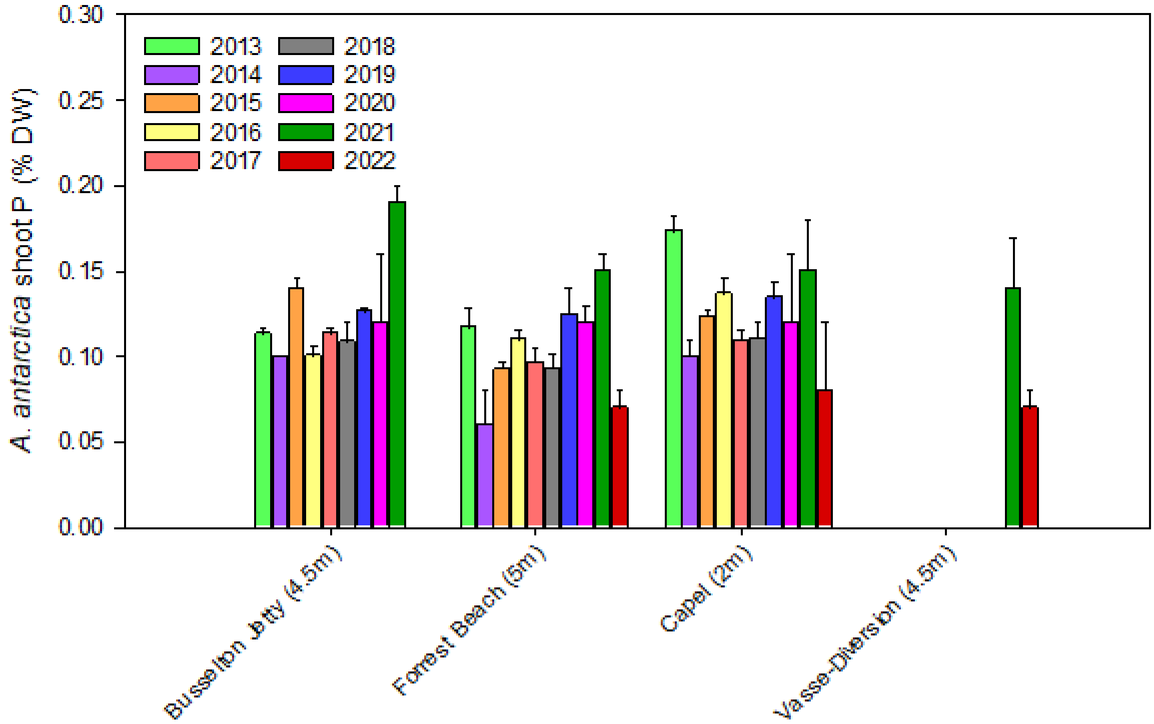


Figure 8: *Nitrogen and phosphorus content (% DW) of* A. antarctica *leaves (average ± se) at the Keep Watch seagrass monitoring sites in 2013-2022. Note that sampling at Busselton Jetty ended in 2021 and with a new site established at Vasse-Diversion drain.*

Nitrogen isotope signals can indicate the main sources of nitrogen seagrasses are accessing. Nitrogen derived from the fixation of atmospheric nitrogen or agricultural fertilisers has a signature close to 0‰. Nitrogen derived from native bushland has a signal between 2-5 ‰, whereas nitrogen derived from animal waste or septic tanks is usually in the order of 5-6 ‰ and nitrogen from treated sewerage is usually around 9 ‰ (Jones & Saxby 2003). In Geographe Bay, nitrogen isotope signals measured in seagrass leaves indicate that the meadows are accessing different sources of nitrogen, and these sources vary among sites.

The $\delta^{15}N$ of *P. sinuosa* leaves ranged from 0.9 to 2.0 ‰. $\delta^{15}N$ signals are similar at most sites with the exception of Vasse Diversion that increased compared to last year and all values are in the range that has been observed in the last ten years (Figure 9). The nitrogen isotope signals in the seagrass leaves indicate that this year seagrasses are mostly receiving a mix of sources, but the main sources could be either from fixation of atmospheric nitrogen or agricultural fertilisers, as the signal is close to 0‰ with other sources contributing a small amount. There is no evidence that nitrogen derived from treated sewerage is the main source for seagrasses, if this was the case, we would expect the signal to be much higher, around 9 ‰.

The $\delta^{15}N$ signal of *Amphibolis* leaves ranged from 2.1-4.0‰, increasing on average at all sites this year (Figure 9). Once again the highest values were observed at Capel indicating a different source of nitrogen at this site. All raw data is in Appendix 5.

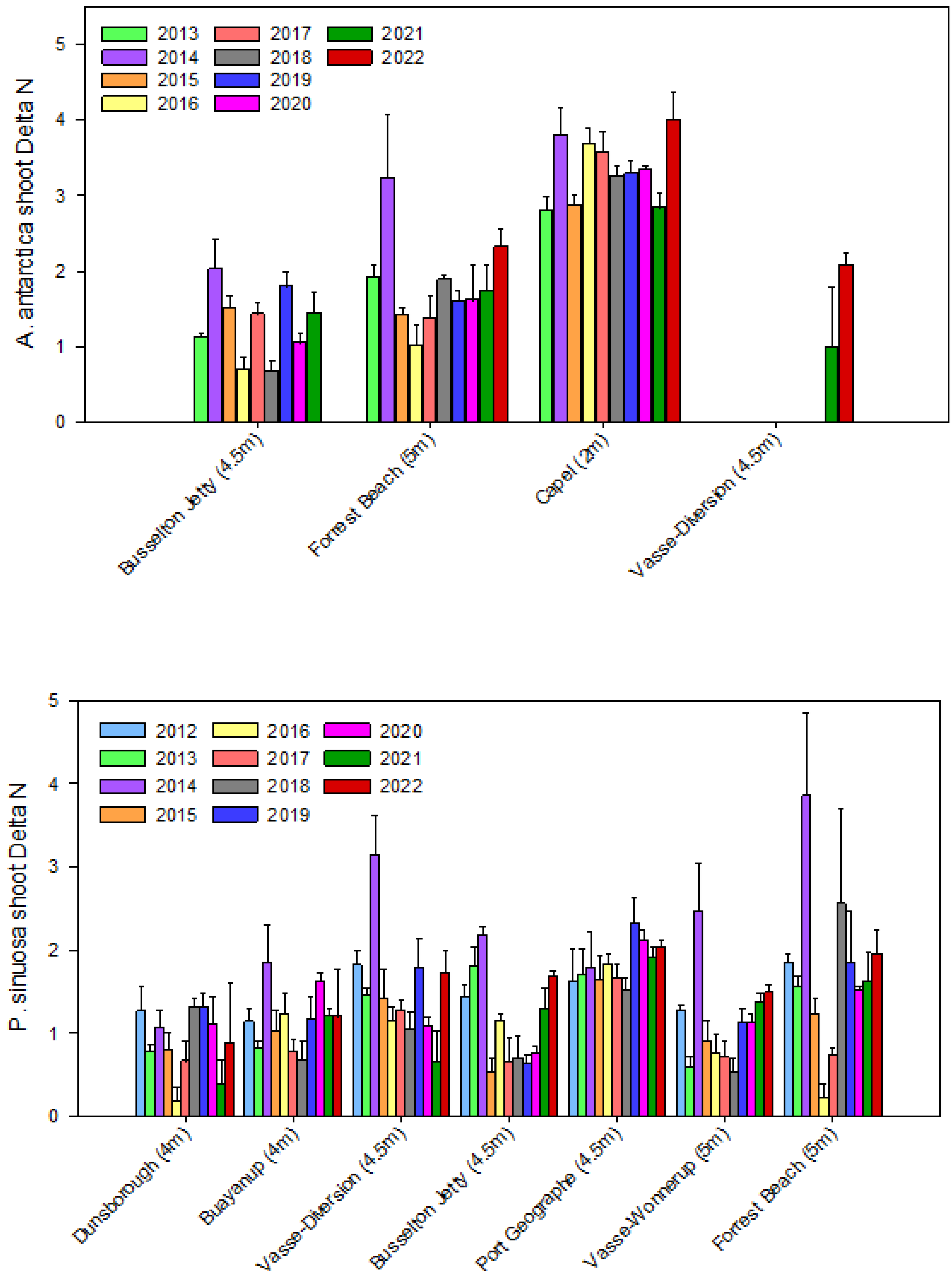


Figure 9: $\delta^{15}N$ of P. sinuosa leaves (Site 1-7) and A. antarctica leaves (Site 4, 6, 7 & 8 average ± se) at the Keep Watch seagrass monitoring sites in 2012-2022 for P. sinuosa and 2013-2022 for A. antarctica. Note that only Capel was measured in 2012 for A. antarctica, and is not included in these graphs.

The epiphytic macroalgae, *Padina* had higher nitrogen and phosphorus content (% DW) at Capel compared to Dunsborough (Figure 10). There was a similar pattern for the macroalgae, *Dictyota*re where the phosphorus concentrations measured were very similar to *Padina* but for nitrogen, the concentration was ~2x greater. Like the information for seagrass, the $\delta^{15}N$ for both algae was higher at Capel compared to Dunsborough, indicating different sources of nitrogen between these two sites (Figure 10).

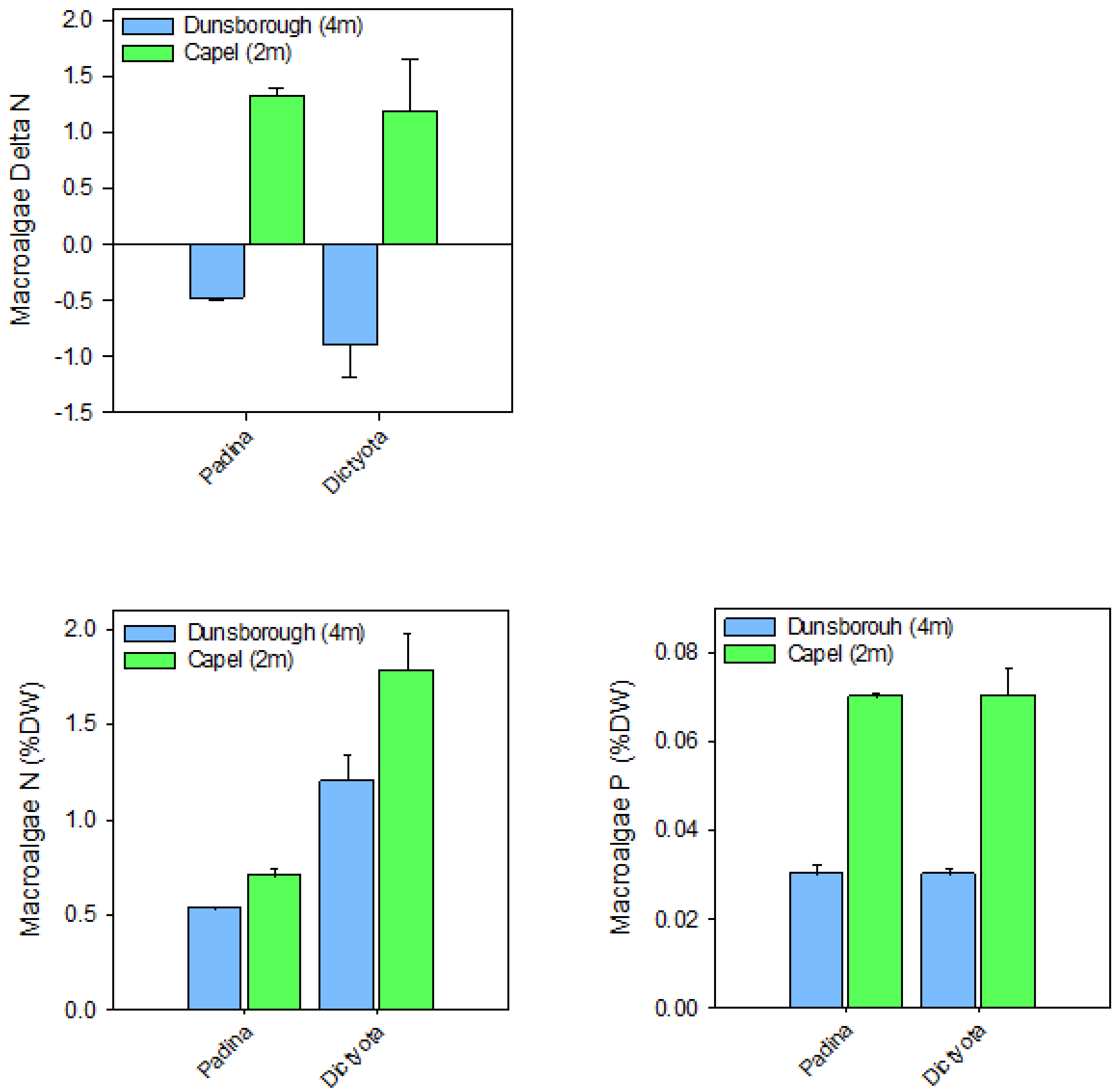


Figure 10: Nutrient (N, P) and $\delta^{15}N$ of two species of epiphytic macroalgae, Padina and Dictyota from two Keep Watch seagrass monitoring sites in 2022, Dunsborough and Capel. Note that there were the only two sites where both algal species where present.

4.6 Water quality

Water temperature at the Keep Watch seagrass sites ranged from 23.6-24.4°C, similar to 2020. Water clarity was high and the Secchi disk was always observed on the bottom (Table 6).

Table 6: *Water quality measures at the Keep Watch seagrass monitoring sites from 2012-2022, *=Secchi disk depth on bottom.*

Site	Secchi disk depth (m)										
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1.	4.2*	3	3	3.2*	3*	3.5*	2.7	2.7	4.0*	3.3	4.0*
2.	3.5	2.5	3*	3.2*	3.5*	2.5*	3*	2.8	3.5*	3.2	3.5*
3. Vasse Diversion	4	3.25	3.5*	3.6*	3.5*	5*	3.3	3	3.5*	3.4	4.0*
4. Busselton Jetty	4.2	2.5	3.5	3.6*	3.5*	2.5*	4*	2.9	3.5*	3.1	4.5*
5. Port Geographe	3.75	2.5	4	4.1*	3.5	4.5*	3.5*	3.2	3.0*	4.5*	3.5*
6. Vasse-Wonnerup	4	2	4.5	4.6*	4.5*	4*	4.5*	4	4.5*	5.4*	5.0*
7. Forrest Beach	5*	2	4	4.2*	4.5*	4*	3.5	3.8	4.5*	5*	5.0*

	Temperature (°C)										
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
1. Dunsborough	22	22.5	23.1	23.3	22.9	22.5	21.2	20.6	23.5	20.0	23.6
2. Buayanup	22.8	22.6	23.5	25.2	23.7	22.8	21.7	21.7	24.4	20.1	23.9
3. Vasse Diversion Drain	23.4	23.8	23.5	24.5	23.9	22	22.1	21.7	24.7	20.9	
4. Busselton Jetty	23.4	27.3	23.3	26.3	22.6	22.5	22.6	22.8	23.6	20.9	
5. Port Geographe	23.4	25.5	23.3	24.3	23	22.5	22.3	22.8	23.7	20.9	
6. Vasse-Wonnerup	23.1	28.4	22.2	26.1	22.3	22.3	21.9	21.6	23.6	21.2	24.4
7. Forrest Beach	22.5	23.5	22.1	25.1	23.3	22.5	21.5	21.7	24.0	21.4	

5 General conclusions

5.1 Rebound in shoot density

No management criteria were triggered in 2022 for all three triggers. Last year, five sites declined, with two, Vasse Diversion and Forrest Beach declining more than 20% but this was reversed this year and these sites had the greatest increases (Figure 11). We are now seeing trends of increasing shoot density from since the program began at two central sites, Vasse Diversion and Busselton Jetty, highlighting that the environmental conditions are conducive for increases in seagrass condition. The other good news for Geographe Bay is that average shoot denisities here are higher than the maximum averages for sites in Perth and Jurien waters. This indicates that human activities and ocean warming is not currently impacting meadows here as is observed further north. It is recommended to continue monitoring to keep track on the condition of the meadows.

Site	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1. Dunsborough	62	64	52	56	61	59	53	56	61	68	63
2. Buayanup	59	66	50	60	57	58	55	63	56	60	66
3. Vasse Diversion Drain	34	37	34	34	29	34	38	41	48	37	41
4. Busselton Jetty	38	38	46	44	45	45	43	52	49	45	49
5. Port Geographe	39	46	42	47	45	35	49	62	50	46	42
6. Vasse-Wonnerup	38	45	51	49	48	50	47	53	51	44	45
7. Forrest Beach	53	61	47	48	50	49	53	52	59	42	49

Figure 11: *Heatmap of changes in average shoot density of* P. sinuosa *over time, 2012-2022, at each Keep Watch seagrass monitoring sites.*

5.2 Algal epiphyte cover consistent

The cover of algae has remained consistent with variations between sites but it is not a concern following this years sampling as there are no obvious impacts to seagrass condition (Figure 12). The dominant algal types remains microalgal accumulations which are not the type commonly associated with nutrient enrichment.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1. Dunsborough	3	2	3	3	2	2	3	3	3	2	3
2. Buayanup	3	2	3	3	4	4	3	1	4	4	4
3. Vasse Diversion Drain	2	3	4	4	4	4	4	2	4	4	4
4. Busselton Jetty	2	2	4	4	3	3	3	2	4	4	4
5. Port Geographe	2	1	2	2	3	3	3	2	3	3	3
6. Vasse-Wonnerup	2	1	2	3	2	2	2	1	2	3	2
7. Forrest Beach	2	1	2	2	2	1	2	1	2	2	1

Figure 12: *Heatmap of changes algal cover on* P. sinuosa *over time, 2012-2022, at each Keep Watch seagrass monitoring sites.The numbers and colours reflect the cover of epiphytic algae with 1=Very low, 2=Low, 3=Moderate, 4=High and 5=Very High*

5.3 Nitrogen exposure is low and no obvious changes in the sources

Overall the nutrient concentrations in seagrass are very low and do not indicate exposure to excess nutrients. Capel continues to have higher nitrogen content and nitrogen isotope values indicating that these meadows are receiving more and a different source of nitrogen compared to other sites. The main potential nitrogen sources based on the higher nitrogen isotope signal (2.8 ‰) indicate nitrogen derived from animal wastes or septic tanks or sources from natural vegetation. Despite the higher nitrogen content at Capel the lower phosphorus levels were maintained, indicating that there continues to be less exposure to phosphorus compared to earlier years.

This year based on a recommendation from the 10 year review meeting, macroalgae was also monitored for nutrient content and nitrogen sources. Two species of algae were collected, *Padina* and *Dictyota* with three independent replicates from two sites, Capel and Dunsborough. The plan was to try and collect from the same three sites where *Amphibolis* samples were collected but it was not possible because the same macroalgal species were not present at these sites. This sampling reiterated that Capel is exposed to higher loads of nitrogen and of a different sources of nitrogen compared to Geographe Bay, providing additional lines of evidence to the seagrass nutrient data. However, the macroalgae also showed significantly higher phosphorus content in both species of macroalgae at Capel, a signal that was no longer obvious in the seagrass samples. Based on this feature, there could be value in continuing to monitor macroalgae, but only one species, as they both showed similar patterns. Due to the more variable nature of epiphytic macroalgae in seagrass meadows we recommend to target both species at all sites, but then only analyse the species with the best coverage (ie 3 replicates at at least two, preferably three sites).

5.4 Keep Watch program continuing

Following the 10 year review meeting with relevant stakeholders it was agreed to continue the annual Keep Watch seagrass monitoring program at the seven shallow seagrass sites. The program has been funded for another five years (2022-2026) with financial support from Water Corp, managed through GeoCatch and supported by DBCA with boats, scientists and rangers. This forms part of the DBCA routine monitoring of the marine park, which without this program would only occur every two years in the shallow water sites.

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Appendix 1: Randomly generated quadrat positions from 2022 survey.

Quadrat #	Bearing	Distance
1	0	8
2	0	10
3	0	16
4	0	18
5	0	21
6	20	23
7	80	8
8	80	10
9	80	15
10	80	18
11	80	20
12	80	23
13	200	4
14	200	8
15	200	12
16	200	14
17	200	16
18	200	24
19	260	5
20	260	8
21	260	13
22	260	15
23	260	17
24	260	19
25	340	6
26	340	9
27	340	10
28	340	16
29	340	18
30	340	25

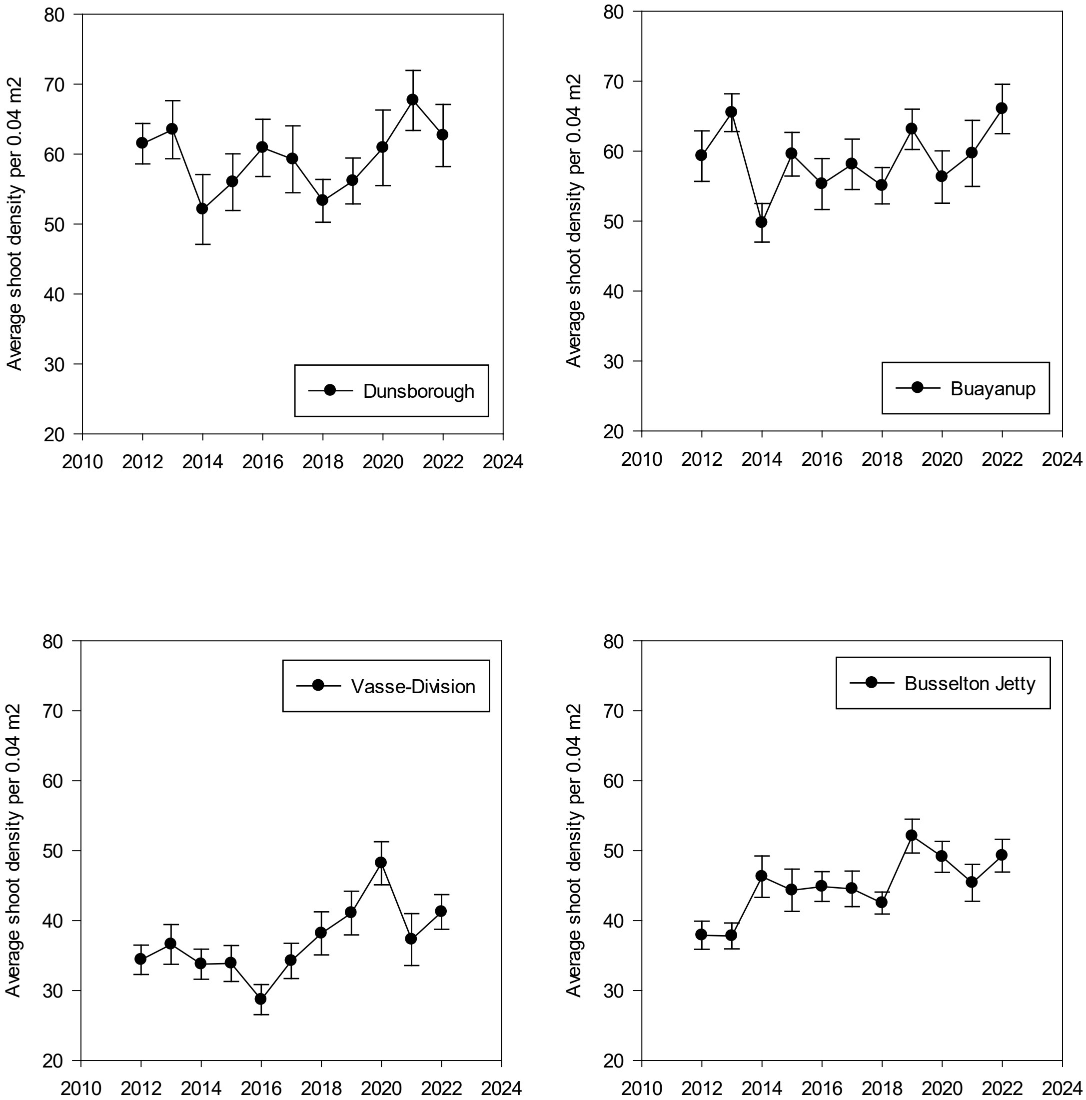
Appendix 2: Raw and summary statistics for shoot density data for the seven Keep Watch Seagrass Monitoring Sites in 2022. The person who counted each quadrat is also included and there were no seedlings observed in any of the quadrats.

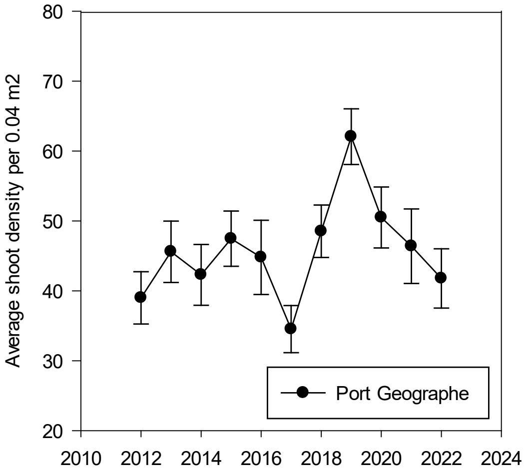
	1. Dunsborough		2. Buayanup		3. Vasse Diversion		4. Busselton Jetty		5. Port Geographe		6. Vasse-Wonnerup		7. Forrest Beach	
Rep	Shoots	Counter	Shoots	Counter	Shoots	Counter	Shoots	Counter	Shoots	Counter	Shoots	Counter	Shoots	Counter
1	58	SB	47	SB	41	IA	43	KM	58	IA	35	IA	39	IA
2	81	SB	84	SB	52	IA	52	IA	24	IA	43	IA	46	IA
3	98	SB	91	SB	45	IA	66	IA	17	IA	39	IA	30	IA
4	110	SB	70	SB	55	IA	44	IA	62	IA	41	IA	35	IA
5	91	SB	92	SB	43	IA	56	IA	57	IA	45	IA	38	IA
6	44	SB	70	SB	62	IA	40	IA	29	IA	37	IA	56	IA
7	81	RC	55	RC	32	RC	75	SB	28	SB	44	RC	49	SB
8	56	RC	66	RC	24	RC	68	SB	22	SB	22	RC	64	SB
9	43	RC	48	RC	20	RC	75	SB	27	SB	30	RC	60	SB
10	38	RC	74	RC	26	RC	53	SB	49	SB	21	RC	63	SB
11	90	RC	84	RC	45	RC	43	SB	81	SB	46	RC	62	SB
12	48	RC	67	RC	48	RC	61	SB	54	SB	35	RC	82	SB
13	76	EB	67	EB	35	EB	41	KM	46	RC	53	EB	74	EB
14	44	EB	36	EB	52	EB	36	RC	57	RC	18	EB	43	EB
15	29	EB	83	EB	29	EB	33	RC	27	RC	46	EB	18	EB
16	45	EB	31	EB	30	EB	39	RC	61	RC	42	EB	44	EB
17	45	EB	67	EB	29	EB	58	RC	10	RC	30	EB	21	EB
18	25	EB	76	EB	31	EB	53	RC	38	RC	50	EB	44	EB
19	64	KM	59	KM	55	KM	59	KM	20	RC	53	SB	42	KM
20	96	KM	26	KM	16	KM	46	KM	96	KM	56	SB	51	KM
21	76	KM	85	KM	54	KM	69	KM	19	KM	65	SB	79	KM
22	48	KM	62	KM	34	KM	44	KM	25	KM	74	SB	73	KM
23	67	KM	65	KM	32	KM	40	KM	12	KM	116	SB	54	KM
24	70	KM	98	KM	68	KM	23	KM	91	KM	49	SB	61	KM
25	118	RC	89	SB	59	RC	42	RC	58	SB	38	IA	43	IA
26	41	SB	31	RC	49	IA	42	IA	43	IA	38	RC	35	SB
27	61	RC	81	SB	61	EB	52	SB	27	IA	42	IA	29	IA
28	39	SB	64	RC	29	RC	45	RC	46	SB	55	EB	57	SB
29	52	EB	45	RC	44	IA	32	KM	28	RC	43	RC	29	EB
30	46	RC	68	EB	37	RC	48	SB			36	IA	47	IA
Average	**62.7**		**66.0**		**41.2**		**49.3**		**41.8**		**44.7**		**48.9**	
Median	**57.0**		**67.0**		**42.0**		**45.5**		**38.0**		**42.5**		**46.5**	
SE	**4.43**		**3.53**		**2.48**		**2.35**		**4.24**		**3.30**		**3.01**	
Stdev	**24.28**		**19.34**		**13.58**		**12.85**		**22.84**		**18.08**		**16.49**	
CV	**0.39**		**0.29**		**0.33**		**0.26**		**0.55**		**0.40**		**0.34**	

Appendix 3: Leaf morphology data for 2022

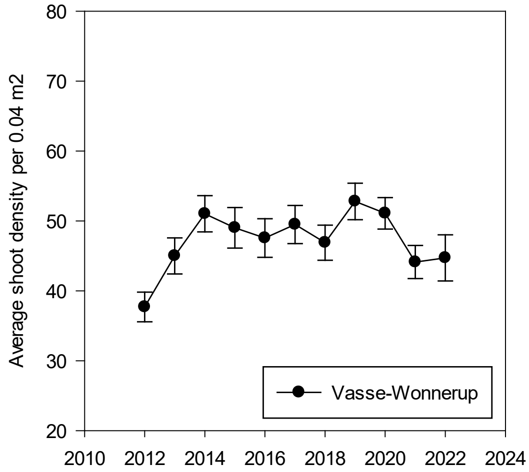
2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022	2022
	S1	S1	S2	S2	S3	S3	S4	S4	S5	S5	S6	S6	S7	S7
	Dun.	Dun.	Buayanup	Buayanup	Vasse Div.	Vasse Div.	Buss Jetty	Buss Jetty	Port Geo	Port Geo	Vasse Won	Vasse Won	Forrest B	Forrest B
Rep	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)
1	53.8	5	69.4	5	38.8	5	73.9	5	44.5	6	65	7	63.5	5
2	53.5	6	81.4	5	90	6	49.3	6	29.1	5	53.3	7	47.9	6
3	56.1	7	70.8	5	80.9	6	43.2	6	31.9	5	56.1	5	58.6	6
4	53.5	5	76.3	5	71	6	54.7	6	47	6	68.5	6	56.5	6
5	59.5	6	65.2	5	40.7	7	48.4	5	42.7	6	90.1	6	62.8	6
6	38.1	6	49	6	78.4	6	72.7	5	40.5	5	74.2	6	72	6
7	41.9	4	58.9	5	71.3	6	72.5	6	40.2	5	60.5	5	59.7	4
8	39	5	57.2	6	52.4	6	57.2	6	30.2	5	45.4	5	51	5
9	50.7	6	58.9	5	72.3	6	52.6	5	52.6	5	46.4	6	52.5	4
10	42.3	6	59.2	6	66.3	6	44.5	5	46.2	5	75.6	5	46.8	4
11	40.5	6	52	6	74.2	6	54.9	6	56.3	5	51.5	6	61.5	7
12	45	5	49.6	5	66.5	6	58.6	6	50.7	5	60.7	6	34.5	6
13	69.3	6	51.7	5	68.9	6	68.2	8	64.7	5	97.1	6	66.2	5
14	74.4	5	44.2	4	76.9	5	73.2	6	45.1	5	66.7	6	54.3	6
15	44.3	5	47.7	6	71.4	6	57.3	6	37.4	6	69.7	6	51.2	4
Average	50.79	5.53	59.43	5.27	68.00	5.93	58.75	5.80	43.94	5.27	65.39	5.87	55.93	5.33
SE	2.81	0.19	2.87	0.15	3.63	0.12	2.78	0.20	2.53	0.12	3.82	0.17	2.38	0.25
Min	38.1	4	44.2	4	38.8	5	43.2	5	29.1	5	45.4	5	34.5	4
Max	74.4	7	81.4	6	90	7	73.9	8	64.7	6	97.1	7	72	7

Appendix 4: Trends over time in seagrass shoot density.

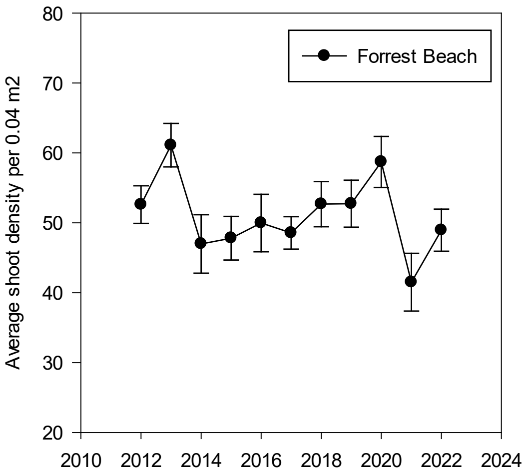




Average shoot density per 0.04 m2
Port Geographe
20
30
40
50
60
70
80
2010
2012
2014
2016
2018
2020
2022
2024



Average shoot density per 0.04 m2
Vasse-Wonnerup
20
30
40
50
60
70
80
2010
2012
2014
2016
2018
2020
2022
2024



Average shoot density per 0.04 m2
Forrest Beach
20
30
40
50
60
70
80
2010
2012
2014
2016
2018
2020
2022
2024

Appendix 5: Nutrient data for 2022 including the original and modified calibrated values for 2020 as well as the calibrated values for 2022 for seagrasses and macroalgae.

		2022	2022	2022
		Modified	Modified	Original
Site	Species	δ15N	N [wt %]	P (% DW)
Dunsborough	Posidonia	-0.41	0.41	0.18
Dunsborough	Posidonia	1.00	0.61	0.15
Dunsborough	Posidonia	2.06	0.44	0.11
Buayanup	Posidonia	0.25	0.48	0.13
Buayanup	Posidonia	1.15	0.71	0.11
Buayanup	Posidonia	2.21	0.80	0.12
Vasse-Diversion	Posidonia	1.21	0.81	0.15
Vasse-Diversion	Posidonia	1.87	0.75	0.13
Vasse-Diversion	Posidonia	2.08	0.55	0.14
Busselton Jetty	Posidonia	1.63	0.50	0.11
Busselton Jetty	Posidonia	1.82	0.44	0.13
Busselton Jetty	Posidonia	1.59	0.47	0.13
Port Geographe	Posidonia	1.89	0.79	0.09
Port Geographe	Posidonia	2.17	0.88	0.15
Port Geographe	Posidonia	2.02	0.95	0.17
Vasse-Wonnerup	Posidonia	1.33	0.52	0.15
Vasse-Wonnerup	Posidonia	1.50	0.50	0.16
Vasse-Wonnerup	Posidonia	1.65	0.41	0.14
Forrest Beach	Posidonia	1.56	0.64	0.15
Forrest Beach	Posidonia	1.75	0.69	0.15
Forrest Beach	Posidonia	2.54	0.72	0.13
Forrest Beach	Amphibolis	2.38	0.58	0.07
Forrest Beach	Amphibolis	1.58	0.60	0.08
Forrest Beach	Amphibolis	1.76	0.43	0.07
Capel	Amphibolis	3.99	0.94	0.06
Capel	Amphibolis	4.22	1.22	0.08
Capel	Amphibolis	2.93	1.50	0.11
Vasse-Diversion	Amphibolis	1.48	0.43	0.07
Vasse-Diversion	Amphibolis	1.48	0.71	0.06
Vasse-Diversion	Amphibolis	1.97	0.70	0.07
Dunsborough	Padina	-0.53	0.56	0.04
Dunsborough	Padina	-0.45	0.51	0.04
Dunsborough	Padina	-0.42	0.52	0.03
Capel	Padina	1.29	0.72	0.07
Capel	Padina	1.46	0.62	0.08
Capel	Padina	1.26	0.78	0.07
Dunsborough	Dictyota	-0.31	0.98	0.03
Dunsborough	Dictyota	-1.17	1.17	0.02
Dunsborough	Dictyota	-1.18	1.45	0.03
Capel	Dictyota	0.71	1.79	0.07
Capel	Dictyota	2.11	1.44	0.06
Capel	Dictyota	0.76	2.13	0.08