Edith Cowan University
Centre for Marine Ecosystems Research

Keep Watch Seagrass Monitoring 2021 Report for GeoCatch

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Cite as:
McMahon and Dunham (2021). Keep Watch Seagrass Monitoring, 2021. Report to GeoCatch. Centre for Marine Ecosystems Research, Edith Cowan University 38 pages.

This work was funded by GeoCatch and Water Corporation and supported in-kind by Department of Biodiversity, Conservation and Attractions.

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Keep Watch Seagrass Monitoring

Annual Report 2021

Investigator: Kathryn McMahon and Natasha Dunham

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

June 2021

1 Executive Summary

1.1 Introduction

This report summarises ten years of data (Feb 2012 - Feb 2021) from the Keep Watch Seagrass Monitoring Program in Geographe Bay. The program was developed 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. 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 2012-2021

Key finding 1

Over 10 years the Keep Watch program has identified no major concerns regarding seagrass health. There have been fluctuations in seagrass shoot density with no significant trends of decline, and no management triggers breached. This year, most sites did have a small to modest decline but for all but one site, this was in the range observed over the ten years. These shoot densities in Geographe Bay are above or in the upper range of other temperate *Posidonia sinuosa* seagrass meadows in Western Australia, highighting the value of this ecosystem.

Key finding 2

Epiphyte cover has fluctuated over time, generally sites in the centre of the bay have the highest epiphyte cover. The last two years have had the highest cover observed with three sites recording high cover. This is a concern as persistent high cover can negatively impact seagrass condition and most sites did experience small declines this year. The most common types of algae present are microalgae, which is not often associated with nutrient enrichment in seagrass ecosystems, although they do respond to increases in nutrient. As no significant seagrass declines were observed, this is not a major concern at this time, unless the algal cover persists or continues to increase into next year.

Key finding 3

Nutrient content of seagrasses in Geographe Bay is relatively low and there was a slight drop compared to last year. The high algal cover persisted which could also be stimulated by nutrients, supporting the value of actions to reduce nutrient loads in the catchment. However, higher exposure to nutrients was not documented. Nutrient concentration varied slightly across years and sites, and the main difference is two times higher nitrogen content at Capel compared to all other sites, indicating higher loads of nutrients reaching seagrasses at Capel.

Key finding 4

The main sources of nitrogen for seagrass at most sites is likely to be from fixation of atmospheric nitrogen or agricultural fertilisers. A 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.

Key finding 5

Since the beginning of the Keep Watch program it has been recommended to undertake seagrass extent mapping every 5 years to link with the annual seagrass monitoring. This now has been arranged and will be undertaken in collaboration with DBCA and DWER in 2021.

1.3 Recommendations

These recommendations are based on the last ten years of Keep Watch monitoring and consider GeoCatch's needs into the future.

Recommendation 1

Continue monitoring seagrass health based on the Keep Watch Monitoring protocol including the quality control in the field and laboratory. *Posidonia sinuosa* meadows should be monitored at seven sites, and nutrient monitoring of *A. antarctica* at three sites. There is a need due to low *A. antarctica* abundance at Busselton Jetty to start collecting this at Vasse Diversion next year. Considering the threat of nutrient enrichment is on-going in the Geographe Bay catchment, monitoring of seagrass health provides an early warning indicator of impacts in Geographe Bay. 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 the collaborative arrangement with ECU, Department of Biodiversity, Conservation and Attractions, GeoCatch and the Water Corporation to coordinate, fund and undertake seagrass monitoring. This is a very effective and beneficial arrangement.

Recommendation 3

The funding for this program has ceased and there will be ten years of data. Long-term information on the health of our ecosystems is highly valuable, enabling managers to assess the effects of management actions as well as local (e.g. anchoring) and global scale (e.g. temperature increases from climate change) pressures. However, this needs to be balanced with other constraints (e.g. funds, time, logistics) and priorities. Therefore, a reassessment of the program is warranted with the key stakeholders to identify the needs and priorities of this program and develop a plan for the future, beyond the current funding.

Recommendation 4

It has been 13 years since seagrass extent mapping was undertaken in Geographe Bay. This is important and complimentary information for this program and it has been recommended to undertake it on a five yearly basis (McMahon 2012). Clearly this has not occurred and should be considered as a priority and included in discussions regarding the plan for this program into the future.

2 Introduction

This document is produced for GeoCatch by Kathryn McMahon and Natasha Dunham from Edith Cowan University. It reports on the Keep Watch seagrass monitoring survey that was undertaken in February 2021 and compares to data from the 2012-2020 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. 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 agreed to by GeoCatch. 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 8th to the 11th February 2021. 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* has been collected at Busselton Jetty (4) and Forrest Beach (7) sites as a comparison to Capel (8) for 9 years (2013-2020). This year *Amphibolis* samples were also collected at Vasse Diversion Drain (3). This was undertaken because the abundance of *A. antarctica* at Busselton Jetty (4) was low and it is not recommended to continue sampling this species at this site into the future. In 2017 there was dieback of *A. antarctica* observed at Busselton Jetty and no recovery into these patches has been observed. Therefore Vasse Diversion Drain which has large patches of *A. antarctica* is an appropriate survey site into the future for this species. Collecting at both sites this year enables comparison between these two sites. The data for these samples are included in the Appendix 5.

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	Species assessed	Rep
1. Dunsborough	S 33.61654°, E 115.12865°	4	11/2/2021	Ps	25
2. Buayanup	S 33.65233°, E 115.24840°	4	11/2/2021	Ps	23
3. Vasse Diversion Drain	S 33.64746°, E 115.32379°	4.5	10/2/2021	Ps, Aa	21
4. Busselton Jetty	S 33.63896°, E 115.34315°	4.5	10/2/2021	Ps, Aa	23
5. Port Geographe	S 33.62846°, E 115.38240°	4.5	09/2/2021	Ps	20
6. Vasse-Wonnerup	S 33.60188°, E 115.42345°	5	10/2/2021	Ps	22
7. Forrest Beach	S 33.57295°, E 115.44908°	5	09/2/2021	Ps, Aa	20
8. Capel	S 33.51394°, E 115.51508°	2	08/2/2021	Aa	

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.

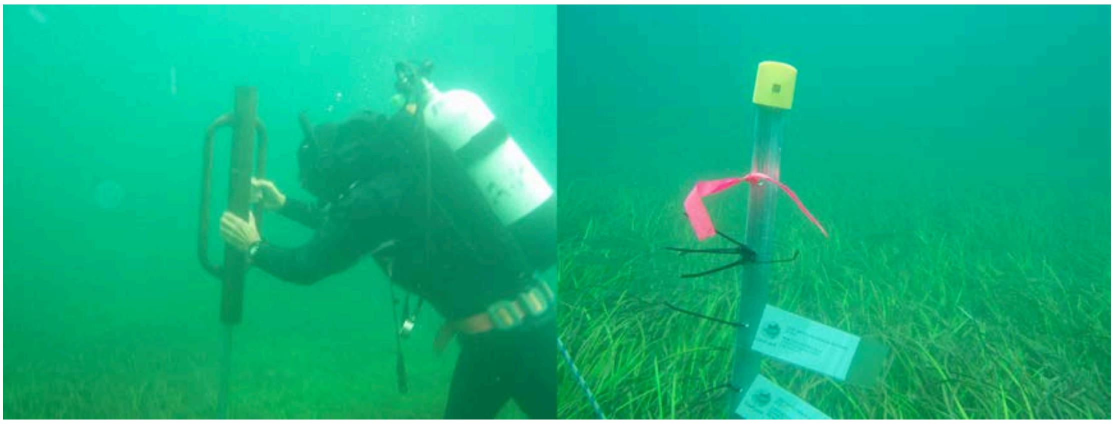


Figure 2: *Left: Banging in permanent marker with pole driver. Right: Star picket with cap and plastic coated site label, indicating center of 50 m diameter Keep Watch seagrass site.*

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. Despite quality checks being carried out, this year after the second day when data was entered it was noted that one diver had much lower shoot counts than all other divers (Appendix. A second quality check was carried out and this diver was not within the 5% error margin. Therefore it was decided to remove this diver's data from the annual counts due to uncertainty with the accuracy. This resulted in the replicates reducing from 30 per site to 20-25 (Table 1).

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.

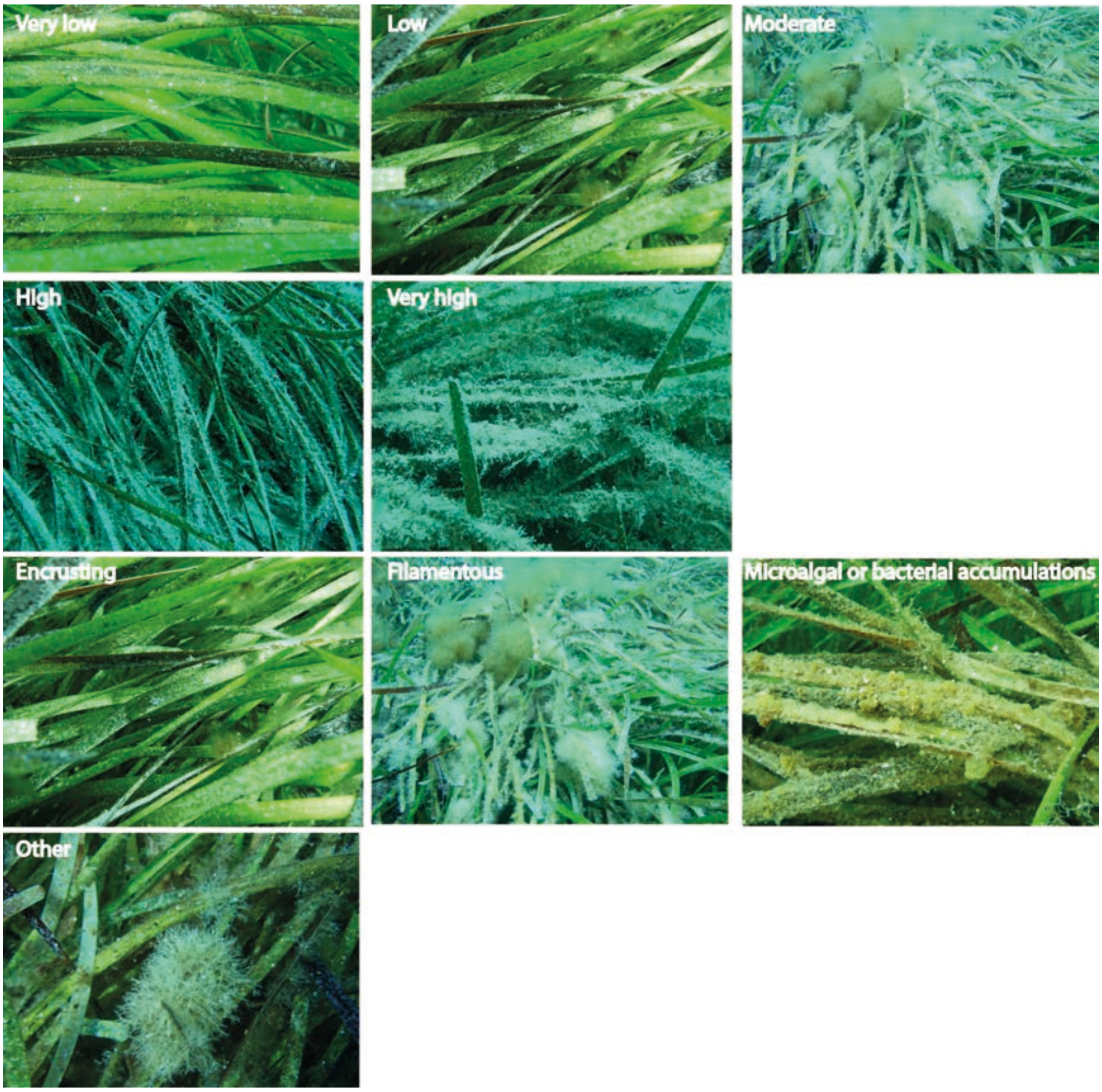


Figure 4: *Classification of epiphytic algal cover and type.*

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.

At each site the Secchi disk depth (m) and temperature were recorded from the boat. In addition temperature loggers in-kind from ECU were installed at the seven *Posidonia* sites to collect local temperature data. These will be switched out every six months. Field work was carried out by Kathryn McMahon (KM) and Ankje Frouws (AF) from ECU with Eden Baxter (EB), Ben French (BF) and Caprice Hyde (CH) from Department of Biodiversity, Conservation and Attractions. Samples were processed and data analysed by Natasha Dunham. The boat and tank fills were provided by Department of Biodiversity, Conservation and Attractions. The monitoring program was funded through sponsorship by Water Corporation.

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 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.

The laboratory that performed the C, N and $\delta^{15}N$ analysis changed in 2020 from UWA to ECU. As there was a slight increase in the %N observed in 2020 compared to previous years it was decided that a re-run of historical samples that had been analysed at the previous laboratory (UWA) was carried out this year, in addition to the standard sampling. Four samples were selected to cover the range of nitrogen content observed in 2019 and re-analysed. There was a consistent difference with the results between the two laboratories. Therefore to make appropriate comparisons over time we have calibrated the ECU data to the UWA laboratory. In this report we have modified both the 2020 and 2021 data using the folling formulas 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 932-1692 shoots m^{-2} across the seven sites (Figure 5). As has been consistent over the life of the program, Dunsborough and Buayanup had the highest shoot density and Vasse Diversion the lowest. The remaining sites ranged between 1037-1211 shoots m^{-2}. All raw data is in Appendix 2.

Compared to last year where three sites decreased in shoot density by up to -19% and the remaining sites had slight increases (between 8 - 17%), this year most sites declined: Busselton Jetty and Port Geographe (-8%), Vasse Wonnerup (-14%), Vasse Diversion (-23%) and Forrest Beach (-29%). However, two sites increased slightly: Buayanup (6%) and Dunsborough (11%) (Table 2). The sites with the greatest declines (Vasse Diversion, Forrest Beach) had been on a trajectory of increasing shoot density up until this year (Figure 5, Appendix 4). Since the first year of monitoring there has been net 17% increase in shoot density at Vasse Diversion but a -13% decline at Forrest Beach. Busselton Jetty (23%), Port Geographe (35%) and Vasse Wonnerup (20%) continue to show the greatest net increases since the start of the program. Interestingly the variations over time continue to be site specific, with little consistency among sites (Appendix 4).

Compared to other seagrass meadows in the state, all monitoring sites in Geographe Bay are well above the minimum average site shoot density. Dunsborough and

Buanyanup are also above the maximum average site shoot density (1 220 m^2) and the remaining sites in Geogrpahe Bay are just below the maximum, except for Vasse Diversion which is 300 shoot m^{-2} below the maximum (Figure 5, Data Courtesy of DBCA from equivalent monitoring programs in the the Shoalwater Bay and Jurien Bay Marine Parks).

P. sinuosa average shoot length ranged from a minimum of 35 cm at Dunsborough to a maximum of 93 cm at Vasse Wonnerup and a range in width of 5.4-6.5 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**	**12-21**
1. Dunsborough	3	-18	7	9	-3	-10	5	8	11	14
2. Buayanup	11	-24	20	-7	2	-5	15	-11	6	8
3. Vasse Diversion	6	-8	0	-15	19	12	8	17	-23	17
4. Busselton Jetty	0	22	-4	1	-1	-5	23	-6	-8	23
5. Port Geographe	17	-7	12	-6	-23	41	28	-19	-8	35
6. Vasse-Wonnerup	19	13	-4	-3	4	-5	13	-3	-14	20
7. Forrest Beach	16	-23	2	5	-3	8	0	11	-29	-13

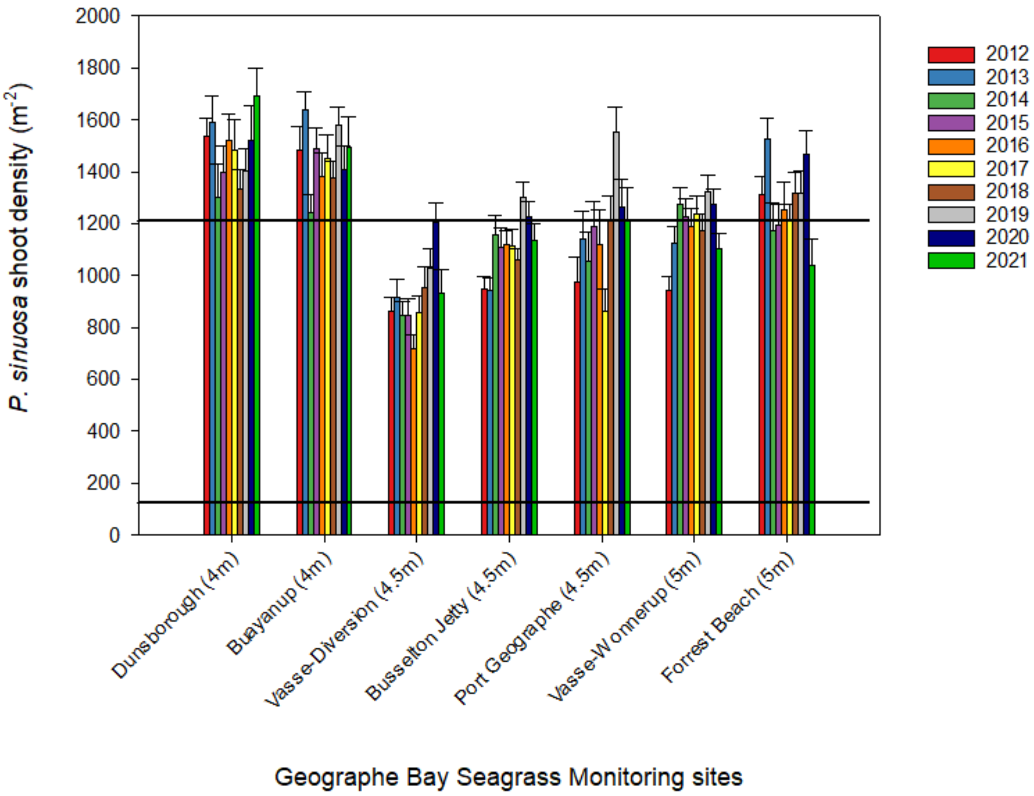


Figure 5: *Shoot density (average m^{-2} ± se) at the seven Keep Watch seagrass monitoring sites with P. sinuosa meadows in January or February 2012-2021. Black lines indicate the minimum and maximum site averages from the reference sites at 3-5 m in Shoalwater Bay and Jurien Bay Marine Parks from 2012-2020 (data courtesy of DBCA, 2021).*

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 2020-2021).

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 2019-2020 & 2020-2021). Although it would be recommended to assess both Forrest Beach and Vasse Diversion Drain in 2022 for Trigger 2 as they are sites that could breach this trigger next year due to the 29% and 23% decline respectively in 2021. Over the entire monitoring program (2012-2021) declines of 20% or more have only occurred in three years but not consecutively, 2013-14 (two sites), 2016-17 (one site) and 2020-21 (two sites). This has generally occurred only once at these sites, with the exception of Forrest Beach where it has occurred twice, this year and in 2013-14.

4.2.3 Trigger 3

No sites showed a significant linear trend over the ten years, nither increasing or decreasing in shoot density (Table 3). When the plots of individual sites are examined (Appendix 4), linear increases in shoot density are obvious at a few sites but only over a subset of the years. For example, Dunsborough has a linear increase in shoot density from 2018 to 2021, Vasse Diversion from 2016 to 2020 and Port Geographe from 2017-2019 followed by a steady decline since (Appendix 4). Forrest Beach has a steady increase in shoot density from 2014 to 2020 with this year's average density decreasing sharply to densities below the original recording in 2012 (Appendix 4).

***Table 3**: Mann-Kendall Trend statistic to assess if there has been a significant decline over time in shoot density from 2012-2021.*

Site Name & #	Significance ($p<0.05$)	Overall slope	R^2
1. Dunsborough	ns	+ve	3%
2. Buayanup	ns	+ve	0%
3. Vasse Diversion	ns	+ve	32%
4. Busselton Jetty	ns	+ve	50%
5. Port Geographe	ns	+ve	62%
6. Vasse-Wonnerup	ns	+ve	19%
7. Forrest Beach	ns	-ve	3%

4.3 Epiphytes

This year epiphyte cover remained relatively stable at all sites, with the exception of Dunsborough which has decreased to low cover after recording moderate cover for the last three years (Table 4). At Vasse Wonnerup the epiphyte cover increased one category from Low to Moderate (Figure 6, Table 4). As was recorded in 2020, across all sites the highest categories of cover were observed with two sites low cover, two moderate and three high covers. The type of epiphyte cover was very consistent among sites, with microalgae being dominant at 5 of the 7 sites (Buayanup, Vasse Diversion, Busselton Jetty, Port Geographe and Vasse Wonnerup) or other forms of algae such as *Dictyota* and *Laurencia* at Dunsborough and Forrest Beach. 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 cover at the Keep Watch seagrass monitoring sites, 2012-2021. 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**
1. Dunsborough	M	L	M	M	L	L	M	M	M	L
2. Buayanup	M	L	M	M	H	H	M	VL	H	H
3. Vasse Diversion Drain	L	M	H	H	H	H	H	L	H	H
4. Busselton Jetty	L	L	H	H	M	M	M	L	H	H
5. Port Geographe	L	VL	L	L	M	M	M	L	M	M
6. Vasse-Wonnerup	L	VL	L	M	L	L	L	VL	L	M
7. Forrest Beach	L	VL	L	L	L	VL	L	VL	L	L
	Algal Type									
	-12	**-13**	**-14**	**-15**	**-16**	**-17**	**-18**	**-19**	**-20**	**-21**
1. Dunsborough	O,f,m	F,O	O	O,m	O	O,e,m	O,m	O,m	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
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
4. Busselton Jetty	M,o	O	M	M,f	O,e,m	M,o,e	O,M	O,m	O,m,e,f	M
5. Port Geographe	E, o	E,M	M,e	M,f	O, f	M,o,e	O,M	M	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
7. Forrest Beach	E, M,o	F,E	M,f	O,e	E,o	E,o	O,e	O	E,m,o	O

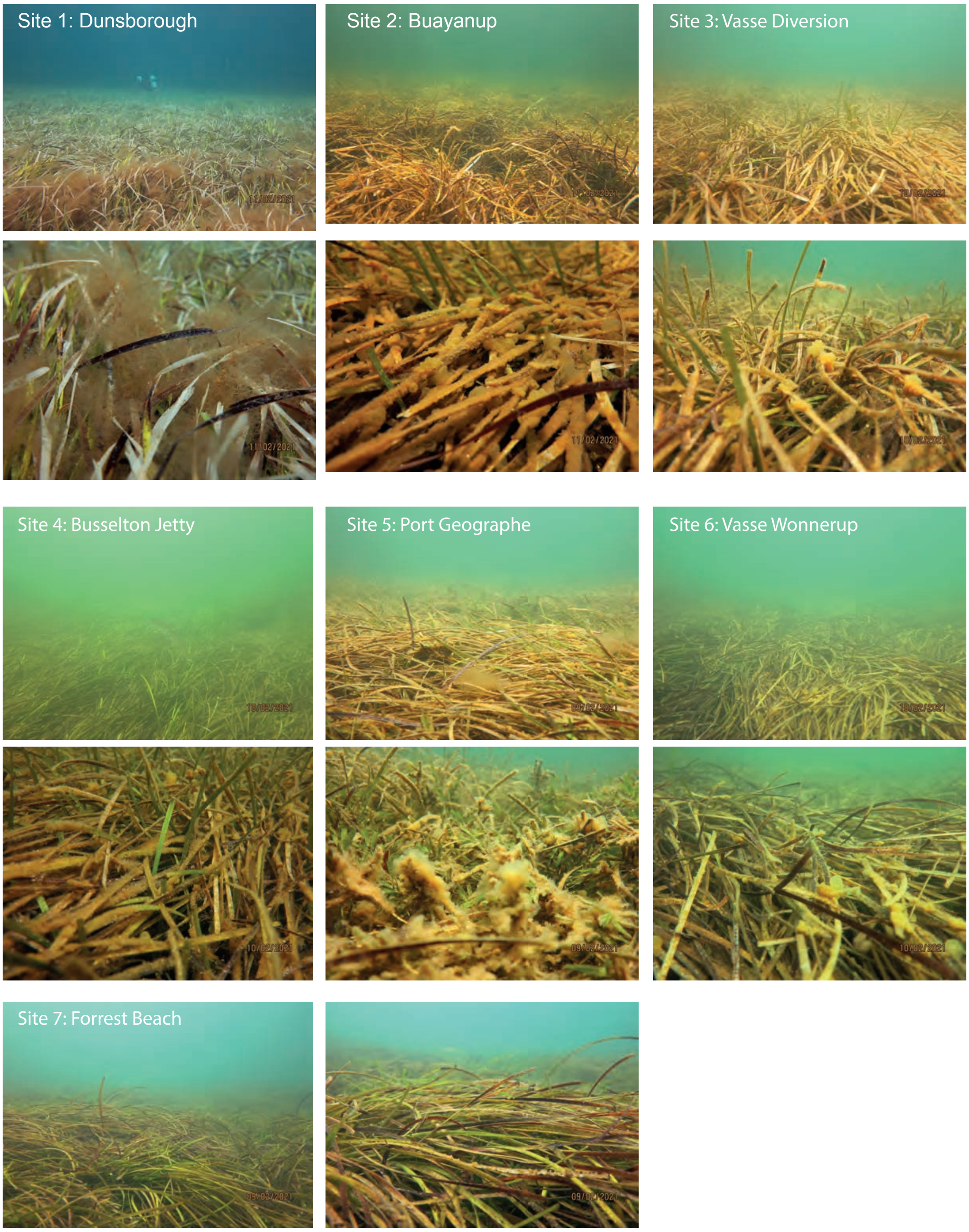


***Figure 6**: Pictures of seagrass meadow and the dominant algal epiphytes at each P. sinuosa site. (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach)*

4.4 Other observations

A. antarctica was observed at all sites except Buayanup and Vasse Wonnerup, although it was had very low abundance at Busselton Jetty. *A. griffithii* was also growing at Forrest Beach and Capel. Seedlings were observed at most sites this year, Dunsborough, Buayanup, Busselton Jetty, Vasse Wonnerup and Forrest Beach. 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

Buayanup, Busselton Jetty and Port Geographe indicating historical and some small scale recent shoot loss. The bare patches at Port Geographe are still present, and the patches of dieback that were observed at Busselton Jetty three years ago appear smaller indicating recovery into the patches by *Posidonia*, but they are still discernable.

Most sites had accumulations of wrack either under the canopy (Dunsborough, Port Geographe, Forrest Beach), on top of the seagrass canopy (Buayanup, Vasse Diversion) or in sand patches on the edge of the meadows (Vasse Diversion, Dunsborough). The white tips on the long leaves at Dunsborough remain, most likely from sun damage due to the shallow and very clear water at this site (Figure 7).

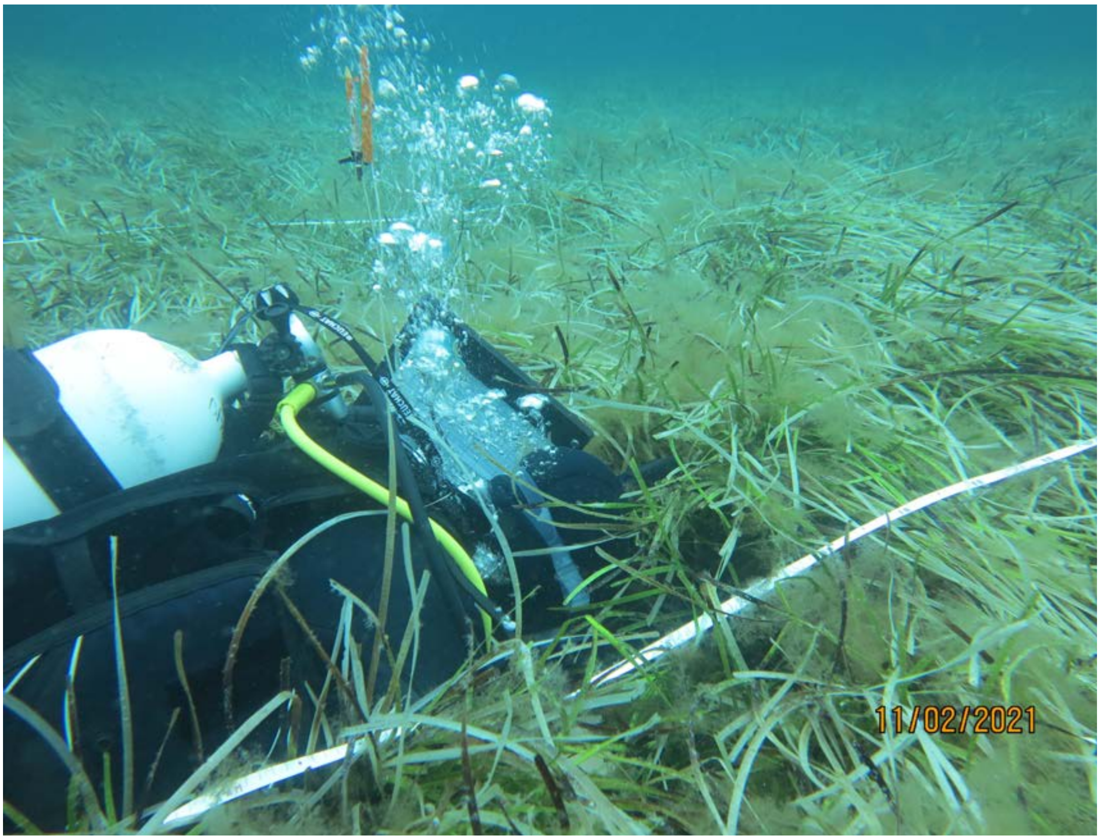


Figure 7*: White tips of leaves obvious at Dunsborough around the diver counting the shoot density.*

The weather during this sampling was overcast, rough and colder than normal which is indicated in the clarity of some of the images (Figure 6).

4.5 Nutrient content

The nutrient data for 2020 and 2021 was calibrated based on the analytical checks carried out this year after switching analytical laboratories. Therefore the values reported from 2020 in this report, are slightly less than those reported in the 2020 annual report (Appendix 5). The nitrogen content of *P. sinuosa* leaves ranged from 0.4-0.7 % N dry weight (DW), very similar to the range observed in 2019 and a slightly lower maximum than 2020 (Figure 8). For all sites except Busselton Jetty there was a slight decrease in concentration compared to last year (Figure 8). The nitrogen content of *A. antarctica* leaves was higher, ranging from 0.7-1.3% N DW, with the highest concentration at Capel (1.4-1.8x higher than the other sites). There continued to be a slight increase in nitrogen content Busselton Jetty and Forrest Beach compared to 2019 and 2020 (Figure 9). There was a decrease at Capel from 1.7 % N DW in 2020 to 1.3 % N DW, similar to concentrations observed in 2017 and 2018.

The phosphorus content of *P. sinuosa* leaves in 2021 ranged from 0.16-0.22% P DW (Figure 8). Three sites, Bussleton Jetty, Vasse Wonnerup and Forrest Beach increased slightly compared to last year (~0.03 % DW) and at some sites there was a high variability between samples. For *A. antarctica* leaves, the phosphorus content ranged from 0.15-0.19% DW and on average there was a slight increase from last year (Figure 9). Busselton Jetty has a slightly higher phosphorus content and Capel is clearly similar to Forrest Beach. All raw data is in Appendix 5.

The *A. antarctica* samples collected fromVasse Diversion for the first time this year was 0.9 ± 0.03% N DW and 0.14 ± 0.03% P DW. This is similar to Busselton Jetty for %N but slightly less for %P.

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 $\delta^{15}N$ 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)**	$\delta^{15}N$	**TN (% DW)**	**TP (% DW)**	$\delta^{15}N$
1994/95 Apr, Jan	(McMahon & Walker 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			

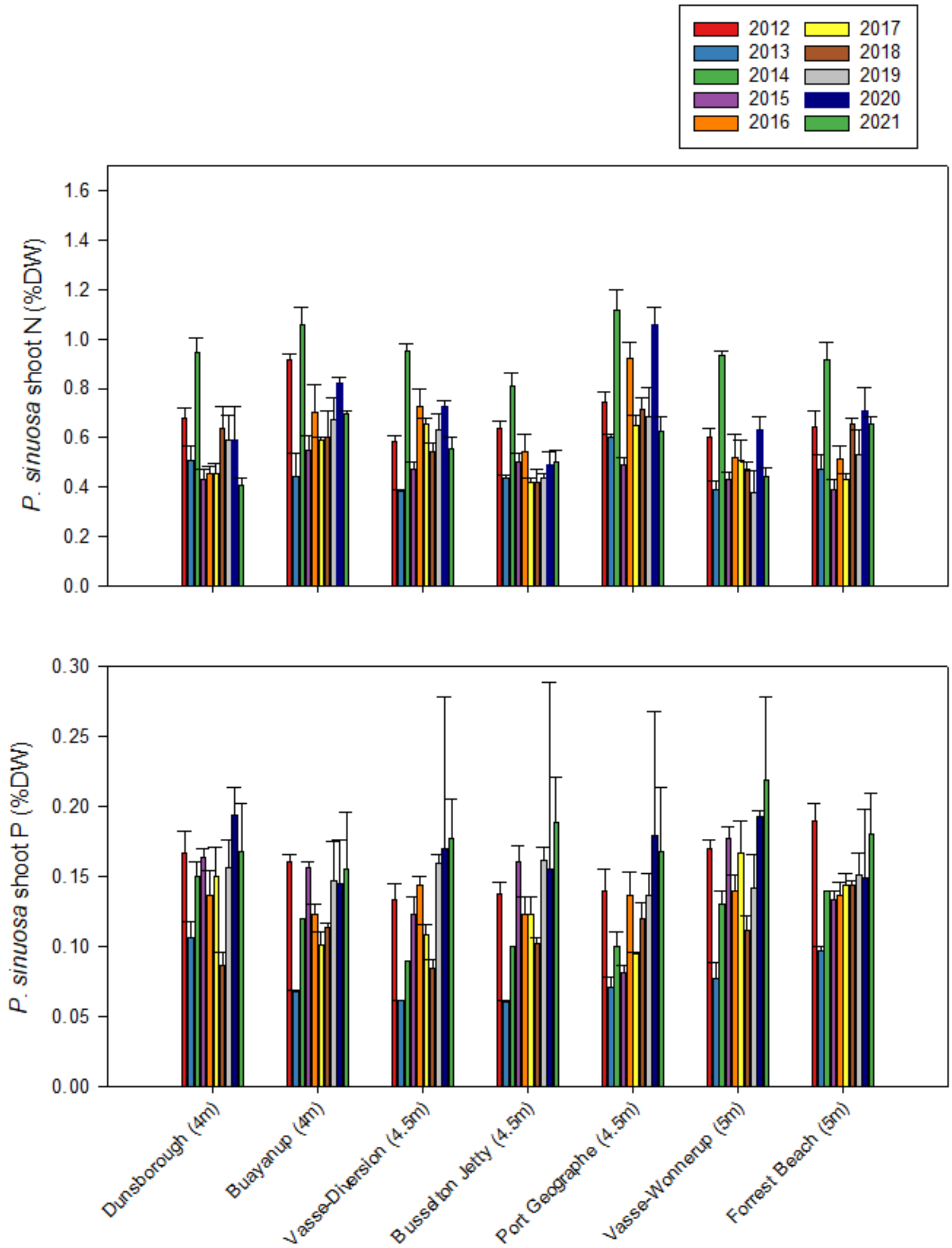
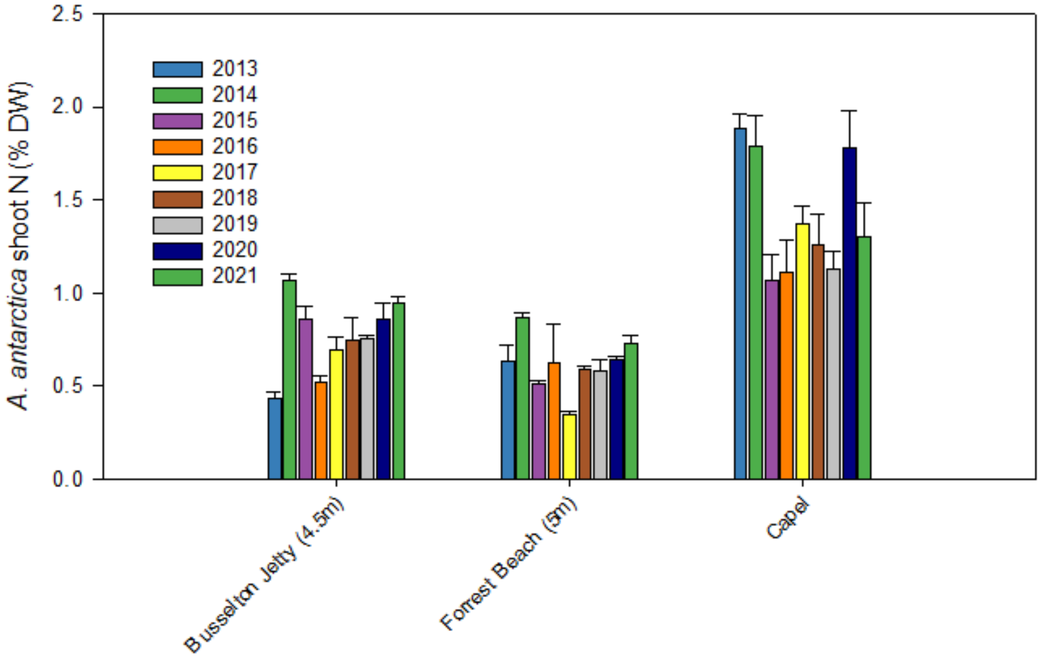


Figure 8: *Nitrogen and phosphorus content (% DW) of* P. sinuosa *leaves (Dunsborough-Forrest Beach) at the Keep Watch Posidonia seagrass monitoring sites in 2012-2021.*



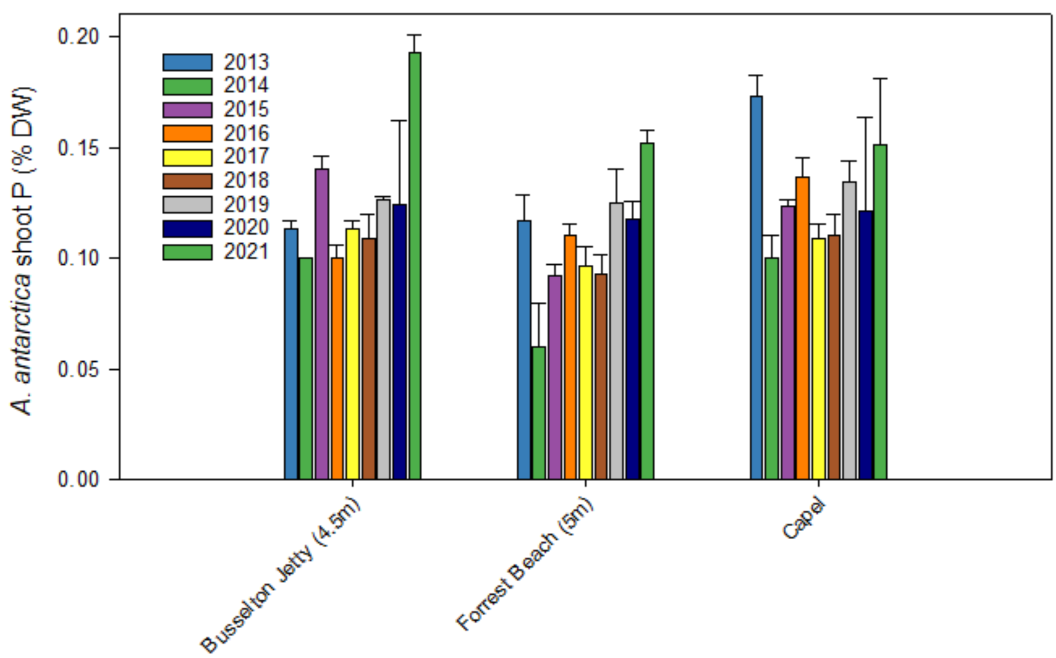


Figure 9: *Nitrogen and phosphorus content (% dw) of* A. antarctica *leaves (average ± se) at the Keep Watch Amphibolis seagrass monitoring sites in 2013-2021.*

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 0.38 to 1.9 ‰. $\delta^{15}N$ signals are lower than last year at Dunsborough, Buayanup, Vasse Diversion and Port Geographe and increased slightly at Busselton Jetty, Vasse Wonnerup and Forrest Beach but remained within the range observed over the last nine years (Figure 10). 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 1.4-2.8‰, increasing slightly at Forrest Beach and Busselton Jetty but decreasing at Capel compared to last year (Figure 10). Once again the highest values were observed at Capel indicating a different source of nitrogen at this site. The $\delta^{15}N$ signal of *Amphibolis* leaves at Vasse Diversion site was 1.0 ± 0.8‰, slightly lower than the Busselton Jetty site. All raw data is in Appendix 5.

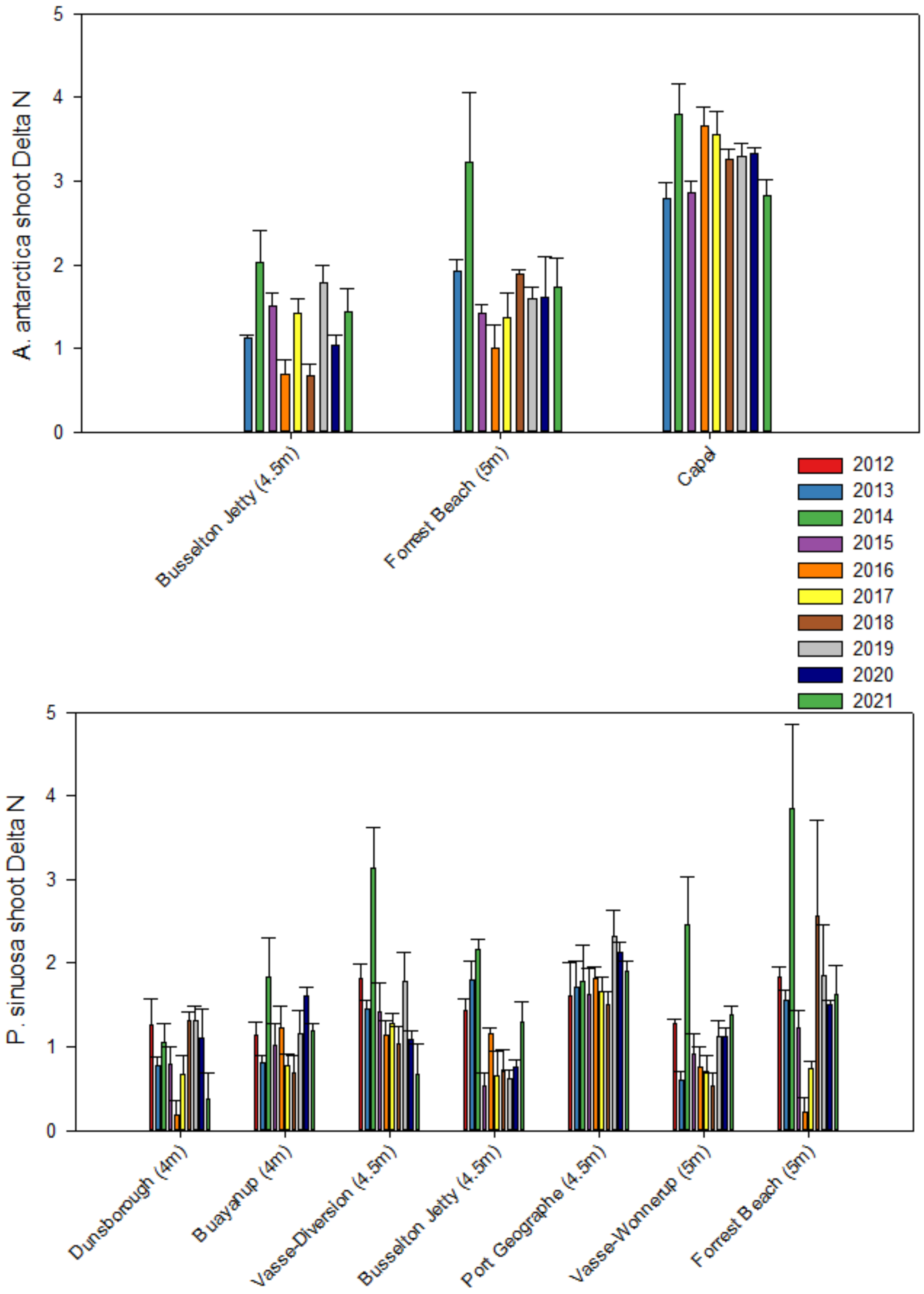


Figure 10: *δ^{15}N of* P. sinuosa *leaves (Site 1-7) and* A. antarctica *leaves (Site 4, 7 & 8 average ± se) at the Keep Watch seagrass monitoring sites in 2012-2021. Note that only Capel was measured in 2012, and is not included in these graphs.*

4.6 Water quality

Water temperature at the Keep Watch seagrass sites ranged from 20-21.4°C, lower than previous years. Water clarity was similar to 2020 observations at Port Geographe, Vasse-Wonnerup and Forrest Beach where the Secchi disk was observed on the bottom but at all other sites the Secchi disk was not visible on the bottom and ranged from 3.1-3.4 m. All other sites water clarity was lower (Table 6).

Table 6: *Water quality measures at the Keep Watch seagrass monitoring sites from 2012-2021, *=Secchi disk depth on bottom.*

Site	Secchi disk depth (m)									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Dunsborough	4.2*	3	3	3.2*	3*	3.5*	2.7	2.7	4.0*	3.3
2. Buayanup	3.5	2.5	3*	3.2*	3.5*	2.5*	3*	2.8	3.5*	3.2
3. Vasse Diversion Drain	4	3.25	3.5*	3.6*	3.5*	5*	3.3	3	3.5*	3.4
4. Busselton Jetty	4.2	2.5	3.5	3.6*	3.5*	2.5*	4*	2.9	3.5*	3.1
5. Port Geographe	3.75	2.5	4	4.1*	3.5	4.5*	3.5*	3.2	3.0*	4.5*
6. Vasse-Wonnerup	4	2	4.5	4.6*	4.5*	4*	4.5*	4	4.5*	5.4*
7. Forrest Beach	5*	2	4	4.2*	4.5*	4*	3.5	3.8	4.5*	5*
	Temperature (°C)									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Dunsborough	22	22.5	23.1	23.3	22.9	22.5	21.2	20.6	23.5	20.0
2. Buayanup	22.8	22.6	23.5	25.2	23.7	22.8	21.7	21.7	24.4	20.1
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
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 Modest declines in shoot density at some sites

No management criteria were triggered in 2021 for all three triggers. Two sites, the most westerly ones near Dunborough increased slightly in shoot density, however the remaining five sites declined, with two, Vasse Diversion and Forrest Beach declining more than 20% activating the first part of Trigger 1. In 2022, this will need to be assessed to ascertain whether another 20% decline has occurred which would result in a breach of Trigger 1. The other sites that declined were between Vasse Diversion and Forrest Beach, but here the declines were lower, < 15%. Although most sites declined, apart from Forrest Beach, the fluctuations are within the ranges observed over the last ten years. It is recommended to continue monitoring to keep track on the condition of the meadows.

Since the start of the monitoring program there have been fluctuations in shoot density, but none that have breached any triggers. The timing of minimum shoot density has varied between sites. For example 2012 for Busselton Jetty and Vasse

Wonnerup, 2014 for Dunsborough and Buayanup and this year for Forrest Beach (Figure 11). This indicates that regional-scale processes are unlikely driving the minimum densities. However, due to more consistent timing of maximum shoot densities, 2018 and 2019 at most sites, regional-scale processes may be influencing maximum abundance (Figure 11). Intermediate shoot densities for all sites tended to occur between 2015 and 2018.

In the context of these small to modest fluctuations the shoot density of *Posidonia* in Geographe Bay, is higher or close to the maximum densities observed compared to other locations in south-west WA where similar monitoring programs by Department of Biodiversity, Conservation and Attractions. Based on this set of information, there continues to be no major concerns for seagrass health in Geographe Bay. The recommendation is to continue monitoring and reassess changes next year.

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

Figure 11: *Heatmap of changes in average shoot density of* P. sinuosa *over time, 2012-2021, at each Keep Watch seagrass monitoring sites. The colouring of the heatmap is allocated on a site by site basis to show the times of low and high shoot density in a site.*

5.2 Algal epiphyte cover increases in 2020

Epiphytes are important components of seagrass ecosystems, contributing to primary production, food and habitat for fauna. The algal epiphyte cover remains at the high levels that were recorded in 2020, with three sites recording a high cover category (Figure 12). The amount of epiphyte cover on seagrasses is promoted by nutrients, but unlike 2020, there is no evidence that seagrasses have had higher exposure to nitrogen based on the seagrass leaf nitrogen content. Previously higher epiphyte cover was associated with greater loads of nutrients entering Geographe Bay and intermediate surface water temperatures (McMahon and Dunham 2019). As higher algae cover over extended periods of time can lead to stress on seagrasses, it is a concern that this high cover is persisting. However, there is not a direct correlation between the amount of epiphyte cover and seagrass decline across all sites in Geographe Bay. Vasse Diversion drain did have high algal cover this and last year and saw a 23% decline this year in shoot density, whereas Forrest Beach with a 29% decline in shoot density this year had low epiphyte cover for the last two years. This re-iterates that the drivers of low shoot density are linked to local rather than regionl-scale processes and the drivers may vary between sites. Vasse Diversion drain is more protected than Forrest Beach and algal cover is more likely to build up over time, whereas at Forrest Beach due to the higher wave energy (Oldham et al 2010) there may be more loss of shoots due to physical disturbance.

The dominant algal types observed in Geographe Bay this year and over the ten years of the program, microalgal accumulations are not those commonly associated with nutrient enrichment. However, Master's student Connor Campbell investigated whether nutrient inputs from the drains discharging into Geographe Bay near seagrass meadows may influence the type of microalgal accummulations on seagrass leaves. He found that that there was no consistent pattern in the abundance and composition of microalgal communities with distance away from drains over small spatial scales (100's m's), but the microalgal community on seagrasses varied between the different drainage systems. The microalgal community near drains with the highest nutrient loads, in this case Vasse Diversion Drain, had the highest biomass and a higher abundance of taxa typically found within nutrient rich or polluted environments (Campbell 2020). This finding provides evidence that the microalgal communities can increase with greater exposure to nutrients and further supports the concern of persistent higher microalgal epiphyte cover on seagrass meadows in Geographe Bay. The areas with higher cover are also in the most protected parts of Geographe Bay (Oldham et al 2010), and as idenitifed above, could interact to enhance the accumulation of these microalgal communities. The relationship between seagrass density, algal cover, nutrient loads and other factors that influence the condition of the seagrass ecosystems such as temperature and wave energy is something to investigate further as part of the review and reassessment of this program.

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

Figure 12: *Heatmap of changes in average shoot density of* P. sinuosa *over time, 2012-2021, at each Keep Watch seagrass monitoring sites. The colouring of the heatmap is allocated on a site by site basis to show the times of low and high shoot density in a site.*

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

The concentration of nitrogen in seagrass leaves tissue has declined slightly this year in contrast to the slight increase last year, and for phosphorus there has been a slight increase. But, overall the nutrient concentrations are very low and do not indicate exposure to excess nutrients. The only site that over the last ten years has consistently stood out from the other sites is Capel, with 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.

Although the work by Campbell (2020) shows that the microalgal abundance on seagrass leaves is greater in seagrass meadows near drains that discharge higher loads of nutrients and the nutrient levels in the leaves are also higher, this pattern is not realised in the Keep Watch Program over the ten years of data. If this was the case, then you would expect higher algal cover where the nitrogen concentrations in seagrass shoots are higher. Even when this assessment is restricted to the central sites where the majority of the drains are located (Vasse-Diversion to Port Geographe), there is no relationship between seagrass nutrient content and algal cover.

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. Dunsborough	0.68	0.51	0.95	0.43	0.46	0.45	0.64	0.59	0.59	0.41
2. Buayanup	0.92	0.45	1.06	0.55	0.70	0.59	0.60	0.67	0.82	0.70
3. Vasse Diversion Drain	0.58	0.39	0.95	0.47	0.73	0.65	0.54	0.63	0.72	0.56
4. Busselton Jetty	0.64	0.44	0.81	0.50	0.55	0.42	0.42	0.44	0.49	0.50
5. Port Geographe	0.74	0.60	1.12	0.49	0.92	0.65	0.72	0.69	1.05	0.63
6. Vasse-Wonnerup	0.60	0.39	0.93	0.43	0.52	0.51	0.47	0.38	0.63	0.44
7. Forrest Beach	0.64	0.47	0.92	0.39	0.51	0.43	0.66	0.53	0.71	0.66

***Figure 12**: Heatmap of changes in* P. sinuosa *average shoot nitrogen content over time, 2012-2021, at each Keep Watch seagrass monitoring site.*

5.4 A reflection of 10 years of Keep Watch seagrasses monitoring in Geographe Bay

Now there is 10 continuous years of annual seagrass monitoring data for the dominant seagrass, *Posidonia sinuosa* in Geographe Bay in relation to the threat of nutrient enrichment. This is a significant achievement as long-term information on the health of our ecosystems are highly valuable, enabling managers to assess the effects of management actions as well as local (e.g. anchoring, catchment management) and global scale (e.g. temperature increases from climate change) pressures. In this context, the data collected is valuable for linking the extensive catchment management activities to reduce nutrient loads reaching the waterways of the Geographe catchment and it's coastal waters and assessing the condition and trends of the valued seagrass meadows, a key assest of the Ngari Capes Marine Park. The temperature data collected by DBCA and the recent installation of temperature loggers at each site will enable interrogation of warming and heatwaves at a site specific scale into the future. This is highly relevant due to the significant impacts that have occurred to temperate seagrasses in Shark Bay linked to heat wave events (Strydom et al 2020). Declines in shoot density have also been observed in Perth waters and Jurien Bay and the hypothesis that this is associated with warming (Fraset et al 2019, DBCA unpublished data). In collaboration with relevant stakeholders (Water Corporation, DWER, DBCA, Fisheries, GeoCatch) a reassessment of the program is warranted to ensure the program is meeting the priorities of stakeholders, identify any further information needs and develop a plan for the future, beyond the current funding.

At this point in time, the Keep Watch seagrass monitoring program does not have a contract in place to continue the monitoring into the future in its current form. However, there is support for it continue from ECU, GeoCatch, Water Corp and DBCA. Both DBCA and WaterCorp have a vested interest to continue this program to meet their reporting needs. The collaborative field partnership with DBCA enables the Keep Watch monitoring sites to be included in DBCA monitoring program as well as reporting for GeoCatch's needs. In addition, there is a broader program with DBCA also monitoring at deeper locations in the bay at ~ 10 m and 20 m, following a similar protocol. Also WaterCorp and GeoCatch carry out water quality monitoring in Geographe Bay linked with their programs. The re-assessment of the program suggested above should consider these programs to maximise the synergies and outcomes.

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Appendix 1: Randomly generated quadrat positions from 2021 survey.

Quadrat #	Bearing	Distance
1	20	6
2	20	14
3	20	18
4	20	20
5	20	23
6	20	25
7	80	3
8	80	5
9	80	7
10	80	9
11	80	16
12	80	20
13	120	4
14	120	7
15	120	9
16	120	11
17	120	13
18	120	21
19	180	5
20	180	8
21	180	13
22	180	15
23	180	17
24	180	19
25	260	5
26	260	11
27	260	14
28	260	20
29	260	22
30	260	24

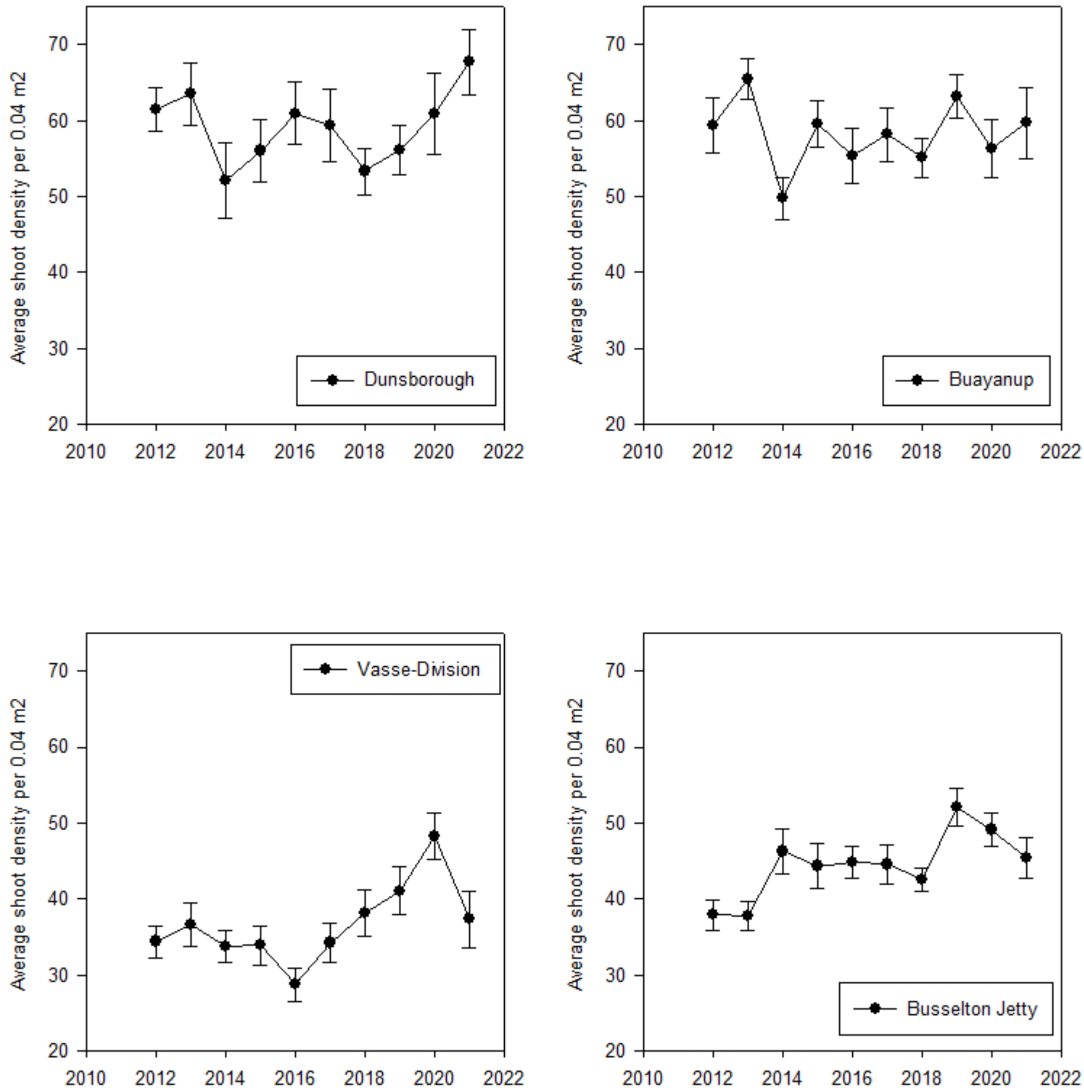
Appendix 2: Raw and summary statistics for shoot density data for the seven Keep Watch Seagrass Monitoring Sites in 2021. Seedling counts, and the person who counted each quadrat is also included.

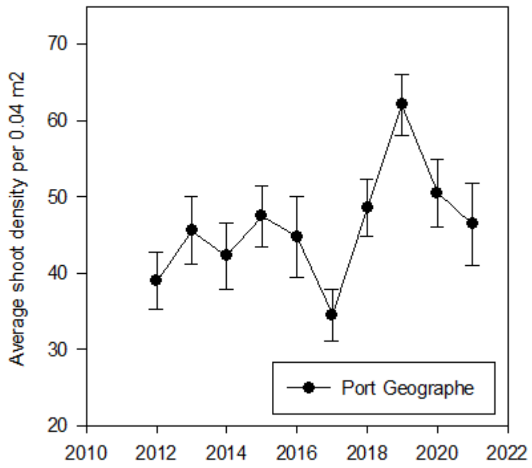
	1. Dunsborough			2. Buayanup			3. Vasse Diversion			4. Busselton Jetty			5. Port Geographe			6. Vasse-Wonnerup			7. Forrest Beach		
Quadrat	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter	Shoots - CH	Seedlings	Counter
1	64	4	AF	78	2	AF	54	1	AF	43	1	AF	65	0	AF	30	2	AF	61	0	AF
2	79	1	AF	87	1	AF	45	1	AF	44	1	AF	26	0	AF	34	1	AF	6	2	AF
3	42	2	AF	50	1	AF	40	0	AF	70	2	AF	33	0	AF	41	2	AF	30	1	AF
4	59	2	AF	77	1	AF	27	0	AF	41	1	AF	56	0	AF	38	0	AF	30	2	AF
5	82	0	AF	65	0	AF	30	1	AF	53	0	AF	89	0	AF	38	0	AF	27	1	AF
6	68	3	AF	63	2	AF	4	0	AF	32	0	AF	56	0	AF	51	1	AF	19	0	AF
7	35	1	KM	-	0	CH	-	0	CH	-	0	CH	7	0	KM	-	0	CH	-	0	CH
8	-	-	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH
9	-	-	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH
10	-	-	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH
11	-	-	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH
12	-	-	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH	-	0	CH
13	58	2	KM	37	2	KM	26	0	KM	45	1	KM	12	0	KM	45	0	KM	55	3	KM
14	48	3	KM	61	0	KM	39	0	KM	54	1	KM	70	0	KM	43	0	KM	14	0	KM
15	66	2	KM	73	0	KM	31	0	KM	50	1	KM	79	0	KM	51	1	KM	64	2	KM
16	57	2	KM	74	0	KM	20	0	KM	69	0	KM	40	0	KM	42	0	KM	56	2	KM
17	64	0	EB	29	0	EB	30	0	KM	54	0	EB	60	0	KM	53	0	KM	60	2	KM
18	41	0	EB	53	0	EB	24	0	EB	38	0	EB	39	0	KM	53	0	EB	45	1	KM
19	65	0	EB	37	0	EB	52	0	EB	36	0	EB	-	0	CH	46	0	EB	-	0	CH
20	83	0	EB	27	0	EB	25	0	EB	29	0	EB	-	0	CH	47	0	EB	-	0	CH
21	84	0	EB	18	0	EB	24	0	EB	55	0	EB	6	1	KM	68	0	EB	-	0	CH
22	55	0	EB	28	0	EB	64	0	EB	39	0	EB	-	-	-	-	0	CH	38	0	BF
23	51	0	EB	41	0	EB	38	0	EB	-	0	CH	30	0	BF	54	0	EB	37	0	BF
24	46	0	EB	99	0	EB	25	0	EB	53	0	EB	55	0	BF	-	0	CH	39	0	BF
25	82	0	BF	-	0	CH	-	0	CH	58	0	BF	-	0	CH	39	0	BF	36	0	BF
26	58	0	BF	65	0	BF	-	0	CH	36	0	BF	-	0	CH	38	0	BF	48	0	BF
27	126	0	BF	85	0	BF	-	0	CH	20	0	BF	70	0	BF	59	0	BF	58	0	BF
28	101	0	BF	65	0	BF	75	0	BF	36	0	BF	40	0	BF	28	0	BF	29	0	BF
29	103	0	BF	74	0	BF	56	0	BF	58	0	BF	30	0	BF	19	0	BF	78	0	BF
30	75	0	BF	87	0	BF	54	0	BF	31	0	BF	65	0	BF	54	0	BF	-	0	CH
Average	**67.7**	**0.9**		**59.7**	**0.3**		**37.3**	**0.1**		**45.4**	**0.3**		**46.4**	**0.0**		**44.1**	**0.2**		**41.5**	**0.5**	
Median	**64.0**	**0.0**		**65.0**	**0.0**		**31.0**	**0.0**		**44.0**	**0.0**		**47.5**	**0.0**		**44.0**	**0.0**		**38.5**	**0.0**	
SE	**4.28**	**0.25**		**4.72**	**0.12**		**3.71**	**0.06**		**2.65**	**0.10**		**5.32**	**0.03**		**2.37**	**0.10**		**4.14**	**0.16**	
Stdev	**21.41**			**22.63**			**16.99**			**12.69**			**23.80**			**11.12**			**18.50**		
CV	**0.32**			**0.38**			**0.46**			**0.28**			**0.51**			**0.25**			**0.45**		

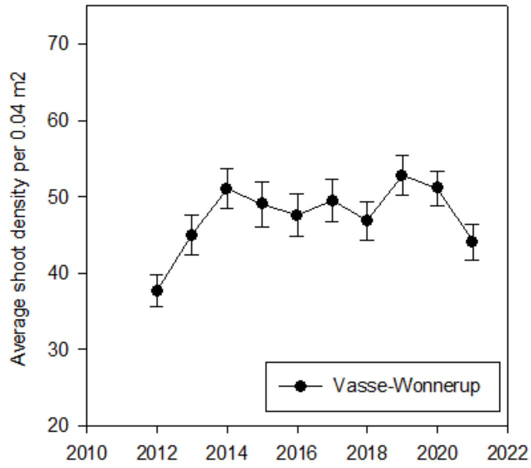
Appendix 3: Leaf morphology data for 2021

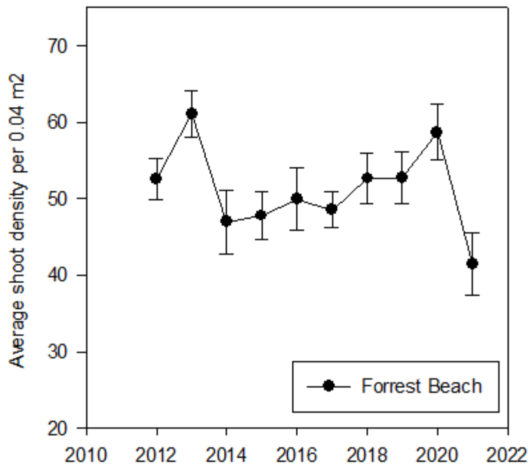
2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021
	S1	S1	S2	S2	S3	S3	S4	S4	S5	S5	S6	S6	S7	S7
	Dun.	Dun.	Buayanup	Buayanup	Vasse Div.	Vasse Div.	Buss Jetty	Buss Jetty	Port Geo	Port Geo	Vasse Won	Vasse Won	Forrest B	Forrest B
Rep	Shoot Length (cm)	Shoot Width (mm)	Shoot Length (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	39.3	6.5	36.5	6.5	57.6	6	47.2	6	52.5	6.5	92.2	6.5	68.2	7
2	37.3	6.5	39	5	36.5	5.5	63.9	6	56.6	5.5	101	7	58.2	6
3	30.8	6	31.3	5	57.4	6	40.2	6.5	42.8	5.5	90.2	6	55.8	6
4	28.7	6	49.3	6	40.7	6.5	36	6.5	51.4	6.5	52.8	6	67.7	5.5
5	35.5	7	35.8	6	49	5.5	54.9	5.5	48.8	5.5	95	6	60.2	5.5
6	41.8	6	28.4	4.5	46.2	6	55.6	5.5	23.9	6	110.1	7	51.4	6.5
7	31.2	5.5	39.9	4	48.8	6	55.3	5	23.6	5	55.7	7	32.2	6.5
8	26.4	5.5	44.6	5	94.1	6	53.2	6.5	74	6	98.2	6.5	38.5	6
9	28.5	5.5	41.1	5.5	76	6	61.3	6	38.5	6	97	7	23	6
10	36.1	5	41.9	5.5	59.1	6	51.5	6	40.3	4.5	110.2	6.5	47.6	6
11	39.9	6	48.4	6.5	53.9	7.5	44.2	6.5	28.8	6	98.1	7	53.9	7
12	33	6	66.9	5.5	42.5	6.5	49.6	5.5	45.8	6	120.5	7	48.2	6
13	45.2	6	43.4	5.5	79.6	6.5	76.8	6.5	21.4	5	101	6.5	38.2	6
14	32.9	6	50.3	5	76	6.5	54.3	6.5	46.5	7	89	6	56.5	6
15	36	7	45.5	6	50.9	7.5	83.3	6	48.5	6	79.4	6.5	40.6	6
Average	34.84	6.03	42.82	5.43	57.89	6.27	55.15	6.03	42.89	5.80	92.69	6.57	49.35	6.13
SE	1.37	0.14	2.37	0.18	4.25	0.15	3.24	0.12	3.67	0.17	4.76	0.11	3.32	0.11

Appendix 4: Trends over time in seagrass shoot density.




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


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


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

Appendix 5: Nutrient data for 2020 and 2021 including the original and modified calibrated values for 2020 as well as the calibrated values for 2021.

		2020	2020	2020	2020	2020	2021	2021	2021
		Original	Modified	Original	Modified	Original	Modified	Modified	Original
Site	**Species**	δ15N	δ15N	N (%DW)	N (% DW)	P (% DW)	δ15N	N [wt %]	P (% DW)
Dunsborough	Posidonia	2.09	1.66	1.03	0.53	0.21	0.94	0.47	0.16
Dunsborough	Posidonia	1.63	1.17	1.33	0.85	0.19	0.31	0.37	0.19
Dunsborough	Posidonia	1.00	0.49	0.90	0.39	0.18	-0.10	0.39	0.15
Buayanup	Posidonia	1.90	1.46	1.30	0.82	0.16	1.18	0.71	0.16
Buayanup	Posidonia	2.22	1.80	1.34	0.86	0.13	1.06	0.70	0.18
Buayanup	Posidonia	2.03	1.59	1.28	0.80	0.14	1.36	0.68	0.13
Vasse-Diversion	Posidonia	1.38	0.90	1.19	0.70	0.23	0.70	0.51	0.16
Vasse-Diversion	Posidonia	1.65	1.19	1.26	0.77	0.17	1.28	0.52	0.21
Vasse-Diversion	Posidonia	1.66	1.20	1.19	0.70	0.11	0.00	0.65	0.16
Busselton Jetty	Posidonia	1.09	0.59	1.08	0.58	0.24	0.79	0.44	0.20
Busselton Jetty	Posidonia	1.38	0.90	0.91	0.40	0.10	1.57	0.59	0.20
Busselton Jetty	Posidonia	1.27	0.78	0.99	0.49	0.12	1.50	0.48	0.17
Port Geographe	Posidonia	2.31	1.90	1.60	1.14	0.19	1.85	0.59	0.15
Port Geographe	Posidonia	2.55	2.15	1.38	0.90	0.12	2.13	0.74	0.19
Port Geographe	Posidonia	2.70	2.31	1.59	1.12	0.23	1.70	0.55	0.17
Vasse-Wonnerup	Posidonia	1.76	1.31	1.22	0.73	0.19	1.33	0.38	0.19
Vasse-Wonnerup	Posidonia	1.60	1.13	1.11	0.61	0.19	1.24	0.49	0.25
Vasse-Wonnerup	Posidonia	1.39	0.91	1.05	0.55	0.20	1.58	0.47	0.22
Forrest Beach	Posidonia	2.01	1.57	1.08	0.58	0.12	1.65	0.66	0.21
Forrest Beach	Posidonia	1.98	1.54	1.37	0.89	0.16	1.00	0.60	0.14
Forrest Beach	Posidonia	1.86	1.41	1.15	0.66	0.17	2.21	0.71	0.19
Busselton Jetty	Amphibolis	1.39	0.91	1.19	0.70	0.10	1.35	1.01	0.19
Busselton Jetty	Amphibolis	1.74	1.28	1.45	0.98	0.15	1.03	0.93	0.20
Busselton Jetty	Amphibolis	1.43	0.95	1.39	0.91	0.12	1.95	0.90	0.19
Forrest Beach	Amphibolis	2.90	2.53	1.17	0.68	0.12	1.10	0.66	0.15
Forrest Beach	Amphibolis	1.38	0.90	1.12	0.63	0.12	1.91	0.72	0.15
Forrest Beach	Amphibolis	1.86	1.41	1.12	0.63	0.11	2.22	0.81	0.15
Capel	Amphibolis	3.52	3.19	2.48	2.07	0.15	2.73	1.03	0.16
Capel	Amphibolis	3.75	3.44	1.83	1.38	0.10	3.20	1.66	0.16
Capel	Amphibolis	3.66	3.34	2.30	1.88	0.11	2.56	1.22	0.13
Vasse-Diversion	Amphibolis						0.58	0.92	0.13
Vasse-Diversion	Amphibolis						1.26	0.90	0.13
Vasse-Diversion	Amphibolis						1.12	0.83	0.10

Appendix 6: Count comparisons between divers at each site.