**Edith Cowan University**
Centre for Marine Ecosystems Research


# Keep Watch Seagrass Monitoring 2025 Report for GeoCatch


Ankje Frouws and Kathryn McMahon




Keep Watch Seagrass Monitoring, 2025. Report to GeoCatch

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## Table of Contents

# Keep Watch Seagrass Monitoring

Annual Report 2025

**Investigator: Ankje Frouws and Kathryn McMahon**

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

**July 2025**

# 1 Executive Summary

## 1.1 Introduction

This report summarises fourteen years of data (Feb 2012 - Feb 2025) 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 and macroalgae 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 2025

***Key finding 1***

Seagrass meadows in Geographe Bay remain healthy with seagrass shoot densities high at all sites. Shoot densities increased at all sites from 2024, and were at an all time high in 2025 compared to other years, and other regions. Highest shoot densities were recorded at Buayanup and Busselton Jetty, with lowest at the Vasse-Wonnerup and Vasse Diversion. No management triggers were breached in 2025.

***Key finding 2***

The epiphyte cover declined from previous years, with epiphyte cover ranging from low to medium, compared to 1-3 sites having a high epiphyte cover in the last five years. There was also an increase in the observation of encrusting algae compared to previous years, but this is likely due to the higher visibility of encrusting algae when epiphyte cover is lower. 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. This was confirmed by both seagrass and macroalgal tissue nutrient content. In addition, the potential for increased/changed nutrient exposure in Forrest Beach based on the increased nitrogen and phosphorus concentration and changed isotope signal in *Dictyota* observed in 2024 has not continued into 2025 and concentrations have lowered or remained similar to 2024 for this site. 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 2025 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 *Dictyota* at Dunsborough, Vasse Diversion, Forrest Beach and Capel. Unlike the seagrass samples, macroalgae indicators suggested higher phosphorus exposure at Capel and an increase in delta N compared to other sites.

# 2 Introduction

This document is produced for GeoCatch by Ankje Frouws and Kathryn McMahon from Edith Cowan University. It reports on the Keep Watch seagrass monitoring survey that was undertaken in February 2025 and compares to data from the 2012-2024 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 antarctica*) but the program mostly focuses on *P. sinuosa* shoot density and leaf tissue nutrients (C, N, P and N isotopes) from seven sites with leaf tissue nutrient data for *A. antarctica* seagrass from three sites. Based on the 10 year review workshop held in Busselton on 17$^{th}$ November 2021 since 2022 samples of macroalgae (*Dictyota* and *Padina*) have also been collected for nutrient and isotope analysis. This is to explore the potential for incorporating algae into the monitoring program as there were concerns raised in the review that macroalgae cover was increasing at Capel. Macroalgae from the genus *Dictyota* were selected as most suitable to include for further monitoring as this genus is most commonly observed among sites. This year macroalgae (*Dictyota*) samples from Dunsborough, Vasse Diversion, Forrest Beach and Capel were included in the nutrient and isotope analysis. All raw data (except for technical replicates) 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, Figure 6). 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 on the 10$^{th}$, 12$^{th}$-15$^{th}$ and on the 17$^{th}$ of February 2025. At Capel (8) there are high relief rocky reefs surrounded by bare sand that can be reached from the shore. On the reef there are patches of *A. antarctica* seagrass and *Dictyota* 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). Since 2022, due to the reduced abundance of *Amphibolis* at Busselton Jetty (4) from the dieback of *A. antarctica* in 2017 and no subsequent recovery, no samples were collected here.

**Table 1:** Details for eight Keep Watch sites, seven in *Posidonia sinuosa (Ps)* meadows (1-7) and one in rocky reef with *Amphibolis antarctica (Aa)* patches (8) in Geographe Bay. One macroalgale species (*D* = *Dictyota*) was also assessed in four of these sites. 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 | 17/02/2025 | *Ps* | *D* |
| 2. Buayanup | S 33.65233°, E 115.24840° | 4 | 13/02/2025 | *Ps* | |
| 3. Vasse Diversion Drain | S 33.64746°, E 115.32379° | 4.5 | 14/02/2025 | *Ps, Aa* | *D* |
| 4. Busselton Jetty | S 33.63896°, E 115.34315° | 4.5 | 12/02/2025 | *Ps* | |
| 5. Port Geographe | S 33.62846°, E 115.38240° | 4.5 | 12/02/2025 | *Ps* | |
| 6. Vasse-Wonnerup | S 33.60188°, E 115.42345° | 5 | 15/02/2025 | *Ps* | |
| 7. Forrest Beach | S 33.57295°, E 115.44908° | 5 | 15/02/2024 | *Ps, Aa* | *D* |
| 8. Capel | S 33.51394°, E 115.51508° | 2 | 10/02/2024 | *Aa* | *D* |

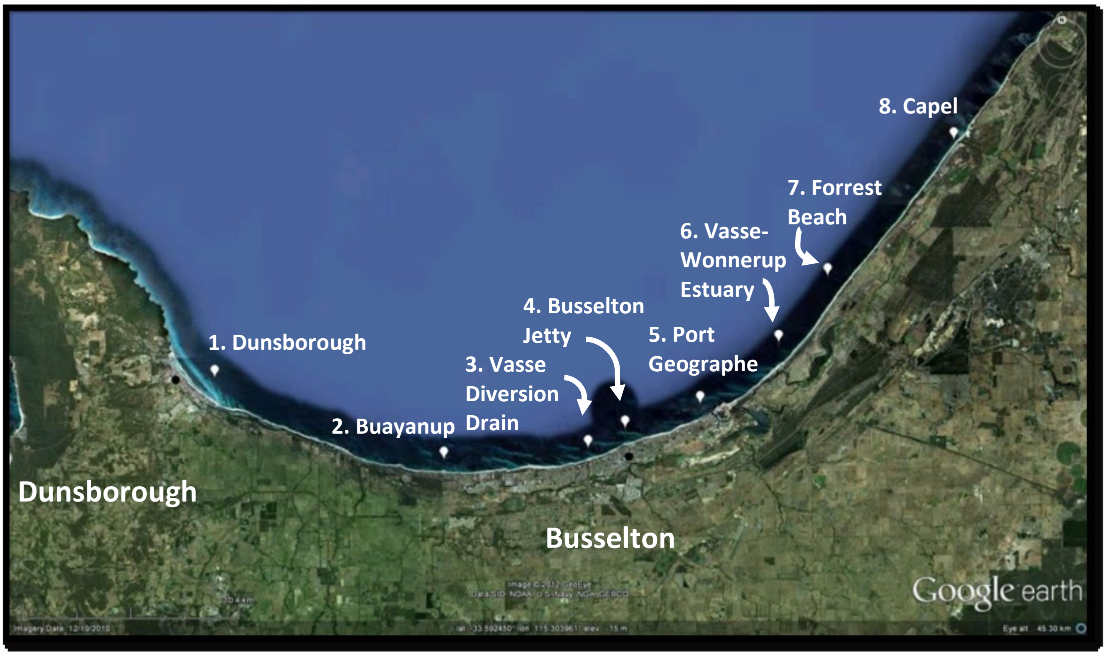



***Figure 1**: Map of Geographe Bay, showing the location of the 8 seagrass sampling sites (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach and 8. Capel).*

Each seagrass site was located at least 30 m from the edge of the meadow and the centre 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. Middle: Star picket with cap indicating centre of 50 m diameter Keep Watch seagrass site. Right: Permanent cattle tag with site label.*

At each site *P. sinuosa* shoot density was counted in 30 0.2 x 0.2 m quadrats (0.04 $m^2$ area). 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 *A. antarctica* or *Amphibolis 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 them 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 shoot for a quadrat with 20 shoots and a maximum difference of 3 shoots for a quadrat with 60 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.

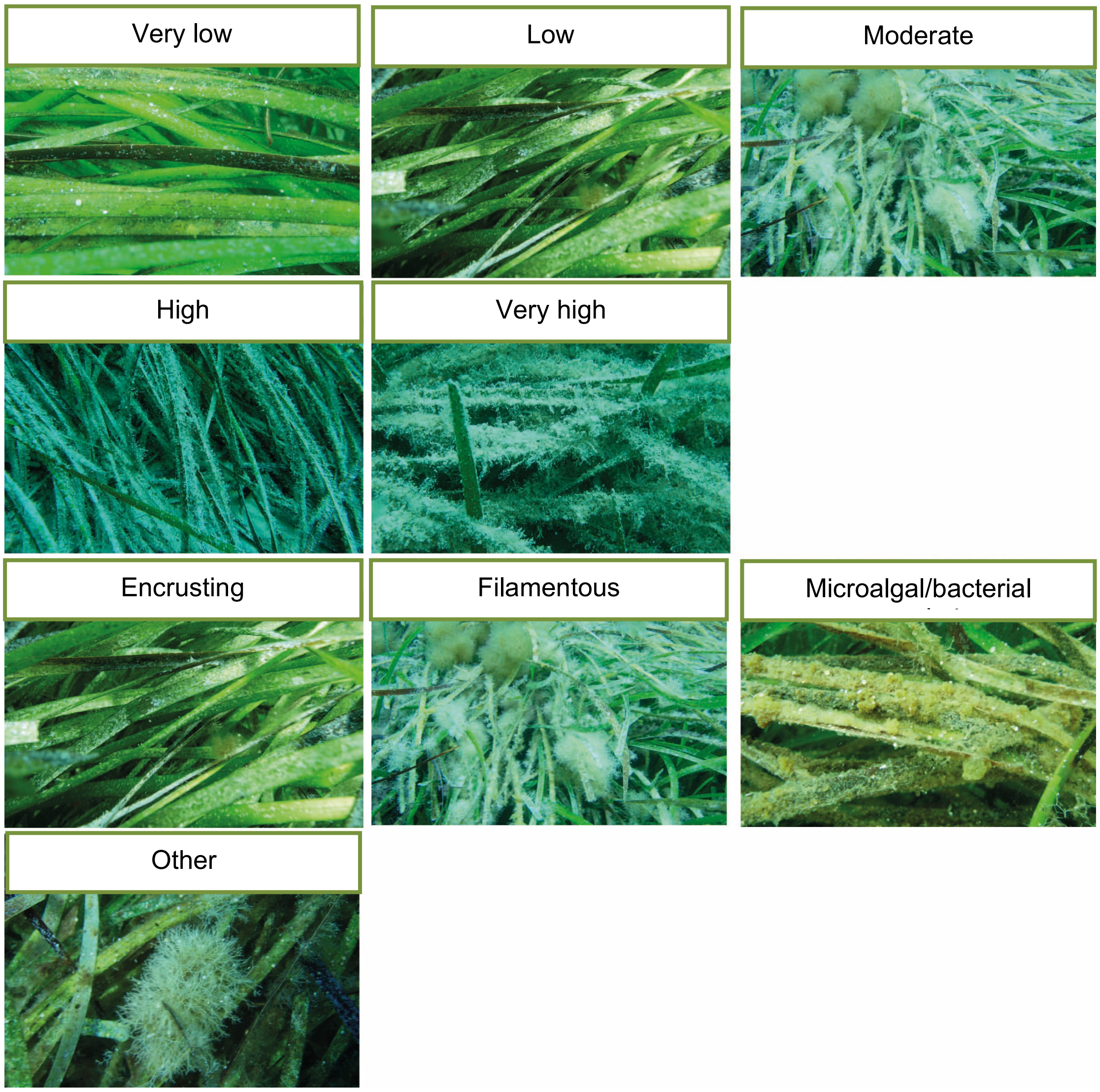



***Figure 4:*** *Classification of epiphytic algal cover (very low-very high) and type (encrusting-other).*

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 total C, N, P as well as nitrogen stable isotope analysis ($\delta^{15}N$) 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 Vasse Diversion, Forrest Beach and Capel sites for the same type of nutrient analysis. Four algal samples (*Dictyota*) were collected at Dunborough, Vasse Diversion, Forrest Beach and Capel for the same type of nutrient analysis as well.

At each site the Secchi disk depth (m) and temperature (°C) were recorded from the boat, salinity was recorded in the laboratory from samples collected in the field. In addition, temperature loggers were retrieved that had been placed at two *Posidonia* sites, Buayanup and Port Geographe, during sampling in 2024, to collect local temperature data. These were provided in-kind from ECU.

Field work was carried out by Raphael Clement (RC) and Ankje Frouws (AF) from ECU with Daisy Church (DC), Richard Evans (RE), Josh Reagan (JR) and Tanika Shalders (TS) from the Department of Biodiversity, Conservation and Attractions (DBCA). Samples were processed and data analysed by Ankje Frouws. This year the DBCA research vessel "Wattern" was used for diving activities. The monitoring program was funded through sponsorship by Water Corporation and in-kind support of Department of Biodiversity, Conservation and Attractions staff.

### 3.1.2 Laboratory processing

In the laboratory the three seagrass shoot samples were measured for total length and width, just above the sheath. Then all algal epiphytes from both the seagrass and algal samples were removed by gently scraping, and the leaves placed in the oven at 60°C for 24 hours or until dry, then ground into a fine powder with a Ball Mill grinder. This material was then analysed for total C, N and $\delta^{15}N$ (external error of analysis 1 standard deviation) at ECU using a continuous flow Thermo Scientific™ EA IsoLink™ IRMS system consisting of a Flash IRMS Elemental Analyzer, Delta V Advantage IRMS and Conflow IV Univeral Interface. Several replicate samples were analysed for quality control and for those samples the mean of both replicate values was used for the C, N and $\delta^{15}N$ value for the sample. 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 2025 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 1490-2023 shoots $m^{-2}$ across the seven sites (Figure 5). Similar to previous years, Buayanup (2023 shoots $m^{-2}$) had the highest shoot density, followed by Busselton Jetty (1860 shoots $m^{-2}$). Vasse-Wonnerup (1490 shoots $m^{-2}$) and Vasse Diversion (1507 shoots $m^{-2}$) had the lowest shoot density. The remaining sites ranged between 1512-1670 shoots $m^{-2}$ and shoot density in four (Buayanup, Vasse Diversion, Busselton Jetty, Port Geographe) of the seven sites showed a strong upward trajectory in this year or the last two years. The minimum and maximum mean shoot density in 2025 are higher, respectively, than the minima and maxima of any of the previous monitoring years. All raw data is in Appendix 2.

Last year one of the seven sites declined by 6%, Dunsborough, while all other sites increased in shoot density from 9-55% (Table 2). This year, all sites increased in shoot density, from 5-47%, with four out of the seven sites increasing >30% in shoot density compared to the previous year. Since the first year of monitoring there has been a net increase at all sites (9-97%) with Busselton Jetty almost doubling in shoot density since monitoring started (Table 2).

Compared to other seagrass meadows in the state, all monitoring sites in Geographe Bay are well above the minimum average site shoot density (294.79 shoots $m^2$). For the second year, all sites are also above the maximum shoot density (729.17 shoots $m^2$) (Figure 5, Data Courtesy of DBCA from equivalent monitoring programs in the the Shoalwater Bay and Jurien Bay Marine Parks). This is a reflection that there is a trend of shoot density decline in regions further north.

*P. sinuosa* average shoot length ranged from a minimum of 36.0 cm at Port Geographe to a maximum of 62.9 cm at Vasse-Wonnerup and a range in average width of 5.0-6.3 mm (Appendix 3).

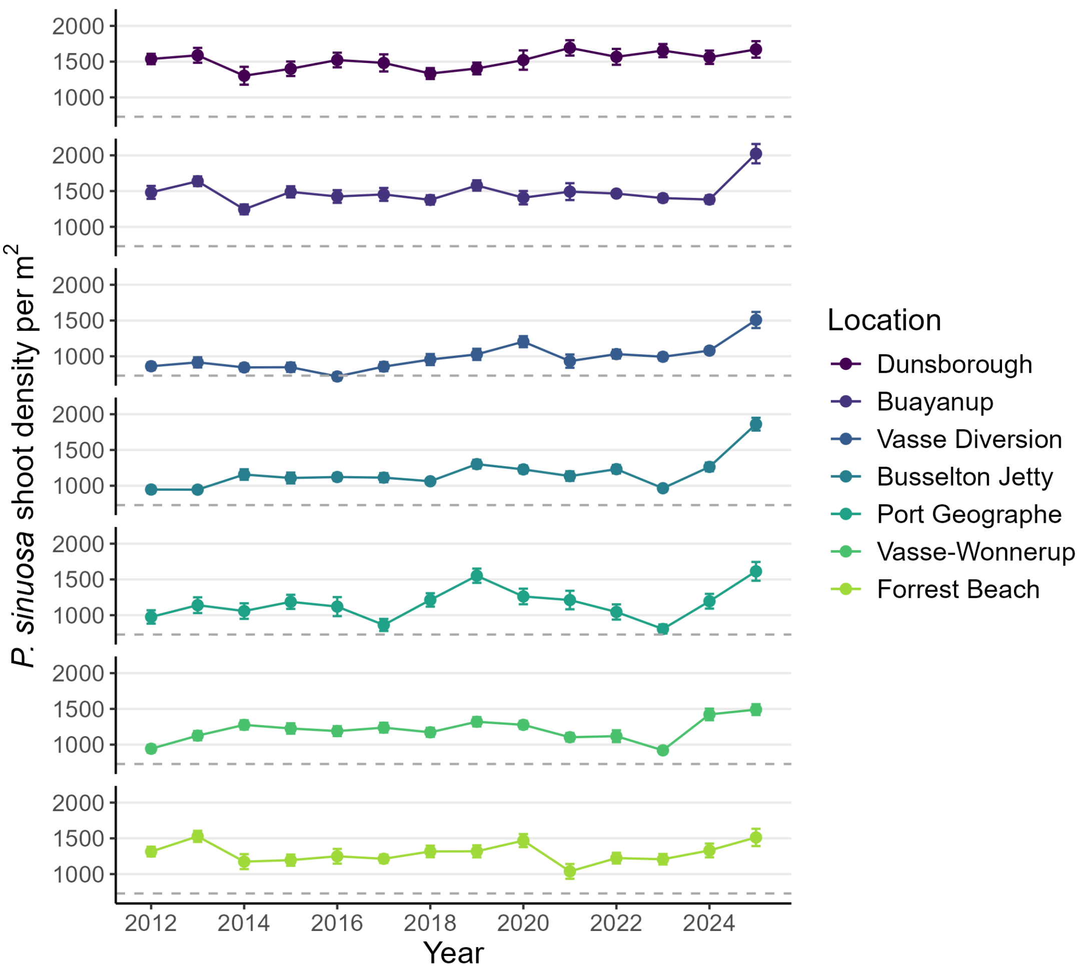



***Figure 5**: Shoot density (average $m^{-2}$ ± se) at the seven Keep Watch seagrass monitoring sites with* P. sinuosa *meadows in January or February 2012-2025. Dark grey dotted lines indicate the maximum site average (729.17 shoots $m^2$) from the reference sites at 3-5 m in Shoalwater Bay and Jurien Bay Marine Parks from 2024 (data courtesy of DBCA, 2025).*

***Table 2**: Change assessment based on Trigger 1 and 2, shown as percentage change in* P. sinuosa *shoot density between years. 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%. Note that the last column shows change over the duration of the monitoring, between 2012-2025.*

| Percentage change in shoot density between years | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Site** | **2012-13** | **2013-14** | **2014-15** | **2015-16** | **2016-17** | **2017-18** | **2018-19** |
| 1. Dunsborough | 3 | -18 | 7 | 9 | -3 | -10 | 5 |
| 2. Buayanup | 11 | -24 | 20 | -7 | 2 | -5 | 15 |
| 3. Vasse Diversion | 6 | -8 | 0 | -15 | 19 | 12 | 8 |
| 4. Busselton Jetty | 0 | 22 | -4 | 1 | -1 | -5 | 23 |
| 5. Port Geographe | 17 | -7 | 12 | -6 | -23 | 41 | 28 |
| 6. Vasse-Wonnerup | 19 | 13 | -4 | -3 | 4 | -5 | 13 |
| 7. Forrest Beach | 16 | -23 | 2 | 5 | -3 | 8 | 0 |

| **Site** | **2019-20** | **2020-21** | **2021-22** | **2022-23** | **2023-24** | **2024-25** | **2012-25** |
|---|---|---|---|---|---|---|---|
| 1. Dunsborough | 8 | 11 | -7 | 6 | -6 | 7 | 9 |
| 2. Buayanup | -11 | 6 | 11 | -17 | 9 | 34 | 37 |
| 3. Vasse Diversion | 17 | -23 | 11 | -4 | 9 | 40 | 75 |
| 4. Busselton Jetty | -6 | -8 | 9 | -22 | 31 | 47 | 97 |
| 5. Port Geographe | -19 | -8 | -10 | -21 | 48 | 32 | 65 |
| 6. Vasse-Wonnerup | -3 | -14 | 1 | -18 | 55 | 5 | 58 |
| 7. Forrest Beach | 11 | -29 | 18 | -1 | 10 | 14 | 15 |

## 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 2024-2025).

### *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 2023-2024 & 2024-2025).

### *4.2.3 Trigger 3*

This threshold was not triggered as no sites showed a significant decline over time. Interestingly, two of the sites, Vasse Diversion and Busselton Jetty, showed a significant, positive, linear trend over the fourteen 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 2012-2025.*

| Site Name & # | Significance (p<0.05) | Overall slope | $R^2$ |
|---|---|---|---|
| 1. Dunsborough | ns | +ve | 27% |
| 2. Buayanup | ns | +ve | 19% |
| 3. Vasse Diversion | significant | +ve | 51% |
| 4. Busselton Jetty | significant | +ve | 37% |
| 5. Port Geographe | ns | +ve | 10% |
| 6. Vasse-Wonnerup | ns | +ve | 13% |
| 7. Forrest Beach | ns | +ve | 3% |

## 4.3 Epiphytes

This year epiphyte cover mainly declined (high to moderate at Buayanup and Port Geographe, high to low at Vasse Diversion and moderate to low at Busselton Jetty) or remained stable (moderate at Dunsborough and Forrest Beach and low at Vasse-Wonnerup) compared to the previous year (Table 4, Figure 6). There have been no sites with high or very high epiphyte cover this year, compared to at least one site each of the previous five years. The levels and spatial patterns are similar to what has been observed since 2020 except for Buayanup, Vasse Diversion and Busselton Jetty, where epiphyte cover was low compared to previous years. The type of epiphyte cover was consistent amongst the four Western sites, with microalgae and encrusting algae both being dominant, while other sites were dominated by either microalgae or encrusting algae. At Vasse Diversion, Vasse-Wonnerup and Forrest Beach several other green and brown algae dominated, examples of those are provided in Figure 6.

*Table 4: Algal epiphyte cover at the Keep Watch seagrass monitoring sites, 2012-2025, Du = Dunsborough, Bu = Buayanup, VD = Vasse Diversion Drain, BJ = Busselton Jetty, PG = Port Geographe, VW = Vasse-Wonnerup, FB = Forrest Beach. Very low (VL), Low (L), Moderate (M), High (H) and Very High (VH). Algal types were filamentous (F), encrusting (E), microalgal aggregations (M) and other (O). If the category is capitalised it means it is dominant, lowercase indicates present but not dominant.*

| Site | Algal cover | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2012** | **-13** | **-14** | **-15** | **-16** | **-17** | **-18** | **-19** | **-20** | **-21** | **-22** | **-23** | **-24** | **2025** |
| Du | M | L | M | M | L | L | M | M | M | L | M | M | M | M |
| Bu | M | L | M | M | H | H | M | VL | H | H | H | H | H | M |
| VD | L | M | H | H | H | H | H | L | H | H | H | M | H | L |
| BJ | L | L | H | H | M | M | M | L | H | H | H | M | M | L |
| PG | L | VL | L | L | M | M | M | L | M | M | M | M | H | M |
| VW | L | VL | L | M | L | L | L | VL | L | M | L | M | L | L |
| FB | L | VL | L | L | L | VL | L | VL | L | L | VL | L | M | M |
| | **Algal Type** | | | | | | | | | | | | | |
| | **2012** | **-13** | **-14** | **-15** | **-16** | **-17** | **-18** | **-19** | **-20** | **-21** | **-22** | **-23** | **-24** | **2025** |
| Du | O,f,m | F,O | O | O,m | O | O,e,m | O,m | O,m | O,m | O | O,m | O | M,o | E,M,o |
| Bu | M,o | E,O | M,o | M,o | M,o | M,e,o | M,o | O,m | M,o,e | M,o | M | M | M,o,f | E,M |
| VD | M,o | E,O | M,o | M,o | M,o | M,o | M,o | O,m | M,o,e,f | M | M,o | M | M,o | E,M,O |
| BJ | M,o | O | M | M,f | O,e,m | M,o,e | O,M | O,m | O,m,e,f | M | M,o | M | M,O | E,M,o |
| PG | E,o | E,M | M,e | M,f | O,f | M,o,e | O,M | M | M,o | M,o | M,o | M | M,O | M,o |
| VW | E,o,m | E,O | M,f | O | E,o,m | E,m | O,M | O | O,e | M | M | O | O | M,O |
| FB | E,M,o | F,E | M,f | O,e | E,o | E,o | O,e | O | E,m,o | O | E,m | E | O,m | E,O |

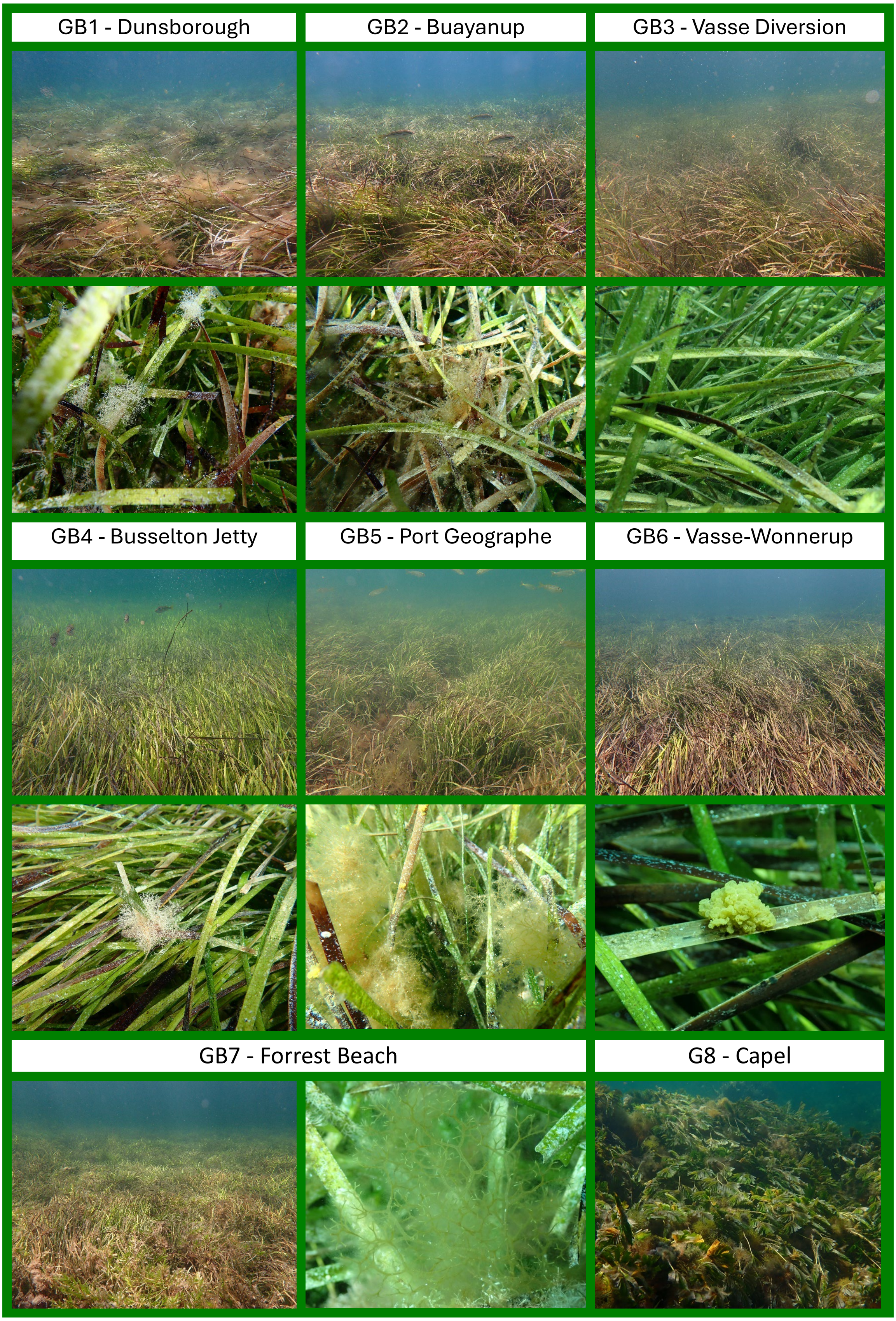



***Figure 6***: *Pictures of seagrass meadow (top picture) and the dominant algal epiphytes (bottom picture) at each* P. sinuosa *site (dominant algal type is shown on the right of the seagrass meadow picture for Forrest Beach). The last picture shows the rocky substrate with macroalgae at the* A. antarctica *site (8. Capel) from 2024, as the high turbidity during sampling this year prevented pictures being taken.*

## 4.4 Other observations

*A. antarctica* was observed at all sites except Buayanup and Vasse-Wonnerup and *A. griffithii* was also growing at Port Geographe, Forrest Beach and Capel while *Halophila ovalis* was seen at Port Geographe. Seedlings of *P. sinuosa* were observed at all *P. sinuosa* sites this year while no flowering shoots had been observed (Appendix 2). Some potential anchor damage was observed in the Vasse-Wonnerup, and blowouts remain at the Dunsborough site since monitoring began, most likely from water movement (Figure 7). Small bare or sparse patches were noted at Vasse Diversion Drain, Port Geographe, Vasse-Wonnerup and Forrest Beach, indicating historical and potentially some small-scale recent shoot loss, but no obvious dead blackened leaves were observed at any of the sites.

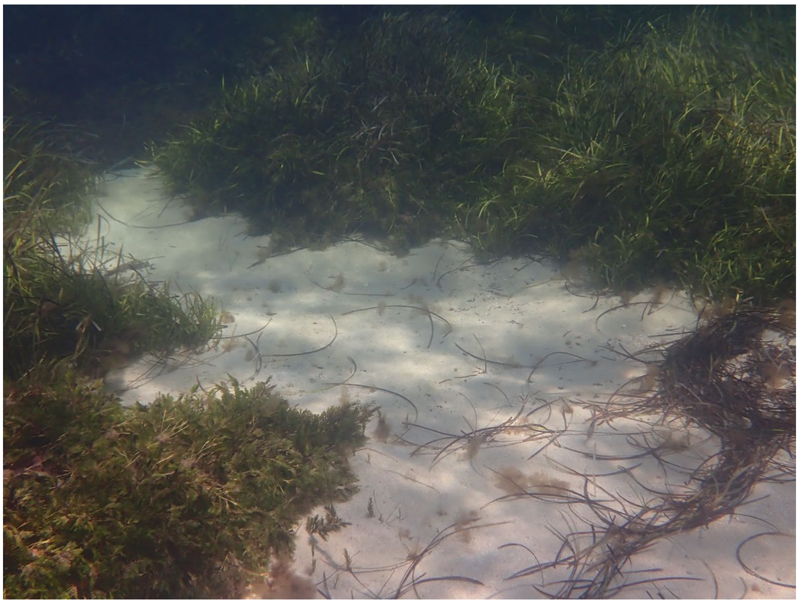


***Figure 7****: Picture of seagrass blowout observed at the Dunsborough site in 2025.*

## 4.5 Nutrient content

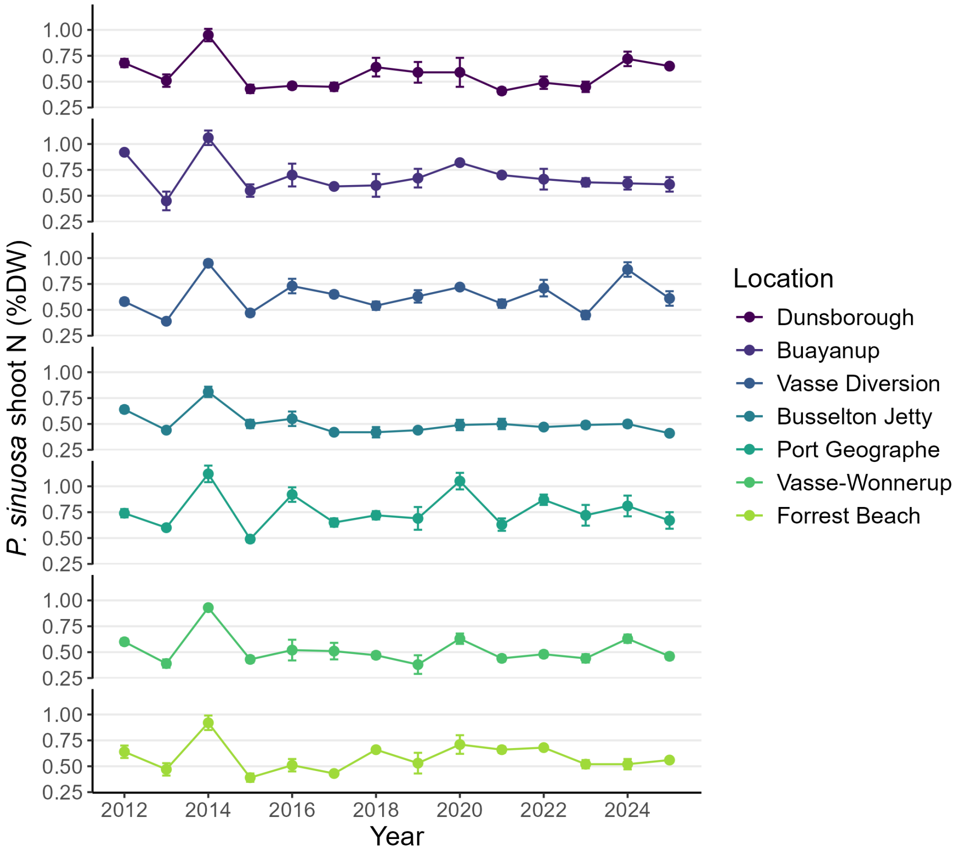
The nitrogen content of *P. sinuosa* leaves ranged from 0.39-0.77% N dry weight (DW), very similar to the range observed in 2024 (Figure 8). The sites that showed an increase in %N DW in 2024 compared to previous years, Dunsborough, Vasse Diversion and Vasse-Wonnerup, showed a decline in %N DW this year. Once again, the nitrogen content of *A. antarctica* leaves was slightly higher, ranging from 0.37-1.30% N DW. The highest nitrogen concentration was at Capel, with an increase in concentration this year after a decline in N DW was observed in 2024 compared to the previous years. A steady increase in nitrogen concentration can be observed at Busselton Jetty over the last couple of years.

The phosphorus content of *P. sinuosa* leaves in 2025 ranged from 0.05-0.18% P DW, very similar to the range observed in 2024 (0.08-0.21% P DW in 2024) (Figure 8). All sites were similar or decreased (Vasse Diversion Drain, Busselton Jetty and Port Geographe) in mean %DW P, compared to last year, with little variability among samples. For *A. antarctica* leaves, the phosphorus content ranged from 0.05-0.10% DW (Figure 9). There was little variation among all sites. All raw data is in Appendix 5.

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

***Table 5****: Comparison of shoot tissue nutrient concentrations and $\delta^{15}N$ 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 | | | |



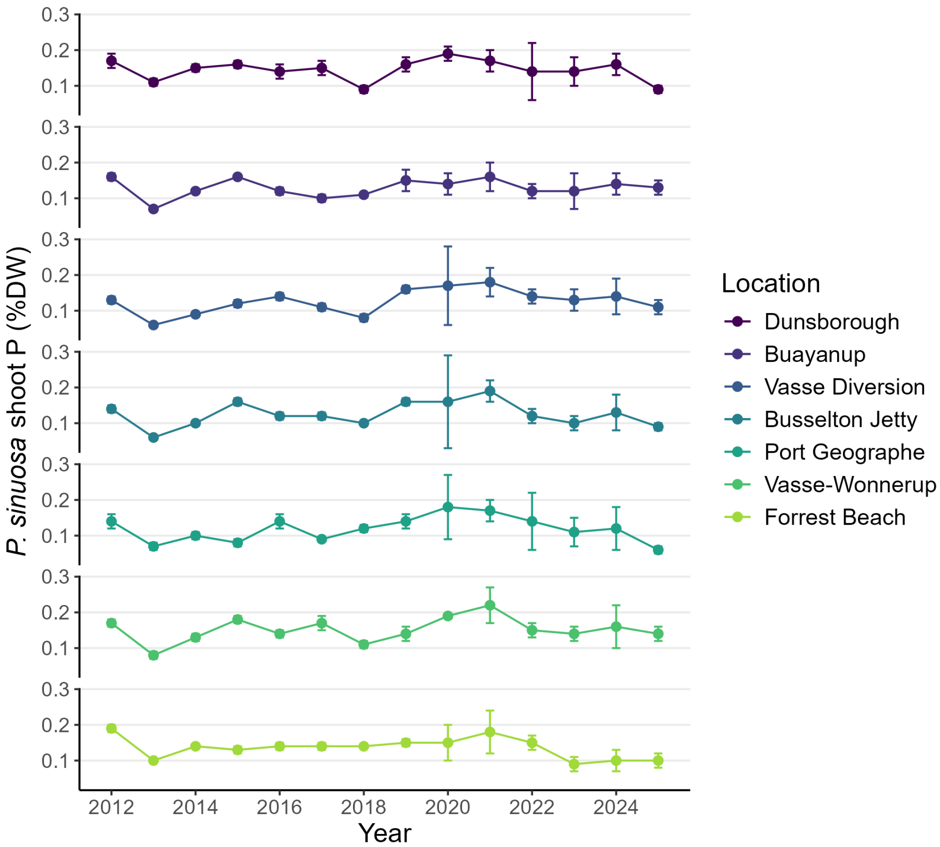
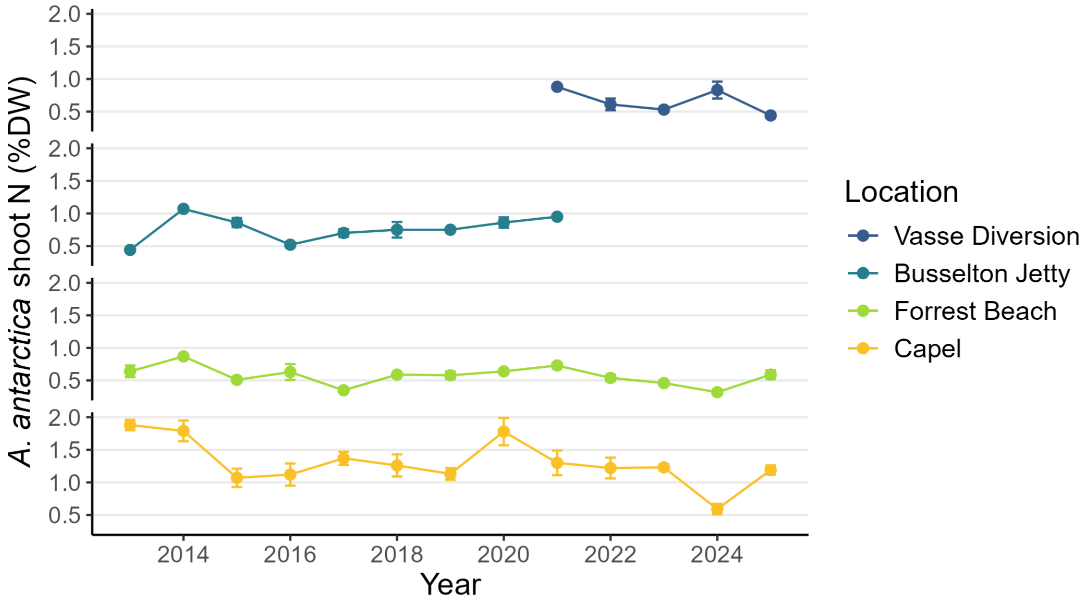




***Figure 8:*** *Nitrogen and phosphorus content (% DW) of* P. sinuosa *leaves (average ± se) at the Keep Watch seagrass monitoring sites (Dunsborough-Forrest Beach) in 2012-2025.*



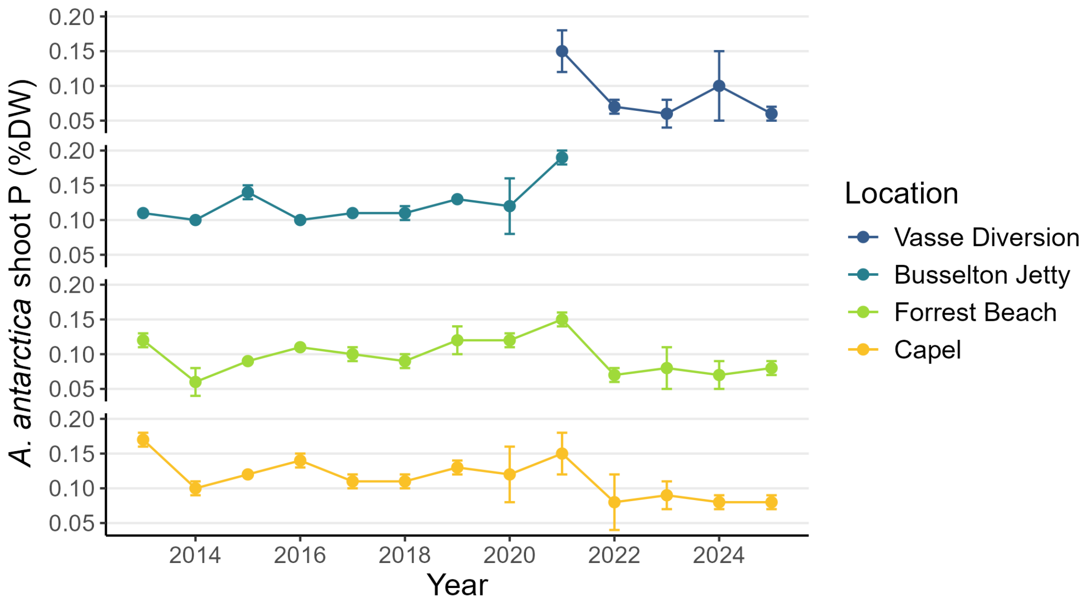




***Figure 9:*** *Nitrogen and phosphorus content (% DW) of* A. antarctica *leaves (average ± se) at the Keep Watch seagrass monitoring sites in 2013-2025 Note that sampling at Busselton Jetty ended in 2021 and with a new site established at Vasse Diversion drain.*

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

The $\delta^{15}N$ of *P. sinuosa* leaves ranged from 0.09 to 2.13 ‰. $\delta^{15}N$ signals increased slightly, dropped slightly or stayed similar compared to last year, but all values are in the range that has been observed in the last ten years, except for Port Geographe where average $\delta^{15}N$ is lower than has been observed in previous years (0.91 ‰) (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 0.99-2.85‰, staying the same or increasing slightly on average at all sites this year compared to 2024 but staying within the range observed in previous years (Figure 10). As in previous years, the highest values were observed at Capel indicating a different source of nitrogen at this site. All raw data is in Appendix 5.

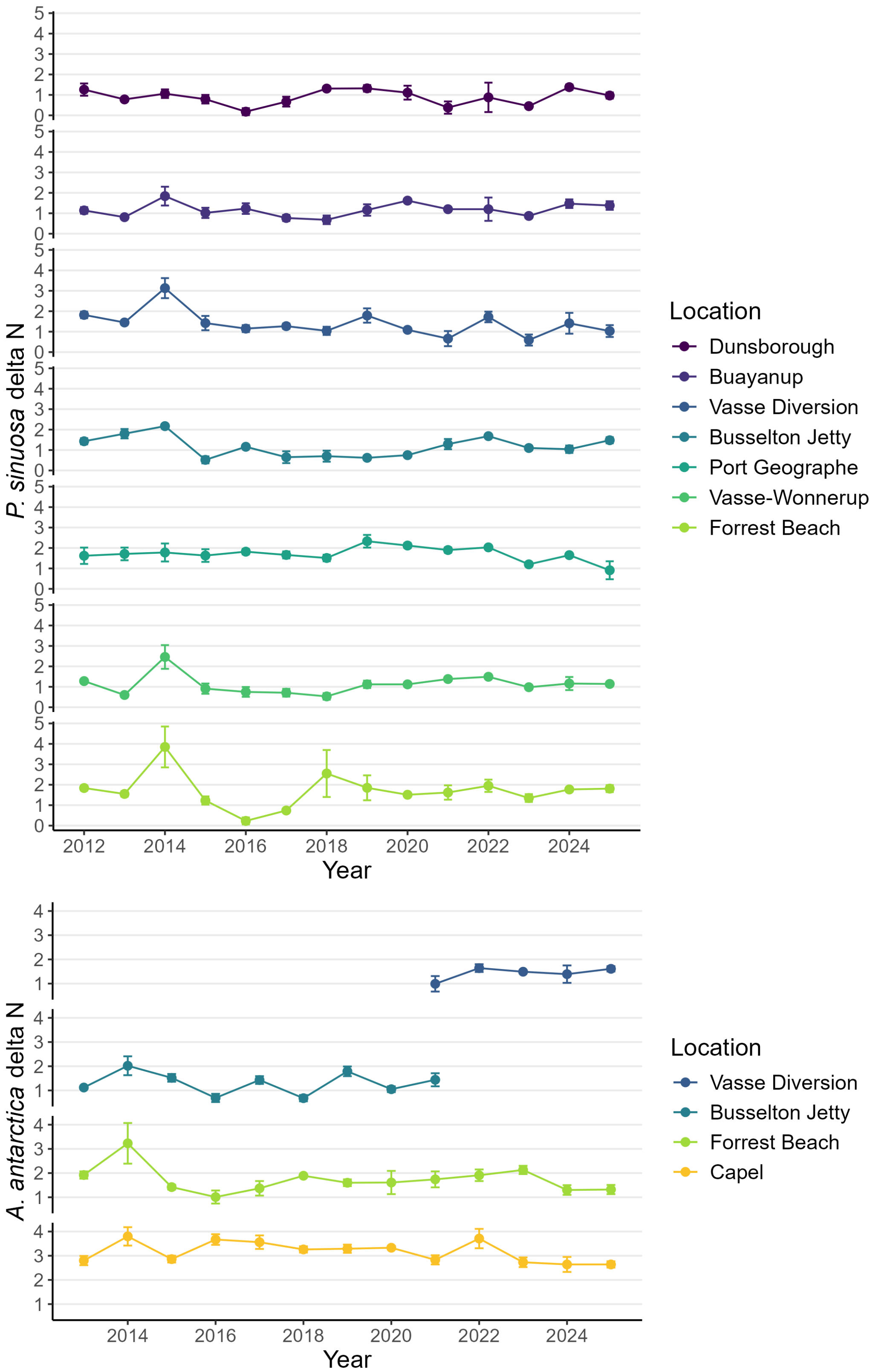



***Figure 10:*** *$\delta^{15}$N of* P. sinuosa *leaves (Site 1-7) and* A. antarctica *leaves (Site 4, 6, 7 & 8; average ± se) at the Keep Watch seagrass monitoring sites in 2012-2025 for* P. sinuosa *and 2013-2025 for* A. antarctica. *Note that only Capel was measured in 2012 for* A. antarctica, *and is not included in these graphs.*

The epiphytic macroalgae, *Dictyota* had higher phosphorus content (% DW) at Capel compared to the other sites, nitrogen content (% DW) lowered in Vasse Diversion, Forrest Beach and Capel and remained the same in Dunsborough compared to previous years, resulting in similar nitrogen levels at all sites this year (Figure 11). The nitrogen and phosphorus content (%DW) and $\delta^{15}N$ that increased last year at Forrest Beach decreased again this year. An increase in $\delta^{15}N$ to 2.20 was observed in Capel this year compared to 0.26 in 2024. $\delta^{15}N$ was around -1 for Dunsborough, Vasse Diversion and Forrest Beach. Like for the seagrass *A. antarctica*, the $\delta^{15}N$ for *Dictyota* was higher at Capel compared to all other sites, indicating different sources of nitrogen between Capel and other sites (Figure 11).

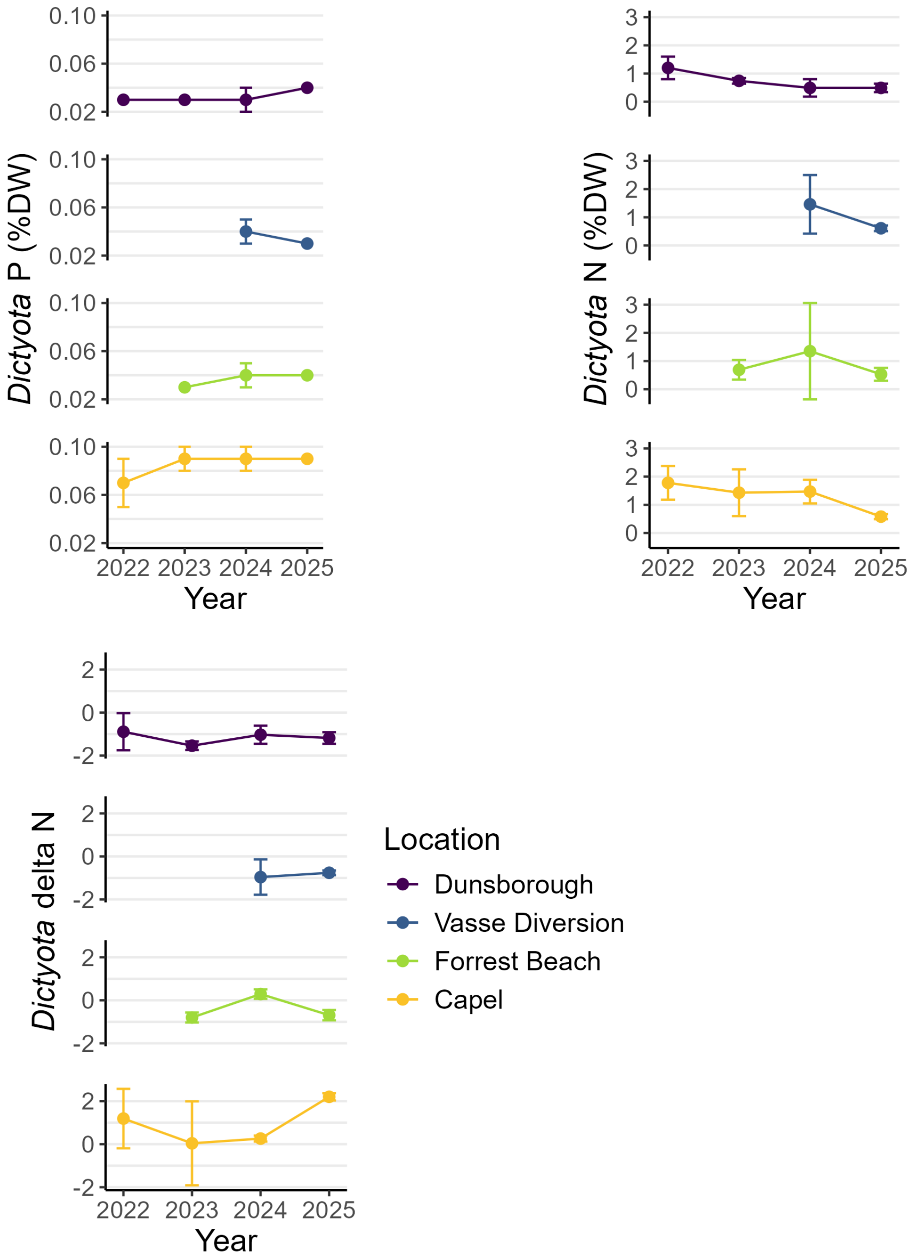



***Figure 11:*** *Nutrient (N, P) and $\delta^{15}N$ of the epiphytic macroalgae* Dictyota *from Keep Watch Seagrass monitoring sites from 2022-2025. Note that Forrest Beach only has been sampled in 2023-2025 and Vasse Diversion only in 2024-2025.*

## 4.6 Water quality

Water temperature at the Keep Watch seagrass sites ranged from 22.5-23.5°C during sampling, within the range observed for previous years. Temperature logger data for Port Geographe indicated a range in temperature from 13.4-26.3°C over the whole year, with peak temperatures in January 2025 (Figure 12). Water clarity was high and the Secchi disk was always observed on the bottom (Table 6).

***Table 6:*** *Water quality measures at the Keep Watch seagrass monitoring sites from 2012-2025, Du = Dunsborough, Bu = Buayanup, VD = Vasse Diversion Drain, BJ = Busselton Jetty, PG = Port Geographe, VW = Vasse-Wonnerup, FB = Forrest Beach, *=Secchi disk depth on bottom.*

| **Site** | **Secchi disk depth (m)** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2012** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **2025** |
| Du | 4.2* | 3 | 3 | 3.2* | 3* | 3.5* | 2.7 | 2.7 | 4.0* | 3.3 | 4.0* | 3.5* | 3.4* | 4.2* |
| Bu | 3.5 | 2.5 | 3* | 3.2* | 3.5* | 2.5* | 3* | 2.8 | 3.5* | 3.2 | 3.5* | 3.5* | 3.2* | 3.8* |
| VD | 4 | 3.25 | 3.5* | 3.6* | 3.5* | 5* | 3.3 | 3 | 3.5* | 3.4 | 4.0* | 4.0* | 3.7* | 4.0* |
| BJ | 4.2 | 2.5 | 3.5 | 3.6* | 3.5* | 2.5* | 4* | 2.9 | 3.5* | 3.1 | 4.5* | 3.7* | 3.3* | 2.4* |
| PG | 3.75 | 2.5 | 4 | 4.1* | 3.5 | 4.5* | 3.5* | 3.2 | 3.0* | 4.5* | 3.5* | 3.6* | 3.3* | 2.7* |
| VW | 4 | 2 | 4.5 | 4.6* | 4.5* | 4* | 4.5* | 4 | 4.5* | 5.4* | 5.0* | 4.6* | 4.1* | 5.2* |
| FB | 5* | 2 | 4 | 4.2* | 4.5* | 4* | 3.5 | 3.8 | 4.5* | 5* | 5.0* | 4.3* | 4.4* | 4.8* |
| | **Temperature (°C)** | | | | | | | | | | | | | |
| | **2012** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** | **2025** |
| Du | 22 | 22.5 | 23.1 | 23.3 | 22.9 | 22.5 | 21.2 | 20.6 | 23.5 | 20.0 | 23.6 | 22.9 | 21.6 | 23.5 |
| Bu | 22.8 | 22.6 | 23.5 | 25.2 | 23.7 | 22.8 | 21.7 | 21.7 | 24.4 | 20.1 | 23.9 | 24.3 | 23.3 | 22.5 |
| VD | 23.4 | 23.8 | 23.5 | 24.5 | 23.9 | 22 | 22.1 | 21.7 | 24.7 | 20.9 | | 24.4 | 23.4 | 22.7 |
| BJ | 23.4 | 27.3 | 23.3 | 26.3 | 22.6 | 22.5 | 22.6 | 22.8 | 23.6 | 20.9 | | 23.3 | 22 | 22.8 |
| PG | 23.4 | 25.5 | 23.3 | 24.3 | 23 | 22.5 | 22.3 | 22.8 | 23.7 | 20.9 | | 24.1 | 23.1 | 23.1 |
| VW | 23.1 | 28.4 | 22.2 | 26.1 | 22.3 | 22.3 | 21.9 | 21.6 | 23.6 | 21.2 | 24.4 | 24.3 | 22 | 23.1 |
| FB | 22.5 | 23.5 | 22.1 | 25.1 | 23.3 | 22.5 | 21.5 | 21.7 | 24.0 | 21.4 | | 23.6 | 22.6 | 23.5 |


**Figure 12**: Temperature logger data for the Port Geographe site from February 2024 until February 2025.

# 5 General conclusions

## 5.1 Rebound in shoot density

With the highest shoot count observed at the majority of sites this year, none of the three management criteria were triggered indicating the meadows are in a healthy condition. These high shout counts and the significant increases since the program began at Vasse Diversion and Busselton Jetty highlight that the environmental conditions are conducive for increases in seagrass condition. This is supported when comparing to other regions (Perth and Jurien Bay) as the average shoot densities in Geographe Bay are higher than the maximum averages in these regions. Also a long-term assessment of *P. sinuosa* condition across the distributional range on the west coast of WA identified that human activities and ocean warming is not currently impacting meadows in Geographe Bay as has been observed further north (Strydom et al., 2020; Webster et al., 2024). It is recommended to continue monitoring to keep track on the condition of the meadows, especially as the Ngari Capes have been recognised as potentially important temperate seagrass refugia (Webster et al., 2024), including being resilient to ocean warming and marine heatwaves (Said et al., 2024). It is possible that the higher shoot densities observed over the last 14 years are due to gradual ocean warming as the optimum temperature for photosynthesis has been derived as 29°C, and as temperature increases productivity will increase (Said et al., 2024).

| Site | 2012 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Dunsborough | 61 | 64 | 52 | 56 | 61 | 59 | 53 | 56 | 61 | 68 | 63 | 66 | 62 | 67 |
| 2. Buayanup | 59 | 66 | 50 | 60 | 57 | 58 | 55 | 63 | 56 | 60 | 59 | 56 | 61 | 81 |
| 3. Vasse Diversion Drain | 34 | 37 | 34 | 34 | 29 | 34 | 38 | 41 | 48 | 37 | 41 | 40 | 43 | 60 |
| 4. Busselton Jetty | 38 | 38 | 46 | 44 | 45 | 45 | 43 | 52 | 49 | 45 | 49 | 39 | 51 | 74 |
| 5. Port Geographe | 39 | 46 | 42 | 47 | 45 | 35 | 49 | 62 | 50 | 48 | 42 | 32 | 49 | 65 |
| 6. Vasse-Wonnerup | 38 | 45 | 51 | 49 | 48 | 50 | 47 | 53 | 51 | 44 | 45 | 37 | 57 | 60 |
| 7. Forrest Beach | 53 | 61 | 47 | 48 | 50 | 49 | 53 | 53 | 59 | 42 | 49 | 48 | 53 | 61 |

***Figure 13:*** *Heatmap of average shoot density of* P. sinuosa *per quadrat (0.04m$^2$) over time, 2012-2025, at each Keep Watch seagrass monitoring sites.*

## 5.2 Algal epiphyte cover consistent

The cover of algae has decreased slightly compared to the previous years from mostly high-moderate to low-moderate which is positive as there is a greater likelihood of impacts to seagrass meadows with longer durations of high epiphyte cover. The current level of epiphyte cover is not of concern and this is supported as there is no obvious impacts to seagrass condition (Figure 14). The dominant algal types remains microalgal accumulations with an increase in observed encrusting algae, which could be due to increased visibility of encrusting algae with lower epiphytic cover. Both microalgal accumulations and encrusting algae are not the type commonly associated with nutrient enrichment. Although it is important to note that lower epiphytic cover has also been observed in some other years since monitoring began (2012, 2013, 2019) after which cover increased again in severity, emphasizing the need to keep monitoring changes in algal cover.

| | 2012 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Dunsborough | 3 | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 |
| 2. Buayanup | 3 | 2 | 3 | 3 | 4 | 4 | 3 | 1 | 4 | 4 | 4 | 4 | 4 | 3 |
| 3. Vasse Diversion Drain | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 4 | 4 | 3 | 4 | 2 |
| 4. Busselton Jetty | 2 | 2 | 4 | 4 | 3 | 3 | 3 | 2 | 4 | 4 | 4 | 3 | 3 | 2 |
| 5. Port Geographe | 2 | 1 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 4 | 3 |
| 6. Vasse-Wonnerup | 2 | 1 | 2 | 3 | 2 | 2 | 2 | 1 | 2 | 3 | 2 | 3 | 2 | 2 |
| 7. Forrest Beach | 2 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | 1 | 2 | 3 | 3 |

***Figure 14:*** *Heatmap of changes in algal cover on* P. sinuosa *over time, 2012-2025, 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 continue to be very low and do not indicate exposure to excess nutrients. At Capel, slightly higher nitrogen content in seagrass and slightly higher phosphorus content in algae indicates higher exposure and also different sources due to the larger nitrogen isotope signal in both species. The main potential nitrogen sources based on the higher nitrogen isotope signal (2.64 ‰ for *A. antarctica*) indicate nitrogen derived from animal wastes or septic tanks or sources from natural vegetation. The nitrogen content (% DW) in *A. antarctica* increased compared to 2024 but is comparable to that observed between 2021 and 2023, indicating that there continues to be less exposure to nutrients compared to earlier years. The increase in nitrogen and phosphorus levels (% DW) and $\delta^{15}N$ values in *Dictyota* in Forrest Beach observed in 2024, has not continued into 2025.

## 5.4 Keep Watch program continuing

Following the 10 year review meeting with relevant stakeholders it was agreed to continue the Keep Watch seagrass monitoring program annually at the seven shallow seagrass sites. The program is funded for one more year with financial support from Water Corp, managed through GeoCatch and supported by DBCA with boats, scientists and rangers. This forms part of the DBCA routine monitoring of the marine park, which without this program would only occur every two years in the shallow water sites. There is value to continue this program into the future due to the good condition and climate refuge value of seagrasses in Geographe Bay.

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## Appendix 1: Randomly generated quadrat positions from 2025 survey.

| Quadrat # | Bearing | Distance (m) |
|---|---|---|
| 1 | 20 | 11 |
| 2 | 20 | 12 |
| 3 | 20 | 15 |
| 4 | 20 | 17 |
| 5 | 20 | 21 |
| 6 | 20 | 24 |
| 7 | 60 | 1 |
| 8 | 60 | 3 |
| 9 | 60 | 4 |
| 10 | 60 | 9 |
| 11 | 60 | 10 |
| 12 | 60 | 11 |
| 13 | 140 | 2 |
| 14 | 140 | 4 |
| 15 | 140 | 17 |
| 16 | 140 | 18 |
| 17 | 140 | 19 |
| 18 | 140 | 20 |
| 19 | 180 | 7 |
| 20 | 180 | 10 |
| 21 | 180 | 15 |
| 22 | 180 | 16 |
| 23 | 180 | 19 |
| 24 | 180 | 20 |
| 25 | 320 | 2 |
| 26 | 320 | 3 |
| 27 | 320 | 9 |
| 28 | 320 | 14 |
| 29 | 320 | 15 |
| 30 | 320 | 18 |

**Appendix 2:** Raw and summary statistics for shoot density data for the seven Keep Watch Seagrass Monitoring Sites in 2025, with the average, mean, standard error (SE), standard deviation (Stdev) and coefficient of variation (CV) shown in the bottom rows. Shoot counts (Sh), number of seedlings (Sl) and the number of flowering shoots (FSh) per quadrat (0.04 $m^2$) are given and the initials of the person who counted each quadrat is also included (C, see also legend below). Columns for Seedlings and/or Flowering shoots are excluded from sites where no seedlings or flowering shoots were observed. The table continues on the next page.

| | 1. Dunsborough | | | 2. Buayanup | | | 3. Vasse Diversion | | | 4. Busselton Jetty | | | 5. Port Geographe | | | 6. Vasse-Wonnerup | | | 7. Forrest Beach | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C |
| 1 | 37 | 2 | TS | 125 | 0 | RC | 63 | 0 | JR | 61 | 2 | AF | 51 | 0 | RE | 26 | 0 | DC | 64 | 1 | TS |
| 2 | 43 | 1 | TS | 132 | 0 | RC | 35 | 0 | JR | 74 | 1 | RE | 65 | 0 | RE | 63 | 2 | DC | 35 | 0 | TS |
| 3 | 64 | 0 | TS | 117 | 0 | RC | 53 | 0 | JR | 113 | 1 | RE | 87 | 0 | RE | 51 | 0 | DC | 37 | 0 | TS |
| 4 | 66 | 5 | TS | 99 | 1 | RC | 92 | 0 | JR | 71 | 1 | RE | 31 | 1 | RE | 75 | 0 | DC | 66 | 0 | TS |
| 5 | 78 | 0 | TS | 91 | 3 | RC | 26 | 0 | JR | 92 | 3 | RE | 72 | 0 | RE | 57 | 1 | DC | 81 | 2 | TS |
| 6 | 52 | 1 | TS | 65 | 1 | RC | 42 | 0 | JR | 74 | 0 | RE | 77 | 1 | RE | 67 | 0 | DC | 55 | 1 | TS |
| 7 | 64 | 1 | DC | 38 | 0 | TS | 69 | 0 | RE | 60 | 0 | AF | 73 | 0 | TA | 70 | 2 | TS | 73 | 0 | RE |
| 8 | 63 | 0 | DC | 92 | 0 | TS | 56 | 0 | RE | 82 | 1 | AF | 66 | 0 | TA | 66 | 1 | TS | 70 | 0 | RE |
| 9 | 89 | 0 | DC | 61 | 0 | TS | 81 | 0 | RE | 81 | 0 | AF | 22 | 0 | TA | 49 | 0 | TS | 71 | 0 | RE |
| 10 | 64 | 0 | DC | 72 | 1 | TS | 43 | 0 | RE | 91 | 0 | AF | 29 | 0 | TA | 15 | 0 | TS | 63 | 0 | RE |
| 11 | 66 | 0 | DC | 53 | 1 | TS | 87 | 0 | RE | 53 | 0 | AF | 30 | 0 | TA | 46 | 0 | TS | 31 | 1 | RE |
| 12 | 62 | 0 | DC | 81 | 0 | TS | 69 | 0 | RE | 93 | 2 | AF | 40 | 0 | TA | 69 | 1 | TS | 31 | 4 | RE |
| 13 | 67 | 0 | RE | 54 | 0 | AF | 51 | 0 | RE | 77 | 0 | TA | 48 | 0 | GS | 73 | 3 | AF | 86 | 0 | AF |
| 14 | 71 | 0 | RE | 36 | 0 | AF | 66 | 0 | RC | 53 | 0 | TA | 57 | 0 | GS | 63 | 2 | AF | 58 | 2 | AF |
| 15 | 108 | 0 | RE | 88 | 0 | AF | 14 | 0 | AF | 25 | 0 | TA | 90 | 0 | GS | 54 | 0 | AF | 20 | 1 | AF |
| 16 | 73 | 1 | RE | 98 | 0 | JR | 42 | 0 | AF | 76 | 0 | TA | 46 | 0 | GS | 57 | 1 | AF | 32 | 0 | AF |
| 17 | 106 | 0 | RE | 73 | 0 | JR | 25 | 1 | AF | 68 | 0 | TA | 72 | 0 | GS | 59 | 1 | AF | 84 | 0 | AF |
| 18 | 83 | 0 | RE | 76 | 0 | JR | 28 | 0 | AF | 38 | 0 | TA | 47 | 0 | GS | 55 | 0 | AF | 71 | 0 | AF |
| 19 | 74 | 0 | AF | 66 | 0 | JR | 102 | 1 | RC | 62 | 0 | TA | 81 | 0 | GS | 46 | 1 | DC | 99 | 0 | RE |
| 20 | 63 | 0 | DC | 109 | 0 | JR | 82 | 1 | RC | 90 | 0 | AF | 58 | 0 | AF | 75 | 0 | TS | 123 | 1 | RE |
| 21 | 96 | 1 | AF | 69 | 0 | RC | 97 | 0 | RC | 68 | 0 | AF | 48 | 0 | RE | 60 | 0 | TS | 37 | 0 | RE |
| 22 | 42 | 3 | AF | 67 | 0 | JR | 64 | 0 | RC | 63 | 0 | AF | 104 | 0 | RE | 82 | 1 | TS | 83 | 0 | RE |

| Rep | 1. Dunsborough | | | 2. Buayanup | | | 3. Vasse Diversion | | | 4. Busselton Jetty | | | 5. Port Geographe | | | 6. Vasse-Wonnerup | | | 7. Forrest Beach | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C | Sh | Sl | C |
| 23 | 17 | 0 | AF | 56 | 0 | JR | 92 | 0 | RC | 88 | 0 | RE | 72 | 0 | AF | 44 | 0 | TS | 56 | 0 | RE |
| 24 | 20 | 0 | AF | 85 | 0 | RC | 69 | 0 | RC | 100 | 0 | RE | 112 | 0 | GS | 74 | 0 | TS | 13 | 0 | RE |
| 25 | 63 | 2 | TS | 120 | 0 | AF | 72 | 0 | RE | 96 | 3 | RC | 80 | 0 | RE | 53 | 0 | DC | 79 | 3 | TS |
| 26 | 83 | 0 | RE | 50 | 0 | TS | 42 | 0 | JR | 52 | 1 | RE | 130 | 0 | RE | 52 | 0 | DC | 20 | 0 | TS |
| 27 | 50 | 0 | RE | 94 | 0 | AF | 38 | 0 | JR | 68 | 0 | TA | 126 | 0 | TA | 100 | 1 | TS | 105 | 0 | TS |
| 28 | 49 | 1 | TS | 148 | 0 | TS | 90 | 0 | RE | 76 | 0 | RE | 43 | 0 | TA | 79 | 0 | AF | 51 | 0 | TS |
| 29 | 53 | 0 | TS | 24 | 0 | TS | 33 | 0 | JR | 104 | 0 | TA | 60 | 0 | TA | 63 | 1 | AF | 67 | 0 | TS |
| 30 | 139 | 3 | RE | 89 | 2 | TS | 86 | 0 | RE | 84 | 0 | RE | 19 | 0 | TA | 45 | 0 | AF | 54 | 0 | TS |
| **Average** | 66.8 | 1.9 | | 80.9 | 1.5 | | 60.3 | 0.1 | | 74.4 | 1.7 | | 64.5 | 1.0 | | 59.6 | 1.4 | | 60.5 | 1.8 | |
| **Median** | 64.0 | 1.0 | | 78.5 | 1.0 | | 63.5 | 0.0 | | 75.0 | 1.0 | | 62.5 | 1.0 | | 59.5 | 1.0 | | 63.5 | 1.0 | |
| **SE** | 4.6 | 0.4 | | 5.4 | 0.3 | | 4.5 | 0.1 | | 3.6 | 0.3 | | 5.2 | 0.0 | | 3.0 | 0.2 | | 4.8 | 0.4 | |
| **Stdev** | 25.2 | 1.3 | | 29.6 | 0.8 | | 24.7 | 0.3 | | 19.5 | 0.9 | | 28.7 | 0.0 | | 16.6 | 0.7 | | 26.5 | 1.1 | |
| **CV** | 0.4 | 0.7 | | 0.4 | 0.6 | | 0.4 | 3.1 | | 0.3 | 0.5 | | 0.4 | 0.0 | | 0.3 | 0.5 | | 0.4 | 0.6 | |

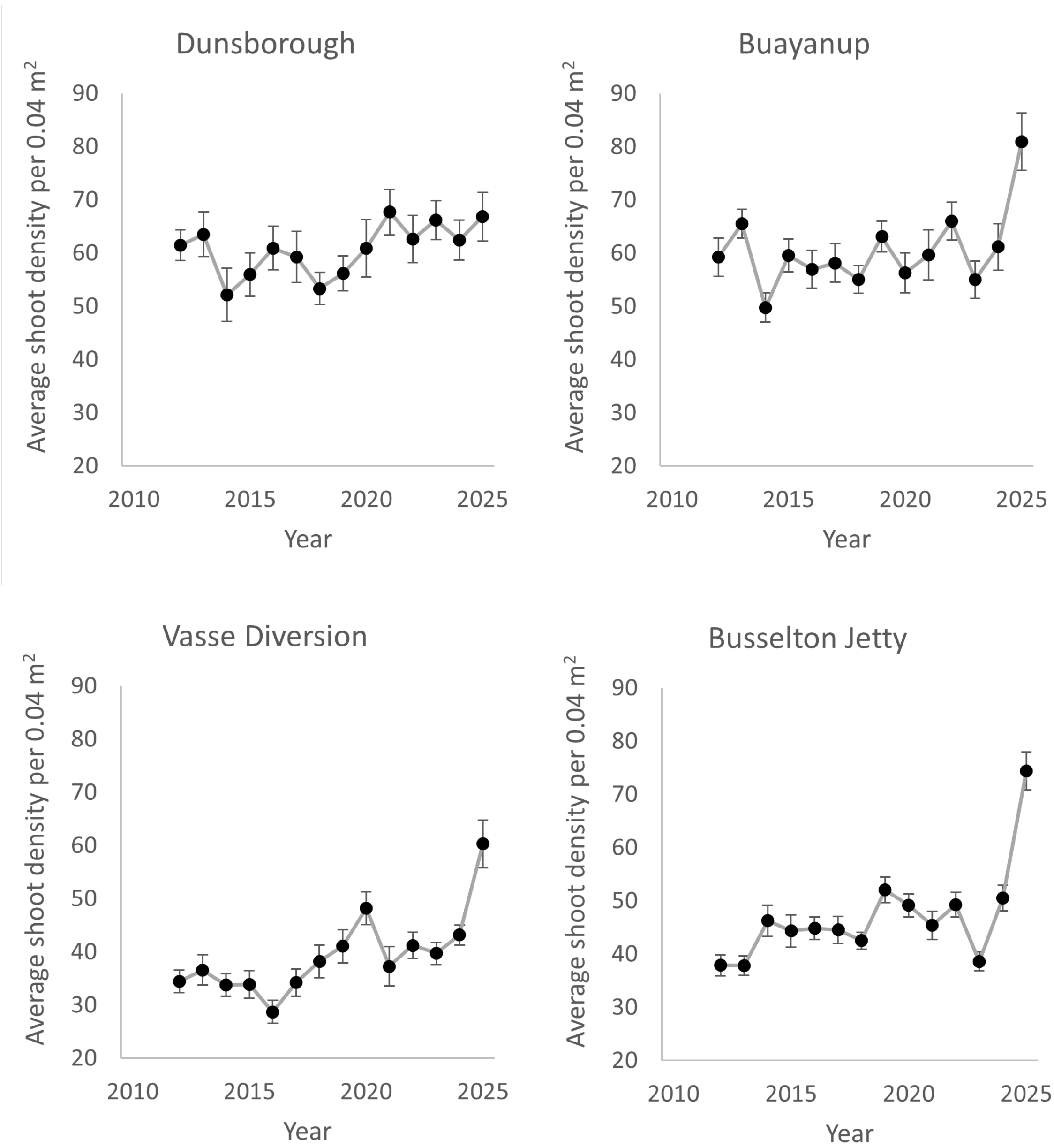
Counter (C)

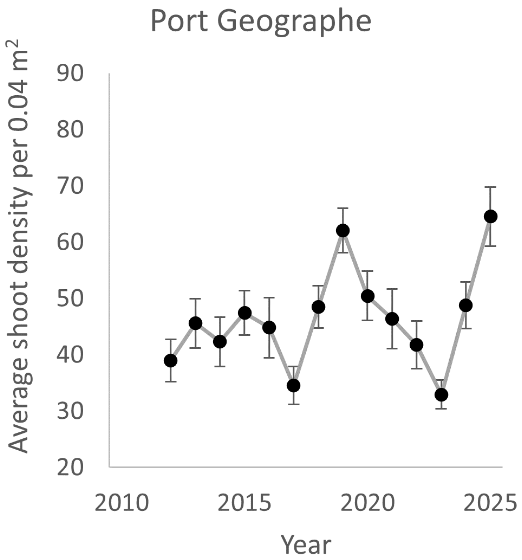
| | |
|---|---|
| **AF** | Anna Frouws |
| **DC** | Daisy Church |
| **JR** | Josh Reagan |
| **RC** | Raphael Clement |
| **RE** | Richard Evans |
| **TS** | Tanika Shalders |

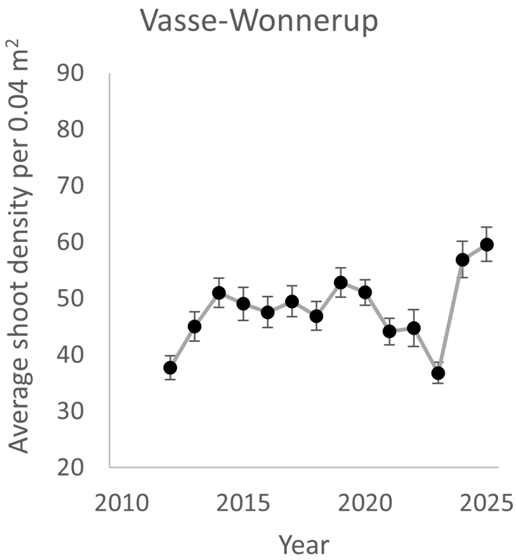
## Appendix 3: Leaf morphology data of *Posidonia sinuosa* for 2025

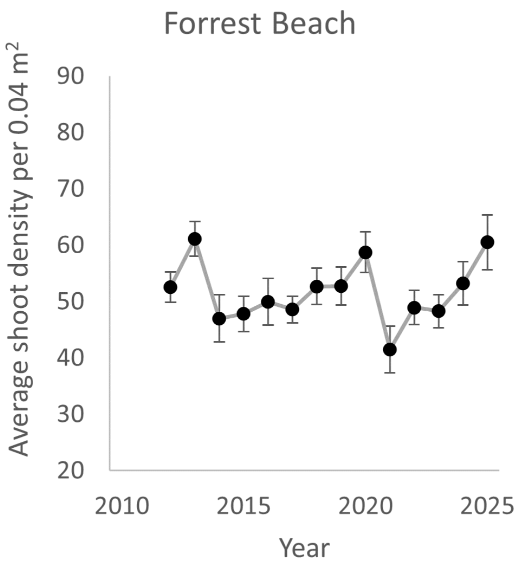
| | S1. Dunsborough | | S2. Buayanup | | S3. Vasse Diversion | | S4. Busselton Jetty | | S5. Port Geographe | | S6. Vasse-Wonnerup | | S7. Forrest Beach | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rep | Shoot Length (cm) | Shoot Width (mm) | Shoot Length (cm) | Shoot Width (mm) | 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 | 37.5 | 5.5 | 48.4 | 5 | 35.6 | 5 | 49.9 | 5.5 | 31.4 | 5.5 | 64.4 | 6 | 39.7 | 5 |
| 2 | 44 | 6 | 46 | 4.5 | 43.2 | 5 | 47 | 5.5 | 19.5 | 5 | 46.7 | 5.5 | 40.4 | 6 |
| 3 | 44.4 | 6.5 | 54.3 | 5.5 | 28 | 6 | 57.9 | 6 | 37.5 | 5 | 57.8 | 6 | 35.6 | 6 |
| 4 | 46.5 | 6 | 40.5 | 5 | 42.3 | 5.5 | 42.4 | 6 | 29 | 5.5 | 58.9 | 7 | 33.4 | 6 |
| 5 | 48.1 | 5.5 | 37.2 | 4 | 43.8 | 5 | 50.5 | 6.5 | 25.7 | 5.5 | 50.3 | 7.5 | 45.7 | 6 |
| 6 | 35.9 | 5 | 50.4 | 5 | 70.2 | 6 | 37.5 | 6 | 38.8 | 6.5 | 79.3 | 6 | 35.8 | 6 |
| 7 | 26.7 | 5.5 | 33.7 | 5.5 | 25 | 5.5 | 37.4 | 5.5 | 32.8 | 5.5 | 62.3 | 6.5 | 29.6 | 6 |
| 8 | 26.6 | 6 | 57.1 | 5.5 | 39.8 | 5 | 52.6 | 7 | 29.1 | 6.5 | 64 | 6 | 32.2 | 7 |
| 9 | 32.9 | 5 | 45.9 | 5 | 57.2 | 6 | 36.4 | 7 | 31.6 | 5.5 | 94.4 | 6 | 29 | 6 |
| 10 | 25.2 | 5.5 | 41.8 | 5.5 | 53.4 | 6.5 | 40.9 | 8 | 59.7 | 5.5 | 57.9 | 7 | 25.5 | 5.5 |
| 11 | 35.7 | 5 | 49.2 | 5 | 24 | 5 | 69.6 | 6 | 36.7 | 6 | 62.9 | 7 | 27.6 | 6 |
| 12 | 40.2 | 6 | 46 | 4.5 | 52.2 | 6.5 | 29.7 | 6 | 38.2 | 6.5 | 43.7 | 6 | 45.9 | 6 |
| 13 | 28 | 5 | 40.4 | 5.5 | 48.7 | 5 | 39.2 | 5.5 | 56.6 | 5.5 | 57.7 | 6 | 45.6 | 6 |
| 14 | 42.5 | 6 | 43.8 | 4 | 55.1 | 6 | 50.7 | 6 | 41.3 | 6 | 70.2 | 6 | 50.8 | 5 |
| 15 | 46.1 | 6.5 | 35.4 | 6 | 53.5 | 5 | 66.6 | 5.5 | 31.4 | 6 | 73.2 | 6 | 52.5 | 5 |
| Mean | 37.4 | 5.7 | 44.7 | 5.0 | 44.8 | 5.5 | 47.2 | 6.1 | 36.0 | 5.7 | 62.9 | 6.3 | 38.0 | 5.8 |
| SE | 2.1 | 0.1 | 1.7 | 0.2 | 3.3 | 0.2 | 2.9 | 0.2 | 2.7 | 0.1 | 3.3 | 0.1 | 2.2 | 0.1 |
| Min | 25.2 | 5.0 | 33.7 | 4.0 | 24.0 | 5.0 | 29.7 | 5.5 | 19.5 | 5.0 | 43.7 | 5.5 | 25.5 | 5.0 |
| Max | 48.1 | 6.5 | 57.1 | 6.0 | 70.2 | 6.5 | 69.6 | 8.0 | 59.7 | 6.5 | 94.4 | 7.5 | 52.5 | 7.0 |

## Appendix 4: Trends over time in seagrass shoot density of *Posidonia sinuosa* from 2012 to 2025.




Port Geographe
Average shoot density per 0.04 m2
90
80
70
60
50
40
30
20
2010
2015
2020
2025
Year


Vasse-Wonnerup
Average shoot density per 0.04 m2
90
80
70
60
50
40
30
20
2010
2015
2020
2025
Year


Forrest Beach
Average shoot density per 0.04 m2
90
80
70
60
50
40
30
20
2010
2015
2020
2025
Year

**Appendix 5: Nutrient data for 2025 including the original (O) and modified (M) calibrated values for 2020 as well as the calibrated values for 2025 for several species (Spec) of seagrasses (*Ps* = *Posidonia sinuosa*, *Aa* = *Amphibolis antarctica*) and macroalgae (*D* = *Dictyota*).**

| Site | Spec | 2020 | | | | | 2025 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | δ15N | | N (% DW) | | P (% DW) | δ15N | | N (% DW) | | P (% DW) |
| | | O | M | O | M | O | O | M | O | M | O |
| 1. Dunsborough | *Ps* | 2.09 | 1.66 | 1.03 | 0.53 | 0.21 | 1.36 | 0.88 | 1.17 | 0.68 | 0.12 |
| 1. Dunsborough | *Ps* | 1.63 | 1.17 | 1.33 | 0.85 | 0.19 | 1.25 | 0.76 | 1.12 | 0.62 | 0.09 |
| 1. Dunsborough | *Ps* | 1.00 | 0.49 | 0.90 | 0.39 | 0.18 | 1.71 | 1.26 | 1.13 | 0.63 | 0.07 |
| 2. Buayanup | *Ps* | 1.90 | 1.46 | 1.30 | 0.82 | 0.16 | 1.62 | 1.16 | 1.03 | 0.52 | 0.16 |
| 2. Buayanup | *Ps* | 2.22 | 1.80 | 1.34 | 0.86 | 0.13 | 1.64 | 1.17 | 1.07 | 0.58 | 0.10 |
| 2. Buayanup | *Ps* | 2.03 | 1.59 | 1.28 | 0.80 | 0.14 | 2.23 | 1.81 | 1.23 | 0.74 | 0.12 |
| 3. Vasse Diversion | *Ps* | 1.38 | 0.90 | 1.19 | 0.70 | 0.23 | 1.00 | 0.49 | 1.13 | 0.63 | 0.08 |
| 3. Vasse Diversion | *Ps* | 1.65 | 1.19 | 1.26 | 0.77 | 0.17 | 1.54 | 1.07 | 1.21 | 0.72 | 0.12 |
| 3. Vasse Diversion | *Ps* | 1.66 | 1.20 | 1.19 | 0.70 | 0.11 | 1.95 | 1.51 | 0.99 | 0.48 | 0.13 |
| 4. Busselton Jetty | *Ps* | 1.09 | 0.59 | 1.08 | 0.58 | 0.24 | 1.79 | 1.34 | 0.90 | 0.39 | 0.07 |
| 4. Busselton Jetty | *Ps* | 1.38 | 0.90 | 0.91 | 0.40 | 0.10 | 2.20 | 1.78 | 0.95 | 0.44 | 0.10 |
| 4. Busselton Jetty | *Ps* | 1.27 | 0.78 | 0.99 | 0.49 | 0.12 | 1.76 | 1.31 | 0.90 | 0.40 | 0.11 |
| 5. Port Geographe | *Ps* | 2.31 | 1.90 | 1.60 | 1.14 | 0.19 | 0.63 | 0.09 | 1.20 | 0.71 | 0.07 |
| 5. Port Geographe | *Ps* | 2.55 | 2.15 | 1.38 | 0.90 | 0.12 | 1.51 | 1.03 | 1.26 | 0.77 | 0.07 |
| 5. Port Geographe | *Ps* | 2.70 | 2.31 | 1.59 | 1.12 | 0.23 | 2.03 | 1.60 | 1.01 | 0.51 | 0.05 |
| 6. Vasse-Wonnerup | *Ps* | 1.76 | 1.31 | 1.22 | 0.73 | 0.19 | 1.58 | 1.11 | 0.98 | 0.47 | 0.18 |
| 6. Vasse-Wonnerup | *Ps* | 1.60 | 1.13 | 1.11 | 0.61 | 0.19 | 1.51 | 1.03 | 1.01 | 0.50 | 0.10 |
| 6. Vasse-Wonnerup | *Ps* | 1.39 | 0.91 | 1.05 | 0.55 | 0.20 | 1.73 | 1.28 | 0.92 | 0.42 | 0.15 |
| 7. Forrest Beach | *Ps* | 2.01 | 1.57 | 1.08 | 0.58 | 0.12 | 2.52 | 2.13 | 1.04 | 0.54 | 0.09 |
| 7. Forrest Beach | *Ps* | 1.98 | 1.54 | 1.37 | 0.89 | 0.16 | 1.96 | 1.53 | 1.06 | 0.56 | 0.07 |
| 7. Forrest Beach | *Ps* | 1.86 | 1.41 | 1.15 | 0.66 | 0.17 | 2.20 | 1.78 | 1.08 | 0.59 | 0.13 |
| 3. Vasse Diversion | *Aa* | | | | | | 2.23 | 1.80 | 0.88 | 0.37 | 0.05 |
| 3. Vasse Diversion | *Aa* | | | | | | 2.05 | 1.62 | 0.98 | 0.48 | 0.07 |
| 3. Vasse Diversion | *Aa* | | | | | | 1.86 | 1.42 | 0.99 | 0.49 | 0.05 |
| 7. Forrest Beach | *Aa* | 2.90 | 2.53 | 1.17 | 0.68 | 0.12 | 2.06 | 1.63 | 1.22 | 0.73 | 0.07 |
| 7. Forrest Beach | *Aa* | 1.38 | 0.90 | 1.12 | 0.63 | 0.12 | 1.46 | 0.99 | 0.99 | 0.49 | 0.09 |
| 7. Forrest Beach | *Aa* | 1.86 | 1.41 | 1.12 | 0.63 | 0.11 | 1.78 | 1.33 | 1.05 | 0.55 | 0.06 |
| 8. Capel | *Aa* | 3.52 | 3.19 | 2.48 | 2.07 | 0.15 | 3.20 | 2.85 | 1.75 | 1.30 | 0.10 |
| 8. Capel | *Aa* | 3.75 | 3.44 | 1.83 | 1.38 | 0.10 | 2.77 | 2.39 | 1.54 | 1.07 | 0.06 |
| 8. Capel | *Aa* | 3.66 | 3.34 | 2.30 | 1.88 | 0.11 | 3.05 | 2.69 | 1.66 | 1.20 | 0.07 |
| 1. Dunsborough | *D* | | | | | | -0.64 | -1.27 | 1.08 | 0.59 | 0.04 |
| 1. Dunsborough | *D* | | | | | | -0.63 | -1.26 | 0.95 | 0.45 | 0.04 |
| 1. Dunsborough | *D* | | | | | | -0.38 | -1.00 | 0.93 | 0.43 | 0.04 |
| 3. Vasse Diversion | *D* | | | | | | -0.18 | -0.78 | 1.05 | 0.55 | 0.03 |
| 3. Vasse Diversion | *D* | | | | | | -0.22 | -0.81 | 1.16 | 0.67 | 0.03 |
| 3. Vasse Diversion | *D* | | | | | | -0.10 | -0.69 | 1.11 | 0.62 | 0.03 |
| 7. Forrest Beach | *D* | | | | | | 0.04 | -0.54 | 1.03 | 0.53 | 0.04 |
| 7. Forrest Beach | *D* | | | | | | -0.13 | -0.72 | 1.16 | 0.66 | 0.04 |
| 7. Forrest Beach | *D* | | | | | | -0.21 | -0.81 | 0.91 | 0.40 | 0.03 |
| 8. Capel | *D* | | | | | | 2.54 | 2.14 | 1.02 | 0.52 | 0.09 |
| 8. Capel | *D* | | | | | | 2.70 | 2.31 | 1.11 | 0.61 | 0.09 |
| 8. Capel | *D* | | | | | | 2.54 | 2.14 | 1.10 | 0.61 | 0.09 |