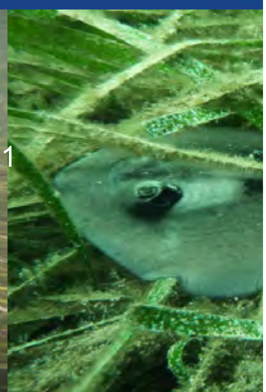
Edith Cowan University
Centre for Marine Ecosystems Research

Keep Watch Seagrass Monitoring 2013 Report for GeoCatch

Kathryn McMahon





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Keep Watch Seagrass Monitoring, 2013. Report to GeoCatch

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Keep Watch Seagrass Monitoring

Annual Report 2013

Investigators: Kathryn McMahon

A project funded by GeoCatch

June 2013

1 Executive Summary

1.1 Introduction

This report summarises data from the first two annual Keep Watch Seagrass Monitoring Program in February 2012 and Jan-Feb 2013. The aim of the Keep Watch program is to assess the health of seagrass meadows in Geographe Bay in relation to the potential threat associated with the predicted nutrient enrichment from the catchment, and as more annual data is collected, assess change over time at each site. This is the first year that change over time can be assessed and additional water quality data has been collected.

1.2 Implications & Conclusions

In general, seagrass meadows in Geographe Bay are healthy, as indicated by *P. sinuosa* shoot density data (no change since 2012 and high compared to other regions in WA) and low nutrient content. One site, Port Geographe that appeared to have had recent loss of shoots in 2012, has shown an increase in shoot density in 2013. Seagrasses at Capel appear to be exposed to a higher amount and different source of nutrients compared to other sites.

1.3 Recommendations:

There are four main recommendations for GeoCatch following this 2013 monitoring.

Recommendation 1

Continue monitoring based on the Keep Watch Monitoring protocol.

Recommendation 2

Continue with nutrient monitoring of *A. antarctica* at three sites.

Recommendation 3

For water quality and light monitoring:

the chemical analysis detection limits of chlorophyll *a*, nitrates and nitrites (NOx) and ammonium (NH4) should be reduced to be at a minimum, but preferably lower than the ANZECC water quality guideline trigger values (See Table 4);

a minimum of 1L or up to 2L of seawater should be filtered for chlorophyll analysis;

the pH meter should be calibrated to read accurately between 7 and 10 pH units; and

when light loggers are downloaded they should be placed together for a minimum period of two hours to cross-calibrate between the two sensors to check that the sensors are not drifting from their calibration.

Recommendation 4

Continue monitoring water quality, where possible at fortnightly intervals and light continuously at Busselton Jetty.

2 Introduction

This document is produced for GeoCatch by Kathryn McMahon from Edith Cowan University. It reports on the Keep Watch seagrass monitoring survey that was undertaken in January and February 2013 and compares data from the February 2012 survey. The aim of this program is to assess seagrass health by examining change over time. There are a number of triggers that have been developed to assess change. Trigger 1 can be assessed this year, but Trigger 2 and Trigger 3 cannot be able to be assessed until 2014 as three years of data is required. This report includes data on *P. sinuosa* shoot density and leaf tissue nutrients (C,N,P and N isotopes), and a summary of all the other observations collected at each site, as well as leaf tissue nutrient data for *Amphibolis antarctica* seagrass from three sites. This is the first year that water quality information collected approximately fortnightly over the year and light data recorded continuously from Busselton Jetty is also presented. All raw data is included in the appendix to this report, and has been submitted to GeoCatch as a digital file. All water quality data is stored on the Department of Water Win Database.

3 Methods for Keep Watch – Seagrass health monitoring program

3.1 Seagrass monitoring

The "Keep Watch" annual seagrass monitoring program is based on the methods recommended by McMahon (2012).

Eight seagrass sites were monitored (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 ranged from 4-5 m depth. All sites, except for Capel have *P. sinuosa* meadows. Sampling occurred from 22nd to the 24th January 2013, except at Dunsborough, which was delayed until 25th February due to a large number of shark sightings in the area. At Capel there are high relief rocky reefs surrounded by bare sand. On the reef there are patches of *Amphibolis antarctica* seagrass that were collected for nutrient analysis in 2m depth. *Amphibolis antarctica* was also collected at Busselton Jetty (4) and Forrest Beach (7) sites as a comparison. This is the first year this has occurred, as in 2012 the tissue nutrient data from Capel was very different to other sites, and it was not clear whether this was due to the nutrient exposure and source or the species of seagrass. Now that we collect *Amphibolis* from other sites so we can make this comparison. Water quality and light monitoring occurs only on Busselton Jetty, near the Busselton Jetty site.

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 WGS80 grid system.

Site Name & #	Coordinates	Depth (m)	Date & Time	Species assessed
1. Dunsborough	S 33.61654°, E 115.12865°	4	25/2/2013 8:30	Ps
2. Buayanup	S 33.65233°, E 115.24840°	4	24/1/2013 09:50	Ps
3. Vasse Diversion Drain	S 33.64746°, E 115.32379°	4.5	24/1/2013 12:30	Ps
4. Busselton Jetty	S 33.63896°, E 115.34315°	4.5	23/1/2013 14:00	Ps, Aa
5. Port Geographe	S 33.62846°, E 115.38240°	4.5	22/1/2013 13:45	Ps
6. Vasse-Wonnerup	S 33.60188°, E 115.42345°	5	23/1/2013 11:30	Ps
7. Forrest Beach	S 33.57295°, E 115.44908°	5	23/1/2013 9:45	Ps, Aa
8. Capel	S 33.51394°, E 115.51508°	2	22/1/2013 12:00	Aa

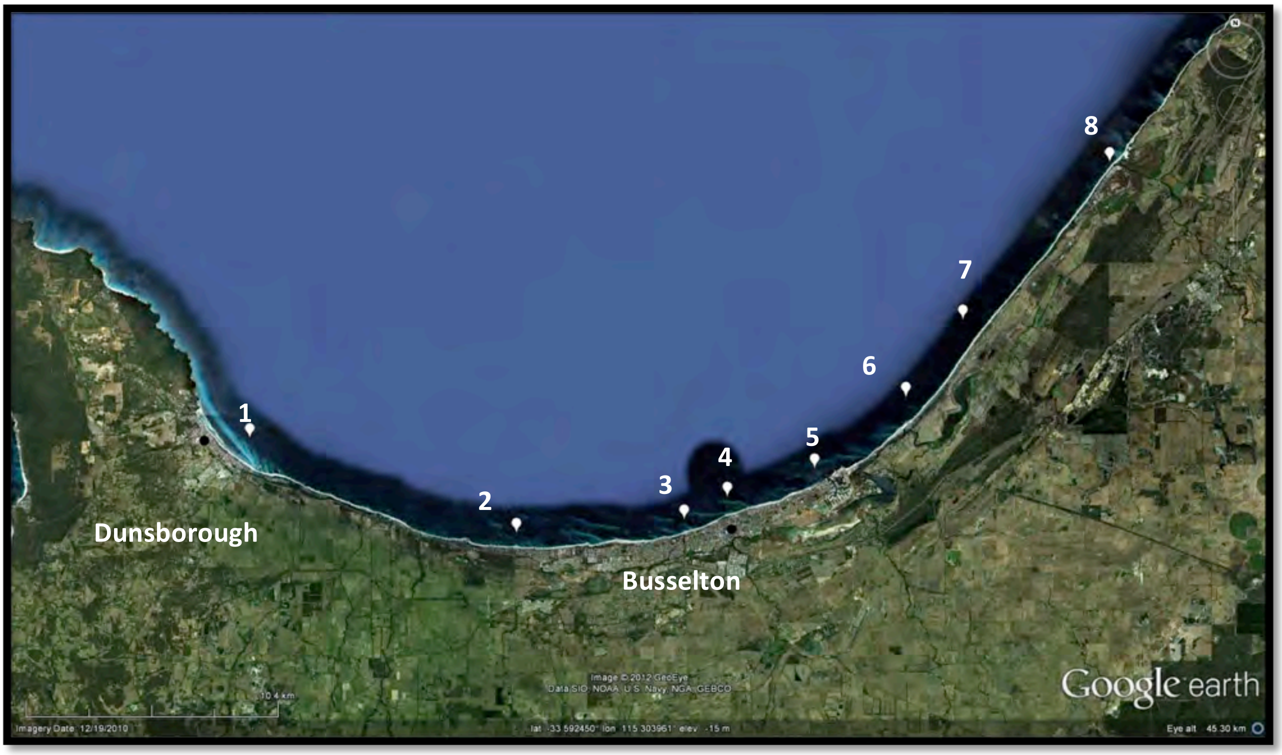

Figure 1: *Map of Geographe Bay, showing the location of the 8 seagrass sampling sites (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach and 8. Capel.*

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, and additional cable ties, which indicated the site number, i.e. 1 for site 1 and 7 for site 7 etc. The exact locations were determined with a differential GPS (using the WSG 84 grid system), on the water surface, directly above the permanent marker.

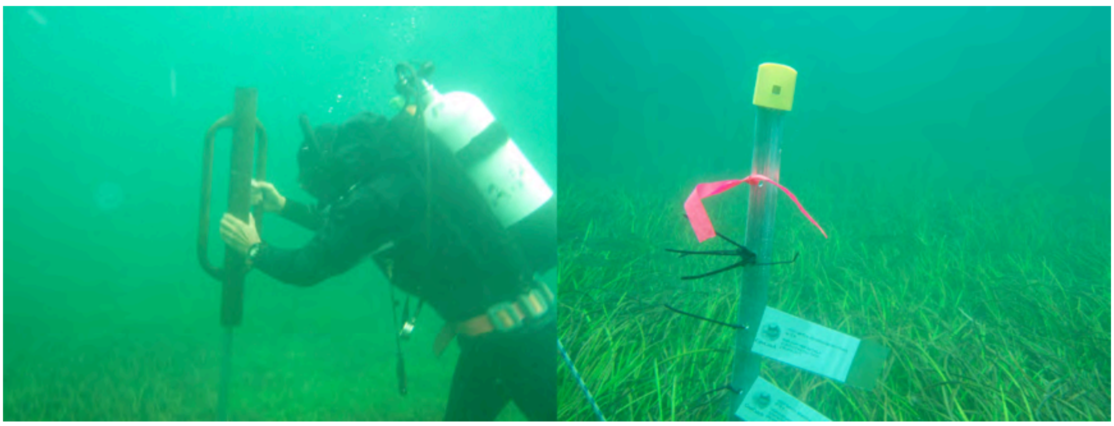

Figure 2: *Left: Banging in permanent marker with pole driver. Right: Star picket with cap and plastic coated site label, indicating center of 50 m diameter Keep Watch seagrass site.*

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 four different quadrats. This was repeated until there was less than a 5% error with counting, i.e. a maximum difference of 1-3 shoots. Then official counting began.

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

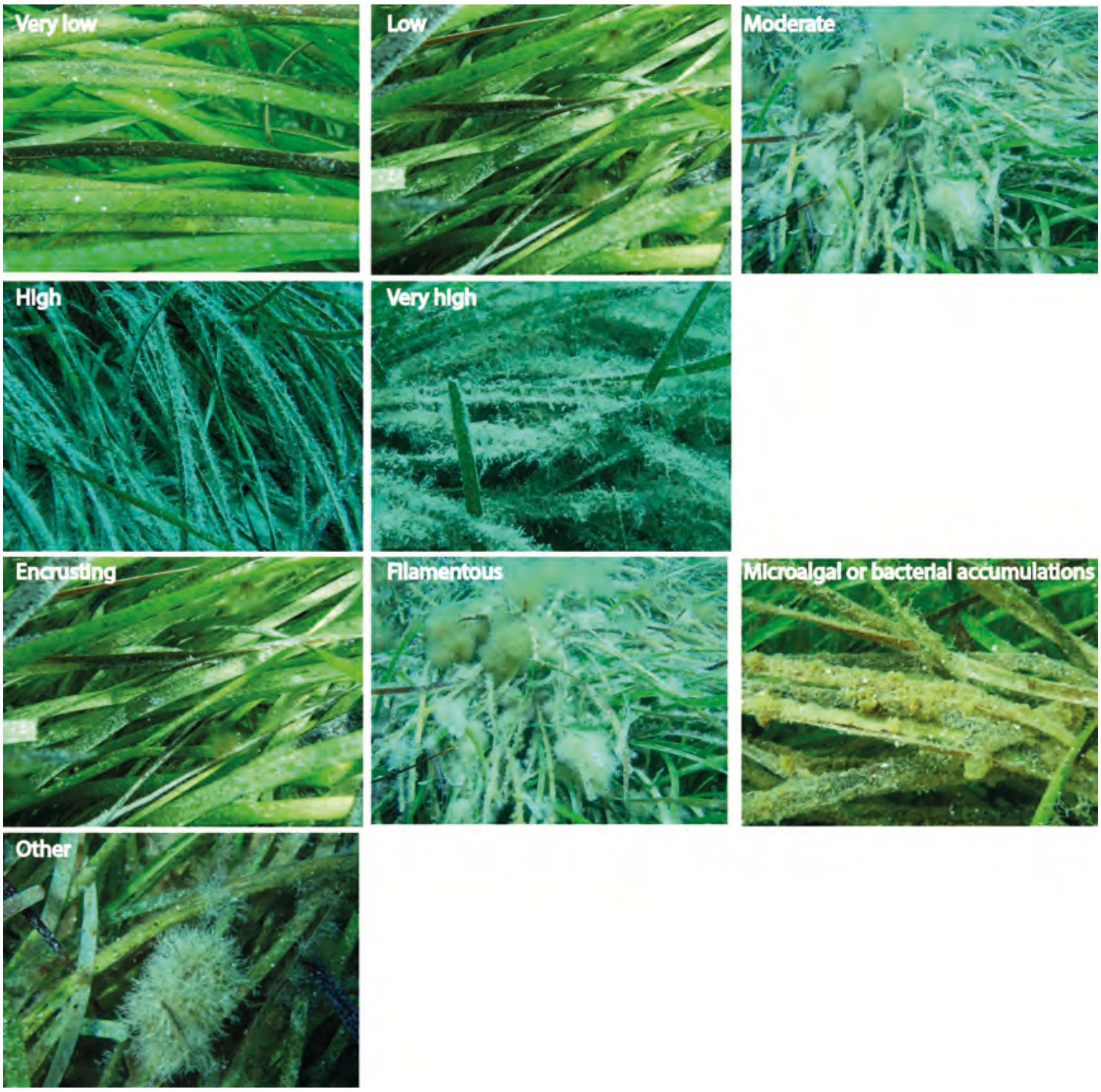

Figure 4: *Classification of epiphytic algal cover and type.*

Finally, the following points were noted: if other seagrass species were present at the site; if there were any bare patches of sand within the meadow, and 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, Busselton Jetty and Forrest Beach sites for the same type of nutrient analysis.

At each site the Secchi disk depth (m) and temperature were recorded from the boat.

In the laboratory the three seagrass shoots 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 50°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 UWA using a continuous flow system consisting of a Delta V Plus mass spectrometer connected with an Thermo Flush 1112 via Conflo IV (Thermo-Finnigan/Germany). Total phosphorus (<0.05 mg.P.g^{-1}) was analysed at Marine and Freshwater Research Laboratory at Murdoch University using method 4500.

3.2 Water quality monitoring at Busselton Jetty

Monitoring of water quality began at Busselton Jetty (115.34380094°, -33.64284918, WGS84°) by Department of Water staff on 12th March 2012. The WIN site ID is 23044912, AWRC reference and Site default site reference is 6100235 and Site Context is Geographe Bay and Site Name Busselton Jetty. All samples were collected following Department of Water Standard procedures (DOW 2009). The plan was to monitor fortnightly but due to weather and other issues, monitoring was carried out at intervals of 1-7 weeks, with a mode of every 2 weeks. At each sampling time *in situ* measurements of Secchi disk depth (but not collected until 7th February 2013), dissolved oxygen (% & mg/L), pH, salinity (mg/L), conductivity (uS/cm compensated to 25°C and temperature were taken just below the surface, apart from Secchi disk depth which was measured through the water column. Surface water samples were collected and filtered where appropriate for analysis of chlorophyll a, b, c and phaeophytin (mg/L), total nitrogen (kjeldhal, TKN), total nitrogen including particulates, total phosphorus, ammonium, nitrate, nitrite and soluble reactive phosphorus (mg/L). Once again this followed standard procedures of the Department of Water (2009, Appendix 2). Water quality data collected up until March 2013 were compared against the ANZECC Water Quality Guidelines for inshore marine waters of south-west Australia (ANZECC 2000).

Light (PAR) was continuously logged underwater near Busselton Jetty in 5m of water (GPS coordinate) and in air on the roof of the Busselton Jetty Aquarium to measure ambient light. This is managed by Busselton Jetty staff. Logging began underwater on 26th Dec 2012 and at the surface on 23rd January 2013. Light was logged with an Odyssey PAR sensor every 10 minutes and the underwater logger also had a cleaner unit, which cleans the logger every 30 minutes to minimize fouling on the sensor. Light was summarized at both locations as total daily irradiance (mol m^{-2}), daily average and maximum instantaneous irradiance (µmol m^{-2} s^{-1}) and for the underwater site, % of surface irradiance. Data was summarized up to March 2013.

4 Results

4.1 Shoot density

Shoot density varied from a site average of 915-1637 shoots m^{-2} across the seven sites, very similar to the site average range in 2012, 942-1536 shoots m^{-2} (Figure 5). Once again, the shallower sites, Dunsborough and Buayanup (3.5 m) had the highest shoot density, followed by Forrest Beach (5 m). The remaining sites at 4.5-5 m had a similar and a lower shoot density relative to the other sites. All raw data is in Appendix 3.

Some sites had very little change from 2012-2013, less than 5% at Dunsborough, Vasse-Diversion and Busselton Jetty. There was an 11% increase at Buayanup, a 16-17% increase at Port Geographe and Forrest Beach and a 19% increase at Vasse-Wonnerup. None of these changes are of concern, and do not trigger the assessment criteria (Trigger 1 is the only criteria that can be assessed this year) (Table 2).

Compared to other sites in Western Australia where similar monitoring is conducted on the same species by Department of Environment and Conservation staff, the shoot densities in Geographe Bay are similar or slightly higher (Figure 5 – dotted lines indicate range of averages at sites in Jurien Bay, Shoalwater Bay, Marmion Marine Park and Shoalwater Bay).

P. sinuosa shoot length ranged from an average minimum of 37 cm at Port Geographe to a maximum of 83 cm at Vasse Wonnerup and a width of 5.9-6.4 mm (Appendix 4).

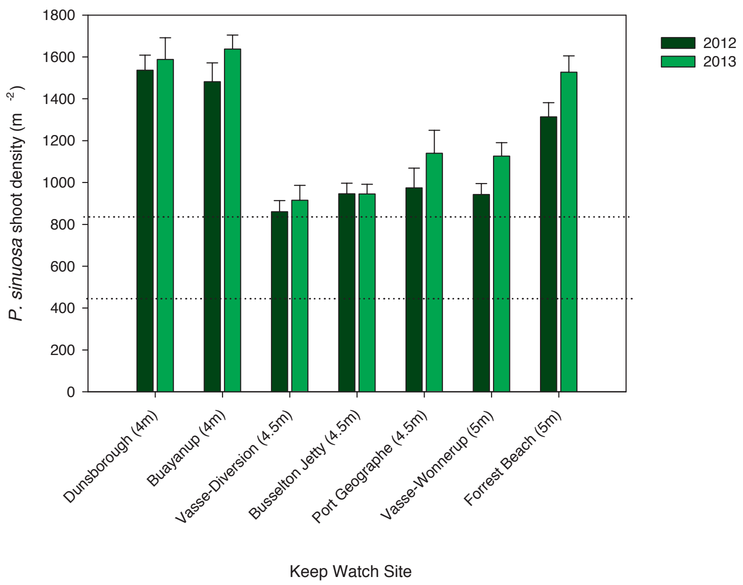

Figure 5: *Shoot density (average m^{-2} ± se) at the seven Keep Watch seagrass monitoring sites with* P. sinuosa *meadows in February 2012. Dotted lines on figure indicate the lower and upper average of shoot densities at other sites monitored in WA by DEC staff in 2012 and 2013 (Unpublished data courtesy of DEC).*

Table 2: Change assessment based on Trigger 1. There is a concern with seagrass health when there is a 50% decline in shoot density from one year to the next.

Site Name & #	Trigger 1 (% change 2012-13)
1. Dunsborough	3
2. Buayanup	11
3. Vasse Diversion Drain	6
4. Busselton Jetty	0
5. Port Geographe	17
6. Vasse-Wonnerup	19
7. Forrest Beach	16

4.2 Algal epiphytes

In 2013, algal cover was generally similar to 2012, slightly lower with 6 out of 7 sites having very low to low cover. The dominant algal types were encrusting algae and others, comprising erect, branching calcified and fleshy algae (Figure 6, Table 3).

Table 3: Algal cover and water quality measures at the Keep Watch seagrass monitoring sites, February 2012. 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. *=Secchi disk depth on bottom.

Site	Algal cover		Algal Type		Secchi disk depth (m)		Temperature (°C)
	2012	2013	2012	2013	2012	2013	2013
1. Dunsborough	Moderate	Low	f,O, m	F,O	4.2*	3	22.5
2. Buayanup	Moderate	Low	o, M	E,O	3.5	2.5	22.6
3. Vasse Diversion Drain	Low	Moderate	o, M	E,O	4.0	3.25	23.8
4. Busselton Jetty	Low	Low	o, M	O	4.2	2.5	27.3
5. Port Geographe	Low	Very low	E, o	E,M	3.75	2.5	25.5
6. Vasse-Wonnerup	Low	Very low	E, o, m	E,O	4.0	2	28.4
7. Forrest Beach	Low	Very Low	E, o, M	F,E	5*	2	23.5

4.3 Other observations

A. antarctica was present at Sites 1, 3, 4, 5, 7 and 8, and *A. griffithii* was also present at Sites 7 and 8. There continued to be signs of recent shoot loss at Port Geographe as there was exposed rhizome without connected shoots, and some evidence of minor shoot loss at Busselton Jetty. Rhizomes were very brittle at Dunsborough, which was not noted last year. Seedlings were observed at Sites 2, 3, 4, 5, 6 and 7, ranging from 1-6 m^{-2} on average (Appendix 3).

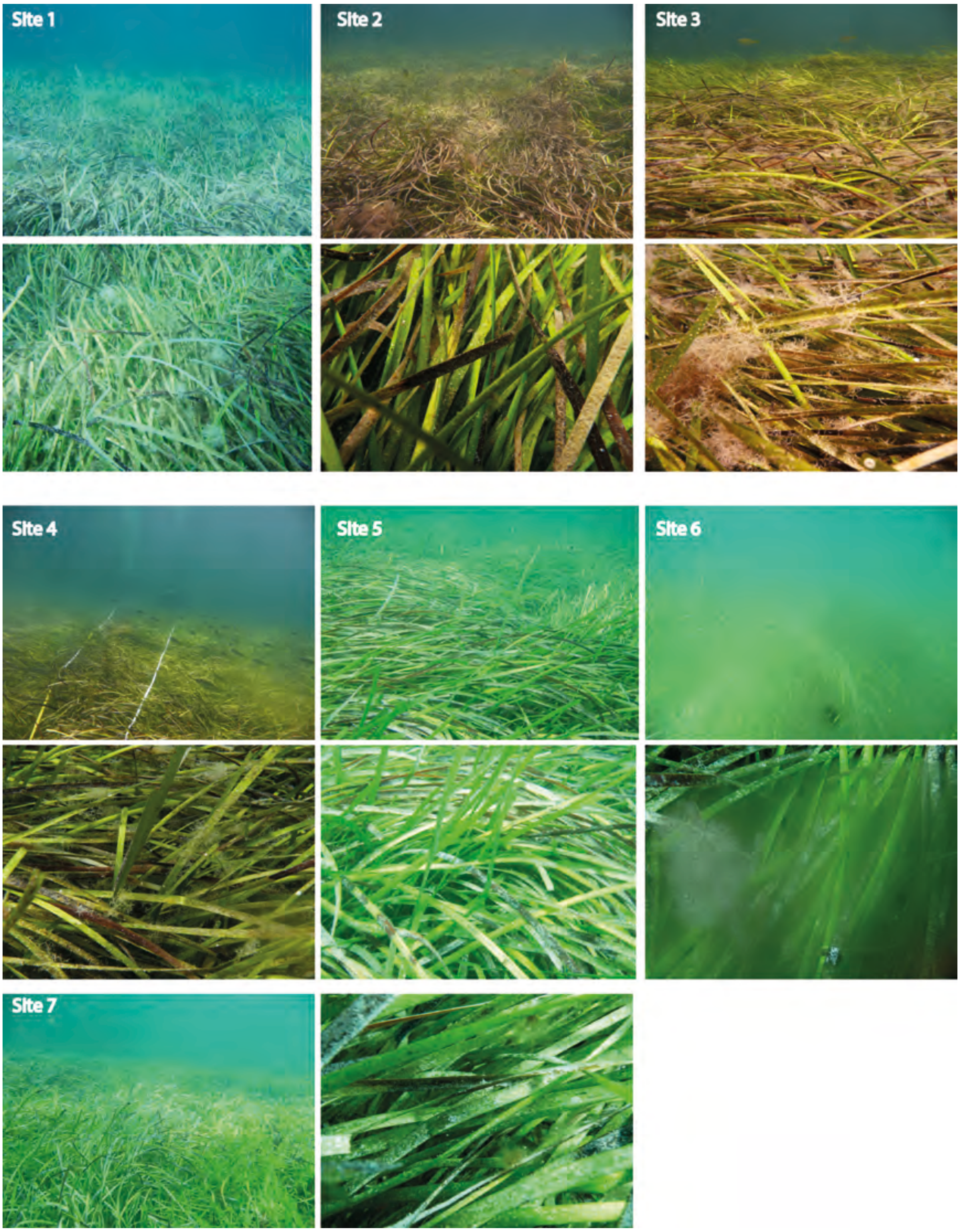

Figure 6: Pictures of seagrass meadow and the dominant algal epiphyte s at each *P. sinuosa* site. (1. Dunsborough, 2. Buayanup, 3. Vasse Diversion Drain, 4. Busselton Jetty, 5. Port Geographe, 6. Vasse-Wonnerup Estuary, 7. Forrest Beach)

4.4 Nutrient content

The nitrogen content of *P. sinuosa* leaves was low, slightly lower than 2012, ranging from site averages of 0.38-0.6% N. The *A. antarctica* leaves at Capel had the highest content, 2.8% and this was higher than the other two sites where *A. antarctica* was collected, 1.12-1.92% DW (Figure 7). The phosphorus content of *P. sinuosa* leaves was also lower than 2012, ranging from 0.06 – 0.11 % P. The *A. antarctica* leaves at Capel had the highest content, 0.17% and this was also higher than the other *A. antarctica* sites, 0.11-0.12% DW (Figure 7).

The $\delta^{15}N$ of *P. sinuosa* leaves ranged from 0.6 – 1.80 ‰, the highest at Busselton Jetty and Port Geographe. Generally these values were lower than 2012, except for the two sites with the higher values. The *A. antarctica* leaves at Capel had the highest $\delta^{15}N$, 2.08 ‰, greater than the other two *A. antarctica* sites, 1.12-1.92‰ (Figure 8).

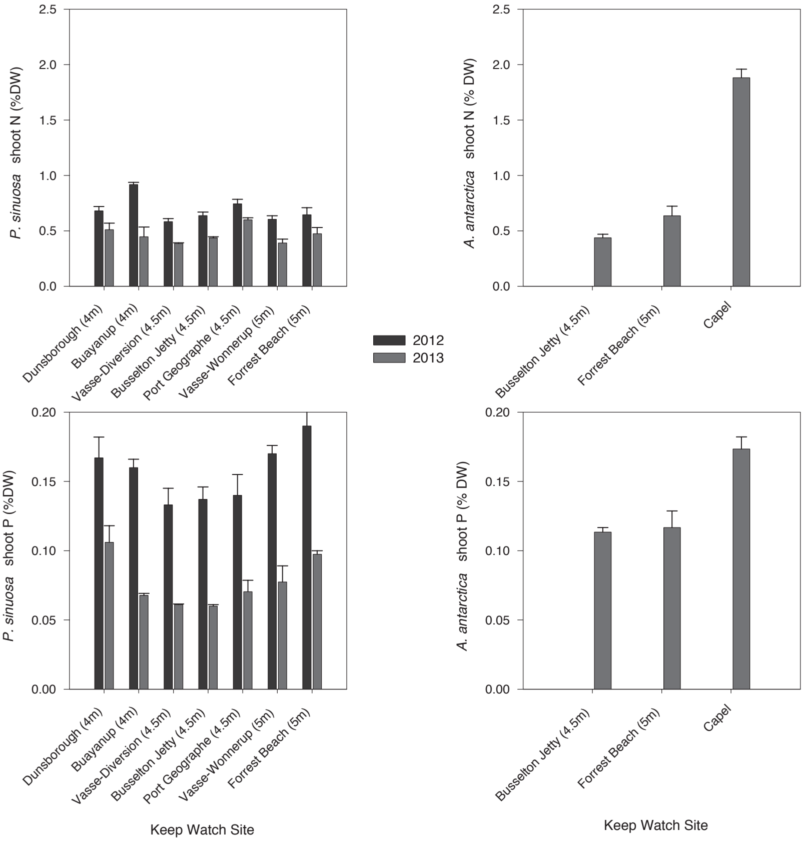

Figure 7: *Nitrogen and phosphorus content (% dw) of* P. sinuosa *leaves (Dunsborough-Forrest Beach) and* A. antarctica *leaves (Capel, average ± se) at the Keep Watch seagrass monitoring sites in 2012 and 2013.*

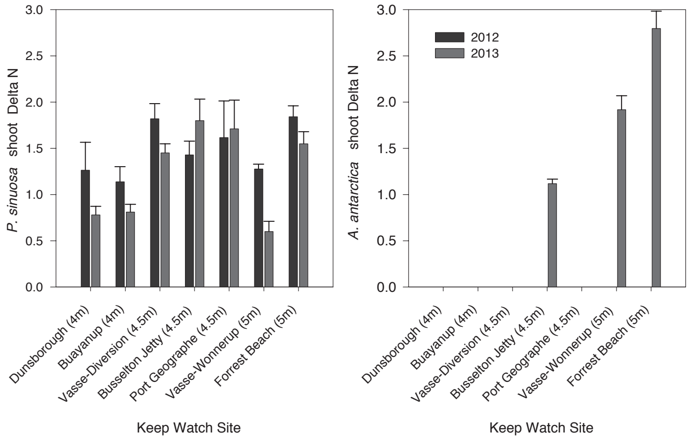

Figure 8: *$\delta^{15}N$ of* P. sinuosa *leaves (Site 1-7) and* A. antarctica *leaves (Site 8, average ± se) at the Keep Watch seagrass monitoring sites in 2012 and 2013.*

4.5 Water quality

Water temperature at the Keep Watch seagrass sites ranged from 22.5-27.8°C. Secchi disk depth ranged from 2.0-3.25m, less than 2012, possibly due to cloudy conditions during sampling (Table 3).

The water quality data collection at Busselton Jetty has been summarized graphically for those variables that trigger values have been derived for in the ANZECC Water Quality Guidelines for physical and chemical stressors for south-west Australia (slightly disturbed systems) (ANZECC 2000 in Table 3.3.6) identified in Table 4 below. When assessing water quality against trigger values it is recommended that site-specific triggers be developed following an understanding of the natural variation in an area. This regular monitoring program will provide the first comprehensive regular and long-term monitoring of water quality in Geographe Bay. In the future more specific trigger values for this region can be derived.

Table 4: Default trigger values for physical and chemical stressors for south-west Australia for slightly disturbed inshore marine ecosystems (Chl a = chlorophyll a, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NOx = oxides of nitrogen, NH4+ = ammonium, DO = dissolved oxygen). The detection limit is that used in the chemical analysis of the chemical variables.

Ecosystem type	Chl a ($\mu g\ L^{-1}$)	TP ($\mu g\ P\ L^{-1}$)	FRP ($\mu g\ P\ L^{-1}$)	TN ($\mu g\ N\ L^{-1}$)	NO_x ($\mu g\ N\ L^{-1}$)	NH_4 (µg N L-1)	DO (% saturation) Lower	pH Lower	pH Upper
Inshore	0.7	20 b	5b	230	5	5	90	8.0	8.4
Detection limit	**1.0**	**5**	**5**	**25**	**10**	**10**			

Note trigger values for Chl a (1.0 µg L^{-1}), TP (40 µg L^{-1}) and FRP (10 µg L^{-1}) are higher in winter when more rainfall is expected.

Chlorophyll *a* concentration ranged from below detection to up to 5 µg L^{-1} (Figure 9, Appendix 6) with an average of 1.2 µg L^{-1} and a median of <1.0 µg L^{-1}. The higher values were observed in July and August 2012, which is expected following rainfall. The ANZECC trigger value for marine inshore waters in the south-west of WA is 0.7 µg L^{-1} in low rainfall periods (e.g. summer) and 1.0 µg L^{-1} in winter. At least 58% of the values were below the detection limit of the laboratory chemical analysis of 1.0 µg L^{-1}. Due to the laboratory detection limit being higher than the trigger value, it is difficult to assess the water quality in relation to the trigger value. In future it is recommended that a lower detection limit be used for the chemical determination of chlorophyll *a* so that the appropriate ANZECC guidelines can be considered. In addition larger volumes of water such as 1-2 L should be filtered rather than 250 mL.

Total nitrogen ranged from below detection up to 590 µg L^{-1} with a mean of 168 µg L^{-1} and a median value of 125 µg L^{-1} (Figure 9, Appendix 6). Similar to chlorophyll concentration, the higher values were observed in July and August. The majority of the readings (80%) and the mean and median were below the trigger value (230 µg L^{-1}). For ammonium and nitrates the detection limit of the chemical analysis was above the recommended trigger value, therefore in future it is recommended that a lower detection limit be used for the chemical determination of NH_3 and NO_x so that the appropriate ANZECC guidelines can be considered. Nitrates ranged from below detection up to 46 µg L^{-1} , the highest values were recorded in July, September and February. The majority of values (84%) as well as the mean (15 µg L^{-1}) and median (12 µg L^{-1}) were above the trigger value of 5 µg L^{-1}. In contrast ammonium, which ranged from below detection to 43 µg L^{-1} had only 40% of readings above the trigger value of 5 µg L^{-1} and the mean (6 µg L^{-1}) was above but the median (<10 µg L^{-1}) was below the trigger value. The maximum concentrations were observed in September (Figure 9, Table 4).

Total phosphorus ranged from below detection to a maximum of 44 µg L^{-1} in July (Figure 10, Appendix 6). Fifty percent of the readings were below detection and 87% were below the trigger value (20 µg L^{-1}) with an average of 6 and a median of 3 µg L^{-1} (Figure 10, Table 4). Most filterable reactive phosphorus readings (90%) were below detection with a maximum of 17 µg L^{-1} detected in September. Ninety two percent of readings were below the trigger value (5 µg L^{-1}), and as a consequence the average (1 µg L^{-1}) and the median (0 µg L^{-1}) were also below the trigger value.

Dissolved oxygen (% saturation) ranged from 81-105%, with minimum values in July (Figure 10, Appendix 6). The trigger value is triggered when the oxygen concentrations fall below 90%. This occurred in 30% of the readings but the mean (93%) and median (92%) were above the trigger value. The recommended pH for inshore waters is a range between 8.0 and 8.4 pH units Table 4). The majority of readings were below this range, ranging from 7.2 to 7.8 pH (Figure 10, Appendix 6). It is recommended that to confirm that these pH's are correct that the pH instrument is calibrated between a pH range of 7 and 10.

Other water quality taken measures from the Busselton Jetty included Secchi disk depth, temperature and salinity. Salinity ranged from 32.4 – 36.4 ppt with an average of 35.0 and a median of 35.2 ppt, and minimums were observed in September. Temperature ranged from 14.6 – 24.7°C with minimums in July and maximums in February, an average of 19.2°C and median of 19.4°C. Secchi disk depth was only recorded from February 2013, and was recorded on the bottom at 3.5 m or to a minimum of 2.5 m (Appendix 6).

On Busselton Jetty light (PAR) ranged from 10 – 79 mol m^{-2} d^{-1} with an average of 56 mol m^{-2} d^{-1} from the 24th January to 3rd April 2013 (Figure 11, Appendix 7). Daily averages were on average 655 umol m^{-2} s^{-1} and daily maxima were on average 2790 umol m^{-2} s^{-1}. Underwater in ~ 5m depth light (PAR) was as expected, significantly less ranging from 4-26 mol m^{-2} d^{-1} with an average of 10 mol m^{-2} d^{-1} from the 27th December 2012 to 3rd April 2013. This was equivalent to 10% of surface irradiance. Daily averages were on average 80 umol m^{-2} s^{-1} and daily maxima were on average 330 umol m^{-2} s^{-1} (Figure 11, Appendix 7).

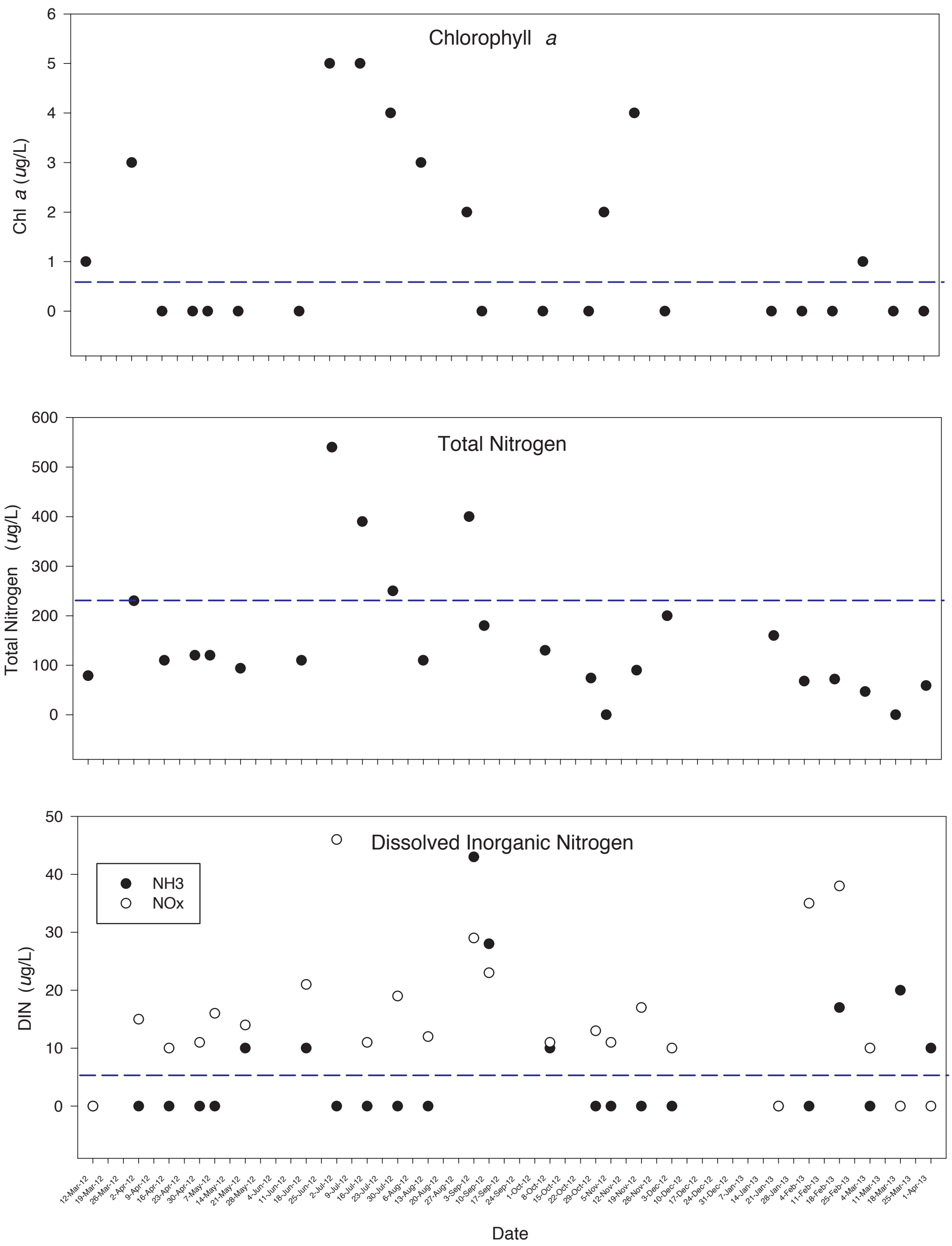

Figure 9: *Chlorophyll* a, total nitrogen and dissolved inorganic nitrogen concentration *(µg L^{-1}) for surface water samples from Busselton Jetty from 12th March 2012 to 1st April 2013. Dotted lines on the graph indicate the ANZECC trigger value and values of 0 indicate below detection limit (see Table 4 for further details of trigger values and detection limits).*

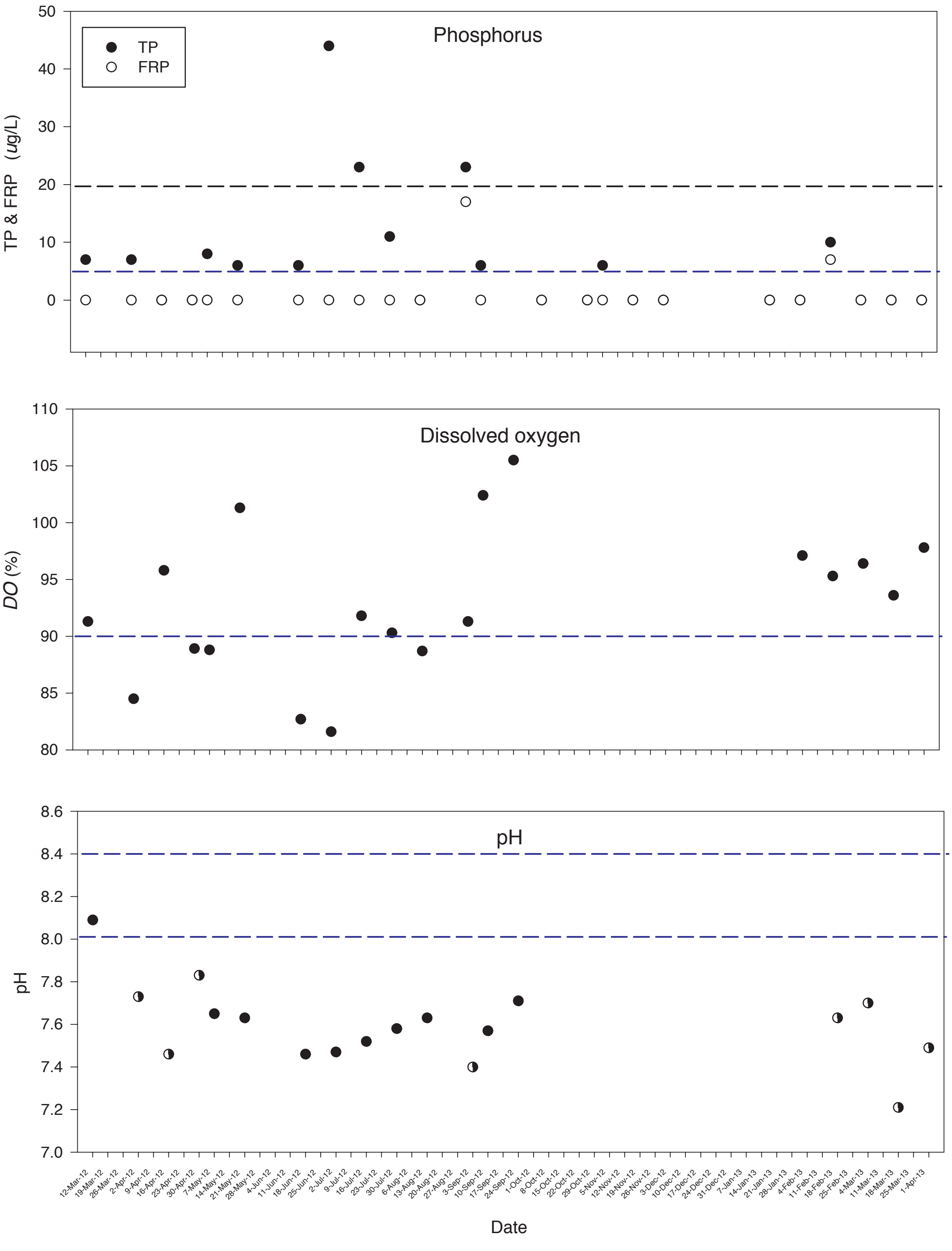

Figure 10: *Total and filterable reactive phosphorus (µg L^{-1}), dissolved oxygen and pH for surface water samples from Busselton Jetty from 12th March 2012 to 1st April 2013. Dotted lines on the graph indicate the ANZECC trigger value and for pH there is an upper and lower value and values of 0 indicate below detection limit (see Table 4 for further details of trigger values and detection limits).*

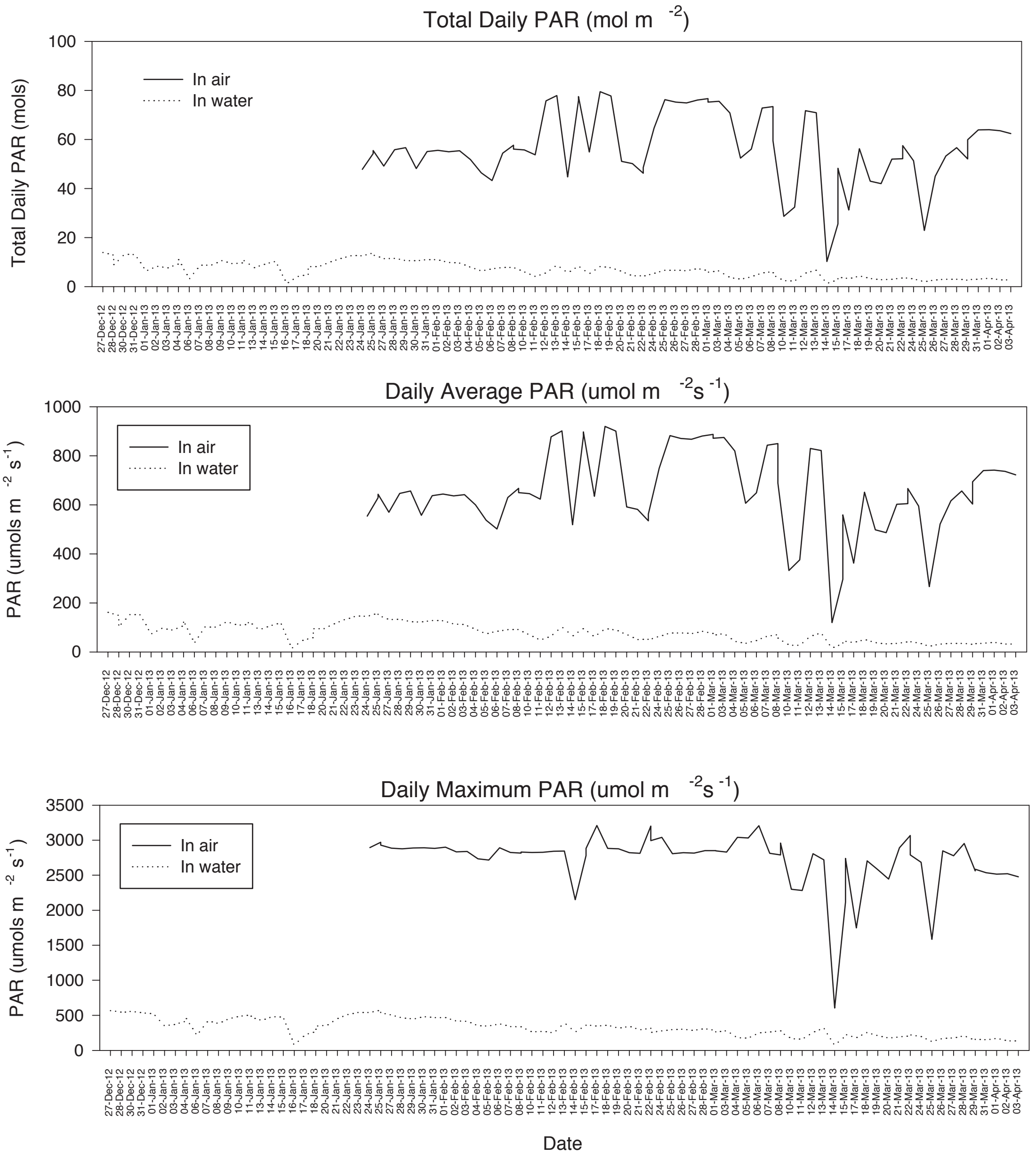

Figure 11: *Total daily light, daily average and maximum in air and underwater in and filterable reactive phosphorus (µg L^{-1}), dissolved oxygen and pH for surface water samples from Busselton Jetty from 12th March 2012 to 1st April 2013. Dotted lines on the graph indicate the ANZECC trigger value and for pH there is an upper and lower value and values of 0 indicate below detection limit (see Table 4 for further details of trigger values and detection limits).*

5 General conclusions and recommendations

This is the second year of monitoring seagrass shoot density and nutrients for the Keep Watch Seagrass monitoring program, and the first year for measuring water quality. The main objective of the Seagrass Watch monitoring program is to assess change at each site, based on the seagrass shoot density data, and to use the additional nutrient data and observations to help to explain some potential reasons for any change or highlight potential concern such as higher algal epiphyte cover or nutrient content or a different nutrient source. A secondary objective is to improve our understanding of the water quality in Geographe Bay by collecting regular water quality data at one site, Busselton Jetty.

There are three triggers to assess change in seagrass shoot density and highlight any sites of concern. Only Trigger 1 could be assessed this year as Trigger 2 and 3 require three years of data to make an assessment.

Trigger 1:

If there is a > 50% reduction in shoot density at a particular site compared to the previous year.

There were no declines in shoot density from 2012 to 2013, in fact some sites increased by up to 19%, and compared to shoot densities of *P. sinuosa* monitored in other parts of WA, the densities recorded in Geographe Bay are similar or higher. Based on these two points, the health of seagrass in Geographe Bay is considered sound. In addition, there were no signs of poor health: no significant algal accumulations were noted nor other disturbances observed. Nutrient concentrations were also low, generally lower than had been observed in 2012. The one site, Port Geographe that appeared to have shoot loss in 2012, still had signs of recent shoot loss in 2013, but there was a positive increase in shoot density from 2012-2013.

Recommendation 1

Continue monitoring based on the Keep Watch Monitoring protocol.

This year was the first time that the seagrass *Amphibolis antarctica* was collected for nutrient analysis at sites additional to Capel. This confirmed observations from 2012, that this species of seagrass at Capel is exposed to more nitrogen and phosphorus and a different source of nitrogen compared to the other two sites as the nutrient concentration and nitrogen isotope signature were higher than the other two sites.

Recommendation 2

There is not a *P. sinuosa* seagrass meadow at Capel, and this Keep Watch monitoring program is using *P. sinuosa* as an indicator species, but due to estimated high loads of nutrients entering Geographe Bay from the Capel catchment, GeoCatch was interested in gaining a better understanding of this nutrient exposure to seagrasses. Therefore in 2012, GeoCatch recommended to continue monitoring the nutrient content of *Amphibolis antarctica* seagrass and to collect additional *A. antarctica* samples from other sites in Geographe Bay as a comparison. Based on the evidence of increased nutrient exposure at this site, it is recommended to continue with the *A. antarctica* nutrient monitoring.

The water quality information collected at Busselton Jetty is providing a base-line data set on temporal variations in water quality at one site in Geographe Bay. With time, and preferably with more spatial resolution, this information could help to develop Geographe Bay specific trigger values for water quality. The first set of data, which does not cover an entire year, indicates higher nutrient and chlorophyll concentrations in winter as would be expected due to winter rains flushing nutrients from the catchment into the nearshore waters. Light peaked in February, but only a limited period of time has been reported on. There are some recommendations to improve the detection limits and data collection of these water quality variables.

Recommendation 3

The chemical analysis detection limits of chloropyll *a*, nitrates and nitrites (NOx) and ammonium (NH4) should be reduced to be at a minimum, but preferably lower than the ANZECC water quality guideline trigger values (See Table 4). A minimum of 1L or up to 2L of seawater should be filtered for chlorophyll analysis, and the pH meter should be calibrated to read accurately between 7 and 10 pH units. When light loggers are downloaded they should be placed together for a minimum period of two hours to cross-calibrate between the two sensors to check that the sensors are not drifting from their calibration.

Recommendation 4

Continue monitoring water quality, where possible at fortnightly intervals and light continuously at Busselton Jetty.

6 References

Department of Environment and Conservation 2013, Unpublished data from seagrass health monitoring in temperate marine parks.

Department of Water (2009). Surface water sampling methods and analysis — technical appendices. Standard operating procedures for water sampling methods and analysis.

McMahon, K. 2012. Proposed methodology for a seagrass health monitoring program in Geographe Bay. Report to GeoCatch. Edith Cowan University, Joondalup.

7 Appendix 1: Randomly generated quadrat positions

Quadrat #	Bearing	Distance
1	0	1
2	0	12
3	20	1
4	20	11
5	20	12
6	40	9
7	60	13
8	100	6
9	100	16
10	100	23
11	140	8
12	140	19
13	140	24
14	140	25
15	160	22
16	200	3
17	200	17
18	240	3
19	260	5
20	260	12
21	260	17
22	280	2
23	280	7
24	280	9
25	280	18
26	320	15
27	340	1
28	340	14
29	340	23
30	340	24

8 Appendix 2: Shoot density data for the seven Keep Watch Seagrass Monitoring Sites including the seedling counts, and the person who counted each quadrat, 2012.

In 20 x 20 cm quadrat																				
2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013
1. Dunsborough			2. Buayanup			3. Vasse Diversion			4. Busselton Jetty			5. Port Geographe			6. Vasse-Wonnerup			7. Forrest Beach		
Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter	Shoots	Seedlings	Counter
94	0	BJ	52	1	BJ	44	0	BJ	36	0	AP	44	0	KM	50	0	BJ	54	1	KM
60	0	BJ	55	0	BJ	48	0	BJ	44	0	AP	76	0	KM	38	1	BJ	56	0	AP
34	0	BJ	75	0	BJ	29	0	BJ	41	0	BJ	55	0	KM	91	0	AC	76	0	KM
35	0	BJ	58	0	BJ	40	0	BJ	39	0	BJ	49	0	BJ	56	1	AC	73	0	AP
97	0	BJ	62	0	BJ	28	0	BJ	24	0	BJ	65	0	AP	46	1	AC	74	0	AC
69	0	BJ	63	0	BJ	38	0	BJ	38	0	AP	45	0	AP	51	1	BJ	56	0	AP
93	0	BJ	52	0	BJ	59	0	BJ	29	1	BJ	23	3	BJ	39	0	BJ	45	0	AC
62	0	BJ	74	0	BJ	32	0	BJ	50	0	BJ	50	0	AP	40	1	AC	51	0	AP
33	0	BJ	61	0	BJ	39	1	BJ	39	0	BJ	65	0	BJ	46	0	AC	53	0	AC
41	0	BJ	73	0	BJ	37	0	BJ	46	0	BJ	39	0	AP	46	0	AC	76	0	AP
52	0	BJ	76	0	AP	34	0	AP	27	0	AP	109	0	BJ	62	2	AC	93	0	AP
67	0	BJ	64	0	AP	32	0	AP	41	0	AP	72	0	AP	39	1	BJ	52	1	AC
61	0	BJ	38	0	AP	35	0	AP	35	0	AP	20	0	AP	34	0	AC	60	3	AC
70	0	BJ	84	0	AP	58	0	AP	31	0	AP	68	0	AP	28	0	AC	44	0	AP
34	0	BJ	72	0	AP	62	0	AP	28	0	BJ	31	0	KM	34	0	BJ	73	3	AC
65	0	KM	64	0	AP	33	0	AP	52	2	BJ	19	0	KM	18	0	KM	68	0	AP
72	0	KM	41	0	AP	40	0	AP	29	0	BJ	76	0	KM	38	0	KM	19	0	AP
80	0	KM	64	0	BJ	12	0	AP	49	0	AP	33	0	KM	32	0	KM	53	0	AP
70	0	KM	45	0	AP	38	0	AP	32	0	KM	48	0	KM	34	0	KM	39	0	AC
63	0	KM	74	1	AC	8	0	AP	50	0	KM	6	0	KM	57	1	KM	90	1	KM
88	0	KM	87	0	AP	58	0	AC	36	0	KM	45	0	KM	58	0	KM	86	0	KM
29	0	KM	75	2	AC	69	0	AC	50	0	KM	42	0	KM	35	0	KM	54	0	KM
36	0	KM	81	0	AC	25	0	AC	18	0	KM	87	0	KM	36	0	KM	47	0	KM
100	0	KM	94	0	AC	26	0	AC	33	0	KM	14	0	KM	51	0	KM	63	0	KM
39	0	KM	78	1	AC	63	0	AC	35	0	KM	34	0	KM	31	0	KM	69	0	KM
45	0	KM	75	0	AC	19	1	AC	42	0	KM	6	0	KM	59	0	KM	74	0	KM
70	0	KM	72	1	AC	17	0	AC	48	1	KM	27	0	KM	54	1	KM	34	0	KM
106	0	KM	70	0	AC	29	0	AC	22	0	KM	42	0	KM	66	0	KM	63	0	KM
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

9 Appendix 3: Leaf morphology data

2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013	2013
	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	62.2	7.8	53.9	6.5	68.0	6.0	75.4	6.5	35.1	6.1	83.8	6.1	93.6	5.8
2	67.3	6.9	49.2	5.5	75.1	5.2	57.2	6.9	32.1	6.0	66.5	6.0	70.6	5.3
3	59.5	7.0	81.9	5.0	73.8	5.8	59.1	6.8	30.9	5.5	86.3	6.0	68.9	6.0
4	72.7	6.9	58.0	5.0	69.8	5.8	69.5	7.0	41.6	5.8	87.4	6.0	68.6	6.8
5	66.6	6.8	65.8	5.5	82.0	6.1	59.3	6.8	36.1	5.7	93.9	6.2	61.7	6.1
6	61.9	6.2	74.3	5.0	88.6	5.3	75.4	6.9	35.8	5.3	75.0	5.0	51.2	4.2
7	65.6	6.0	73.1	5.6	73.2	6.0	67.0	6.0	32.5	6.0	75.2	6.7	44.4	5.8
8	61.0	6.2	56.6	6.0	68.0	5.2	71.7	6.5	31.8	4.9	70.9	6.1	46.9	5.9
9	53.4	5.0	50.6	6.7	66.0	6.3	65.0	6.1	37.4	5.8	89.8	6.0	36.9	6.1
10	51.5	5.8	55.4	6.0	76.7	6.0	78.5	7.0	35.9	6.2	81.3	6.2	33.0	5.8
11	43.3	5.2	70.2	6.5	92.0	6.5	85.9	5.5	40.9	5.3	91.7	6.6	77.1	6.0
12	44.5	5.2	73.7	6.0	77.6	7.0	97.2	6.1	37.7	5.9	77.6	5.8	55.9	6.1
13	46.6	5.0	69.6	6.7	77.9	6.8	72.4	6.0	47.2	5.5	90.2	7.0	68.8	5.9
14	44.7	4.9	65.6	5.5	89.5	6.8	85.7	6.0	37.3	5.7	86.0	6.8	77.2	5.9
15	58.0	4.8	74.4	6.0	88.2	7.0	86.4	6.1	46.6	5.5	93.1	6.9	50.4	6.1
average	57.3	6.0	64.8	5.8	77.8	6.1	73.7	6.4	37.3	5.7	83.2	6.2	60.3	5.9
se	2.4	0.2	2.6	0.2	2.2	0.2	3.0	0.1	1.3	0.1	2.2	0.1	4.3	0.1

10 Appendix 4: Nutrient data

Site	Rep	Species	δ^{15}N [‰ AIR]	δ^{13}C [‰ VPDB]	N [wt %]	C [wt %]	P (%)		δ^{15}N [‰ AIR]	N [wt %]	P (%)
Dunsborough	1	Posidonia	0.78	-10.66	0.42	38.41	0.093	avg	0.78	0.51	0.11
Dunsborough	2	Posidonia	0.93	-11.31	0.48	39.64	0.095	se	0.092661	0.05922	0.012014
Dunsborough	3	Posidonia	0.61	-10.84	0.62	38.91	0.130				
Buayanup	1	Posidonia	0.88	-10.56	0.62	38.29	0.070	avg	0.81	0.45	0.07
Buayanup	2	Posidonia	0.92	-8.49	0.32	38.41	0.068	se	0.085009	0.088642	0.001453
Buayanup	3	Posidonia	0.64	-10.06	0.40	39.28	0.065				
Vasse Diversion Drain	1	Posidonia	1.28	-8.73	0.39	38.16	0.061	avg	1.45	0.38	0.06
Vasse Diversion Drain	2	Posidonia	1.46	-9.07	0.39	38.01	0.062	se	0.098723	0.006885	0.000577
Vasse Diversion Drain	3	Posidonia	1.62	-9.11	0.37	37.69	0.060				
Busselton Jetty	1	Posidonia	1.53	-8.91	0.42	39.05	0.058	avg	1.80	0.44	0.06
Busselton Jetty	2	Posidonia	2.26	-9.07	0.46	37.85	0.061	se	0.231719	0.011186	0.001
Busselton Jetty	3	Posidonia	1.60	-8.12	0.43	38.26	0.061				
Port Geo	1	Posidonia	1.65	-8.58	0.61	39.95	0.058	avg	1.71	0.60	0.07
Port Geo	2	Posidonia	2.28	-9.71	0.57	40.55	0.086	se	0.311998	0.016999	0.008253
Port Geo	3	Posidonia	1.21	-10.79	0.63	39.96	0.067				
Vasse-Wonnerup	1	Posidonia	0.67	-10.65	0.45	40.18	0.080	avg	0.60	0.39	0.08
Vasse-Wonnerup	2	Posidonia	0.75	-10.17	0.40	39.13	0.096	se	0.110921	0.035176	0.011624
Vasse-Wonnerup	3	Posidonia	0.38	-9.52	0.33	38.64	0.056				
Forrest Beach	1	Posidonia	1.30	-9.76	0.40	38.58	0.100	avg	1.55	0.47	0.10
Forrest Beach	2	Posidonia	1.62	-10.06	0.44	38.96	0.092	se	0.129886	0.05649	0.002667
Forrest Beach	3	Posidonia	1.74	-11.56	0.58	39.39	0.100				
Busselton Jetty	1	Amphibolis	1.21	-11.78	0.37	38.55	0.110	avg	1.12	0.44	0.11
Busselton Jetty	2	Amphibolis	1.10	-11.52	0.48	39.45	0.120	se	0.049367	0.033051	0.003333
Busselton Jetty	3	Amphibolis	1.04	-11.91	0.45	38.88	0.110				
Forrest Beach	1	Amphibolis	2.09	-13.09	0.70	39.08	0.140	avg	1.92	0.64	0.12
Forrest Beach	2	Amphibolis	2.05	-12.51	0.74	38.97	0.100	se	0.151296	0.085943	0.012019
Forrest Beach	3	Amphibolis	1.62	-13.14	0.47	39.97	0.110				
Capel	1	Amphibolis	2.44	-13.17	2.04	40.56	0.190	avg	2.80	1.88	0.17
Capel	2	Amphibolis	2.89	-13.39	1.79	38.56	0.170	se	0.185959	0.078239	0.008819
Capel	3	Amphibolis	3.06	-13.37	1.81	39.45	0.160				

11 Appendix 5: Water quality data from Busselton Jetty

Week start date	Collection Date	Collection Time	Chlorophyll a (by vol) | mg/L	Total chlorophyll mg/L	Phaeophytin a (by vol) | mg/L	N (tot) {TN, pTN} | mg/L	NH3-N/NH4-N (sol) | mg/L	NO3-N (sol) | mg/L	N (tot kjel) {TKN} | mg/L	P (tot) {TP, pTP} | mg/L	PO4-P (sol react) {SRP, FRP} | mg/L	O - DO % | %	O - DO (in situ) | mg/L	pH | no units	Salinity | mg/L	Cond comp 25 deg C (in situ) | uS/cm	Temperature (in situ) | deg C	Secchi depth | m
12-Mar-12	15-Mar-12	14:45:00	1	3	0	83	0	0	79	7	0	91.3	6.37	8.09	35.83	54400	22.47	
19-Mar-12																		
26-Mar-12																		
2-Apr-12	03-Apr-12	12:15:00	3	7	0	250	0	15	230	7	0	84.5	6.12	7.73	35.51	54100	20.82	
9-Apr-12																		
16-Apr-12	20-Apr-12	13:10:00	0	0	1	120	0	10	110	0	0	95.8	6.98	7.46	35.18	53700	20.21	
23-Apr-12																		
30-Apr-12	03-May-12	13:00:00	0	0	3	130	0	11	120	0	0	88.9	6.5	7.83	35.24	53900	19.93	
7-May-12	10-May-12	12:05:00	0	3	2	140	0	16	120	8	0	88.8	6.81	7.65	35.34	54200	18	
14-May-12																		
21-May-12	23-May-12	14:00:00	0	0	1	110	10	14	94	6	0	101.3	7.43	7.63	35.17	53900	17.6	
28-May-12																		
4-Jun-12																		
11-Jun-12																		
18-Jun-12	21-Jun-12	15:20:00	0	0	2	130	10	21	110	6	0	82.7	6.67	7.46	34.4	53000	15.88	
25-Jun-12																		
2-Jul-12	05-Jul-12	14:00:00	5	7	5	590	0	46	540	44	0	81.6	7.22	7.47	34.46	53300	14.57	
9-Jul-12																		
16-Jul-12	18-Jul-12	14:45:00	5	7	5	400	0	11	390	23	0	91.8	7.56	7.52	34.48	53200	14.89	
23-Jul-12																		
30-Jul-12	02-Aug-12	14:30:00	4	6	0	270	0	19	250	11	0	90.3	7.42	7.58	33.88	52900	14.6	
6-Aug-12																		
13-Aug-12	16-Aug-12	15:20:00	3	8	0	120	0	12	110	0	0	88.7	7.23	7.63	34.37	52800	15.62	
20-Aug-12																		
27-Aug-12																		
3-Sep-12	05-Sep-12	13:20:00	2	4	3	430	43	29	400	23	17	91.3	7.37	7.4	32.39	50200	16.1	
10-Sep-12	13-Sep-12	15:25:00	0	1	0	210	28	23	180	6	0	102.4	7.99	7.57	33.38	51700	18.12	
17-Sep-12																		
24-Sep-12	27-Sep-12	0:00:00										105.5	7.93	7.71	34.55	52900	19.38	
1-Oct-12																		
8-Oct-12	11-Oct-12	15:05:00	0	1	2	150	10	11	130	0	0							
15-Oct-12																		
22-Oct-12																		
29-Oct-12	29-Oct-12	14:50:00	0	0	0	86	0	13	74	0	0							
5-Nov-12	08-Nov-12	15:10:00	2	5	0	0	0	11	0	6	0							
12-Nov-13																		
19-Nov-12	22-Nov-12	14:00:00	4	5	7	110	0	17	90	0	0							
26-Nov-12																		
3-Dec-12	05-Dec-12	13:50:00	0	1	1	210	0	10	200	0	0							
10-Dec-12																		
17-Dec-12																		
24-Dec-12																		
31-Dec-12																		
7-Jan-13																		
14-Jan-13																		
21-Jan-13	22-Jan-13	13:40:00	0	0	2	170	0	0	160	0	0							
28-Jan-13																		
4-Feb-13	07-Feb-13	13:20:00	0	0	2	100	0	35	68	0	0	97.1	6.53		35.96	54400	24.7	
11-Feb-13																		
18-Feb-13	21-Feb-13	15:40:00	0	0	0	110	17	38	72	10	7	95.3	6.45	7.63	36.24	54800	24.47	3.5a
25-Feb-13																		
4-Mar-13	07-Mar-13	13:40:00	1	1	0	57	0	10	47	0	0	96.4	6.58	7.7	36.35	55000	23.77	2.5
11-Mar-13																		
18-Mar-13	21-Mar-13	15:20:00	0	3	1	0	20	0	0	0	0	93.6	6.66	7.21	36.01	54700	21.66	3
25-Mar-13																		
1-Apr-13	03-Apr-13	13:15:00	0	2	0	66	10	0	59	0	0	97.8	6.89	7.49	35.89	54400	22.2	3.5a
		Prop below detection limit	0.58	0.33	0.42	0.08	0.67	0.17	0.08	0.50	0.92							
		Prop above (or below for DO) trigger value	0.42			0.21	0.33	0.84		0.13	0.08	0.32						
		Average	1.25	2.67	1.54	168.42	6.17	15.5	151.38	6.54	1	92.9		7.60	34.98		19.21	
		Median	0	1.5	1	125	0	12.5	110	3	0	91.8		7.61	35.18		19.38	
		Min	0			0	0	0		0	0	81.6		7.21	32.39		14.57	
		Max	5			590	43	46		44	17	105.5		8.09	36.35		24.70	

12 Appendix 6: Light data from Busselton Jetty

	IN AIR	IN AIR	IN AIR	IN WATER	IN WATER	IN WATER	IN
	Average daily	Daily max	Total daily	Average daily	Daily max	Total daily	% [illegible]
	umol m-2 s-1	umol m-2 s-1	mol m-2	umol m-2 s-1	umol m-2 s-1	mol m-2	
Date and time	TOTAL daily	Average daily	Daily max				
27-Dec-12				160.589183	566.2074	13.8749054	
28-Dec-12				148.335413	545.952	12.8161796	
28-Dec-12				101.469592	537.603	8.76697272	
30-Dec-12				152.327404	556.1886	13.1610877	
31-Dec-12				150.501817	532.884	13.003357	
01-Jan-13				72.9509	522.72	6.30295776	
02-Jan-13				95.6671375	349.6416	8.26564068	
03-Jan-13				88.1187542	370.26	7.61346036	
04-Jan-13				106.622679	417.7404	9.21219948	
04-Jan-13				127.462913	457.9608	11.0127956	
06-Jan-13				35.7867583	213.9522	3.09197592	
07-Jan-13				101.703525	416.5788	8.78718456	
08-Jan-13				100.250517	382.0212	8.66164464	
09-Jan-13				122.372846	451.935	10.5730139	
10-Jan-13				108.164421	487.7994	9.34540596	
11-Jan-13				111.442513	504.4974	9.62863308	
11-Jan-13				124.550846	471.9726	10.7611931	
13-Jan-13				89.6050375	426.2346	7.74187524	
14-Jan-13				105.688963	482.064	9.13152636	
15-Jan-13				118.830571	471.3192	10.2669613	
16-Jan-13				14.2043917	74.5602	1.22725944	
17-Jan-13				46.71205	223.3176	4.03592112	
18-Jan-13				58.1324333	265.1352	5.02264224	
18-Jan-13				93.8138208	345.213	8.10551412	
20-Jan-13				94.8483708	353.9976	8.19489924	
21-Jan-13				115.686083	452.5158	9.9952776	
22-Jan-13				132.712296	512.556	11.4663424	
23-Jan-13				146.179596	541.959	12.6299171	
24-Jan-13	553.446528	2896.2	47.81778	144.692304	540.5796	12.5014151	2[illegible]
25-Jan-13	628.134028	2969.1	54.27078	158.289175	576.444	13.6761847	2[illegible]
25-Jan-13	642.607639	2928.7	55.5213	149.411808	535.4976	12.9091802	2[illegible]
27-Jan-13	569.082639	2885.9	49.16874	131.818913	503.2632	11.389154	2[illegible]
28-Jan-13	646.177778	2877.3	55.82976	132.754142	463.188	11.4699578	2[illegible]
29-Jan-13	656.142361	2888.9	56.6907	122.65165	446.3448	10.5971026	1[illegible]
30-Jan-13	557.014583	2890.8	48.12606	121.686171	480.0312	10.5136852	2[illegible]
31-Jan-13	637.272222	2881.2	55.06032	127.605088	465.8742	11.0250796	2[illegible]

	IN AIR	IN AIR	IN AIR	IN WATER	IN WATER	IN WATER	IN WATER
Date and time	Average daily	Daily max	Total daily	Average daily	Daily max	Total daily	% surface irra
	umol m-2 s-1	umol m-2 s-1	mol m-2	umol m-2 s-1	umol m-2 s-1	mol m-2	
01-Feb-13	643.219444	2898.3	55.57416	126.525163	465.1482	10.931774	19.670606
02-Feb-13	636.489583	2833.2	54.9927	113.684038	417.5952	9.82230084	17.8610995
03-Feb-13	640.838194	2836.9	55.36842	110.603075	414.4734	9.55610568	17.2591266
04-Feb-13	599.855556	2733.1	51.82752	91.57885	350.0046	7.91241264	15.266817
05-Feb-13	536.690278	2716.9	46.37004	73.6400958	347.9718	6.36250428	13.7211533
06-Feb-13	501.067361	2891.7	43.29222	83.8000625	377.2296	7.2403254	16.7243107
07-Feb-13	629.184722	2823.2	54.36156	90.1107167	338.316	7.78556592	14.3218221
08-Feb-13	666.895833	2814.6	57.6198	90.80445	335.9202	7.84550448	13.615987
08-Feb-13	649.101389	2829.9	56.08236	89.8011583	334.2504	7.75882008	13.834689
10-Feb-13	645.497222	2824.9	55.77096	69.2856083	260.997	5.98627656	10.7336803
11-Feb-13	622.584722	2826.3	53.79132	47.9351583	269.7816	4.14159768	7.69937916
12-Feb-13	876.815972	2842.7	75.7569	64.4723292	246.7674	5.57040924	7.35300579
13-Feb-13	901.308681	2844.6	77.87307	101.515975	391.7496	8.77098024	11.2631751
14-Feb-13	518.215278	2151.5	44.7738	64.8998625	261.8682	5.60734812	12.5237262
15-Feb-13	878.641667	2780	75.91464	95.51135	355.5222	8.25218064	10.8703415
15-Feb-13	897.193056	2881.8	77.51748	96.9351167	364.7424	8.37519408	10.8042652
17-Feb-13	634.914583	3208	54.85662	60.6371333	345.3582	5.23904832	9.55043953
18-Feb-13	919.609028	2882.7	79.45422	94.4112583	360.3864	8.15713272	10.2664562
19-Feb-13	900.170833	2877.8	77.77476	88.8195458	315.084	7.67400876	9.86696553
20-Feb-13	591.410764	2819.5	51.09789	70.8661708	340.0584	6.12283716	11.9825636
21-Feb-13	580.918056	2812.6	50.19132	49.8948542	292.5054	4.3109154	8.58896598
22-Feb-13	534.951042	3201	46.21977	51.3266875	316.6086	4.4346258	9.59465138
22-Feb-13	562.036111	2993.6	48.55992	48.0889292	254.9712	4.15488348	8.55619919
24-Feb-13	748.269792	3040.8	64.65051	62.7304333	277.6224	5.41990944	8.38339781
25-Feb-13	882.029167	2807.8	76.20732	76.5057792	294.5382	6.61009932	8.67383779
26-Feb-13	870.452778	2820.2	75.20712	77.0986792	299.2572	6.66132588	8.8573075
27-Feb-13	867.418056	2815.4	74.94492	74.4876	285.1002	6.43572864	8.58727802
28-Feb-13	880.288194	2849.7	76.0569	83.9402208	309.4212	7.25243508	9.53553863

	IN AIR	IN AIR	IN AIR	IN WATER	IN WATER	IN WATER	IN WATER
Date and time	Average daily	Daily max	Total daily	Average daily	Daily max	Total daily	% surface irra
	umol m-2 s-1	umol m-2 s-1	mol m-2	umol m-2 s-1	umol m-2 s-1	mol m-2	
01-Mar-13	886.795139	2851	76.6191	74.8737917	283.0674	6.4690956	8.44318923
01-Mar-13	871.438194	2847.6	75.29226	67.920325	258.819	5.86831608	7.79404959
03-Mar-13	874.858333	2828.6	75.58776	74.055025	280.0908	6.39835416	8.46480192
04-Mar-13	819.939931	3040.5	70.84281	42.3994083	178.0152	3.66330888	5.17103836
05-Mar-13	606.063542	3031.2	52.36389	34.1875417	174.0948	2.9538036	5.64091705
06-Mar-13	648.907639	3205.5	56.06562	46.3031708	251.7042	4.00059396	7.13555644
07-Mar-13	842.979167	2810.6	72.8334	63.9716917	260.9244	5.52715416	7.58876307
08-Mar-13	849.00625	2790.4	73.35414	69.9722833	279.0744	6.04560528	8.24166881
08-Mar-13	688.504861	2959	59.48682	54.8735	260.0532	4.7410704	7.96995099
10-Mar-13	332.172222	2298	28.69968	27.7236208	165.528	2.39532084	8.3461587
11-Mar-13	375.020139	2280.5	32.40174	26.3785042	158.1954	2.27910276	7.03389003
12-Mar-13	829.934028	2805.8	71.7063	63.8592625	255.7698	5.51744028	7.69449864
13-Mar-13	820.695139	2717.9	70.90806	76.7034125	317.7702	6.62717484	9.34615168
14-Mar-13	119.085417	605.2	10.28898	15.0276958	71.874	1.29839292	12.6192579
15-Mar-13	296.174306	2116.7	25.58946	33.1444208	201.7554	2.86367796	11.1908495
15-Mar-13	558.588889	2739.6	48.26208	44.2522208	225.06	3.82339188	7.92214484
17-Mar-13	362.015972	1748	31.27818	37.5901625	180.4836	3.24779004	10.3835646
18-Mar-13	651.03125	2704.3	56.2491	49.6135292	254.826	4.28660892	7.62076001
19-Mar-13	497.795833	2578.5	43.00956	37.6673	208.2168	3.25445472	7.56681705
20-Mar-13	486.292361	2443.1	42.01566	32.1068458	173.6592	2.77403148	6.60237511
21-Mar-13	601.700694	2891.3	51.98694	34.760275	192.39	3.00328776	5.7770043
22-Mar-13	604.124306	3066.6	52.19634	40.749775	206.1114	3.52078056	6.74526329
22-Mar-13	665.527083	2789.6	57.50154	42.1916917	219.6876	3.64536216	6.33959049
24-Mar-13	594.204861	2686.1	51.3393	36.2642042	195.5844	3.13322724	6.10298006
25-Mar-13	265.557639	1584.5	22.94418	22.5952375	124.2912	1.95222852	8.50860009
26-Mar-13	520.7625	2847.8	44.99388	31.7014958	170.1018	2.73900924	6.0875151
27-Mar-13	616.0625	2776.1	53.2278	34.0635167	176.1276	2.94308784	5.52923067
28-Mar-13	655.830556	2954	56.66376	34.9619417	205.2402	3.02071176	5.33094126
29-Mar-13	602.714583	2562.5	52.07454	30.2540333	140.844	2.61394848	5.01962856
29-Mar-13	693.302083	2585.1	59.9013	32.394725	161.8254	2.79890424	4.67252671
31-Mar-13	739.809722	2536.4	63.91956	35.2941875	149.556	3.0494178	4.7707115
01-Apr-13	740.915972	2515.1	64.01514	38.8536042	169.3032	3.3569514	5.24399603
02-Apr-13	736.061111	2520.3	63.59568	32.3231333	135.3264	2.79271872	4.39136545
03-Apr-13	721.925	2477.3	62.37432	31.5774708	134.3826	2.72829348	4.37406529
average	**655.453462**	**2729.59286**	**56.6311791**	**78.7159121**	**326.41849**	**6.8010548**	**10.6643112**
min	**119.085417**	**605.2**	**10.28898**	**14.2043917**	**71.874**	**1.22725944**	**4.37406529**
max	**919.609028**	**3208**	**79.45422**	**160.589183**	**576.444**	**13.8749054**	**26.1438634**
median	**642.913542**	**2825.6**	**55.54773**	**74.6806958**	**315.8463**	**6.45241212**	**8.588122**