Edith Cowan University
Centre for Marine Ecosystems Research

Keep Watch Seagrass Monitoring 2023 Report for GeoCatch

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Keep Watch Seagrass Monitoring

Annual Report 2023

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.

July 2023

1 Executive Summary

1.1 Introduction

This report summarises twelve years of data (Feb 2012 - Feb 2023) 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, as well as for epiphytic algae at a subset of sites.

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 is also used as a comparison to assess inter-annual and site variations.

1.2 Key findings 2023

Key finding 1

Seagrass meadows in Geographe Bay remain healthy with seagrass shoot densities high at all sites compared to other similar meadows in Western Australia. Shoot densities mostly decreased or remained stable with the highest shoot densities recorded at Dunsbrough and Buayanup with lowest at the Port Geographe and Vasse-Wonnerup. No managagement triggers were breached in 2023.

Key finding 2

The ephiphyte cover was similar to previous years with sites varying from low to high cover. 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 2023 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 2 other 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 2023 and compares to data from the 2012-2022 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.

The program is funded through collaborative sponsorship from GeoCatch Catchment Council, 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 antarctica*) but the program mostly focuses on *P. sinuosa* shoot density and leaf tissue nutrients (N, P and N isotopes) from seven sites with leaf tissue nutrient data for *A. antarctica* seagrass from three sites. In addition, based on the 10 year review workshop held in Busselton on 17th November 2021, since 2022 samples of macroalgae have also been collected at Capel, Forrest Beach and Dunsborough for nutrient and nitrogen isotope analysis to provide an additional line of evidence for understanding nutrient pollution. 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 three 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 8th to the 10th February 2023. 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). The epiphytic algae *Dictyota* growing on *P. sinuosa* was collected at Dunsborough (1), Forrest Beach (7) and Capel (8) for nutrient analysis.

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.

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	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	Dictyota
8. Capel	S 33.51394°, E 115.51508°	2	21/2/2022	Aa	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.

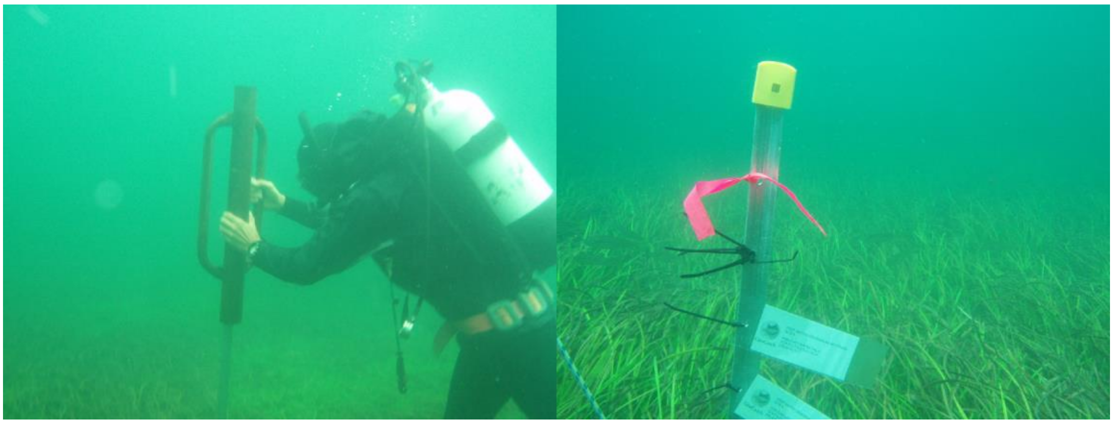


Figure 2: *Left: Banging in permanent marker with pole driver. Right: Star picket with cap and plastic coated site label, indicating center of 50 m diameter Keep Watch seagrass site.*

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.

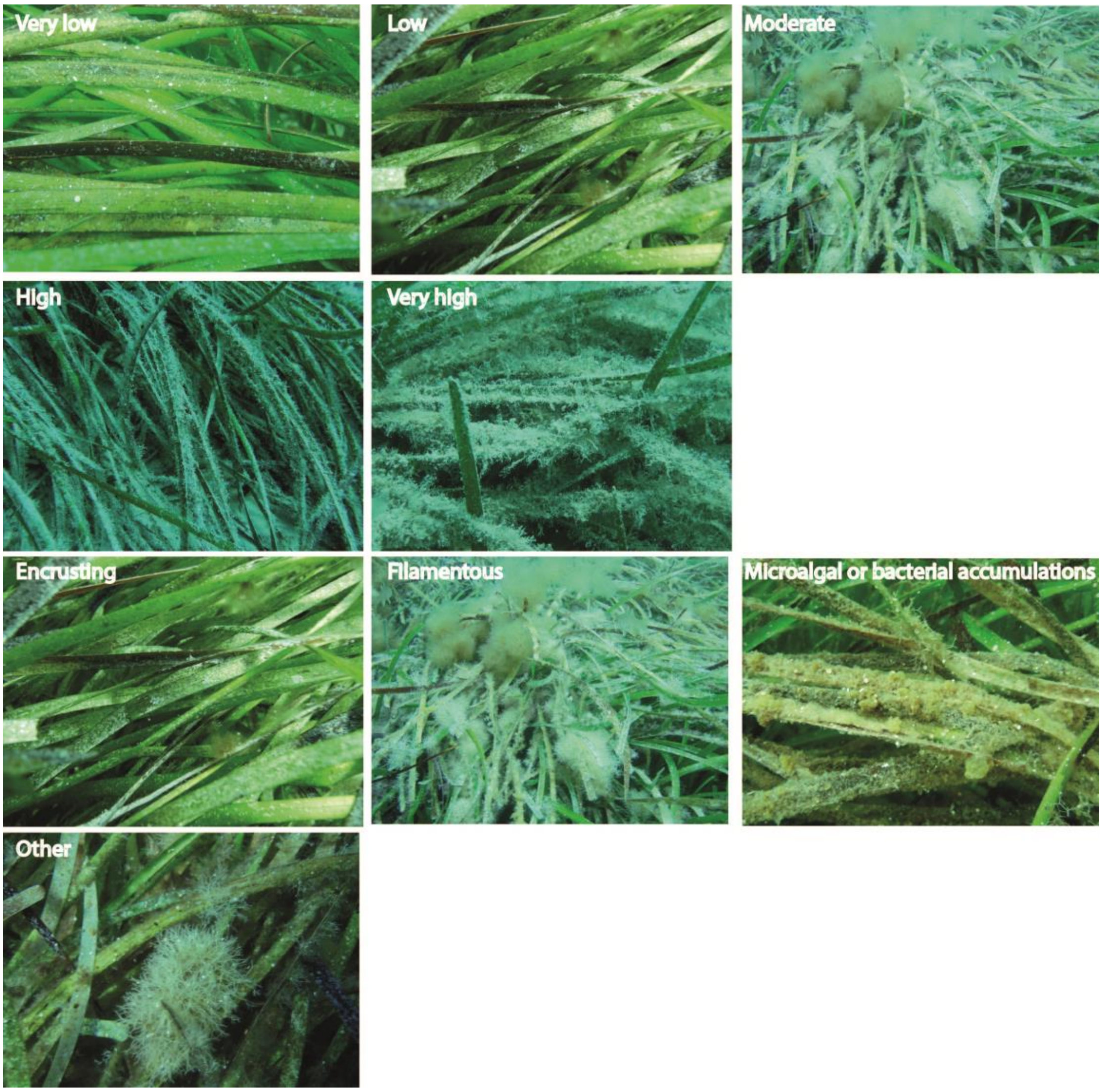


Figure 4: *Classification of epiphytic algal cover and type.*

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 and TP 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. There was one species that overlapped at each site and was processed, the dichotomously branching brown algae, *Dictyota*. At each site the Secchi disk depth (m) and surface water temperature was recorded from the boat.

Field work was carried out by Kathryn McMahon (KM) from ECU with Sahira Bell (SB), Eden Harris (EH), Kye Adams (KA), Glen Sutton (GS) and Dave Lierich (DL) from Department of Biodiversity, Conservation and Attractions. Samples were processed and data analysed by Ankje Frouws. The boat was provided in-kind from the Department of Biodiversity, Conservation and Attractions. The monitoring program was funded through sponsorship by Geographe Catchment Council, 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 2023 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 807-1654 shoots m^{-2} across the seven sites (Figure 5). Dunsborough (1654 shoots m^{-2}) and Buayanup (1402 shoots m^{-2}) continue to have the highest shoot density with Port Geographe (806 shoots m^{-2}) the lowest. The remaining sites ranged between 920-1208 shoots m^{-2}. All raw data is in Appendix 2.

This year four of the seven sites declined by 17-22%, Buayanup, Busselton Jetty, Port Geographe and Vasse-Wonnerup. All other sites had neglible change. Most sites have a similar shoot density to the time monitoring began, but this year both Port Geographe and Buayanup were slightly lower (7-15%). Compared to other seagrass meadows in the state, all monitoring sites in Geographe Bay are well above the minimum average site shoot density. This is a reflection that there is a trend of shoot density decline in regions further north but not in Geographe Bay.

P. sinuosa average shoot length ranged from a minimum of 47 cm at Forrest Beach to a maximum of 61 cm at Vasse Diversion and a range in average width of 5-6 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**	**22-23**
1. Dunsborough	3	-18	7	9	-3	-10	5	8	11	-7	6
2. Buayanup	11	-24	20	-7	2	-5	15	-11	6	11	-17
3. Vasse Diversion	6	-8	0	-15	19	12	8	17	-23	11	-4
4. Busselton Jetty	0	22	-4	1	-1	-5	23	-6	-8	9	-22
5. Port Geographe	17	-7	12	-6	-23	41	28	-19	-8	-10	-21
6. Vasse-Wonnerup	19	13	-4	-3	4	-5	13	-3	-14	1	-18
7. Forrest Beach	16	-23	2	5	-3	8	0	11	-29	18	-1

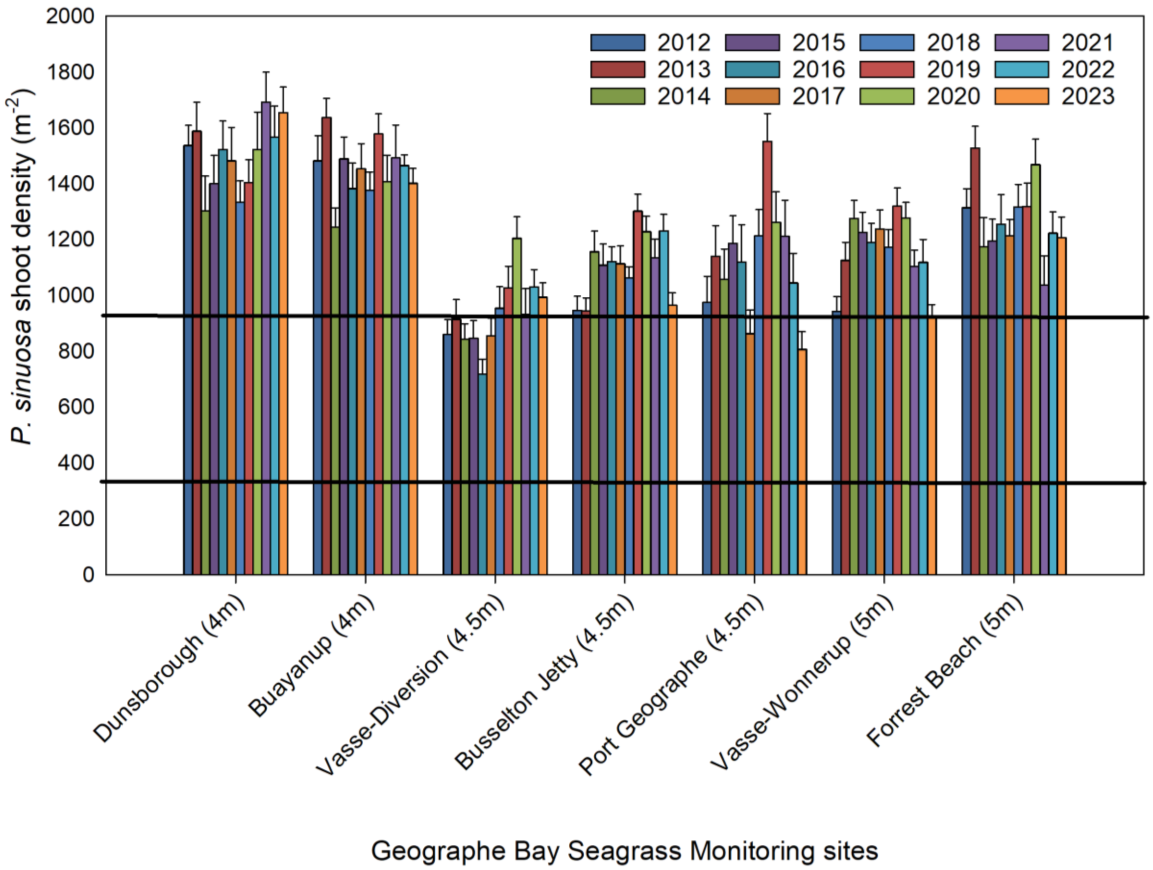


***Figure 5**: Shoot density (average m^{-2} ± se) at the seven Keep Watch seagrass monitoring sites with* P. sinuosa *meadows in January or February 2012-2023. Black lines indicate the minimum and maximum site averages from the reference sites at 3-5 m in Shoalwater Bay and Jurien Bay Marine Parks from 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 2022-2023).

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 2021-2022 & 2022-2023).

4.2.3 Trigger 3

This threshold was not triggered as no sites showed a significant decline over time. Two of the seven sites showed a negative slope but this was not significant and this explained a very small component of the variation over the years. One site, Vasse Diversion continued to show a significant, positive, linear trend over the twelve 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	17%
2. Buayanup	ns	+ve	1%
3. Vasse Diversion	significant	+ve	36%
4. Busselton Jetty	ns	+ve	17%
5. Port Geographe	ns	+ve	0%
6. Vasse-Wonnerup	ns	-ve	1%
7. Forrest Beach	ns	-ve	8%

4.3 Epiphytes

This year epiphyte cover either stayed consistent, increased or declined by one category. The central site Buayanup had high cover with moderate cover at the other sites (Dunsborough, Vasse-Diversion to Vasse-Wonnerup) and with low cover at Forrest Beach (Table 4). The type of epiphyte cover was very consistent amongst the four central sites, with microalgae being dominant. At Dunsborough fine branching brown algae such as *Dictyota* was the dominat type, at Vasse-Wonnerup brown spaghetti-like epiphytes and at Forrest Beach it was encrusting algae. 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, 2012-2023. 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**	**-23**
1. Dunsborough	M	L	M	M	L	L	M	M	M	L	M	M
2. Buayanup	M	L	M	M	H	H	M	VL	H	H	H	H
3. Vasse Diversion Drain	L	M	H	H	H	H	H	L	H	H	H	M
4. Busselton Jetty	L	L	H	H	M	M	M	L	H	H	H	M
5. Port Geographe	L	VL	L	L	M	M	M	L	M	M	M	M
6. Vasse-Wonnerup	L	VL	L	M	L	L	L	VL	L	M	L	M
7. Forrest Beach	L	VL	L	L	L	VL	L	VL	L	L	VL	L
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	O
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	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	M
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	M
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	M
6. Vasse-Wonnerup	E, o, m	E,O	M,f	O	E,o,m	E,m	O,M	O	O,e	M	M	O
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	E

4.4 Nutrient content

The nitrogen content of *P. sinuosa* leaves ranged from 0.4-0.7% N dry weight (DW), very similar to the range observed in previous years (Figure 6). 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 (~2.5x higher than the other sites, Figure 7).

The phosphorus content of *P. sinuosa* leaves in 2022 ranged from 0.09-0.14% P DW (Figure 6). The majority of sites were similar to last year with the exception of Forrest Beach where the lowest concentration to date at this site was measured (0.09% P DW). For *A. antarctica* leaves, the phosphorus content was similar to last year from 0.06-0.09% DW (Figure 7). 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.

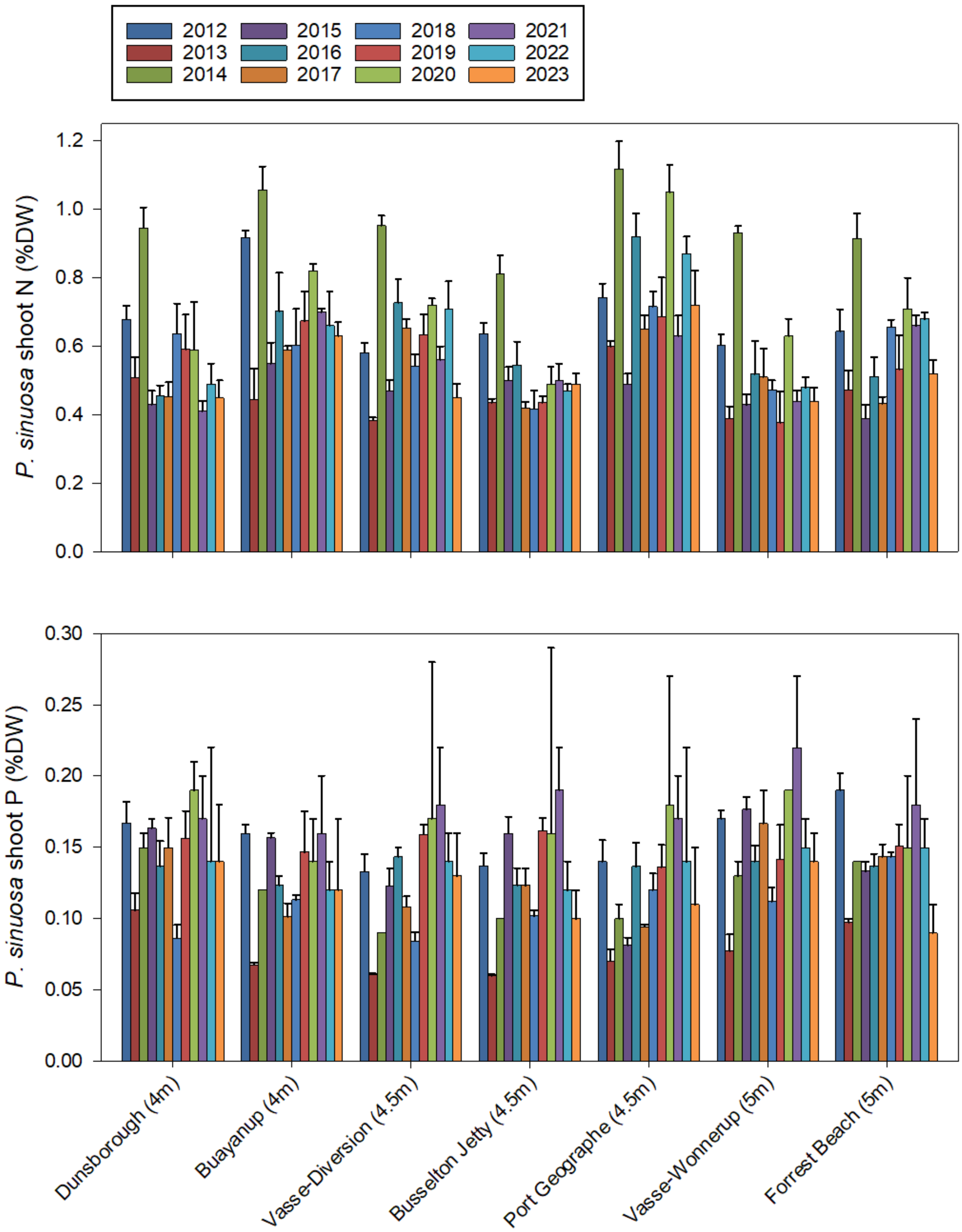


Figure 6: *Nitrogen and phosphorus content (% DW) of* P. sinuosa *leaves (Dunsborough-Forrest Beach) at the Keep Watch seagrass monitoring sites in 2012-2023.*

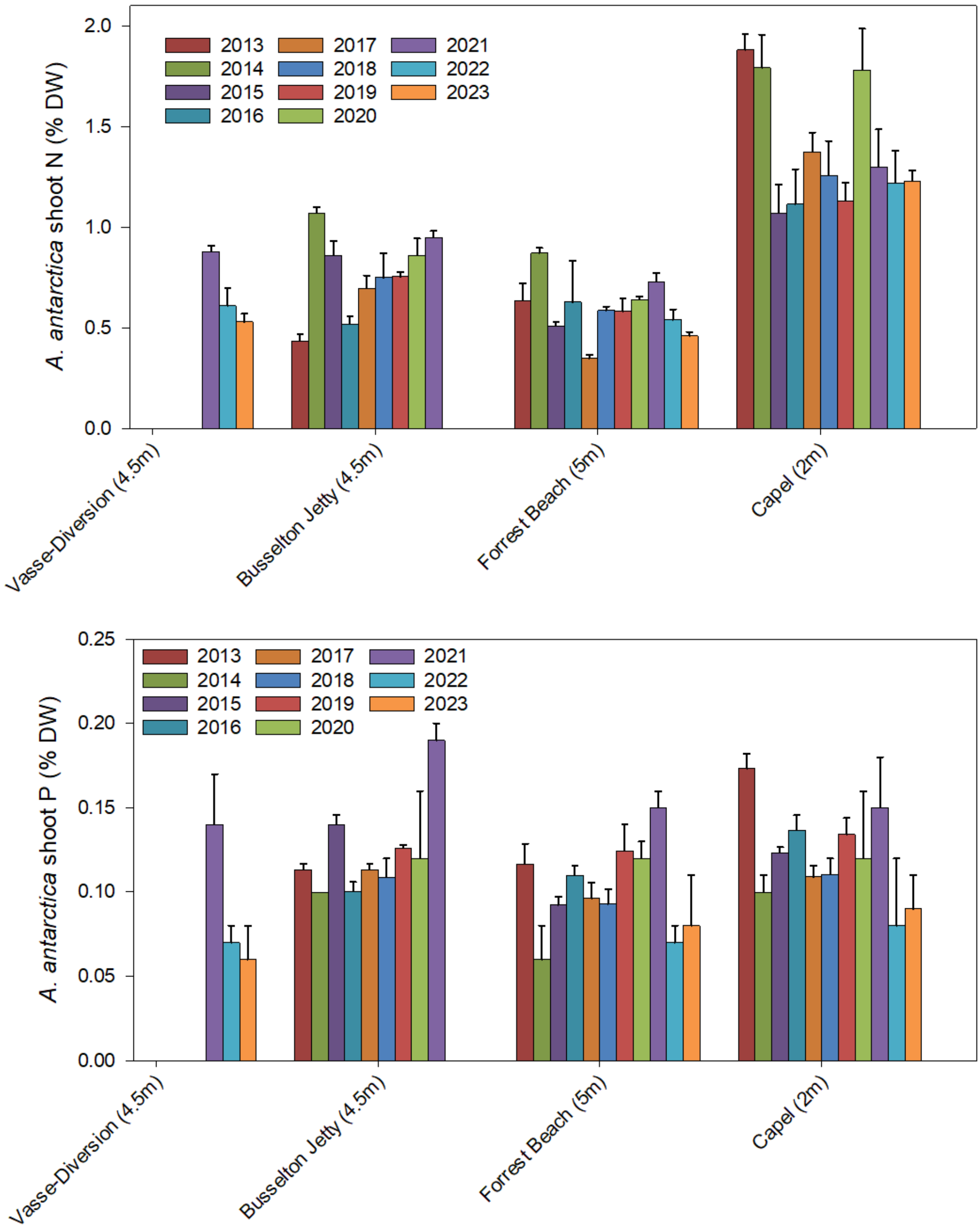
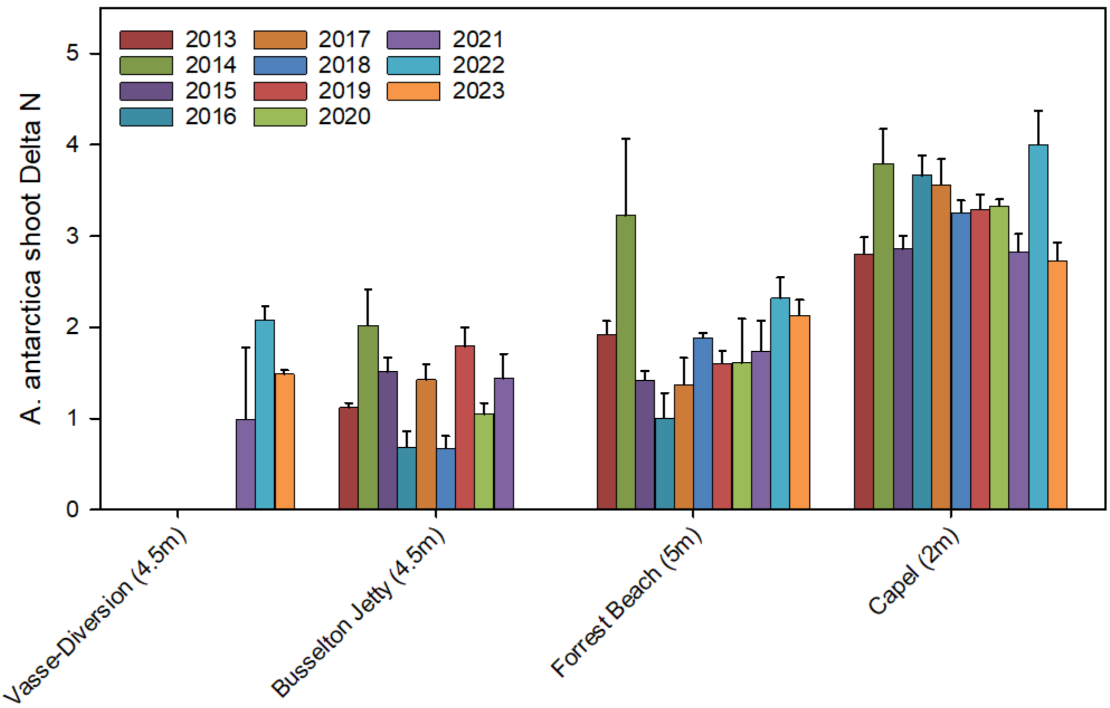


Figure 7: *Nitrogen and phosphorus content (% DW) of* A. antarctica *leaves (average ± se) at the Keep Watch seagrass monitoring sites in 2013-2023. Note that sampling at Busselton Jetty ended in 2021 and with a new site established at Vasse-Diversion drain.*

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).

The $\delta^{15}N$ of *P. sinuosa* leaves ranged from 0.4 to 1.4 ‰. $\delta^{15}N$, slightly lower at most sites this year and all values are in the range that has been observed in the last twelve years (Figure 8). 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‰. 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 1.5-2.7‰, slightly lower at Capel and Vasse Diversion but slightly higher at Forrest Beach compared to last year (Figure 8). 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.



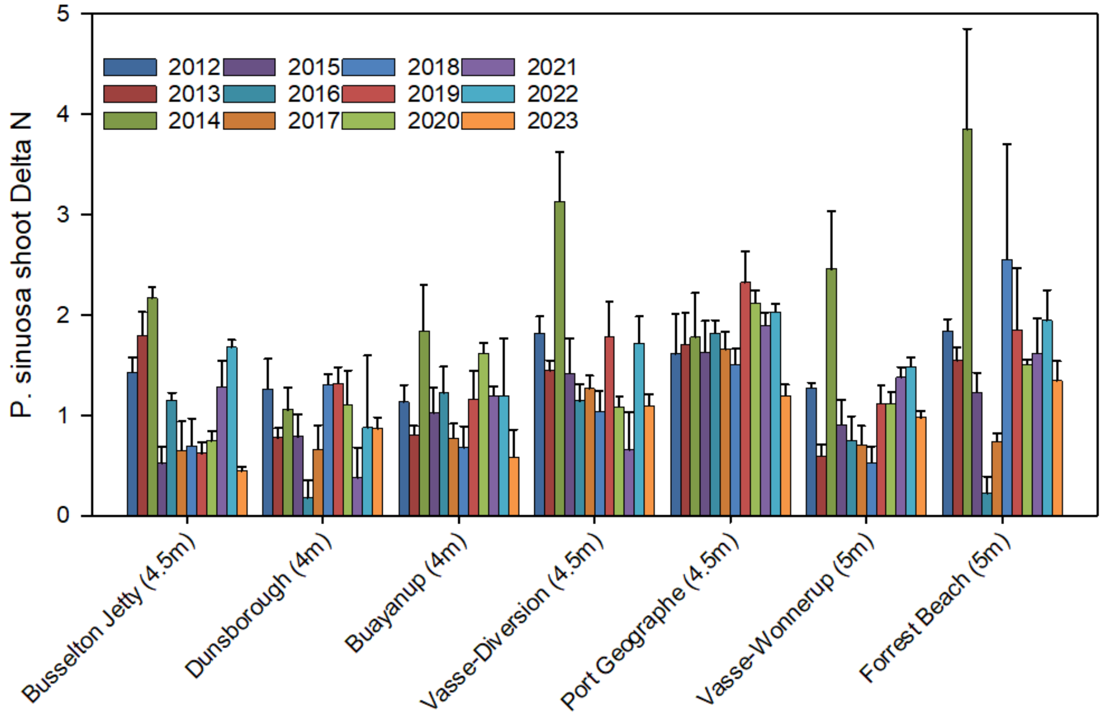


Figure 8: *δ^15^N of* P. sinuosa *leaves (Site 1-7) and* A. antarctica *leaves (Site 4, 6, 7 & 8 average ± se) at the Keep Watch seagrass monitoring sites in 2012-2023 for* P. sinuosa *and 2013-2023 for* A. antarctica*. Note that only Capel was measured in 2012 for* A. antarctica*, and is not included in these graphs.*

The epiphytic macroalgae, *Dictyota* had higher nitrogen and phosphorus content (% DW) at Capel compared to Dunsborough and Forrest Beach, ~2-3x higher (Figure 9). Like the information for seagrass, the $\delta^{15}N$ for the algae was also higher at Capel, indicating different sources of nitrogen at Capel (Figure 10). Note that this year algae was collected from an additional site at Forrest Beach and it was most similar to the Dunsborough site.

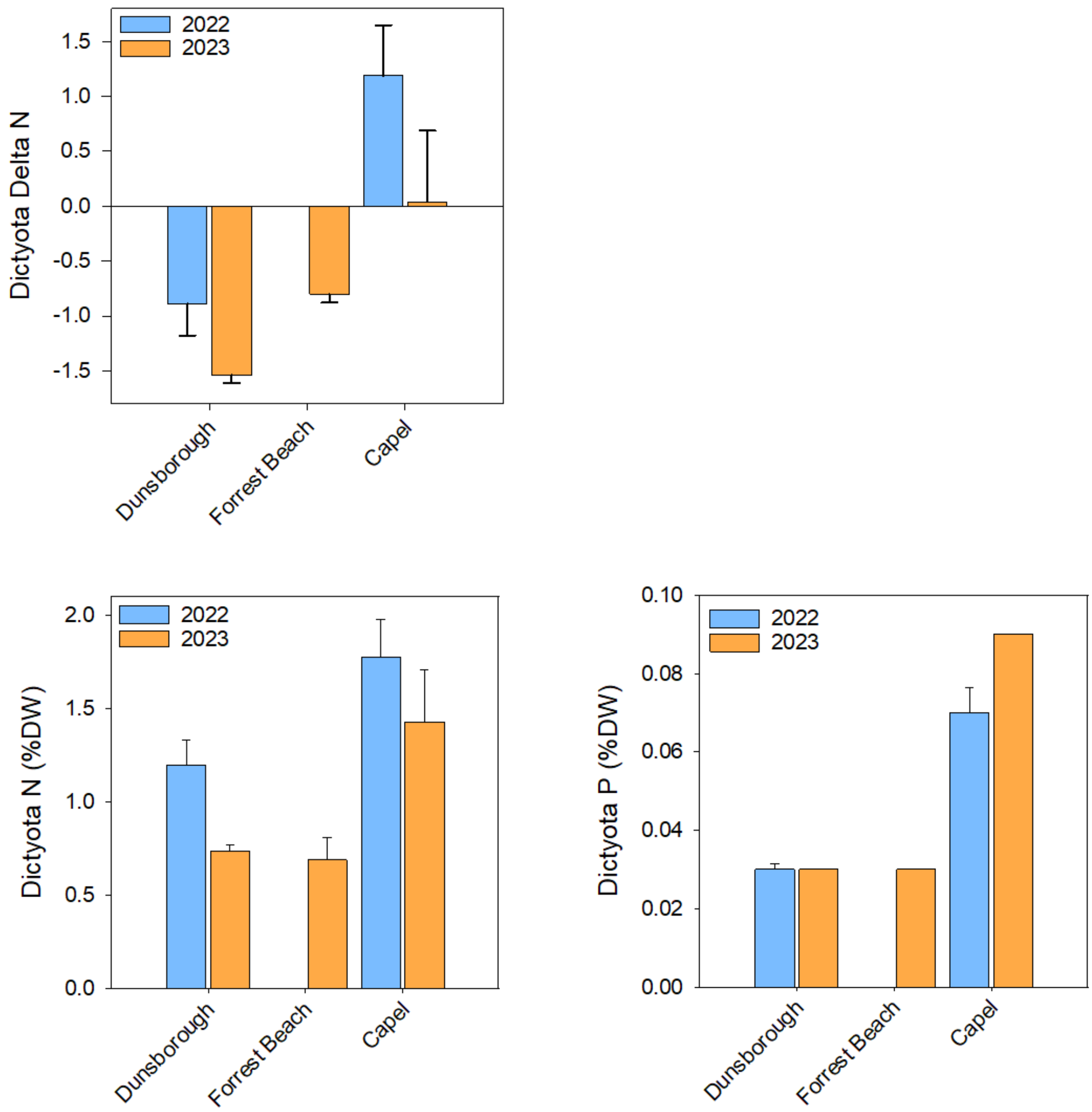


Figure 9: *Nutrient (N, P) and $\delta^{15}N$ of the epiphytic macroalgae* Dictyota from two *Keep Watch seagrass monitoring sites in 2022 and 2023, Dunsborough and Capel and one Keep Watch Seagrass monitoring site in 2023, Forrest Beach.*

4.5 Water quality

Water temperature at the Keep Watch seagrass sites ranged from 22.9-24.4°C. Water clarity was high and the Secchi disk was always observed on the bottom (Table 5).

Table 5: *Water quality measures at the Keep Watch seagrass monitoring sites from 2012-2023, *=Secchi disk depth on bottom.*

Site	**Secchi disk depth (m)**											
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1. Dunsborough	4.2*	3	3	3.2*	3*	3.5*	2.7	2.7	4.0*	3.3	4.0*	3.5*
2. Buayanup	3.5	2.5	3*	3.2*	3.5*	2.5*	3*	2.8	3.5*	3.2	3.5*	3.5*
3. Vasse Diversion	4	3.25	3.5*	3.6*	3.5*	5*	3.3	3	3.5*	3.4	4.0*	4.0*
4. Busselton Jetty	4.2	2.5	3.5	3.6*	3.5*	2.5*	4*	2.9	3.5*	3.1	4.5*	3.7*
5. Port Geographe	3.75	2.5	4	4.1*	3.5	4.5*	3.5*	3.2	3.0*	4.5*	3.5*	3.6*
6. Vasse-Wonnerup	4	2	4.5	4.6*	4.5*	4*	4.5*	4	4.5*	5.4*	5.0*	4.6*
7. Forrest Beach	5*	2	4	4.2*	4.5*	4*	3.5	3.8	4.5*	5*	5.0*	4.3*

	Temperature (°C)											
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1. Dunsborough	22	22.5	23.1	23.3	22.9	22.5	21.2	20.6	23.5	20.0	23.6	22.9
2. Buayanup	22.8	22.6	23.5	25.2	23.7	22.8	21.7	21.7	24.4	20.1	23.9	24.3
3. Vasse Diversion	23.4	23.8	23.5	24.5	23.9	22	22.1	21.7	24.7	20.9		24.4
4. Busselton Jetty	23.4	27.3	23.3	26.3	22.6	22.5	22.6	22.8	23.6	20.9		23.3
5. Port Geographe	23.4	25.5	23.3	24.3	23	22.5	22.3	22.8	23.7	20.9		24.1
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	24.3
7. Forrest Beach	22.5	23.5	22.1	25.1	23.3	22.5	21.5	21.7	24.0	21.4		23.6

5 General conclusions

5.1 Shoot density indicates healthy conditions

Once again, in 2023 none of the three management criteria were triggered. Last year, five sites either increased or remained stable, whereas this year four sites declined and three increased or remained stable. The two sites with greaer than 20% decline were central sites, Busselton Jetty and Port Geographe. This is the first time a greater than 20% decline has been observed at Busselton Jetty and the second for Port Geogrpahe. (Figure 10). Overall there are no significant declines since 2012 when the program began and one site Vasse-Diversion has a significant increase. The average shoot denisity in Geographe Bay continues to be 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	2023
1. Dunsborough	61	64	52	56	61	59	53	56	61	68	63	66
2. Buayanup	59	66	50	60	57	58	55	63	56	60	59	56
3. Vasse Diversion	34	37	34	34	29	34	38	41	48	37	41	40
4. Busselton Jetty	38	38	46	44	45	45	43	52	49	45	49	39
5. Port Geographe	39	46	42	47	45	35	49	62	50	48	42	32
6. Vasse-Wonnerup	38	45	51	49	48	50	47	53	51	44	45	37
7. Forrest Beach	53	61	47	48	50	49	53	53	59	42	49	48

Figure 10: *Heatmap of changes in average shoot density of* P. sinuosa *over time, 2012-2023, at each Keep Watch seagrass monitoring sites.*

5.2 Algal epiphyte cover consistent

The patterns in cover of algae among sites has remained consistent and is slightly lower than last year. There are no major concerns as there are no obvious links with algal cover and seagrass condition (Figure 11). 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	2023
1. Dunsborough	3	2	3	3	2	2	3	3	3	2	3	3
2. Buayanup	3	2	3	3	4	4	3	1	4	4	4	4
3. Vasse Diversion Drain	2	3	4	4	4	4	4	2	4	4	4	3
4. Busselton Jetty	2	2	4	4	3	3	3	2	4	4	4	3
5. Port Geographe	2	1	2	2	3	3	3	2	3	3	3	3
6. Vasse-Wonnerup	2	1	2	3	2	2	2	1	2	3	2	3
7. Forrest Beach	2	1	2	2	2	1	2	1	2	2	1	2

Figure 11: *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 and macroalage are very low and do not indicate exposure to excess nutrients. Capel continues to have higher nitrogen 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 (2.7 ‰) indicate nitrogen derived from animal wastes or septic tanks or sources from natural vegetation. Although the seagrass phosphorus levels were not elevated at Capel, there were indications of higher phosphorus levels in the macroalgae compared to other sites. This was also observed last year, highlighting the value of multiple species to discern nutrient exposure due to the different timescales over which they incorporate nutrients.

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Appendix 1: Randomly generated quadrat positions from 2023 survey.

Quadrat #	Bearing	Distance
1	80	2
2	80	6
3	80	15
4	80	20
5	80	23
6	80	25
7	120	10
8	120	13
9	120	16
10	120	19
11	120	20
12	120	23
13	240	4
14	240	16
15	240	18
16	240	20
17	240	23
18	240	25
19	300	2
20	300	6
21	300	11
22	300	15
23	300	23
24	300	25
25	340	1
26	340	4
27	340	9
28	340	12
29	340	16
30	340	24

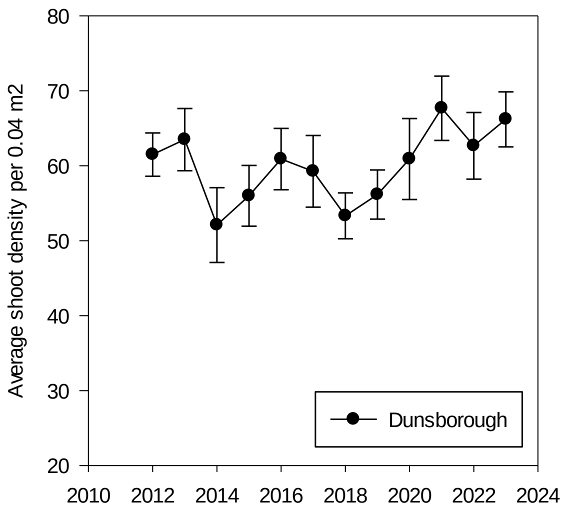
Appendix 2: Raw and summary statistics for shoot density data for the seven Keep Watch Seagrass Monitoring Sites in 2023.

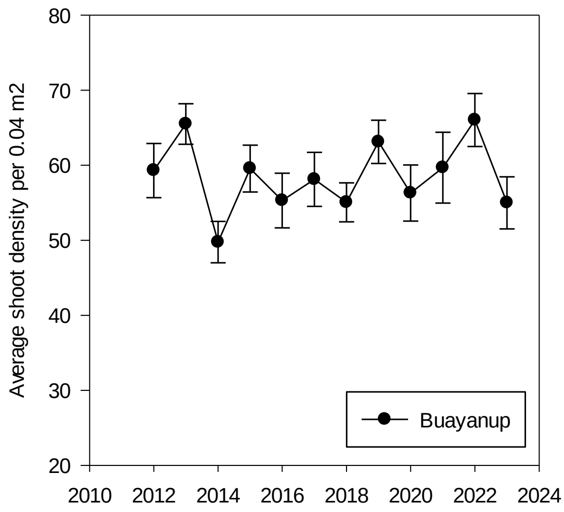
	1. Dunsborough			2. Buayanup			3. Vasse Diversion			4. Busselton Jetty			5. Port Geographe			6. Vasse-Wonnerup			7. Forrest Beach		
Rep	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter
1	45	1	GS	45	3	GS	48	0	GS	46	0	GS	17	0	GS	39	0	GS	43	0	KM
2	49	0	GS	61	0	GS	33	0	GS	29	0	GS	15	0	GS	29	0	GS	50	5	KM
3	51	0	GS	45	0	GS	29	0	GS	39	0	GS	23	0	GS	24	0	GS	60	3	KM
4	66	0	GS	41	0	GS	51	0	GS	29	0	GS	27	1	GS	31	1	GS	48	2	KM
5	52	6	GS	49	0	GS	36	1	GS	44	0	GS	29	0	GS	26	0	GS	56	2	KM
6	54	3	GS	42	0	GS	42	0	GS	28	0	GS	33	0	GS	29	0	GS	56	3	KM
7	55	0	KA	23	0	DL	39	0	DL	33	0	KA	37	0	SB	38	0	KA	18	0	KA
8	65	0	KA	47	0	DL	47	3	DL	33	0	KA	31	0	SB	40	0	KA	45	0	KA
9	63	0	KA	65	0	DL	48	1	DL	31	0	KA	17	0	SB	37	0	KA	54	0	KA
10	44	0	KA	75	0	DL	66	0	DL	35	0	KA	46	0	SB	40	0	KA	57	0	KA
11	81	0	KA	50	0	DL	46	0	DL	42	0	KA	48	0	SB	32	0	KA	34	2	KA
12	57	0	KA	37	0	DL	41	0	DL	48	0	KA	33	0	SB	35	0	KA	26	0	KA
13	46	0	SB	115	0	SB	30	0	KA	55	1	EH	28	0	EH	45	0	EH	38	0	SB
14	87	0	SB	72	2	SB	37	0	KA	31	3	EH	17	0	EH	42	1	EH	22	3	SB
15	129	0	SB	78	1	SB	37	0	KA	33	1	EH	39	0	EH	44	0	EH	78	1	SB
16	97	0	SB	84	0	SB	21	0	KA	31	0	EH	45	0	EH	42	1	EH	52	2	SB
17	67	0	SB	48	0	SB	43	0	KA	17	0	EH	28	0	EH	35	2	EH	45	1	SB
18	90	0	SB	61	0	SB	17	0	KA	41	1	EH	15	0	EH	34	2	EH	72	0	SB
19	53	3	KM	53	0	KM	20	1	KM	52	3	KM	14	0	KM	52	3	KM	49	2	SB
20	67	0	KM	48	1	KM	36	1	KM	56	2	KM	46	2	KM	32	2	KM	67	0	SB
21	69	0	KM	63	2	KM	33	0	KM	41	3	KM	36	0	KM	40	2	KM	49	1	SB
22	38	0	KM	51	2	KM	28	2	KM	47	0	KM	23	0	KM	60	0	KM	40	0	SB
23	85	2	KM	76	3	KM	43	0	KM	29	3	KM	42	0	KM	66	2	KM	49	1	SB
24	54	2	KM	62	2	KM	49	3	KM	55	2	KM	49	0	KM	46	2	KM	87	1	SB
25	49	0	KA	34	5	SB	34	0	KA	42	1	KM	68	0	SB	29	2		64	2	KA
26	81	0	SB	42	5	SB	39	0	DL	52	3	KM	16	1	GS	25	0		29	1	KA
27	61	0	GS	44	2	GS	54	0	GS	35	0	KM	42	0	EH	32	0		46	2	KA
28	64	0	KA	33	1	KM	64	0	KM	42	3	KM	22	0	GS	35	2		53	2	KM
29	66	0	SB	72	1	DL	44	2	KM	35	1	KM	52	0	SB	22	0		31	4	KA
30	100	0	KM	34	0	SB	37	0	DL	27	2	GS	50	0	SB	23	0	GS	31	2	KM
Average	**66.2**	**0.6**		**55.0**	**1.0**		**39.7**	**0.5**		**38.6**	**1.0**		**32.9**	**0.1**		**36.8**	**0.7**		**48.3**	**1.4**	
Median	**63.5**	**0.0**		**49.5**	**0.0**		**39.0**	**0.0**		**37.0**	**0.0**		**32.0**	**0.0**		**35.0**	**0.0**		**49.0**	**1.0**	
SE	**3.67**	**0.25**		**3.47**	**0.27**		**2.08**	**0.16**		**1.79**	**0.22**		**2.53**	**0.08**		**1.87**	**0.18**		**2.93**	**0.24**	
Stdev	**20.11**	**1.36**		**19.02**	**1.46**		**11.37**	**0.90**		**9.80**	**1.22**		**13.84**	**0.43**		**10.25**	**0.98**		**16.03**	**1.33**	
CV	**0.30**	**2.39**		**0.35**	**1.46**		**0.29**	**1.93**		**0.25**	**1.26**		**0.42**	**3.26**		**0.28**	**1.34**		**0.33**	**0.95**	

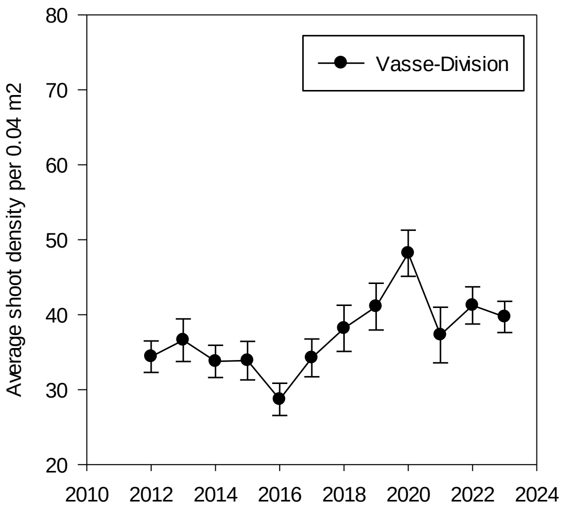
Appendix 3: Leaf morphology data for 2023

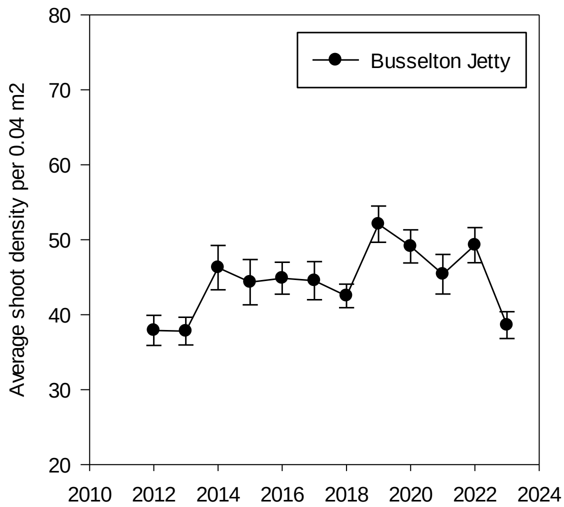
	S1. Dunsborough		S2. Buayanup		S3. Vasse Diversion		S4. Busselton Jetty		S5. Port Geographe		S6. Vasse-Wonnerup		S7. Forrest Beach	
Rep	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (cm)	Shoot Width (mm)
1	63.5	7.0	72.0	5.0	61.3	6.5	64.5	5.0	73.0	6.0	44.5	6.5	40.0	6.0
2	57.8	6.5	51.0	5.5	50.2	6.5	63.2	5.0	52.0	6.0	48.0	5.0	34.5	6.0
3	66.0	6.5	62.8	5.0	74.4	6.0	53.9	5.0	63.2	6.5	80.2	6.0	42.0	6.0
4	71.0	6.0	51.8	5.0	55.8	7.0	68.9	5.0	72.0	6.5	61.2	6.0	33.5	6.0
5	61.5	6.5	48.0	4.5	58.5	5.5	58.5	5.0	57.0	7.0	78.0	6.5	33.2	6.0
6	46.0	6.0	52.1	5.0	63.5	5.5	47.0	7.0	52.5	6.0	39.5	4.5	57.0	7.0
7	64.2	6.0	53.0	4.5	83.9	6.0	45.8	5.0	51.8	5.5	49.0	5.0	59.0	6.0
8	50.5	5.5	53.5	5.0	57.5	7.0	59.8	6.0	50.2	5.5	44.0	4.0	51.6	6.0
9	46.5	5.0	50.0	5.5	71.4	6.5	45.2	6.0	47.3	6.0	60.7	6.5	49.3	5.5
10	58.5	5.0	45.2	5.0	49.8	7.0	73.8	5.5	45.5	5.5	48.8	7.0	42.6	5.5
11	54.7	5.5	46.1	5.0	60.9	6.0	37.2	5.0	66.5	7.0	76.5	5.0	59.2	6.0
12	52.0	6.0	61.5	4.0	73.8	6.0	44.7	5.5	60.1	6.0	83.0	6.0	54.2	5.5
13	61.3	6.0	50.8	5.5	46.0	6.0	58.5	6.0	50.4	6.0	50.0	6.5	53.4	5.0
14	52.0	5.5	49.3	5.0	48.5	6.0	40.3	5.0	56.3	5.5	59.8	7.0	59.9	6.0
15	66.0	5.0	73.0	5.0	65.4	6.0	59.0	5.0	62.0	5.5	84.5	6.0	42.0	5.0
Average	58.1	5.9	54.7	5.0	61.4	6.2	54.7	5.4	57.3	6.0	60.5	5.8	47.4	5.8
SE	2.0	0.2	2.2	0.1	2.8	0.1	2.8	0.2	2.2	0.1	4.1	0.2	2.5	0.1
Min	46.0	5.0	45.2	4.0	46.0	5.5	37.2	5.0	45.5	5.5	39.5	4.0	33.2	5.0
Max	71.0	7.0	73.0	5.5	83.9	7.0	73.8	7.0	73.0	7.0	84.5	7.0	59.9	7.0

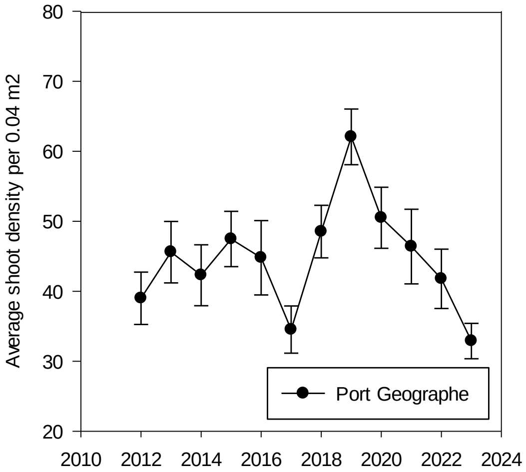
Appendix 4: Trends over time in seagrass shoot density.

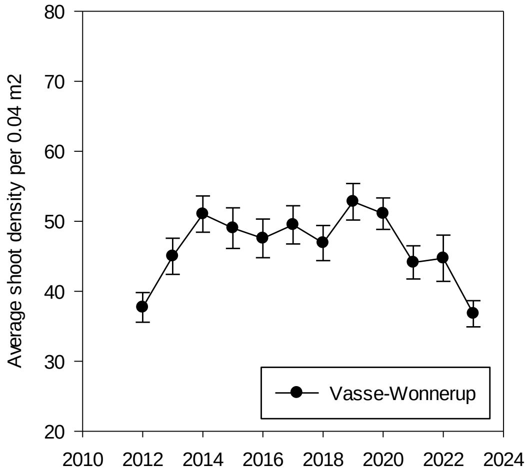


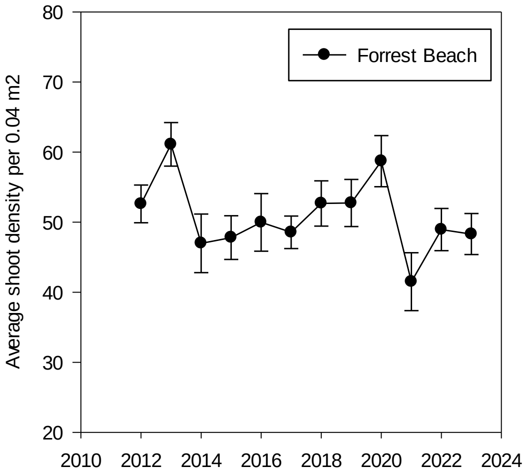







Average shoot density per 0.04 m2
Port Geographe
80
70
60
50
40
30
20
2010
2012
2014
2016
2018
2020
2022
2024


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


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

Appendix 5: Nutrient data for 2023 including the original and modified calibrated values for seagrasses and macroalgae.

Site	Species	Modifiedδ15N [‰ AIR	Modified N [wt %]	P (% DW)
Dunsborough	Posidonia	0.39	0.50	0.17
Dunsborough	Posidonia	0.44	0.52	0.12
Dunsborough	Posidonia	0.52	0.35	0.14
Buayanup	Posidonia	0.81	0.57	0.12
Buayanup	Posidonia	1.08	0.71	0.15
Buayanup	Posidonia	0.73	0.61	0.10
Vasse-Diversion	Posidonia	0.83	0.38	0.14
Vasse-Diversion	Posidonia	0.05	0.53	0.13
Vasse-Diversion	Posidonia	0.90	0.44	0.11
Busselton Jetty	Posidonia	1.07	0.46	0.09
Busselton Jetty	Posidonia	1.30	0.56	0.10
Busselton Jetty	Posidonia	0.92	0.45	0.11
Port Geographe	Posidonia	1.30	0.58	0.11
Port Geographe	Posidonia	0.97	0.67	0.08
Port Geographe	Posidonia	1.31	0.90	0.13
Vasse-Wonnerup	Posidonia	1.08	0.51	0.15
Vasse-Wonnerup	Posidonia	1.01	0.38	0.13
Vasse-Wonnerup	Posidonia	0.85	0.44	0.13
Forrest Beach	Posidonia	1.65	0.56	0.10
Forrest Beach	Posidonia	1.39	0.56	0.09
Forrest Beach	Posidonia	1.00	0.44	0.08
Vasse-Diversion	Amphibolis	1.47	0.57	0.07
Vasse-Diversion	Amphibolis	1.43	0.57	0.05
Vasse-Diversion	Amphibolis	1.56	0.45	0.07
Forrest Beach	Amphibolis	2.22	0.49	0.08
Forrest Beach	Amphibolis	2.36	0.44	0.10
Forrest Beach	Amphibolis	1.81	0.44	0.07
Capel	Amphibolis	2.48	1.13	0.09
Capel	Amphibolis	2.61	1.26	0.08
Capel	Amphibolis	3.12	1.29	0.10
Dunsborough	Dictyota	-1.57	0.78	0.03
Dunsborough	Dictyota	-1.62	0.76	0.03
Dunsborough	Dictyota	-1.41	0.67	0.03
Forrest Beach	Dictyota	-0.83	0.57	0.03
Forrest Beach	Dictyota	-0.65	0.58	0.03
Forrest Beach	Dictyota	-0.91	0.92	0.04
Capel	Dictyota	0.78	0.99	0.08
Capel	Dictyota	0.60	1.38	0.09
Capel	Dictyota	-1.25	1.94	0.08