Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program
(July 2018 – July 2019)

Nathan Waltham, Christina Buelow, Jordan Iles, James Whinney, Blake

Report No. 19/31

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A Report for North Queensland Bulk Ports Corporation

Report No. 19/31

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EXECUTIVE SUMMARY

Background

1. North Queensland Bulk Ports has implemented an ambient marine water quality monitoring program surrounding the Ports of Mackay and Hay Point since July 2014. The objective of the program is to progress a long term water quality dataset to characterise marine water quality conditions within the Mackay region that will support future planned port activities.
2. This program has incorporated a combination of spot field measurements and high frequency continuous data loggers, laboratory analysis for a range of nutrient, herbicides and heavy metals.
3. Sites extend approximately 60km along the Mackay coastline, from Slade Islet to Freshwater Point, and offshore to Keswick Island. Sites in the network align with key sensitive receptor habitats (e.g. corals or seagrass), along with key features in the study region (e.g. river flow points). Coral and seagrass receptor habitat assessments are completed and available in companion reports available on the TropWATER website (www.tropwater.com).

Climatic conditions

1. The total 2018/19 wet season rainfall at Plane Creek Sugar Mill (17 km linear from Hay Point) was 1465 mm, this is the second highest rainfall total as part of this ambient program, however, unlike in past years the total rainfall was spread over several events that extended into July 2019.
2. The daily average wind speed and direction recorded at Mackay airport for this reporting period was predominantly from the south east and south west. The strongest winds (>24 km h^{-1}) were predominantly from the south east (more than 55 % of the days).

Water chemistry

1. Field water quality conditions were measured at all sites for water temperature, electrical conductivity, pH, dissolved oxygen, and secchi disk depth on a ~6 weekly basis, for three depth horizons (surface (0.2m), mid water and bottom).
2. Seasonal differences in water quality were minor, except for temperature which continues to be highest during the summer months.
3. Water column was well mixed during each survey, with little differences among the three horizons examined. Secchi disk to depth ratio (Zsd:Z) ranged between 9 and 100 % of the water column at sites, suggesting that optical water clarity on survey days were generally good.
4. Particulate nitrogen concentrations continue to exceed water quality guidelines, and were generally higher during the 2018/2019 monitoring period in comparison to previous reporting periods
5. Chlorophyll-*a* concentrations were generally elevated above the guidelines, and were particularly high in January 2019 – probably in response to elevated available nutrient concentrations during these months.
6. Continuing elevated nutrients and chlorophyll-*a* concentrations in the region highlights persistent local sources contributing to these concentrations (i.e. catchment runoff from agriculture or urban centres).
7. Copper concentrations exceeded ANZECC 95 % protection guideline values at MKY_AMB2 in March 2019. All other metals in the ultra-trace suite were present at concentrations lower than guideline values, and/or lower than analytical detection limits.
8. Ametryn, Atrazine, Diuron, and Hexaninone were detected at several monitoring sites, particularly during the wet season survey (March 2019). Diuron concentrations exceeded water quality objectives at three sites in March 2019.

9. An assessment of the plankton community (both phytoplankton and zooplankton) was completed during this reporting period. There was a clear separation in the plankton community between most surveys, suggesting seasonal and inter-annual variation, and a weak relationship with available nutrients.
10. *Trichodesmium* blooms have been noted across the region during most surveys for the past few years, primarily during late spring and early summer. These algal blooms may contribute to elevated nutrient levels through nutrient reprocessing.

High frequency loggers

1. Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment, and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week. This is similar to the pattern observed in long term annual data sets at these sites.
2. Another important finding here was that deposition data did not indicate large deposits occurring at any of the monitored sites, and this is likely attributed to re-suspension of sediment by wave energy. SSC continues to regularly exceed relevant water quality guidelines at all sites, indicating that the development of local water quality guidelines is prudent. As part of this local water quality guideline development, it is recommended that the guidelines apply to benthic waters, adjacent to sensitive receptor habitats, rather than the current approach of surface water guidelines that can we well away from important habitats in the region.
3. Fine-scale patterns of photosynthetically active radiation (PAR) continue to be driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids – this trend was particularly the case given the extended wet season rainfall and runoff in the region following the monsoon that covered the region in February 2019.
4. Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter. Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites, and sites of closer proximity to one another were more similar than distant sites.
5. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations, the relationship between these two parameters is not always strong. At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats. For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.
6. Overall there was little consistent difference between wet and dry season PAR levels, suggesting that the increase in available light during the wet season is offset by the increased cloud cover, which has been a pattern found in previous years. Most sites showed no

difference between wet and dry, while AMB 1 and 2, showed increases of mean and median values during the dry season and AMB 12 showed a decrease in mean and median values.

Recommendations

1. The program this reporting period included nine monitoring sites, which has allowed us to continue characterising water quality in the Mackay region. It is recommended that these same nine sites remain for the 2019/20 period
2. Plankton assemblage sampling should continue. We now have several years of plankton data (since November 2015), which will allow examination of environmental drivers of plankton species composition within and among years to be explored in future reports.

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1 INTRODUCTION

1.1 Port operations

The Port of Mackay and the Port of Hay Point are situated on the central Queensland Coast (Figure 1.1). The Port of Mackay is located approximately four kilometers north of the Pioneer River, and is enclosed by large break walls that protect the port and marina property, while also allowing exchange of oceanic waters. The port has a series of operational and associated loading/unloading facilities, and an extensive marina operation and commercial fishing fleet. The port is operated by North Queensland Bulk Ports Corporation (NQBP).

The Port of Hay Point is situated approximately 40kms to the south of Pioneer River and Mackay City. Two coal terminals operate in the port: 1) Dalrymple Bay Coal Terminal; and 2) BMA Hay Point Coal Terminal. Similar to Port of Mackay, NQBP is the authority for the port but does not directly operate these facilities.

In both ports, routine maintenance dredging is necessary to maintain declared navigational depths within the swing basin and berth areas, departure path and aprons, and Tug Harbour at the Port of Hay Point. For the Port of Mackay, the most recent dredging campaign was completed in 2013, while the last maintenance dredging campaign undertaken by NQBP at the Port of Hay Point was completed in 2010. Any dredging activity necessary in the operating ports in the region are undertaken in accordance with Commonwealth and State approvals with management objectives guided by the Port of Mackay Long Term Dredge Management Plan and the Port of Hay Point Dredge Management Plan.

1.2 Program outline

Routine maintenance dredging is periodically required at the Port of Mackay and Hay Point to maintain vessel navigational depths. NQBP are committed to complete a range of monitoring programs specific to each dredge campaign with the objective of identifying direct impacts of the dredging activity. In order to better define the potential impacts associated with port operations and to characterise the natural variability in key water quality parameters within the adjacent sensitive habitats, NQBP committed an ambient marine water quality monitoring program in and around the coastal waters of the Port of Hay Point and the Port of Mackay (Figure 1.1; Table 1.1). As part of this program, water quality parameters are being investigated at a range of sites, including a control site in the southern Whitsunday Islands (Keswick Island; AMB12). This monitoring program contains a range of ambient water quality components that collectively continue to characterise the natural variability in key water quality parameters, including those experienced at the nearest sensitive receiving habitats for both Ports.

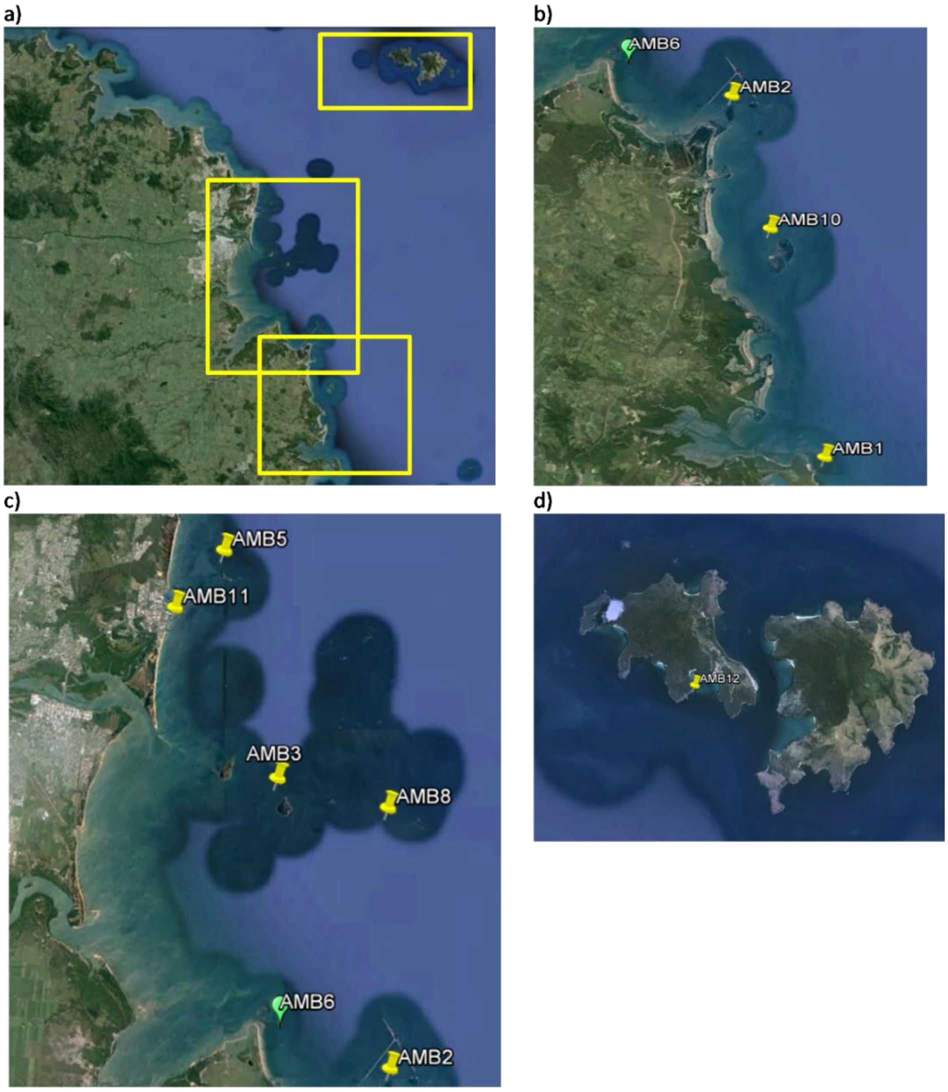

Figure 1.1 Locations of the ambient marine water quality monitoring program sites during 2018/19 program.

Table 1.1 Locations of the ambient marine water quality monitoring program sites

Location	AMB site no.	Lat.	Long.	Water quality	Deposition/PAR logger
Freshwater Point	MKY_AMB1	-21.42	149.34	Yes	Yes
Hay Reef	MKY_AMB2	-21.26	149.30	Yes	Yes
Round Top Island	MKY_AMB3B	-21.17	149.26	Yes	Yes
Slade Island	MKY_AMB5	-21.09	149.24	Yes	Yes
Dudgeon Point	MKY_AMB6B	-21.24	149.25	Yes	PAR logger only
Spoil Grounds	MKY_AMB8	-21.18	149.30	Yes	Yes
Victor Island	MKY_AMB10	-21.32	149.32	Yes	Yes
Mackay Harbour	MKY_AMB11	-21.11	149.22	Yes	No
Keswick Island	MKY_AMB12	-20.93	149.42	Yes	Yes

1.3 Rainfall and river flows

Total rainfall during the 2018/2019 wet season period was 1465 mm, placing it as a slightly above average wet season in comparison to wet season totals since 1910/1911 (Figure 1.2). Rainfall in recent years has also been highlighted indicating the high inter-annual variability of rainfall. This highlights the necessity for a long term commitment to ambient marine monitoring programs to capture and understand this variability.

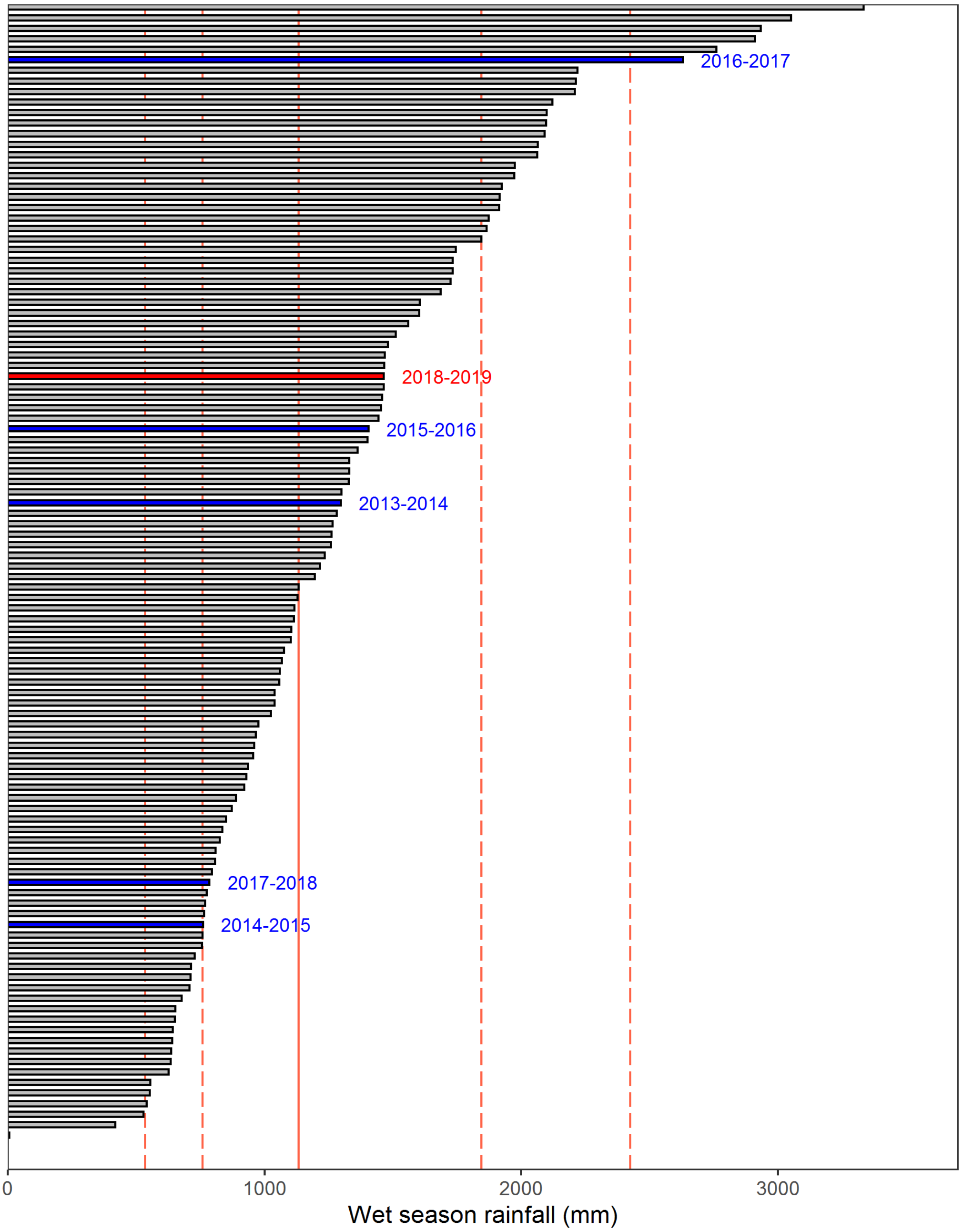

Figure 1.2 Wet season rainfall for the Bowen region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Bureau of Meteorology Plane Creek Sugar Mill weather station (Station number 033059). Totals were calculated for the wet season period 1st November to 31st March for each reporting year. Red bar represents the current 2018/19 ambient marine water quality monitoring period, blue bars show total rainfall over the previous five reporting years. Solid red line represents median wet season rainfall 1910/11 to 2018/19 and dashed red lines represent 5th, 20th, 80th, and 95th percentiles.

A hydrograph for Pioneer River shows an increase in river discharge during the 2018/2019 reporting period in comparison to the 2017/18 reporting period (Figure 1.3). Specifically there was a sustained discharge event throughout February 2019. Heavy rainfall occurred in late January and early February

2019 due to the convergence of an active monsoon trough and slow-moving low-pressure system (Figure 1.4) causing increased river discharge.

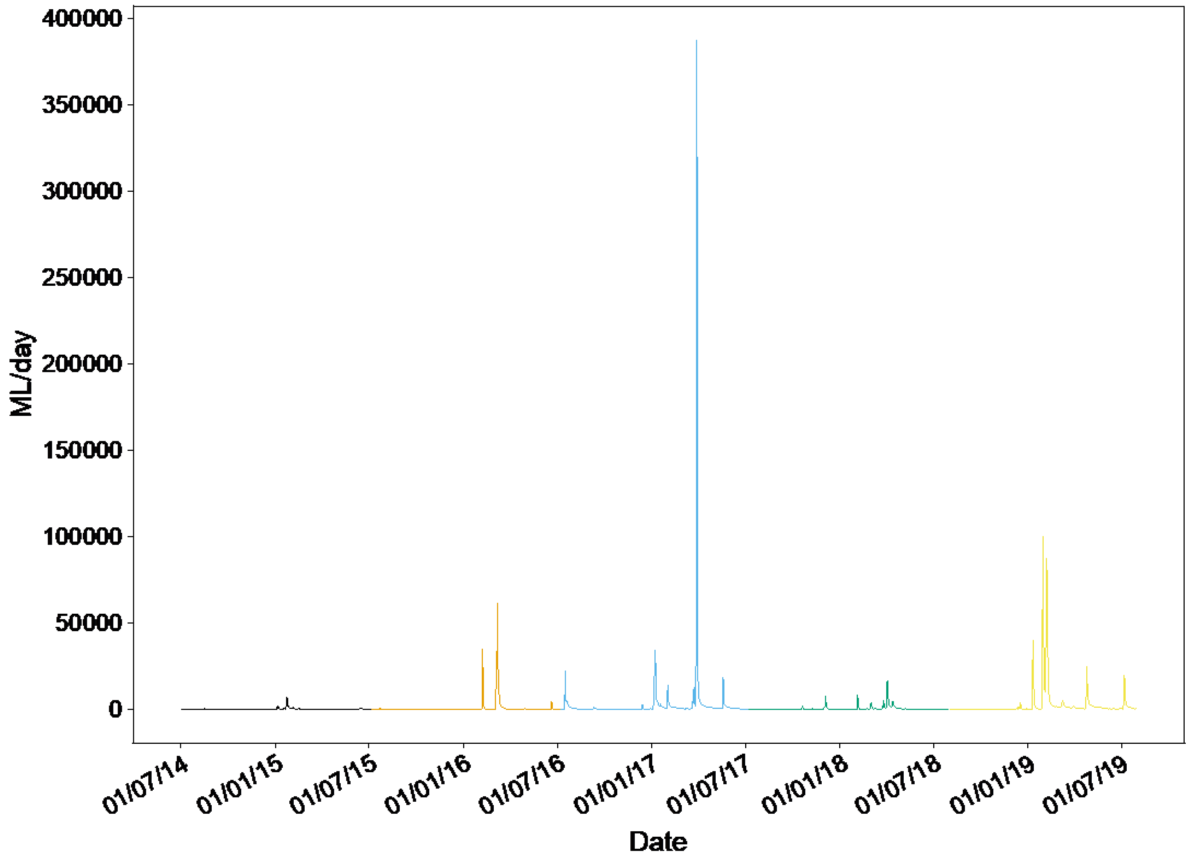

Figure 1.3 Discharge (ML d^{-1}) recorded for the Pioneer River (station number: 125007A) since 2014. The line colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, yellow = 2018/2019.

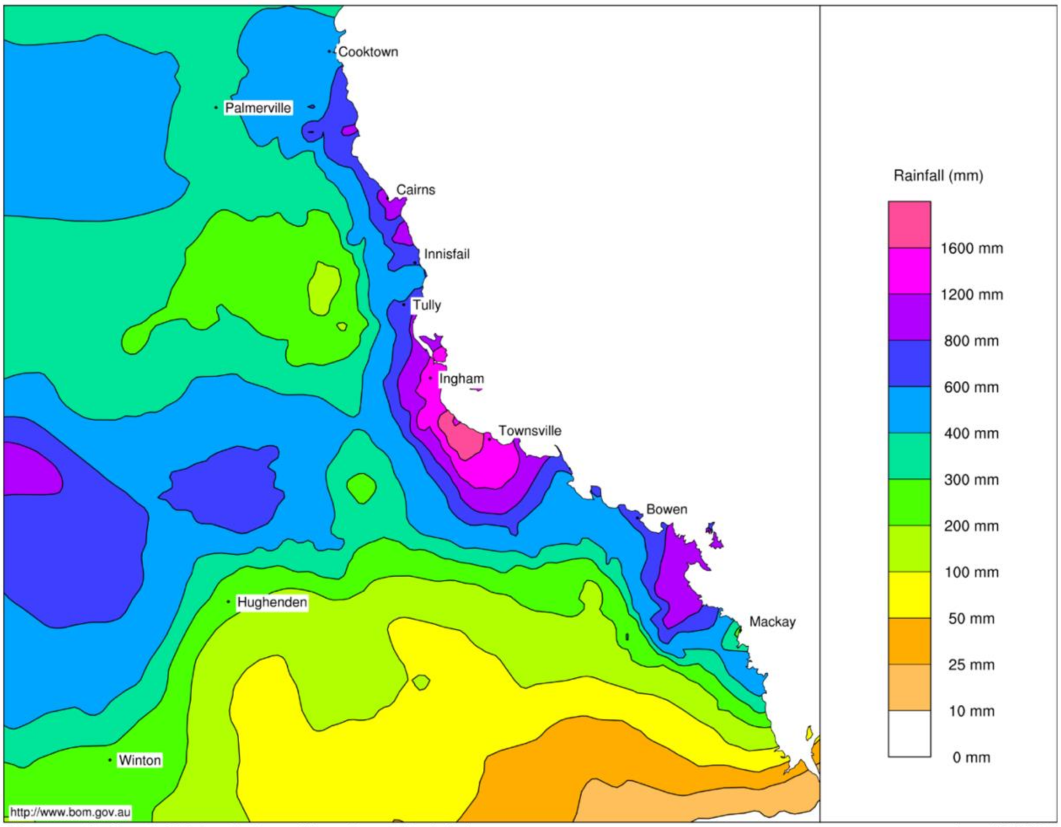

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Figure 1.4 Heavy rainfall occurred in the region between 26th January to 9th February 2019 due to the convergence of an active monsoon trough and slow-moving low pressure system. Source: Commonwealth of Australia 2019, Special Climate Statement 69 – an extended period of heavy rainfall and flooding in tropical Queensland.

1.4 Wind for Mackay Airport

The daily average wind speed and direction recorded at Mackay airport for the reporting period (2018/2019) is predominantly from the south east and south west, with more than 55 % of the days reaching wind speeds greater than 24 km h^{-1} (Figure 1.5). Overall, the dominance of south east winds is consistent with previous monitoring periods, and wind rarely came from the north east direction during this reporting period (< 5 % of the days in 2018/2019).

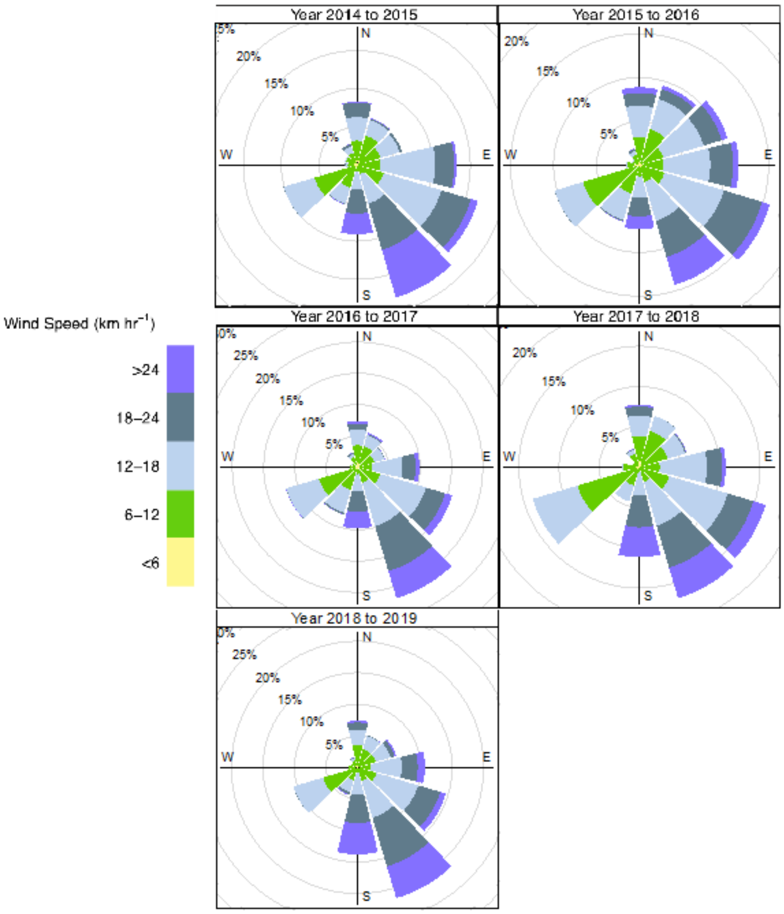


Figure 1.5 Daily average wind direction and strength recorded in Mackay airport during each monitoring period.

1.5 Project objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region within and adjacent to Port of Mackay and Hay Point. This report provides a review and analysis of data collected between July 2018 and July 2019, while in some cases comparing to data collected over previous years. These data are part of a long term commitment to monitor and characterise receiving water quality conditions in the Port of Hay Point and Port of Mackay, in particular to support future planned asset management and protection for both these ports.

2 METHODOLOGY

2.1 Ambient water quality

Spot water quality samples were collected at sites approximately on a 6 week basis from a research vessel (Table 2.1). A multiprobe was used to measure water temperature, salinity, dissolved oxygen (%), pH, and turbidity (Figure 2.1). The multiprobe was calibrated against standard solutions in the laboratory prior to each monitoring event. These field *in-situ* measurements are recorded at three depths: a) surface (0.25m); b) mid-depth; and c) bottom. In addition to spot measurements, secchi disk depth was recorded as a measure of the optical clarity of the water column. Depth profiles of photosyntecially active radiation were recorded using a LiCor underwater sensor to calculate light attenuation in the water column. The measurements assist in characterising water quality conditions in the water column, building on the data collected in these waters since 2014.

A review of available reports reveals that water quality conditions in the coastal region of Mackay and Hay Point are variable (Waltham et al., 2015, Waltham, et al., 2016, Waltham et al., 2017), and is strongly influenced by local activities and contributing catchment runoff during and following rainfall in the region. On this basis, and in considering key priority outcomes outlined in recently published Coastal Strategic Assessment and Marine Strategic Assessments for the Great Barrier Reef World Heritage area (DEHP, 2013; GBRMPA, 2013), the water quality program design below was completed. The list of parameters examined consisted:

- Ultra-trace dissolved metals : arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn);
- Nutrients (particulate nitrogen and phosphorus);
- Chlorophyll-*a*;
- Pesticides/herbicides (Low LOR suite (EP234(A-I)) including: diuron, ametryn, atrazine, terbutryn. Note that pesticides are suspected to be in low concentrations during periods of low rainfall runoff, and only detectable following rainfall. As a consequence sampling of only two events at all sites for pesticides, one during the dry and a wet season – though note that the timing of each are dependent on prevailing weather conditions, so the timing of each survey could differ from year to year; and
- Phytoplankton and zooplankton collection occurred four times across this reporting period. The timing of sample collection, similar to pesticides/herbicides, is dependent on prevailing weather conditions, to capture a range of different conditions ranging from wet, dry, late dry, late wet, post wet etc. This strategy maximises the opportunity to sample under different conditions, and overtime a stronger understanding of the variability of plankton communities is possible.

Figure 2.1 TropWATER staff conducting field water quality sampling

Table 2.1 Summary of instrument maintenance and water quality surveys completed during the 2018/19 reporting period

Date	Nutrients, Chlorophyll-*a*	Metals, herbicides	Plankton	Logger maintenance
July 2018	Yes	-	-	Yes
August 2018	Yes	Yes	Yes	Yes
October 2018	Yes	-	-	Yes
January 2019	Yes	-	Yes	Yes
March 2019	Yes	Yes	Yes	Yes
May 2019	Yes	-	-	Yes
July 2019	Yes	-	Yes	Yes

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e., DEHP 2013; APHA 2008 Standards Australia 1998). Field collected water samples were stored on ice in eskies immediately during field trips aboard the vessel, and transported back to refrigeration, before delivery to the TropWATER laboratory. For chlorophyll analysis, water was placed into a 1L dark plastic bottle and placed on ice for transportation back to refrigeration. For dissolved metals and nutrients, water was passed through a 0.45 µm disposable membrane filter (Sartorius), fitted to a sterile 60 mL syringe (Livingstone), and placed into 60 mL bottles (metals) and 10 mL bottles (nutrients) for analysis in the laboratory. (The use of these field sampling equipment and procedures have been previously shown to reduce the risk of contamination of samples, contributing to false positive results for reporting; TropWATER, 2015). Unfiltered sample for total nitrogen and total phosphorus analysis were frozen in a 60 mL tube. All samples are kept in the dark and cold until processing in the laboratory, except nutrients which are stored frozen until processing.

Water for chlorophyll *a* determination was filtered through a Whatman 0.45 µm GF/F glass-fibre filter with the addition of approximately 0.2 mL of magnesium carbonate within (less than) 12 hours of collection. Filters are then wrapped in aluminium foil and kept frozen until time of extraction. Pigment determinations from acetone extracts of the material retained on the filters were completed using spectrophotometry.

Water samples were analysed using the defined analysis methods and detection limits outlined in Table 2.2. In summary, all nutrients were analysed using colorimetric method on OI Analytical Flow IV

Segmented Flow Analysers. Total nitrogen and total phosphorus and total filterable nitrogen and total filterable phosphorus were analysed simultaneously after alkaline persulphate digestion. Filterable heavy metals and pesticides were sent for external analyse at Australian Laboratory Service (ALS).

Water quality results are presented throughout this report as boxplots where the median is denoted as the centre line, the box represent the 20th and 80th quantiles, and whiskers represent the 5th and 95th percentile.

Table 2.2 Water analyses performed during the program

Parameter	APHA method number	Reporting limit
Routine water quality analyses		
pH	4500-H$^+$ B	-
Conductivity (EC)	2510 B	5 µS/cm
Total Suspended Solids (TSS)	2540 D @ 103 - 105°C	0.2 mg/L
Turbidity	2130 B	0.1 NTU
Salinity		
Dissolved Oxygen		
Light Attenuation		
Pesticides/herbicides		
Organophosphate pesticides	In house LC/MS method: EP234A	0.0002-0.001 µg/L
Thiocarbamates and Carbamates	In house LC/MS method: EP234B	0.0002 µg/L
Thiobencarb		
Dinitroanilines	In house LC/MS method: EP234C	0.001 µg/L
Pendimethalin		
Triazinone Herbicides	In house LC/MS method: EP234D	0.0002 µg/L
Hexazinone		
Conazole and Aminopyrimidine Fungicides	In house LC/MS method: EP234E	0.0002 µg/L
Propiconazole, Hexaconazole, Difenoconazole, Flusilazole, Penconazole		
Phenylurea Thizdiazolurea Uracil and Sulfonylurea Herbicides	In house LC/MS method: EP234F	0.0002 µg/L
Diuron, Ametryn, Atrazine, Cyanazine, Prometryn, Propazine, Simazine, Terbuthylazine, Terbutryn		
Nutrients		
Total Nitrogen and Phosphorus (TN/TP)	Simultaneous 4500-NO$_3^-$ F and 4500-P F analyses after alkaline persulphate digestion	25 µg N/L 5 µg P/L
Filterable nutrients (nitrate, nitrite, ammonia, Nox)	4500-NO$_3^-$ F	1 µg N/L
Ammonia	4500- NH$_3$ G	1 mg N/L
Filterable Reactive Phosphorus (FRP)	4500-P F	1 µg P/L
Chlorophyll	10200-H	0.1 µg/L
Trace Metals		
Arsenic, Cadmium, Copper, Lead, Nickel, Silver, Zinc, Mercury	3125B ORC/ICP/MS	0.05 to 100 µg/L

2.2 Plankton community

At all sites, a 60 µm plankton net (for phytoplankton) and a 500 µm plankton net (for zooplankton) was towed behind the research vessel at approximately 6 kts for approximately 100 m. A GPS waypoint was recorded at the start and end of each plankton tow. At the end of each plankton tow, the nets were retrieved, and the contents retained in the plastic jar attached to the net were immediately transferred to preservation containers. Samples were identified with the aid of dissecting and light microscopes to the lowest possible taxon.

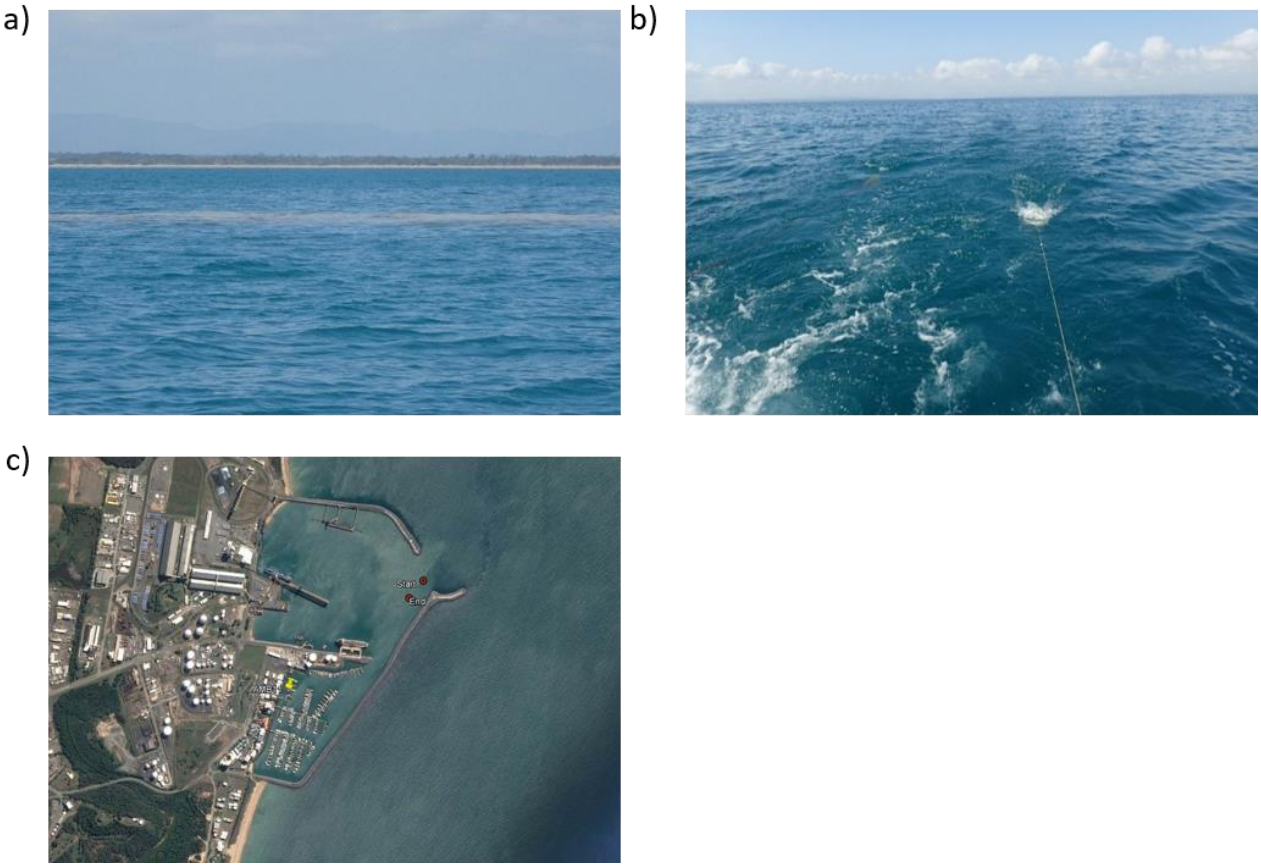


Figure 2.2 Example plankton sample during November 2015 survey. a) *Trichodesmium* bloom on sea surface; b) phytoplankton (60 µm) tow behind the survey vessel; and c) AMB 11 (Mackay Harbour) yellow dot ambient marine water quality site, black dots start and end of plankton tow

2.3 Multiparameter water quality logger

Sediment deposition, turbidity, photosynthetically available radiation (PAR), water depth, root mean squared (RMS) water depth and water temperature were measured at each site using multiparameter water quality instruments manufactured at the Marine Geophysics Laboratory, School of Engineering and Physical Sciences, James Cook University (Figure 2.3). These instruments are based on a Campbell's Scientific 1000 data logger that has been programmed to measure and store these marine physical parameters using specifically designed sensors.

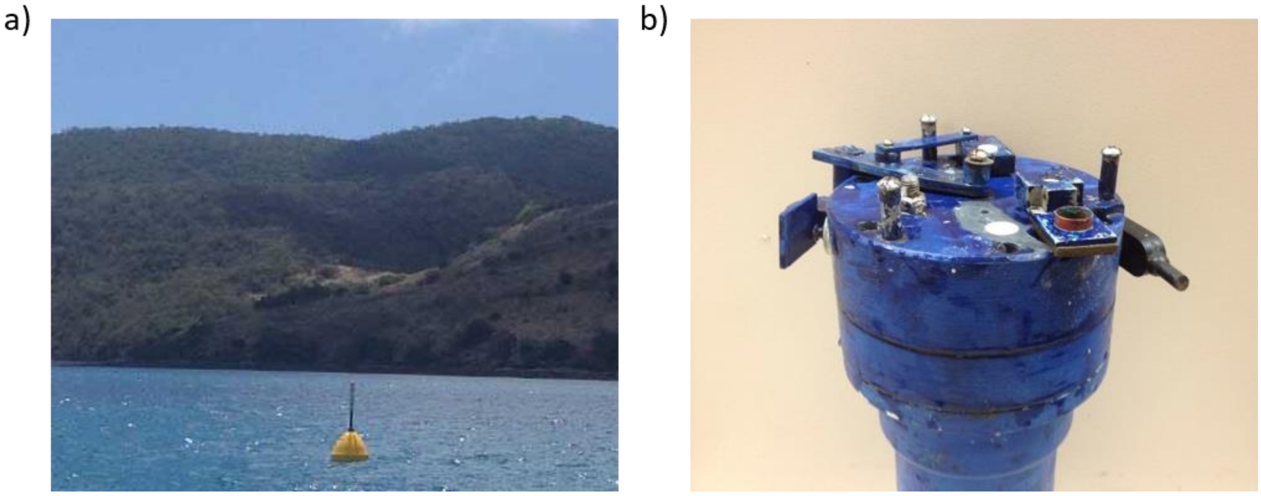


Figure 2.3 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

2.3.1 Turbidity

The turbidity sensor provides data in Nephelometric Turbidity Unit's equivalent (NTUe) and can be calibrated to Suspended Sediment Concentration (SSC) in mg L^{-1} (Larcombe et al., 1995). The sensor is located on the side of the logger, pointing parallel light-emitting diodes (LED) and transmitted through a fibre optic bundle. The backscatter probe takes 250 samples in an eight second period to attain an accurate turbidity value. The logger is programmed to take these measurements at 10 minute intervals. The sensor interface is cleaned by a mechanical wiper at a two hour interval allowing for long deployment periods where bio-fouling would otherwise seriously affect readings.

It must be noted the international turbidity standard ISO7027 defines NTU only for 90 degree scatter, however, the Marine Geophysics Laboratory instruments obtain an NTUe value using 180 degree backscatter as it allows for much more effective cleaning. Because particle size influences the angular scattering functions of incident light (Ludwig and Hanes 1990; Conner and De Visser 1992; Wolanski et al., 1994; Bunt et al., 1999), instruments using different scattering angles can provide different measurements of turbidity (in NTU). This has to be acknowledged if later comparison between instruments collecting NTUe and NTU are to be made. To enhance the data, all sites were calibrated to provide a measure of SSC (mg/L) and enable for the accurate comparison between 90 degree backscatter and 180 degree backscatter measurements.

2.3.2 Sediment deposition

Deposition is recorded in Accumulated Suspended Sediment Deposition (ASSD) (mg cm^{-2}). The sensor is wiped clean of deposited sediment at a 2 hour interval to reduce bio-fouling and enable sensor sensitivity to remain high. The deposition sensor is positioned inside a small cup shape (16 mm diameter × 18 mm deep) located on the flat plate surface of the instrument facing towards the water surface. Deposited sediment produces a backscatter of light that is detected by the sensor. Deposited sediment is calculated by subtracting, from the measured data point, the value taken after the sensor was last wiped clean. This removes influence of turbidity from the value and re-zeros the deposition sensor every 2 hours.

If a major deposition event is in progress, the sensor reading will increase rapidly and will be considerably above the turbidity sensor response. Gross deposition will appear as irregular spikes in the data where the sediment is not removed by the wiper but by resuspension due to wave or current stress. When a major net deposition event is in progress the deposited sediment will be removed by the wiper and the deposition sensor reading should fall back to a value similar to the turbidity sensor. The data will have a characteristic zigzag response as it rises, perhaps quite gently, and falls dramatically after the wipe (Ridd et al., 2001).

Deposition data is provided as a measurement of deposited sediment in mg cm^{-2} and as a deposition rate in mg cm^{-2} d^{-1}. The deposition rate is calculated over the 2 hour interval between sensor wipes and averaged over the day for a daily deposition rate. The deposition rate is useful in deposition analysis as it describes more accurately the net deposition of sediment by smoothing spikes resulting from gross deposition events.

2.3.3 Pressure

A pressure sensor is located on the horizontal surface of the water quality logging instrument. The pressure sensor is used to determine changes in water depth due to tide and to produce a proxy for wave action. Each time a pressure measurement is made the pressure sensor takes 10 measurements over a period of 10 seconds. From these 10 measurements, average water depth (m) and Root Mean Square (RMS) water height are calculated. RMS water height, D_{rms}, is calculated as follows:

$$D_{rms} = \sqrt{\sum_{n=1}^{10} (D_n - \overline{D})^2 / n}$$

Equation 1 : where D_n is the nth of the 10 readings and $\overline{D}$ is the mean water depth of the n readings.

The average water depth and RMS water depth can be used to analyse the influence that tide and water depth may have on turbidity, deposition and light levels at an instrument location. The RMS water height is a measure of short term variation in pressure at the sensor. Changes in pressure over a 10 second time period at the sensor are caused by wave energy. RMS water height can be used to analyse the link between wave re-suspension and SSC. It is important to clearly establish that RMS water height is not a measurement of wave height at the sea surface. What it does provide is a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. For example, two sites both have the same surface wave height, site one is 10 m deep and has a measurement of 0.01 RMS water height and site two is 1m deep and has a measurement of 0.08 RMS water height. Even though the surface wave height is the same at both sites, the RMS water height is greater at the shallower site and we would expect more re-suspension due to wave shear stress at this site.

2.3.4 Water temperature

Water temperature values are obtained with a thermistor that records every 10 minutes. The sensor is installed within a bolt that protrudes from the instrument and gives sensitive temperature measurements.

2.3.5 Photosynthetically Active Radiation (PAR)

A PAR sensor, positioned on the horizontal surface of the water quality logging instrument, takes a PAR measurement at ten (10) minute intervals for a one second period. To determine total daily PAR (mol m^{-2} d^{-1}) the values recorded are multiplied by 600 to provide of PAR for a 10 minute period and then summed for each day.

2.4 Marotte current meter

The Marotte HS (High Sampling Rate) is a drag-tilt current meter invented at the Marine Geophysics Laboratory (Figure 2.4). The instrument records current speed and direction with an inbuilt accelerometer and magnetometer. The current speed and direction data are smoothed over a 10-minute period. The instruments are deployed attached the nephelometer frames and data is download when the instruments are retrieved. Inclusion of this current meter has been added to the program as a way to trial new technology, gather new data and to value add to project outcomes and deliverables.

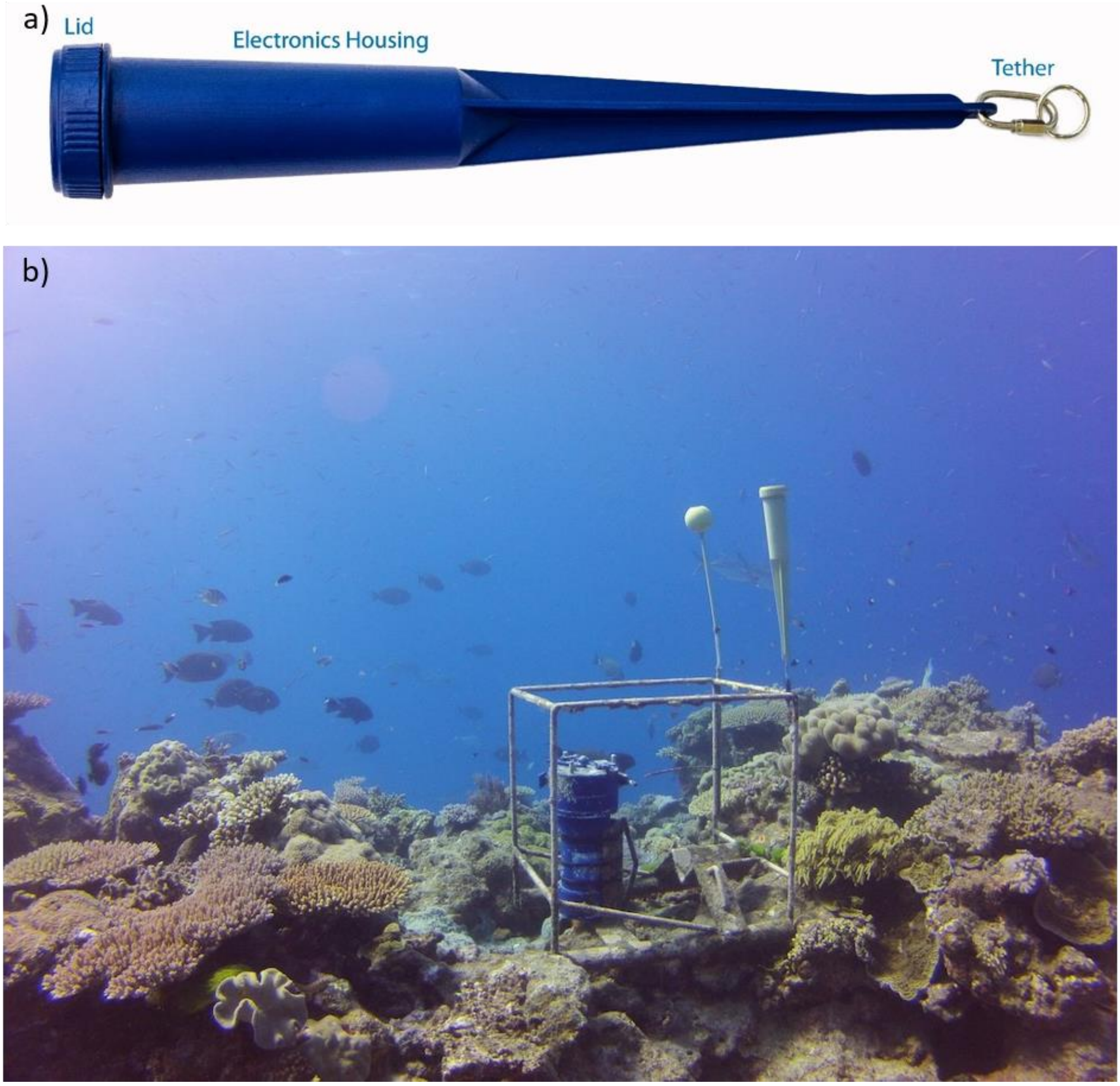


Figure 2.4 a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte at Moore Reef. Image courtesy of Eric Fisher

2.4.1 Measuring environmental controls on SSC

Stepwise regression analysis was used to investigate the environmental controls on SSC at the ambient sites, with data selected including:

(a) Ambient sites:

[1] "Freshwater Point"
[2] "Hay Point Reef"
[3] "Keswick Is"
[4] "Round Top Is"
[5] "Slade Is"
[6] "Victor Is"

(b) River Gauge Station:

[1] "Sandy"
[2] "Pioneer"

(c) Wind Station:

[1] "Station 33119 – Mackay"

(d) Tide Gauge Station:

[1] "Port of Mackay"

In this assessment, the environmental parameters with control on SSC were analysed by stepwise regression analysis followed by relative importance analysis (Grömping, 2006) using R language (R Core Team, 2015). The stepwise analysis allowed the selection of the environmental variables that explain the SSC variability in the water column. The relative importance analysis allowed these selected variables to be ranked based on their overall explanation of the SSC variability. In order to visualize the effect of each environmental parameter selected in the stepwise analysis, a partial plot analysis (Crawley, 2007) was carried out. These partial plots indicate the dependence between SSC and each selected variable when all the other variables in the model are kept constant (Crawley, 2007). The data set used in the stepwise analysis was log-transformed, if needed, to satisfy requirements for regression analysis. For each site, all the following variables were tested in an initial model against SSC: RMS of water depth, mean daily wind, maximum tide amplitude and the Pioneer and Sandy River discharges. These rivers were selected due to their proximity to the sampling sites. The Rocky River gauge station was ceased in November, 2014, so it was not include in the analysis. Maximum tide amplitude was calculated as the maximum absolute difference between two consecutive maximum or minimum tide readings. Wind components were calculated as the mean value of 8 daily measurements decomposed to in two diagonals, NE-SW and NW-SE. Variables presenting autocorrelation were excluded based on a variance inflation test (Fox and Monett, 1992) > 4 and outliers were removed based on Bonferroni Outlier Test (Cook and Weisberg 1982).

3 RESULTS AND DISCUSSION

3.1 Ambient water quality

3.1.1 Spot water quality physio-chemical

For the reporting period between July 2018 and July 2019 water temperature ranged between 20 and 30 °C, which is consistent with previous reporting periods (Figure 3.1). There continues to be a strong seasonal effect on water temperatures in the region, with the highest water temperatures observed during surveys in the summer months, and cool water temperatures observed during the winter months. These patterns are consistent throughout the water column, indicating that the water column profile is vertically well mixed. There are no guidelines for water temperature in coastal areas, however, temperature is an essential interpretative aid for ecological assessment in environments. For example, species such as fish and other animals have thermal stress point which causes discomfort and could be misconstrued as being a toxicological impact (example are the coral trout; Johansen et al. 2015). There were no observed or known impacts on aquatic species in the region during this monitoring period.

Electrical conductivity (EC) was stable across all sites, with little evidence of changing conditions through the water column (Figure 3.2). Overall EC has remained between 51 mS cm^{-1} and 57 mS cm^{-1}, generally indicating oceanic conditions. It is important to note that during September 2017 to October 2018 salinity (ppt) was recorded in the field. To correct for this, we generated a relationship between water sample measured EC during trips and field salinity records, and then back calculated for EC measurements in the field. While the relationship between laboratory EC and salinity was good, the corrected EC field data (shown in Figure 3.2) appears to be more stable among sites and surveys in this reporting period. The data is presented here for completeness, but use of these data will require caution.

Dissolved oxygen saturation levels ranged between 80 to 125 % (Figure 3.3). There was some local variability among sites, with the lowest levels recorded at AMB11 (Mackay Marina) at the bottom horizon (and this has been a common observation over the years). The reason for the lower dissolved oxygen in the marina is possibly due to the enclosed nature of this facility, with reduced tidal exchange and therefore circulation of waters, and a small wind fetch which may limit re-oxygenating the water column profile. However, despite these data during each survey fish are continually present in the marina, suggesting that conditions are not critical or require management intervention. If periods occurred when conditions were critical, then it seems fish could easily swim out of the marina facility. For all other sites, the water column continues to be well mixed although there is a subtle oxycline with dissolved oxygen concentrations decreasing with depth.

Field pH measurements were stable across sites and depths primarily ranging between 8.0 and 8.5 during 2018/2019 (Figure 3.4). However, surface measurements were slightly more acidic (< 7.9) in comparison to bottom measurements (Figure 3.4a), although still within expected range for marine waters (ANZECC, 2000). Similar to previous monitoring periods, pH levels were relatively stable across all sites during 2017-2018 (Figure 3.4b).

Field turbidity measurements typically ranged between <1 to 150 NTU during 2018-2019 (Figure 3.5). Turbidity was similar among sites and relatively consistent throughout the water column during this reporting period (Figure 3.5b). Secchi disk depth (m) is a vertical measure of the optical clarity of water column and ranged between 1 and 16 m (Figure 3.6a). The range measured is a response to localised variation in water quality, most likely a difference in tidal stage among sites during a survey – some sites may have been surveyed on an ebbing or flooding tide where water depth was lower or higher, short term localised changes in turbidity that is associated with tide (see section 3.2) or algal blooms that reduce vertical clarity. The secchi disk depth to depth ratio (Zsd:Z, Figure 3.6b) is a more relevant calculation for water clarity, which corrects the secchi disk depth for water depth. This ratio ranged between 9 and 100% of the water column, which means that water clarity ranged between 9% of the water through to the entire water column.

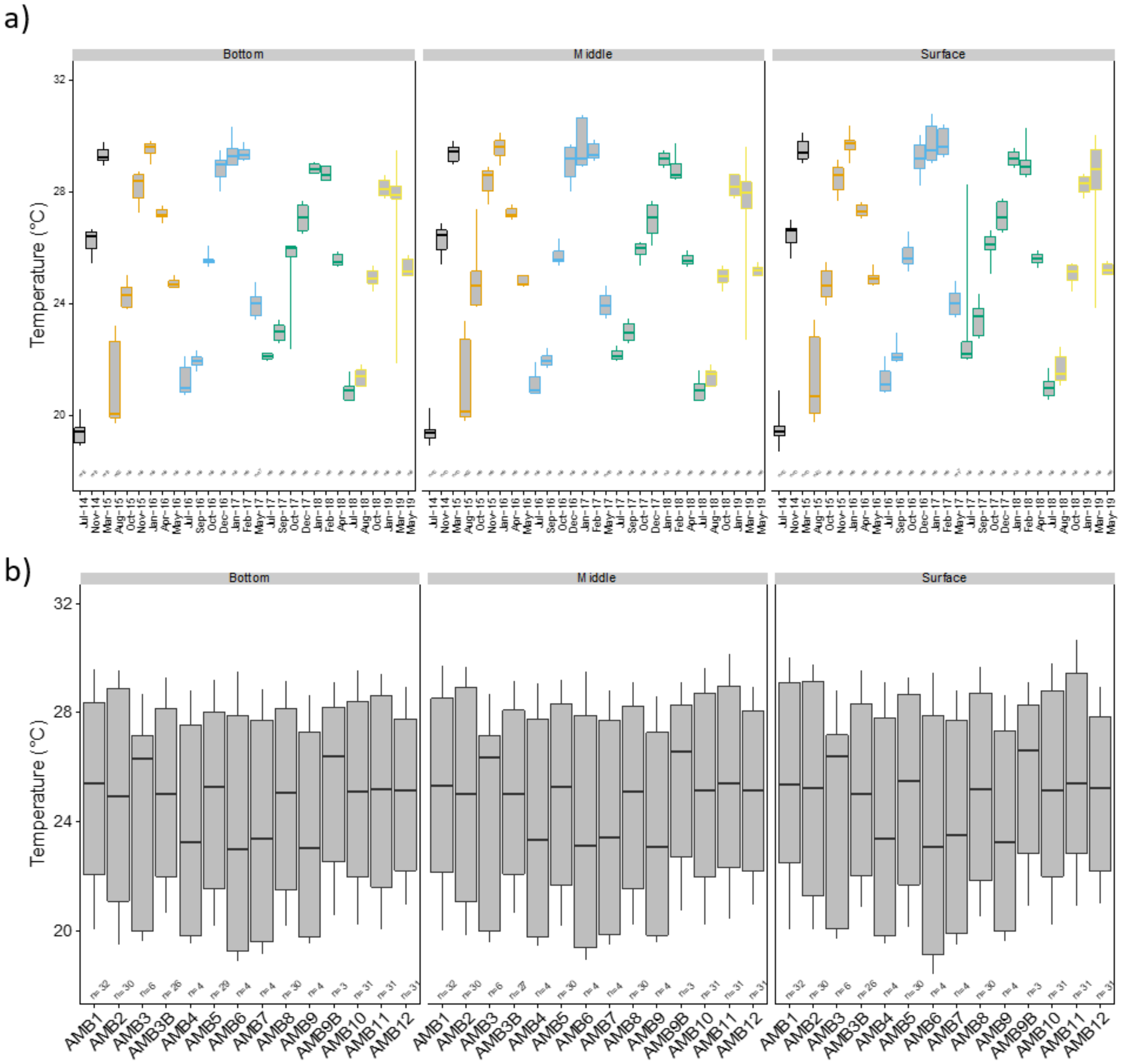


Figure 3.1 Water temperature box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2019)

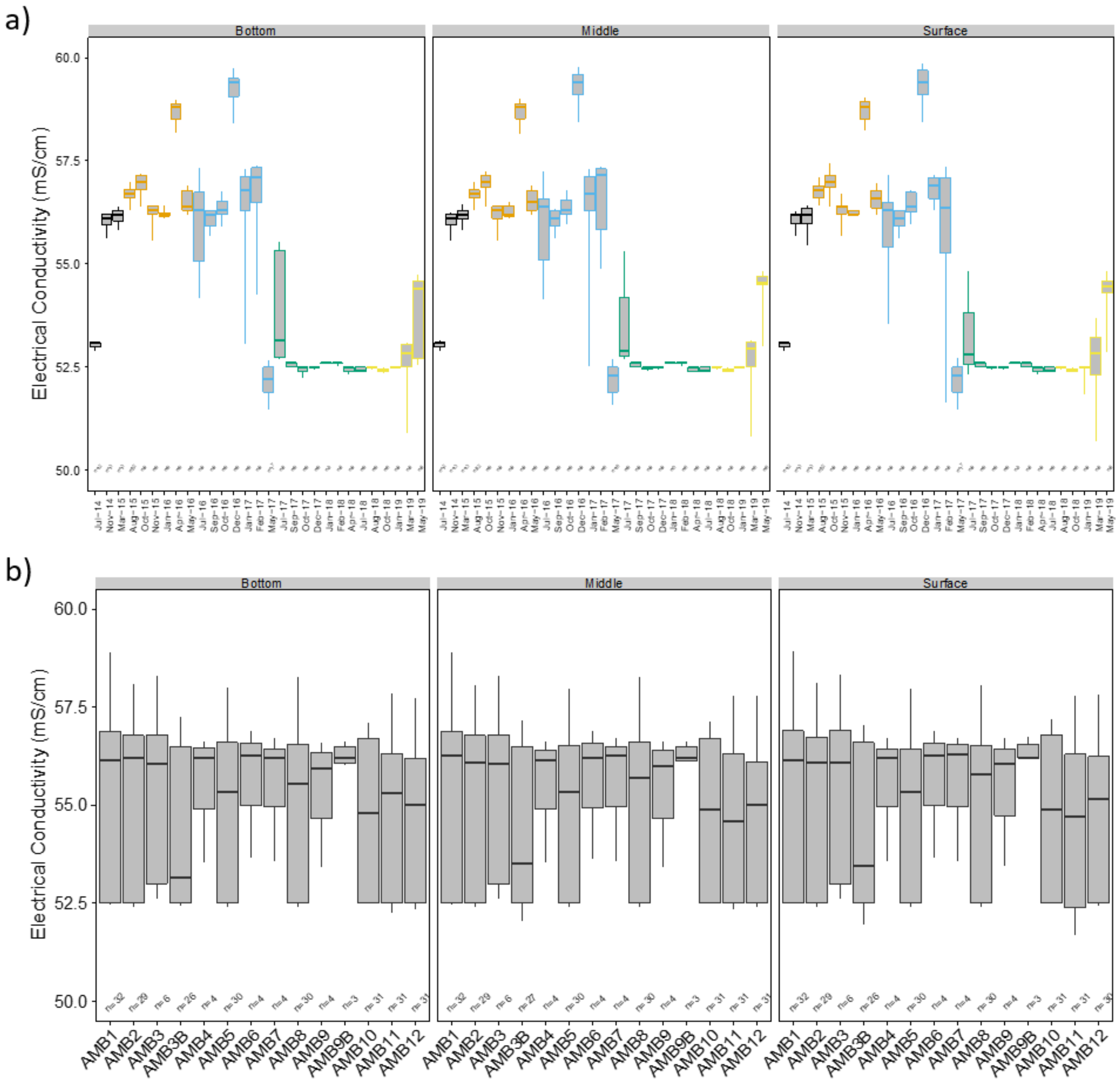


Figure 3.2 Electrical conductivity box plots recorded: (a) three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2019)

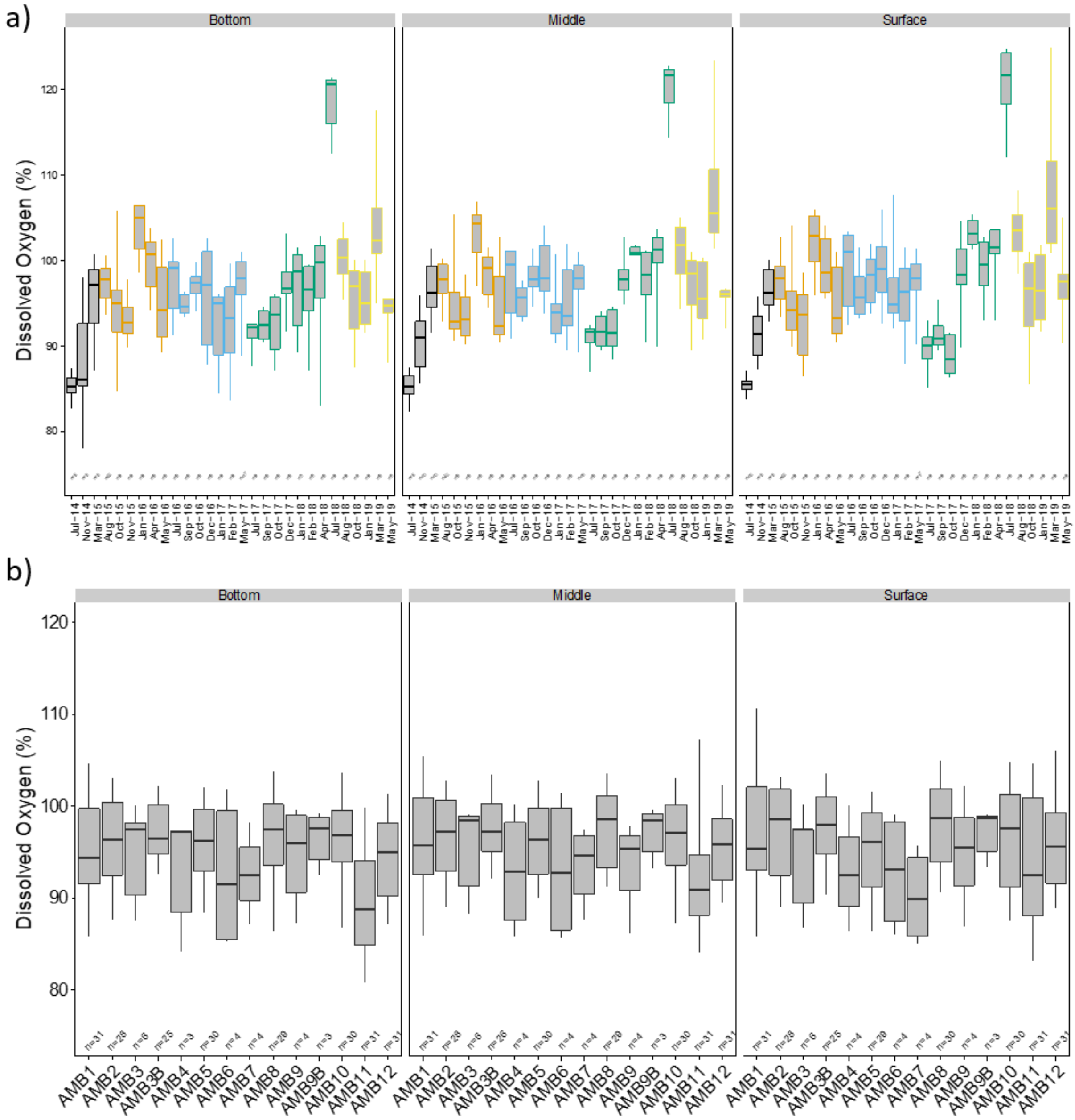


Figure 3.3 Dissolved oxygen box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018, and yellow = 2018/2019; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2019)

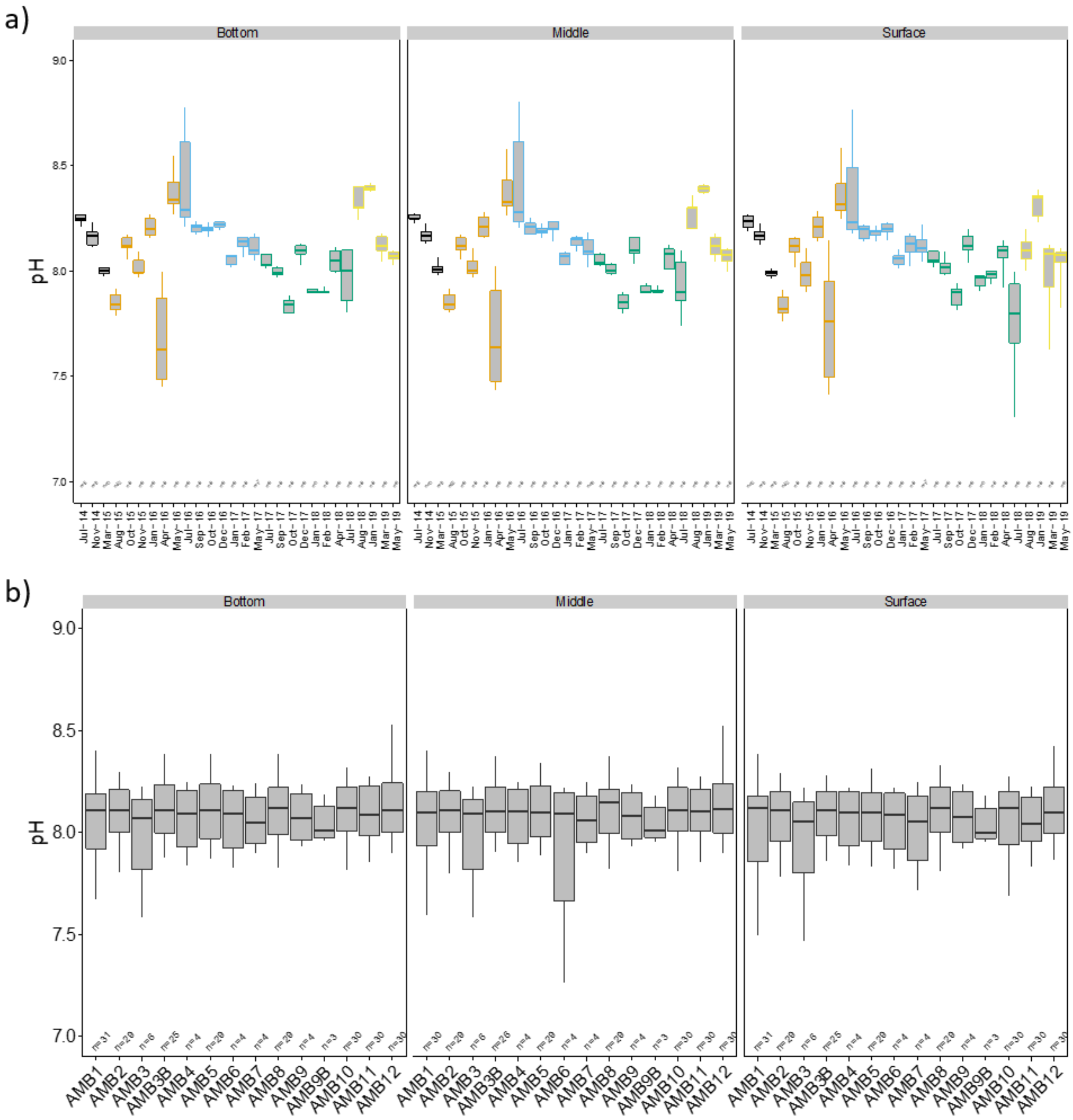


Figure 3.4 pH box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2019)

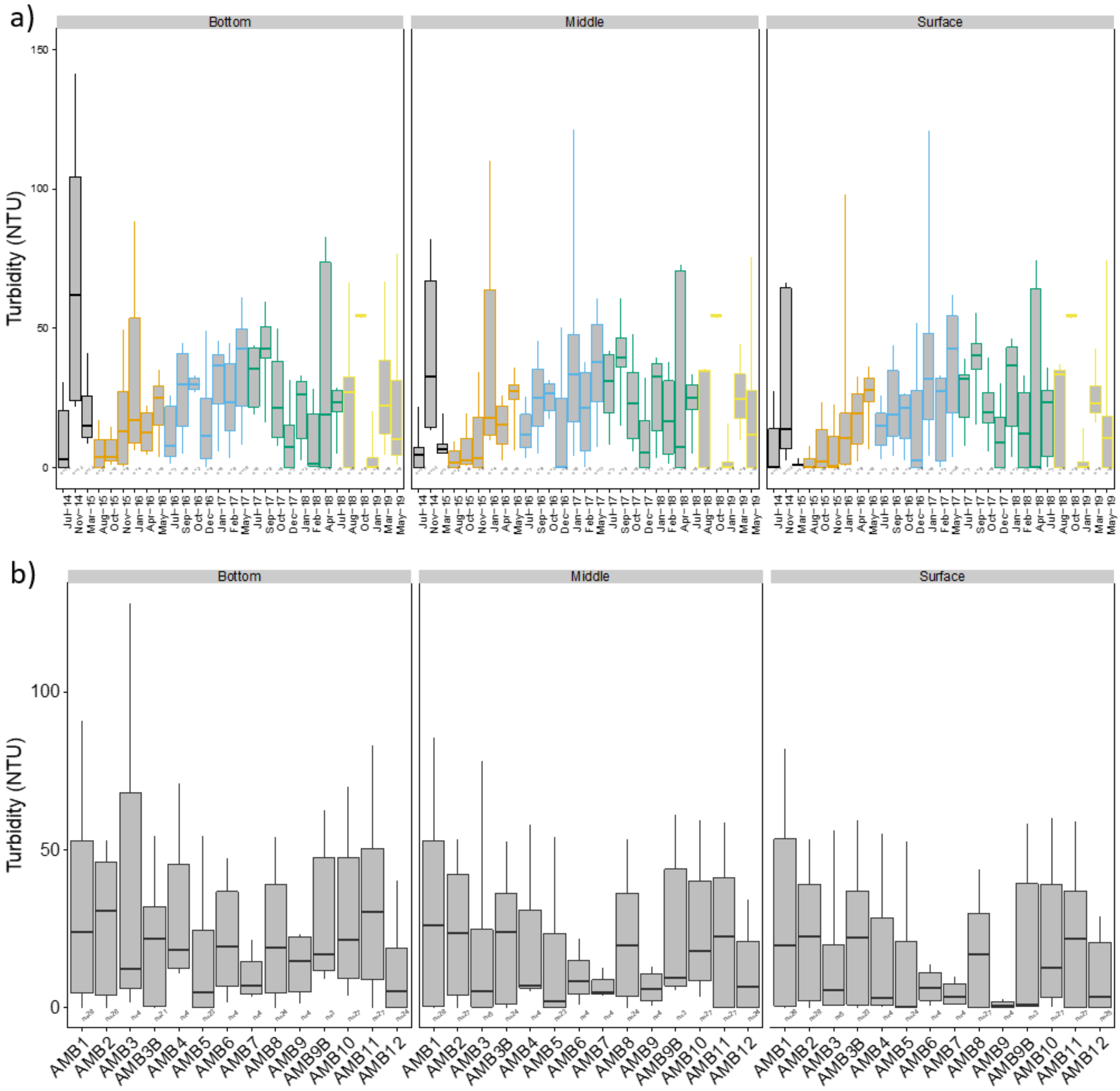


Figure 3.5 Turbidity box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2019)

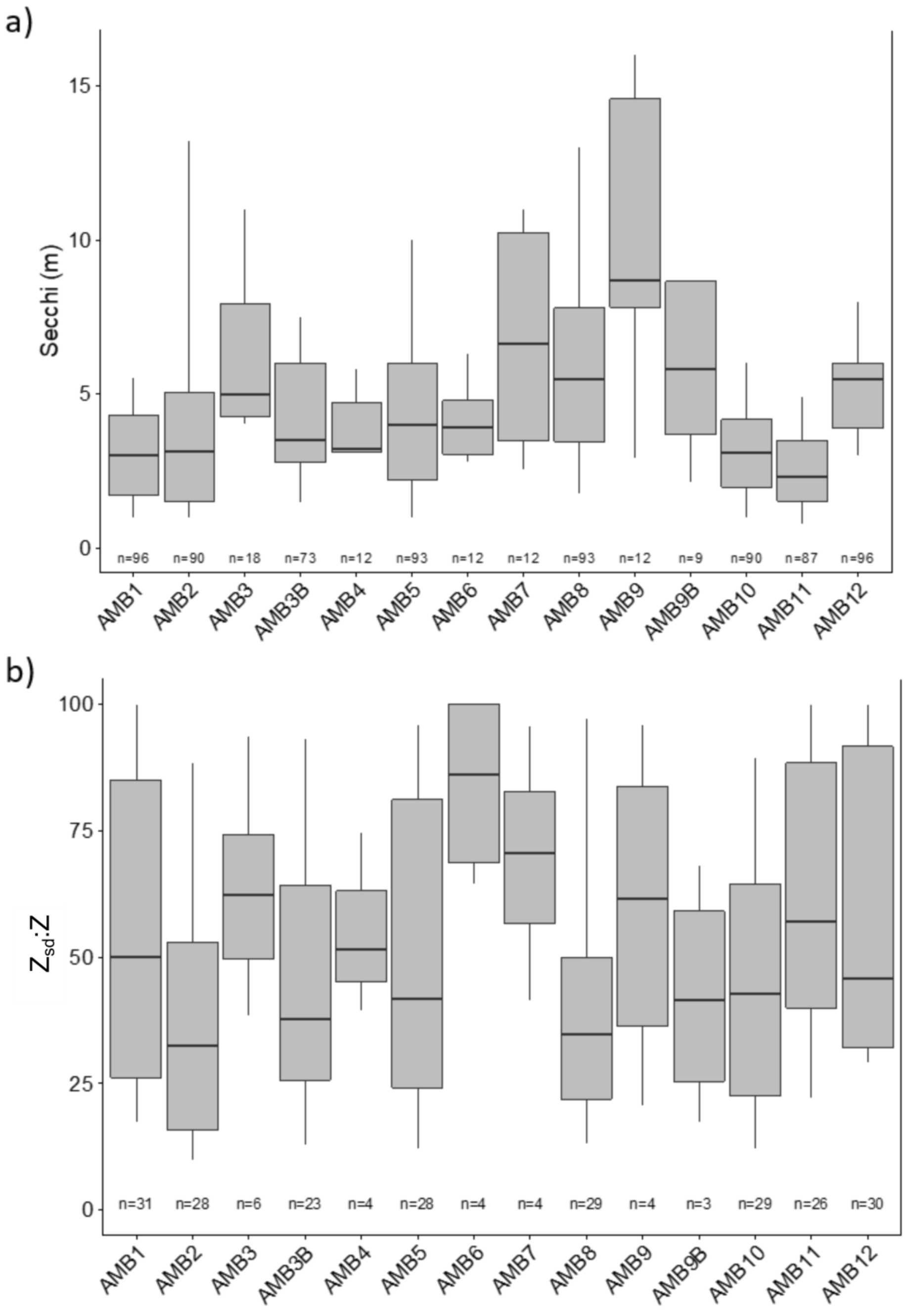


Figure 3.6 a) Water secchi disk depth for all sites (surveys pooled for all monitoring periods 2014-2019); and (b) light attention depth to depth ratio (Zsd:Z) for sites (surveys pooled for all monitoring periods 2014-2019)

3.1.2 Nutrients and chlorophyll-*a*

Particulate nitrogen (PN) and phosphorus (PP) concentrations were compared to local water quality guidelines for the Mackay-Whitsunday Water Quality Improvement Plan (Folker et al. 2014; Drewry et al. 2008), the Water Quality Guidelines for the Great Barrier Marine Park Authority (GBRMPA, 2010) and the Queensland Water Quality Guidelines (DEHP, 2013). Particulate nitrogen concentrations continue to exceed the guidelines, and were generally higher during the 2018/2019 monitoring period in comparison to previous reporting periods (Figure 3.7a). Despite high concentrations during certain months, PN is generally similar across all sites (Figure 3.7b).

High concentrations of PN might be associated with the contribution from local land use activities, and with this year's rainfall extending into July 2019, there would be still some base flow from rivers potentially contributing nutrient loadings to this coastal region (Brodie et al. 2012; Kroon et al. 2012; Schaffelke et al. 2012; Logan et al. 2014). In addition, other sources of the nutrients might be via remobilisation of coastal sediments, and release of available nutrients adsorbed to coastal sediments (Devlin et al. 2012). In addition, elevated nutrients might also be related to reprocessing of nutrients with algal blooms, where there has been an obvious *Trichodesmium* (a marine cyanobacteria; Capone et al. 1997) bloom across the region during most surveys, but most notably during late spring and early summer surveys. This pattern has been recorded for the past few years (Waltham et al., 2018).

Particulate phosphorus concentrations continue to be variable from survey to survey and site to site with no apparent seasonal pattern (Figure 3.8). October 2018, January 2019, and April 2019 showed the highest concentration of PP over the entire monitoring period, exceeding the Mackay-Whitsunday water quality objective values (Folker et al., 2014). AMB11 (Mackay Marina) and AMB2 (Hay Reef) showed the highest concentrations, which might related to local urban stormwater runoff (Figure 3.8b).

Chlorophyll-*a* concentrations were generally elevated above the guidelines, and were particularly high in January 2019 (Figure 3.9). This has been a trend since the program commenced over all five monitoring periods (2014-2019).

Relationships between nutrient levels (i.e. PN, PP, Chlorophyll-*a*, and Phaeophytin-*a*) across all sites and sampling periods were positive but weak (correlation coefficients (r) ranged between 0.11 – 0.4; Figure 3.10). Principal component analysis was used to further explore patterns in nutrient concentrations among sites. The PCA showed that most coastal sites have higher nutrient, chlorophyll-*a,* and phaeophytin-*a* levels in comparison to offshore sites (Figure 3.11). However, one exception is AMB5, which is an offshore site with relatively high nutrient, chlorophyll-*a*, and phaeophytin-*a* concentrations (Figure 3.11).

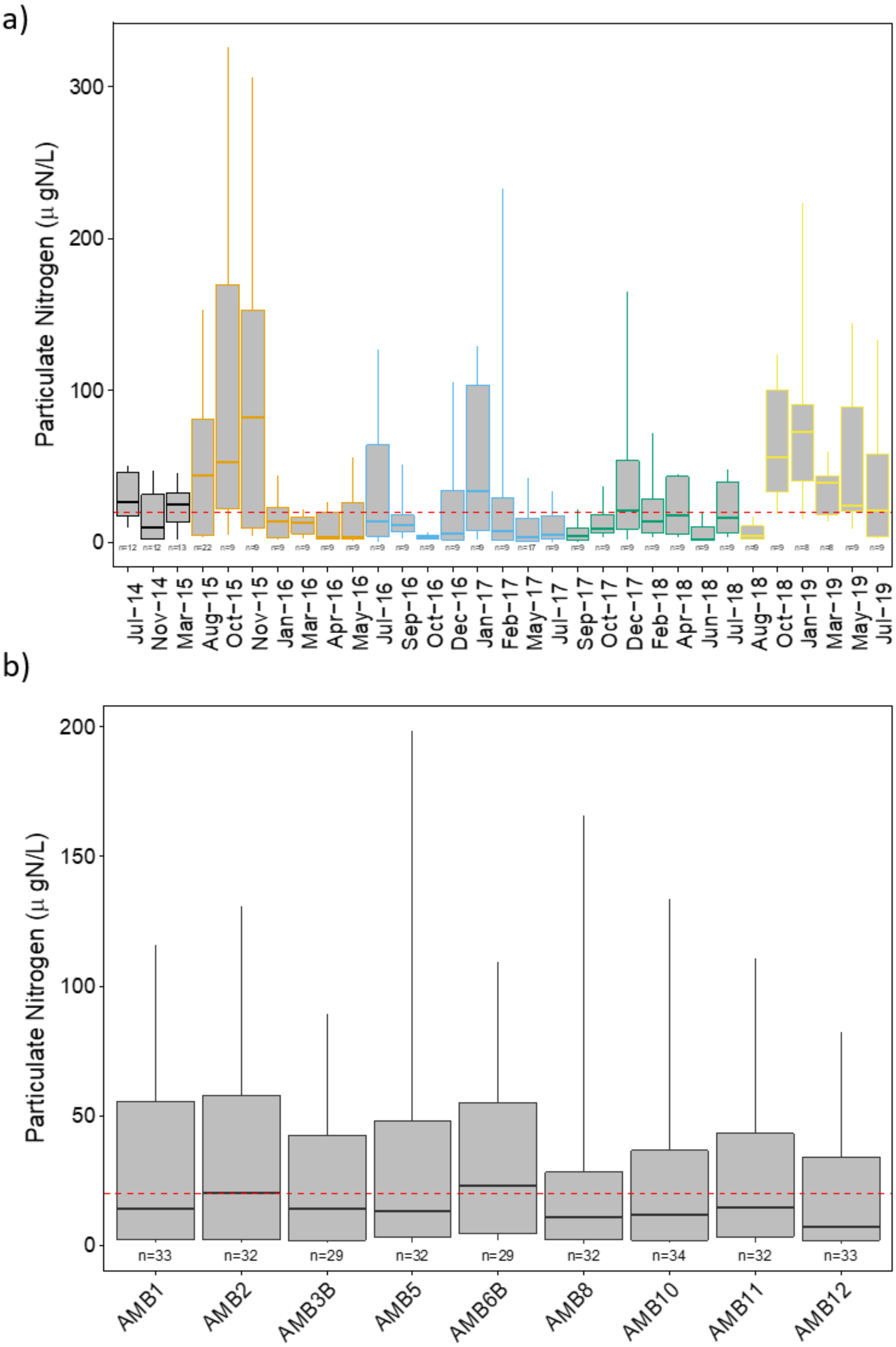


Figure 3.7 Particulate nitrogen box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) pooled at each site across all four sampling periods during 2014-2019

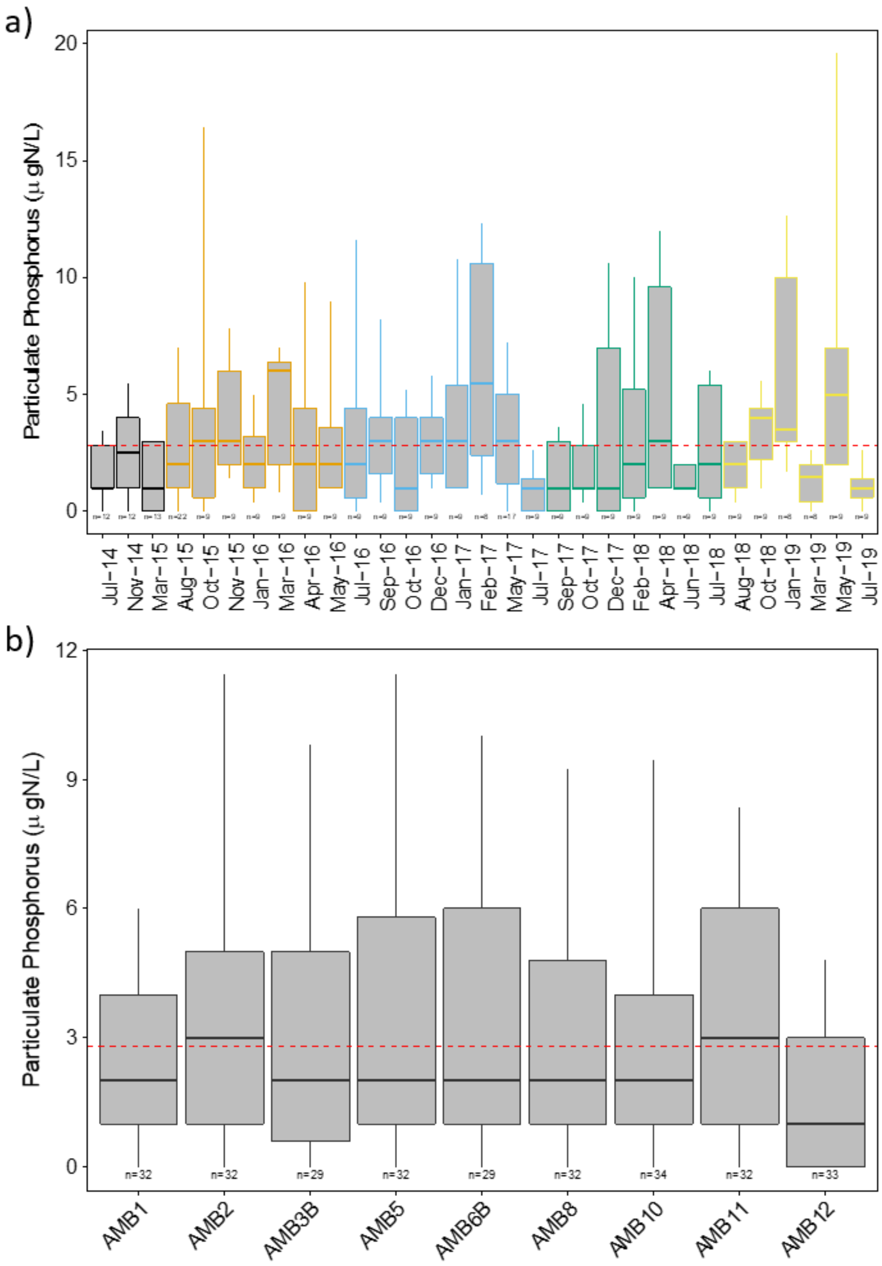


Figure 3.8 Particulate phosphorus box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) pooled at each site across all four sampling periods during 2014-2019

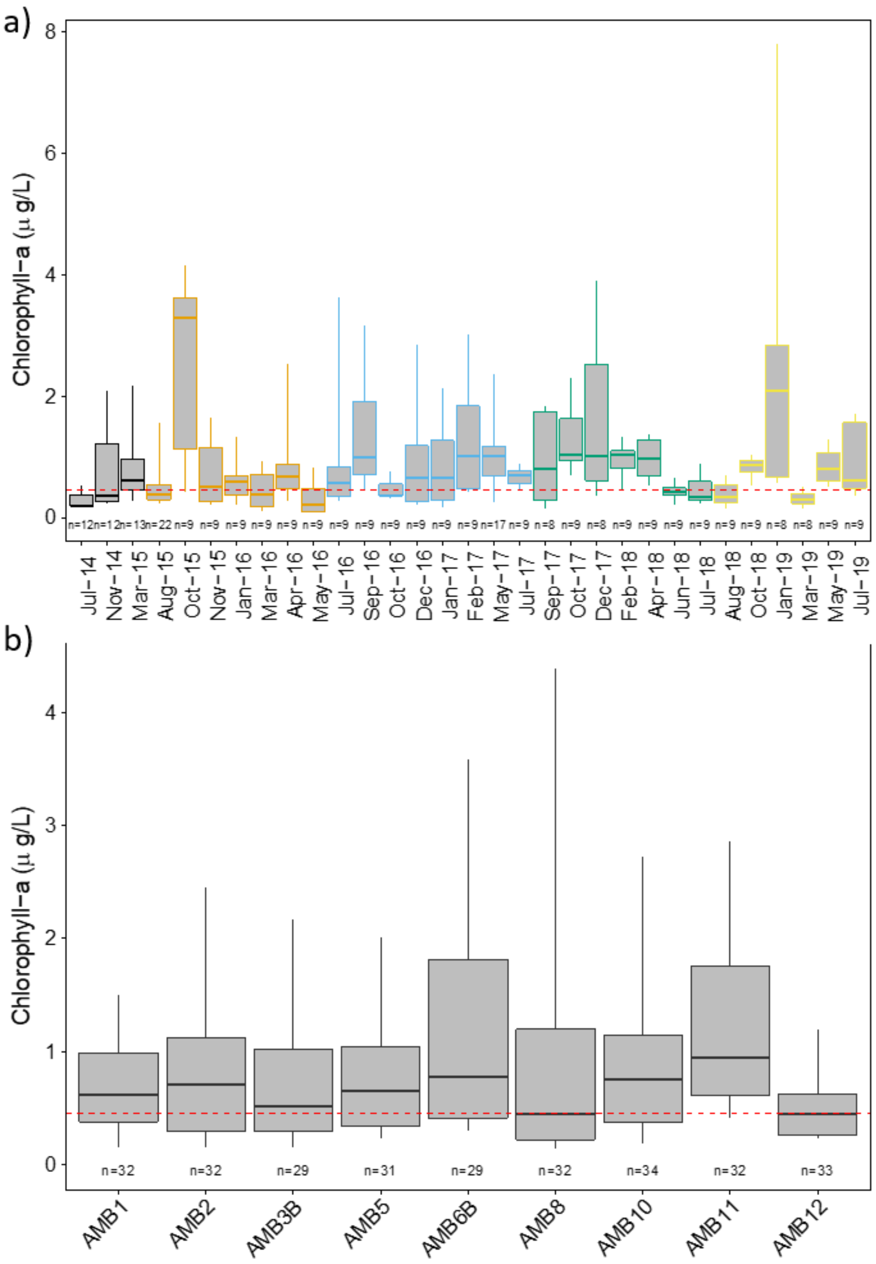


Figure 3.9 Chlorophyll-*a* box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017, green = 2017/2018, and yellow = 2018/2019; and (b) pooled at each site across all four sampling periods during 2014-2019

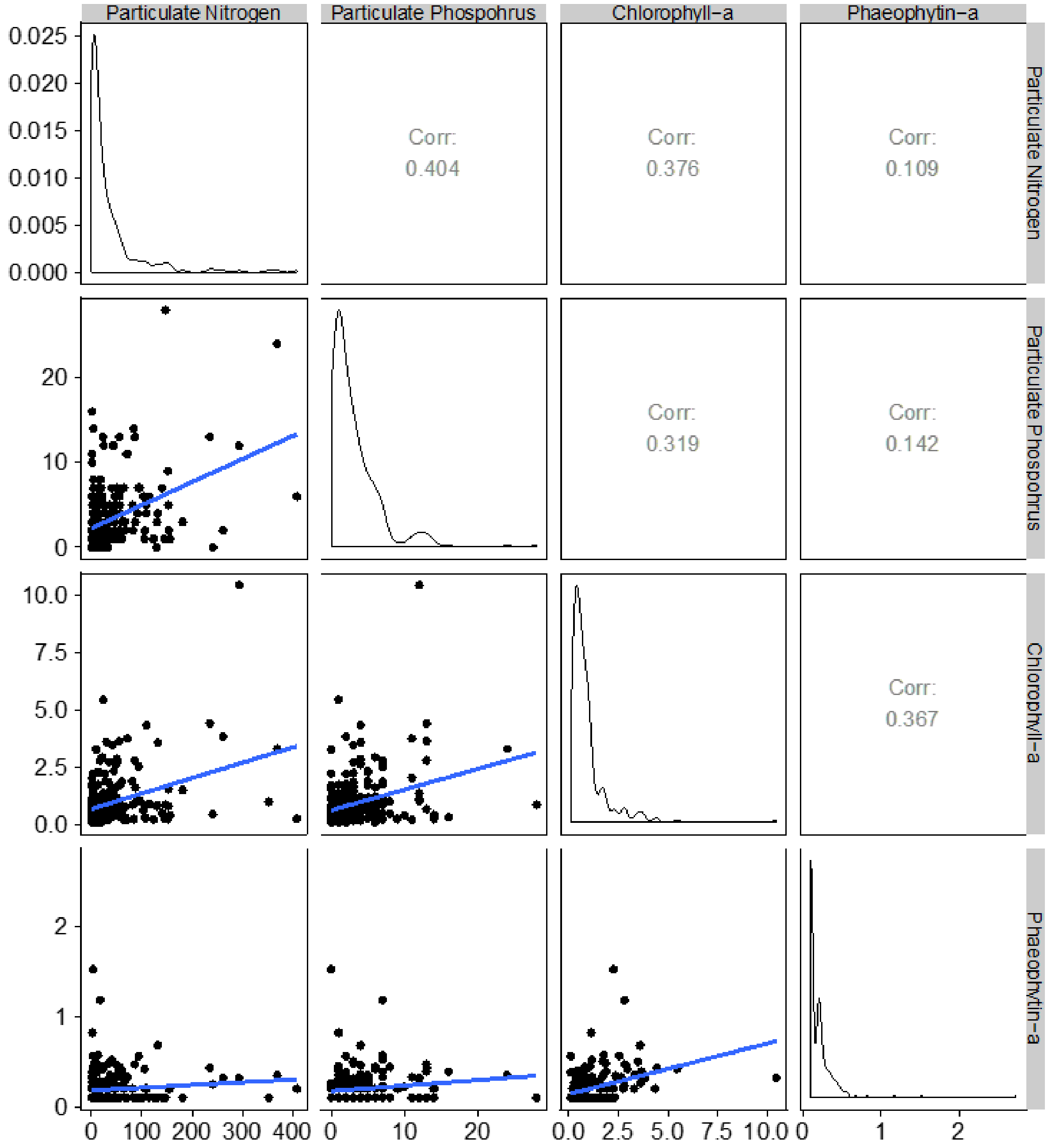


Figure 3.10 Scatterplot of nutrient relationships at pooled across all sites and surveys. Lines of best fit with 95 % confidence intervals are displayed in blue, and correlation coefficients are shown in corresponding plots. Density plots show log-normal distribution of the data, and therefore non-parametric spearman correlation was used.

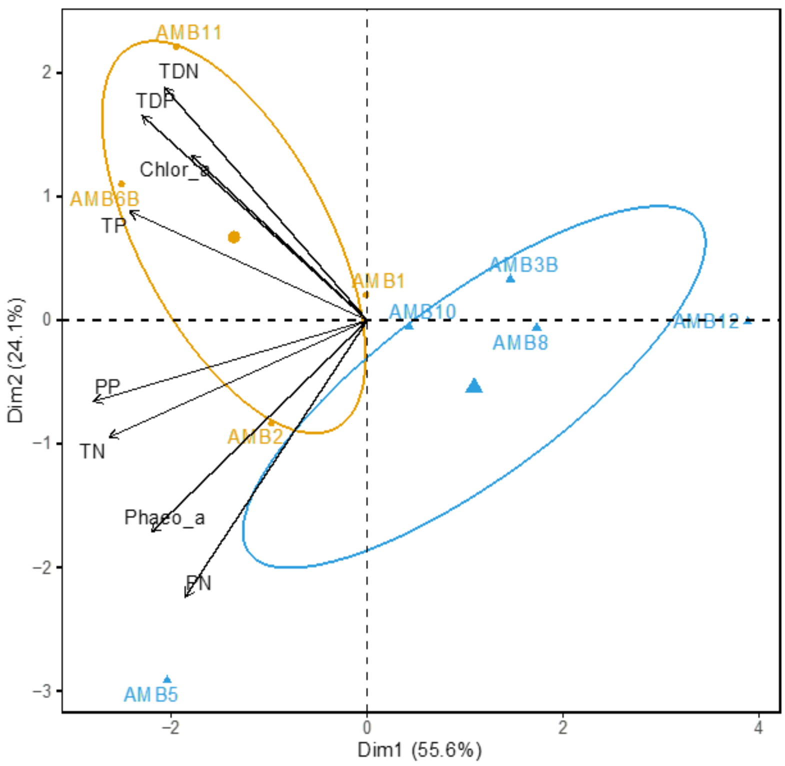


Figure 3.11 Principal components analysis (PCA) exploring relationships between nutrients (black vectors) and sites (blue = offshore, orange = coastal) across all monitoring periods throughout 2014-2019. The 95% confidence interval ellipses show differences between offshore and coastal sites. Nutrient labels are abbreviated as follows: PP = Particulate Phosphorus, PN = Particulate Nitrogen, TP = Total Phosphorus, TN = Total Nitrogen, TDP = Total Dissolved Phosphorus, TDN = Total Dissolved Nitrogen, Chlor_a = Chlorophyll-*a*, Phaeo_a = Phaeophytin-*a*. Total variance explained by PC1 and PC2 = 79.7 %.

3.1.3 Ultra-trace water heavy metals

Ultra-trace heavy metal concentrations were compared to the ANZECC and ARMCANZ 2000 water quality guidelines (ANZECC, 2000). Copper concentrations exceeded ANZECC 95 % protection guideline values at MKY_AMB2 in March 2019. All other metals in the ultra-trace suite were present at concentrations lower than guideline values, and/or lower than analytical detection limits (Table 3.1). No ANZECC guideline has been established for arsenic. Arsenic is released into the environment naturally by weathering of arsenic-containing rocks and volcanic activity. It can be in the form of As (III) or As (V), which can be toxic to marine aquatic life. A low reliability marine guideline trigger value of 4.5 µg L^{-1} for As (V) and 2.3 µg L^{-1} for As (III) has been derived (ANZECC, 2000), however, these trigger guidelines are only an indicative interim working level. Measured concentrations seem to be below these low reliability guidelines.

Table 3.1 Summary statistics for filterable metals recorded at all sites during the program. Values are pooled across sites. Values are compared to the ANZECC 95% protection guideline values (2000). (-) sample not collected

		Arsenic	Cadmium	Copper	Lead	Nickel	Silver	Zinc	Mercury
	Unit	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	mg/L
	LOR	-	0.2	1	0.2	0.5	0.1	5	0.001
	ANZECC	-	5.5	1.3	4.4	70	1.4	15	0.4
Jul-14	Mean	1.5	<0.2	<1	0.3	<0.5	<0.1	<5	<0.0001
	Min	1.3	<0.2	<1	0.2	<0.5	<0.1	<5	<0.0001
	Max	1.6	<0.2	2	0.3	<0.5	<0.1	<5	<0.0001
Nov-14	Mean	1.3	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	0.8	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.5	<0.2	1	<0.2	<0.5	<0.1	<5	<0.0001
Mar-15	Mean	1.7	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.9	<0.2	2	<0.2	<0.5	<0.1	<5	<0.0001
Aug-15	Mean	1.2	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.1	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.3	<0.2	1	<0.2	<0.5	<0.1	<5	<0.0001
Nov-15	Mean	1.7	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.9	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
Mar-16	Mean	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.7	<0.2	1	<0.2	<0.5	<0.1	<5	<0.0001
Dec-16	Mean	1.7	<0.2	<1	<0.2	<0.5	3.3	<5	<0.0001
	Min	1.6	<0.2	<1	<0.2	<0.5	2.6	<5	<0.0001
	Max	1.9	<0.2	<1	<0.2	0.6	5.2	<5	<0.0001
May-17	Mean	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.4	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.8	<0.2	<1	<0.2	0.7	<0.1	<5	<0.0001
Apr-18	Mean	1.8	<0.2	<1	<0.2	<0.5	<0.1	5	<0.0001
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	2	<0.2	<1	<0.2	0.5	<0.1	7	<0.0001
Aug-18	Mean	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.2	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	1.8	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
Mar-19	Mean	1.8	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Min	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	2	<0.2	3	0.4	<0.5	<0.1	<5	<0.0001
Overall	Mean	1.6	<0.2	<1	<0.2	0.6	0.3	<5	<0.0001
	Min	0.8	<0.2	<1	<0.2	<0.5	<0.1	<5	<0.0001
	Max	2	<0.2	3	0.4	0.7	5.2	7	<0.0001

3.1.4 Water pesticides and herbicides

The major pesticides and herbicides were not detected at concentrations above reporting limits (Table 3.2). Where possible, these concentrations were compared to the water quality improvement guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) and all detected concentrations were well below the 95% protection values. The Mackay-Whitsunday Water Quality Improvement Plan's water quality objectives (2014), however, use a region wide guideline of 0.01 µg L^{-1} (LOD unchanged since 2008). During this reporting period, Hexaninone, Diuron and Atrazine were again detected, and probably represent pollution from catchments in the local area, which land use is predominately sugar cane (Lewis et al., 2009). Similar to the first year of reporting (Waltham et al. 2015), it should be noted that although all detected pesticide levels were below 95 % protection guidelines, the period of study is focused on post wet and late dry season conditions.

Table 3.2 Summary (average) statistics for pesticides/herbicides recorded at all sites during the program (all values are µg L^{-1}). Values are pooled across sites for each survey and compared to the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) 95 % protection level. Mackay-Whitsunday Water Quality Improvement Plan 2014-2021 Water Quality Objectives (WQO's) are also included to assess tracking

Survey	Guideline	Atrazine	Ametyn	Diuron	Hexazinone	Tebutryn
	GBRMPA (2010)	1.4	1.0	1.6	1.2	-
	WQO (WQIP 2014)	0.01	0.01	0.01	0.01	0.01
July 2014		0.0006	<0.0004	0.0069	0.0005	0.0009
March 2015		0.0004	<0.0002	0.0045	0.0003	<0.0002
November 2015		0.0004	0.0002	0.0097	0.003	<0.0002
March 2016		<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
December 2016		0.0003	<0.0002	0.0002	0.0003	<0.0002
May 2017		0.0002	<0.0002	<0.0002	0.0005	<0.0002
April 2018		0.0007	<0.0002	0.004	0.0013	0.0001
August 2018		<0.0002	<0.0002	0.0015	0.0005	0.0001
March 2019		0.0036	<0.0002	0.0099	0.0026	0.0001

3.1.5 Ordination of data

Principal components analysis (PCA) was used to explore relationships between physiochemical and nutrient data collected at the water surface at each site during each sampling campaign. Results indicate that 37.9 % of the variability among sites and sampling campaigns are explained by the physiochemical and nutrient variables (Figure 3.12). Electrical conductivity (EC) and pH are negatively correlated with dissolved oxygen (DO), and these parameters show inter-annual (Figure 3.12a) and seasonal differences among sites (Figure 3.10B). Alternatively, particulate nutrients (PN and PP) and chlorophyll-*a* are all correlated with the first principal component that explains the most variability (Dim1, 24.8 %), with the highest values of these parameters occurring typically in 2015 and 2019 (Figure 3.12b). Higher temperatures are also associated with wet season (Figure 3.12b).

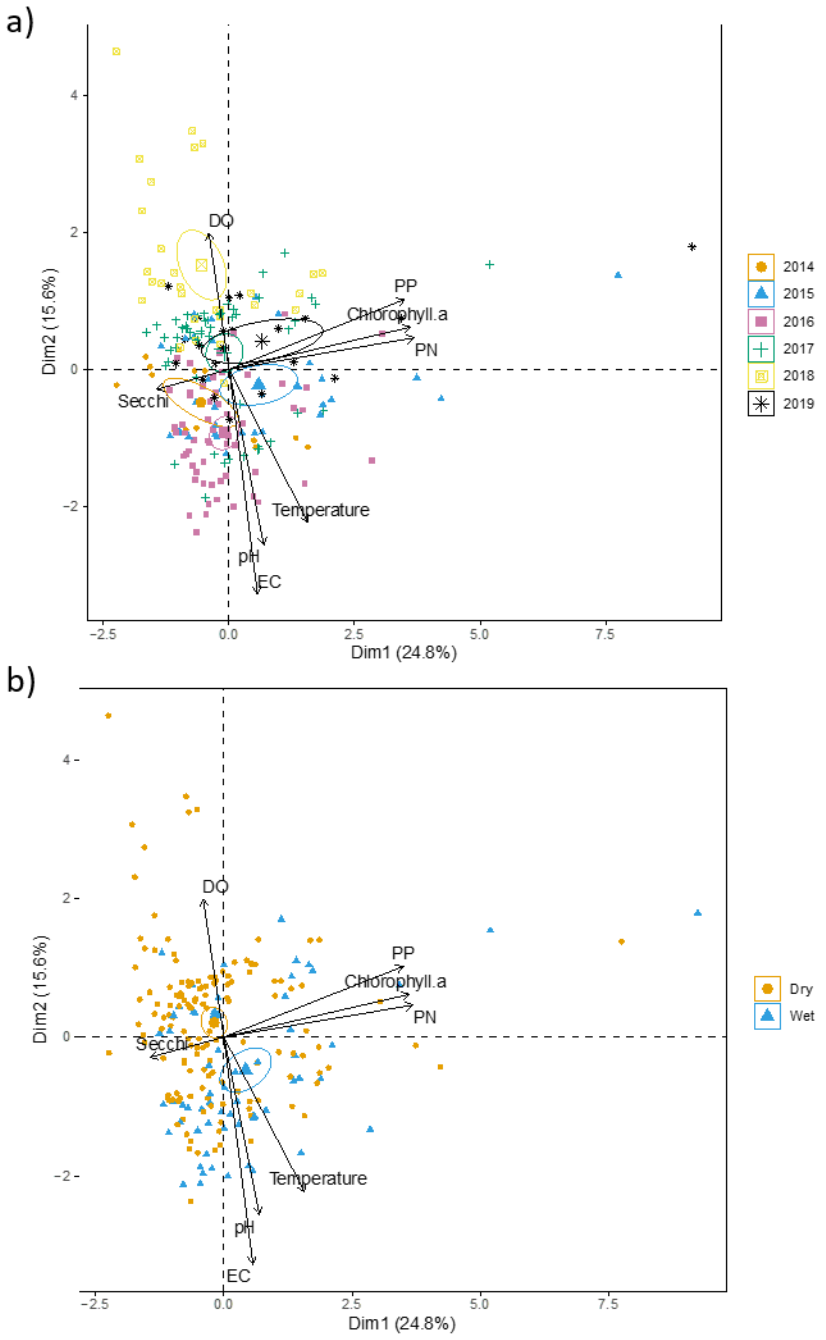


Figure 3.12 Principal components analysis (PCA) exploring relationships between nutrients and physiochemical parameters (black vectors) and monitoring sites. The 95 % confidence interval ellipses show overall differences between: A) sites grouped by year and B) sites grouped by season. Vector labels are abbreviated as follows: PP = Particulate Phosphorus, PN = Particulate Nitrogen, EC = Electrical Conductivity, and DO = Dissolved Oxygen. Total variance explained by Dimension 1 and Dimension 2 = 40.4 %

3.2 Plankton communities

3.2.1 Diversity and abundance

A total of 91 phytoplankton species have been identified, comprising cyanobacteria, diatoms, flagellates and green algae taxa. Several species were recorded at all sites, including *Azpeitia* spp, *Bacillaria* spp, *Bacteriastrum* spp, *Bellerochea* spp, *Rhizosolenia* spp, *Chaetoceros* spp, *Chaetoceros* *simplex*, *Ceratium* spp, *Eucampia* spp, *Guinardia* spp, *Hillea* spp, *Odontella sinesis*, *Pleurosigma* spp, and *Navicula* spp. Dudgeon reef (AMB6B) had the highest phytoplankton species richness in February 2018 (29 species), while Freshwater point (AMB1) had the lowest species richness in September 2017 (4 species) (Figure 3.13a). The large increases in phytoplankton abundance at Victor Islet (AMB10), Slade Island (AMB5) and Round Top Island (AMB3B) in September 2017 were driven primarily by *Trichodesmium* spp, which have not been identified to such abundance since (Figure 3.13b).

A total of 54 different species of zooplankton were recorded during all surveys. Several species were recorded at all sites, including Acartia pacifica, Calanopia elliptica, Dictocysta spp., Echinoidea, Flaccisagitta enflata, Favella serrata, Gammaridea, Gastropoda, fish larvae and eggs, Lucifer penicillifer, Oikopleura diocia, and Siphonophorae. Dudgeon reef (AMB6B) had the highest diversity of zooplankton species in November 2015 (19 species), while Round Top Island (AMB3B) had the lowest zooplankton species diversity (3 species) in July 2019 (Figure 3.14a). The total abundance of zooplankton peaked at different times of the year at each site, and was highest at Dudgeon reef (AMB6B) in April 2016 (Figure 3.14b).

Overall, the species composition of phytoplankton and zooplankton communities differed primarily between years (Figure 3.15 & Figure 3.16). In particular, the species composition of plankton communities were distinct in 2015 and 2016, while phytoplankton species composition was similar across surveys conducted in 2017-2019 (Figure 3.15). For zooplankton, species composition in 2017 was distinct from highly similar communities in 2018 and 2019 (Figure 3.16).

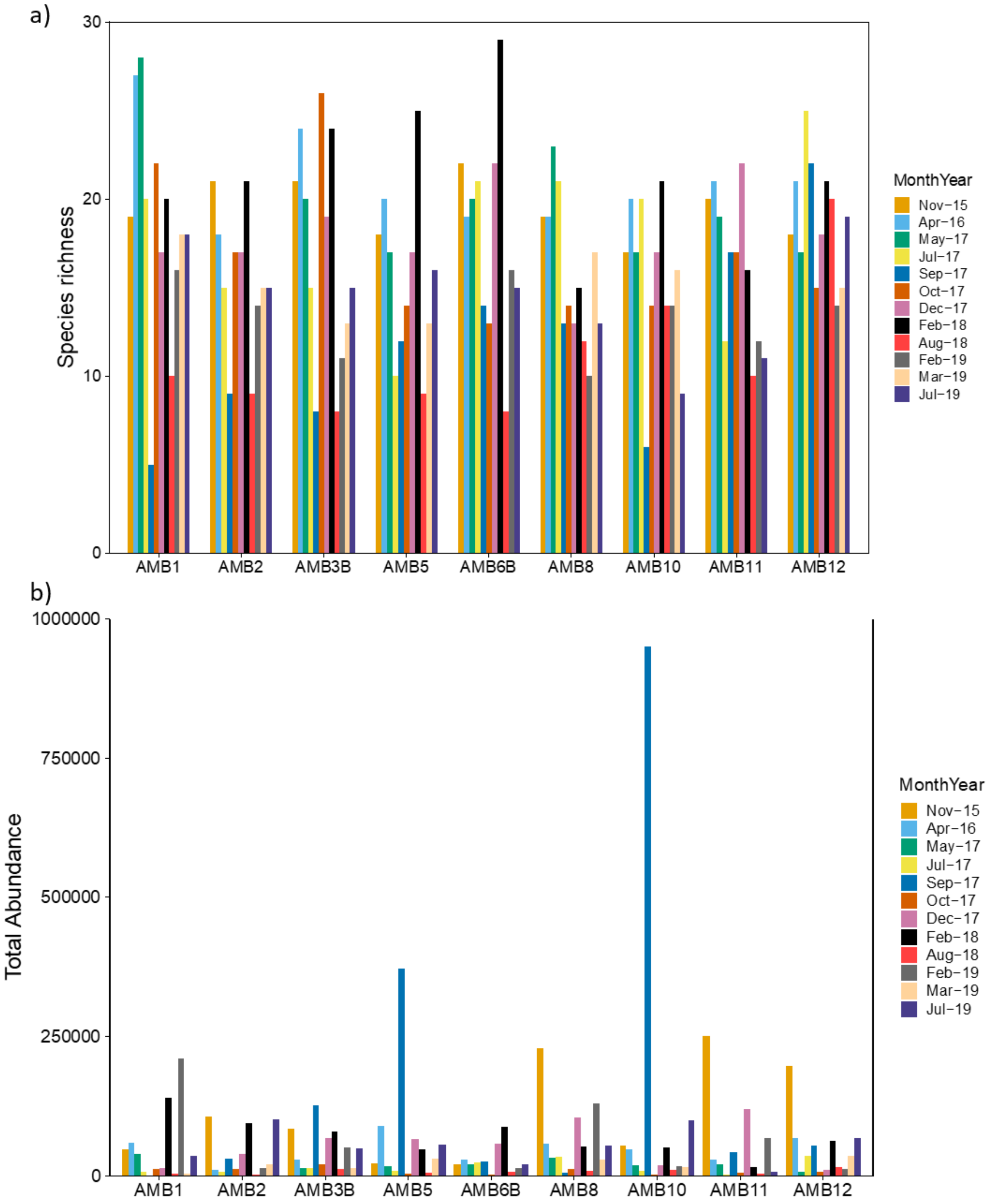


Figure 3.13 a) Species richness of phytoplankton; and b) total abundance of phytoplankton at each site for each survey

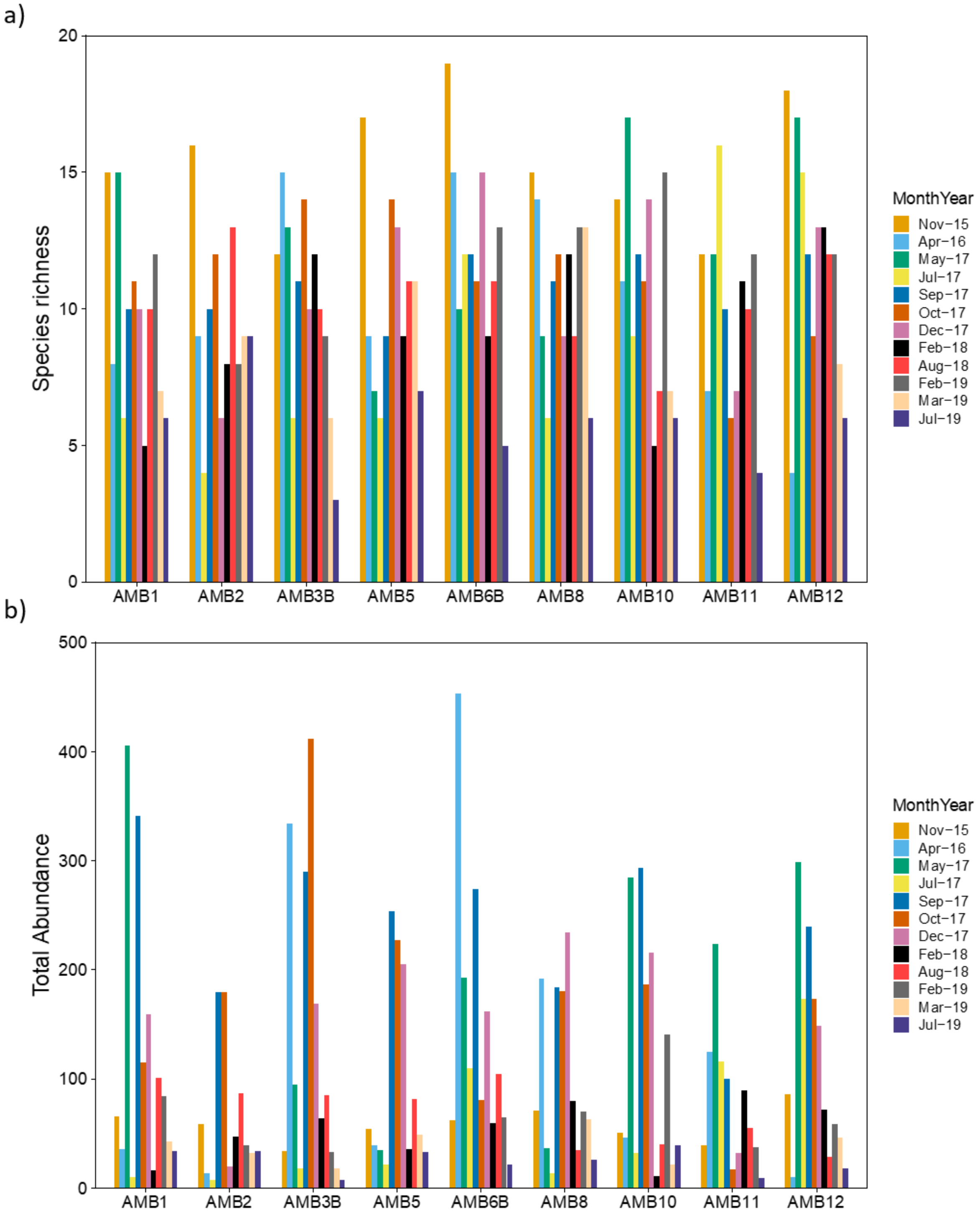


Figure 3.14 a) Species richness of zooplankton and b) total abundance of zooplankton at each site for each survey

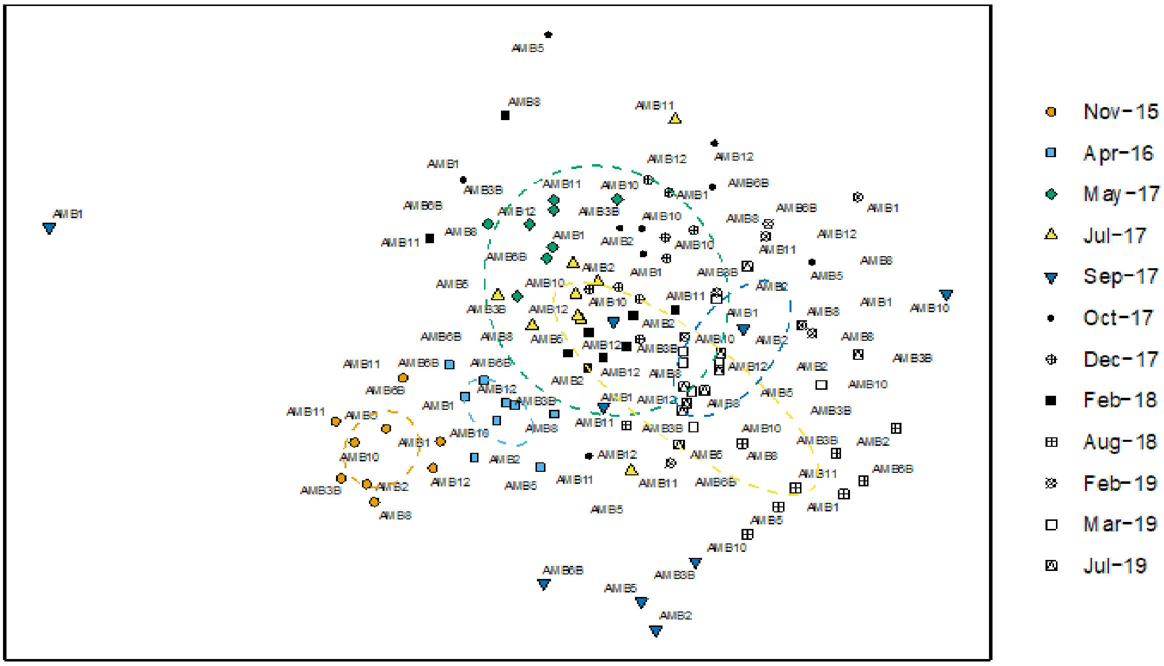


Figure 3.15 Non-dimensional ordination plot for phytoplankton collected during six survey periods throughout 2015-2019. Dashed lines represent 95 % confidence interval ellipses for each year: orange = 2015, light blue = 2016, green = 2017, yellow = 2018, and dark blue = 2019. Data has been squared root transformed on the Bray Curtis distance matrix (2D stress = 0.25)

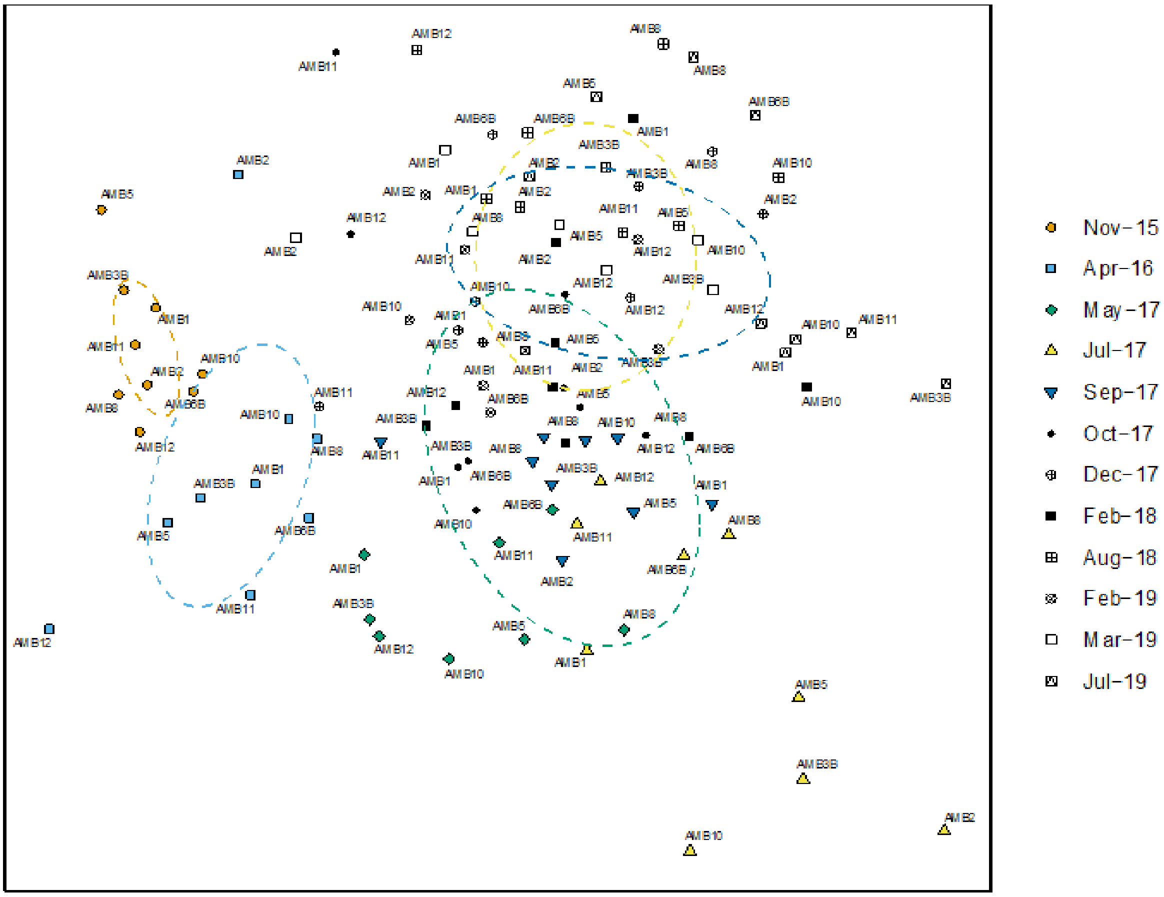


Figure 3.16 Non-dimensional ordination plot for zooplankton collected during six survey periods throughout 2015-2019. Dashed lines represent 95 % confidence interval ellipses for each year: orange = 2015, light blue = 2016, green = 2017, yellow = 2018, and dark blue = 2019. Data has been squared root transformed on the Bray Curtis distance matrix (2D stress = 0.25)

3.3 Multiparameter water quality logger

Instruments were deployed at seven sites from July 2018 to July 2019 (Table 1.1). Using standard statistics, we describe observed trends and differences between sites and discuss the driving forces in these environments. Several loggers were not retrieved or flooded leading gaps in the data, including Sept - Jan at Spoil grounds, Oct - Jan at Slade, and Oct - Jan and May - June at Hay Reef.

Data is presented as an annual statistical summary of root mean square water height (RMS; m), suspended sediment concentration (SSC; mg L^{-1}), sediment deposition rate (mg cm^{-2} day^{-1}), water temperature (°C), and photosynthetically available radiation (PAR; mol m^{-2} day^{-1}) for each site. The summary is depicted using box plots, whereby the central diamonds represent the mean value, the central line represents the median value, and the central box represents the range of the 25 and 75 % quartiles. The vertical bars represent the range of the 90th and 10th percentiles. Time series and monthly summaries are included in the appendices.

3.3.1 RMS water height

AMB12 had lower RMS values than all other sites with a median of less than 0.01 m and the lowest variance in RMS values (Figure 3.17, Table 3.3). These results are due to the site being positioned in the lee of Keswick and St Bees Islands that shelter it from wind and waves. AMB2 and AMB3 have median RMS ≤0.02; AMB1, AMB8, and AMB10 have median RMS ≤0.03; AMB5 had the highest median RMS ≤0.05.

The RMS water height time series shows that large peaks occur at the same time across multiple sites throughout the year (Appendix A2). These synchronised peaks are due to weather driven wave events being the strongest driver of wave shear stress on the ocean floor. Differences in RMS among sites is due to variations in site exposure and water depth. The monthly summaries indicated that RMS was typically highest in December-February (Appendix A3).

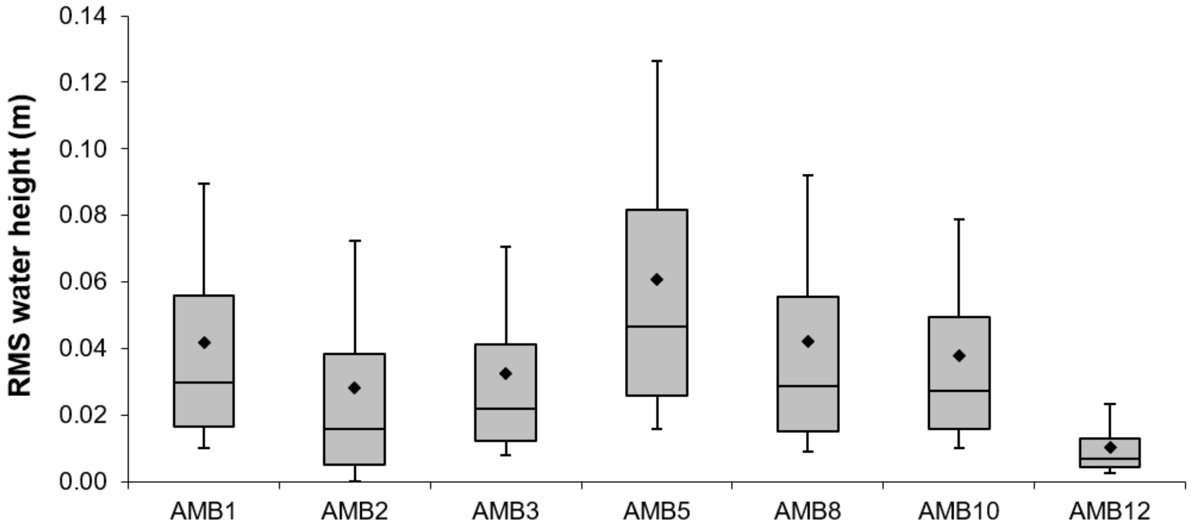


Figure 3.17 Box plot of root mean square (RMS) of water height (m) from July 2018 to July 2019. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamonds represent the mean values.

Table 3.3 Summary of RMS water height (m) from July 2018 to July 2019.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil ground	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	0.042	0.028	0.033	0.061	0.042	0.038	0.010
Median	0.030	0.016	0.022	0.046	0.029	0.027	0.007
Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower quartile	0.016	0.005	0.012	0.026	0.015	0.016	0.004
Upper quartile	0.056	0.038	0.041	0.082	0.055	0.049	0.013
Maximum	0.388	3.853	0.375	0.639	3.338	0.378	0.166
90th percentile	0.090	0.072	0.071	0.126	0.092	0.079	0.023
10th percentile	0.010	0.000	0.008	0.016	0.009	0.010	0.002
n	51234	27470	52644	32146	23648	52399	52686
St. Dev	0.037	0.042	0.032	0.049	0.046	0.032	0.011
St. Error	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

3.3.2 NTUe/SSC

The NTUe/SSC time series data at each site follows a typical pattern of low background values with recurring peak events (Appendix A2). These peak events occurred at the same times at each site and often coincide with peaks in RMS water height. Peaks in SSC occurred throughout the year (Appendix A3). This is a typical pattern as identified in past reports and is similar to data collected in coastal locations in north Queensland (Ridd et al., 2001). Differences in SSC between sites result from differences in RMS water height, site depth, benthic geology, hydrodynamics and proximity to river mouths. High variance in NTUe/SSC is the result of large spikes in suspended sediment driven by the re-suspension of sediment due to weather driven wave events.

AMB3 and AMB12 had median SSC values below 1 mg L^{-1} and the least variance in SSC (Figure 3.18, Table 3.4). Several factors contribute to low SSC at AMB3, including that the site is sheltered from trade south east weather systems which could result in less re-suspension of sediments by wave energy and that the coarse sediment at this site is not resuspended easily. AMB1, AMB2, AMB5, and AMB10 had higher median SSC (2 - 7 mg L^{-1}). These sites are closer to the coast and are likely affected by coastal currents moving across shallow areas with high resuspension rates (Macdonald et al. 2013).

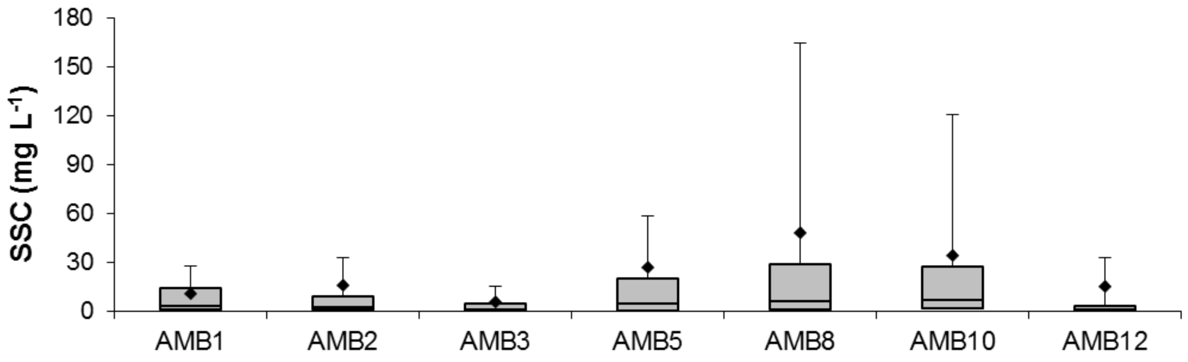


Figure 3.18 Box plot of suspended sediment concentration (SSC; mg L^{-1}) from July 2018 to July 2019. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.4 Summary of suspended sediment concentration (mg L^{-1}) from July 2018 to July 2019.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil ground	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	10.66	16.05	5.62	26.71	48.02	34.01	14.92
Median	2.97	2.02	0.90	4.22	5.87	6.71	0.78
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lower quartile	0.70	0.62	0.25	0.33	1.09	1.80	0.23
Upper quartile	14.09	8.59	4.62	19.48	28.33	27.01	2.71
Maximum	270.09	2624.75	490.17	2677.49	1138.00	646.23	1148.58
90th percentile	27.81	32.98	15.27	58.57	164.80	120.96	32.87
10th percentile	0.00	0.16	0.00	0.00	0.43	0.60	0.00
n	43094	23500	21109	26561	29421	37756	42506
St. Dev	18.98	79.00	18.43	113.48	107.10	67.38	52.10
St. Error	0.09	0.52	0.13	0.70	0.62	0.35	0.25

3.3.3 Deposition

Deposition of sediment is a natural process in all coastal marine waters. Suspended sediment deposits in environments where wave energy is not sufficient to keep sediment suspended in the water column.

The time series of deposition rates indicate that deposition peaks following RMS events but with a lag so that peak deposition occurs when RMS has decreased to near background levels (Appendix A2). An explanation for this lag is that as waves resuspend sediment, little deposition occurs because the energy in the system keeps sediment in suspension. However, when waves decrease and there is no longer enough energy in the system to keep sediment in suspension, deposition occurs.

Management of marine habitats requires that sediment deposition be monitored for changes from ambient values. The Water Quality Guidelines for the Great Barrier Reef Marine Park (2010) set a sediment deposition trigger value at a mean annual value of 3 mg cm^{-2} day^{-1} and a daily maximum of 15 mg cm^{-2} day^{-1}. However, the Guidelines suggest that 10 mg cm^{-2} day^{-1} sedimentation is valid in areas of coarse sediment, large grainsize, or low organic content.

AMB3 and AMB5 had the highest median deposition rates while AMB10 and AMB12 had the lowest deposition rates (Figure 3.19, Table 3.5). There was a clear distinction among the upper quartiles whereby the upper quartiles were ≥21 mg cm^{-2} d^{-1} for AMB1, AMB2, AMB3, AMB5, and AMB8 compared to ≤11 mg cm^{-2} d^{-1} for AMB10 and AMB12. The most deposition occurred in March-April at several sites (Appendix A3).

Differences in deposition rates may be more easily visualised by estimating the thickness of the sediment deposited. For example, using the relationship between density, mass and volume; a median deposition value of 5 mg cm^{-2} day^{-1} is equivalent to a layer of sediment of thickness less than 35 µm, assuming a sediment density of 1.5 g cm^{-3}.

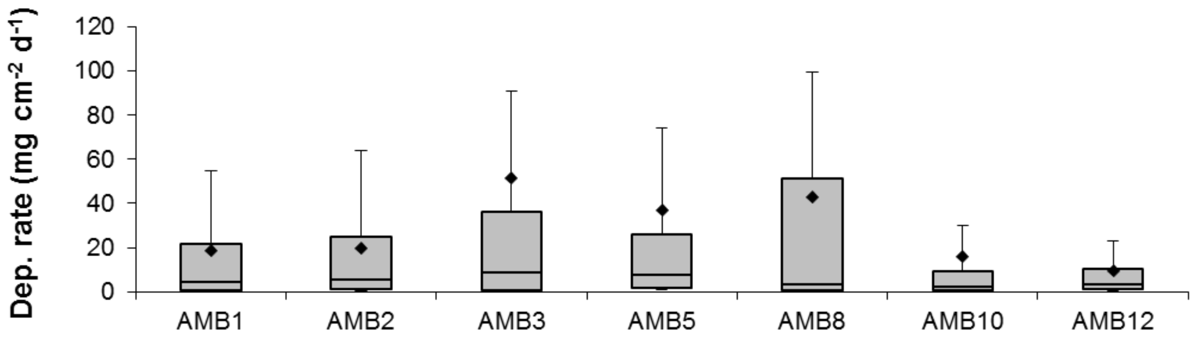


Figure 3.19 Box plot of two-hourly deposition rate (mg cm^{-2} day^{-1}) at the seven sites for the monitoring period a) July 2018 to July 2019, and b) from July 2017 to July 2018.

Table 3.5 Summary of the mean daily deposition rate (mg cm^{-2} day^{-1}) statistics from July 2018 to July 2019.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil ground	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	18.53	20.04	51.43	37.01	43.04	15.79	9.74
Median	4.65	5.64	8.68	7.52	3.44	2.34	3.66
Minimum	0.05	0.03	0.00	0.03	0.00	0.01	0.00
Lower quartile	0.85	1.13	0.90	1.84	0.55	0.66	1.33
Upper quartile	21.64	25.17	36.03	25.80	51.33	9.12	10.57
Maximum	223.47	148.43	1050.50	1250.19	475.86	792.79	172.91
90th percentile	54.71	63.66	90.71	74.05	149.79	30.08	23.27
10th percentile	0.23	0.27	0.25	0.86	0.13	0.20	0.50
n	238	176	347	230	206	279	344
St. Dev	30.16	29.58	139.99	114.79	78.13	61.43	18.60
St. Error	1.96	2.23	7.52	7.57	5.44	3.68	1.00

3.3.4 Water temperature

Water temperature was similar among all sites (Figure 3.20, Table 3.6). Mean monthly temperature peaked between December and March at approximately 28 °C (Appendix A3); a factor that was also observed in the field in-situ water temperature surveys. The lowest mean monthly temperatures were observed between May to July, where values dropped to 20 - 21 °C (Appendix A3). Decreases in temperature over short time periods match with increases in RMS water depth. Water temperature is generally not considered to be a compliance condition for approval operations, however the temperature data presented here holds importance in future interpretation of ecological processes in the region, and across the GBR (e.g. Johanson et al., 2015).

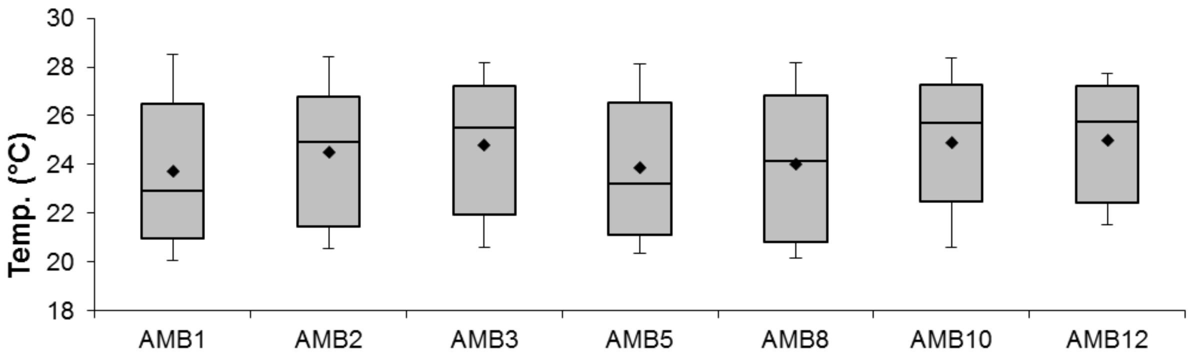


Figure 3.20 Box plot of the water temperature (°C) from July 2018 to July 2019. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.6 Summary of water temperature (°C) for the monitoring period from July 2018 to July 2019.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil ground	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	23.70	24.49	24.79	23.87	23.99	24.88	23.70
Median	22.90	24.94	25.50	23.21	24.12	25.70	22.90
Minimum	18.86	19.32	19.62	19.57	19.56	19.40	18.86
Lower quartile	20.97	21.44	21.93	21.08	20.83	22.49	20.97
Upper quartile	26.47	26.80	27.22	26.55	26.83	27.28	26.47
Maximum	29.92	31.66	29.70	29.30	28.93	34.55	29.92
90th percentile	28.52	28.40	28.17	28.15	28.16	28.35	28.52
10th percentile	20.04	20.56	20.59	20.36	20.17	20.57	20.04
n	37064	27444	52602	37160	30103	51124	37064
St. Dev	3.05	2.87	2.90	2.88	3.07	2.91	3.05
St. Error	0.02	0.02	0.01	0.01	0.02	0.01	0.02

3.3.5 Photosynthetically active radiation (PAR)

Benthic PAR was influenced by water depth, as the lowest PAR was measured at deepest site (AMB 8; Figure 3.21, Table 3.7). The highest median PAR was measured at AMB12, which is the farthest site from shore and also the site with the lowest SSC (Figure 3.18). Three sites had upper quartiles ≥2.8 mol m^{-2} d^{-1} (AMB3, AMB10, AMB12), indicating that 25 % of days at these sites had greater than 2.8 mol m^{-2} d^{-1}.

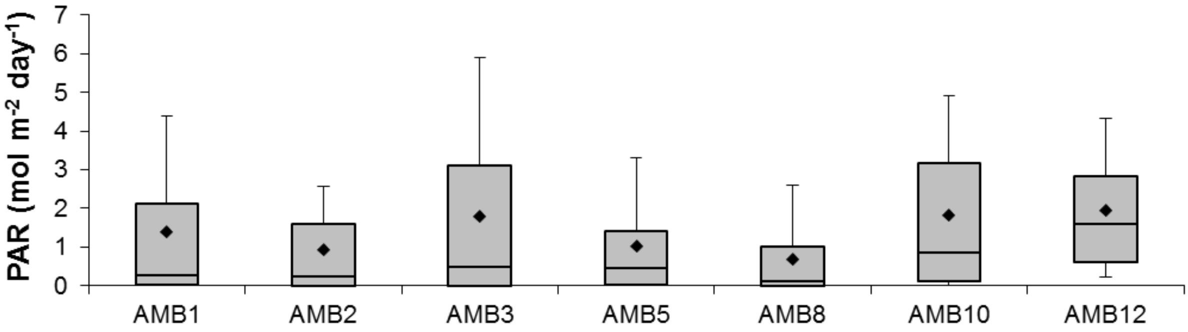


Figure 3.21 Box plot of PAR (mol m^{-2} day^{-1}) from July 2018 to July 2019. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.7 Summary of PAR (mol m^{-2} day^{-1}) from July 2018 to July 2019.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil ground	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	1.40	0.92	1.80	1.02	0.69	1.81	1.95
Median	0.26	0.25	0.50	0.44	0.12	0.86	1.58
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lower quartile	0.01	0.00	0.01	0.01	0.00	0.12	0.61
Upper quartile	2.12	1.61	3.11	1.42	1.01	3.17	2.82
Maximum	11.62	5.60	11.33	6.26	5.03	8.95	7.77
90th percentile	4.40	2.56	5.89	3.32	2.61	4.91	4.33
10th percentile	0.00	0.00	0.00	0.00	0.00	0.01	0.23
n	356	186	365	257	211	365	365
St. Dev	2.13	1.22	2.42	1.38	1.06	2.07	1.66
St. Error	0.11	0.09	0.13	0.09	0.07	0.11	0.09

Benthic PAR was highly variable throughout the year. For most sites, PAR was highest in July-September and in March during this reporting period (Figure 3.22). Semi-regular oscillations between low and high PAR were overridden by larger episodic events caused by storms or rainfall which occurred frequently during this reporting period (Figure 3.23).

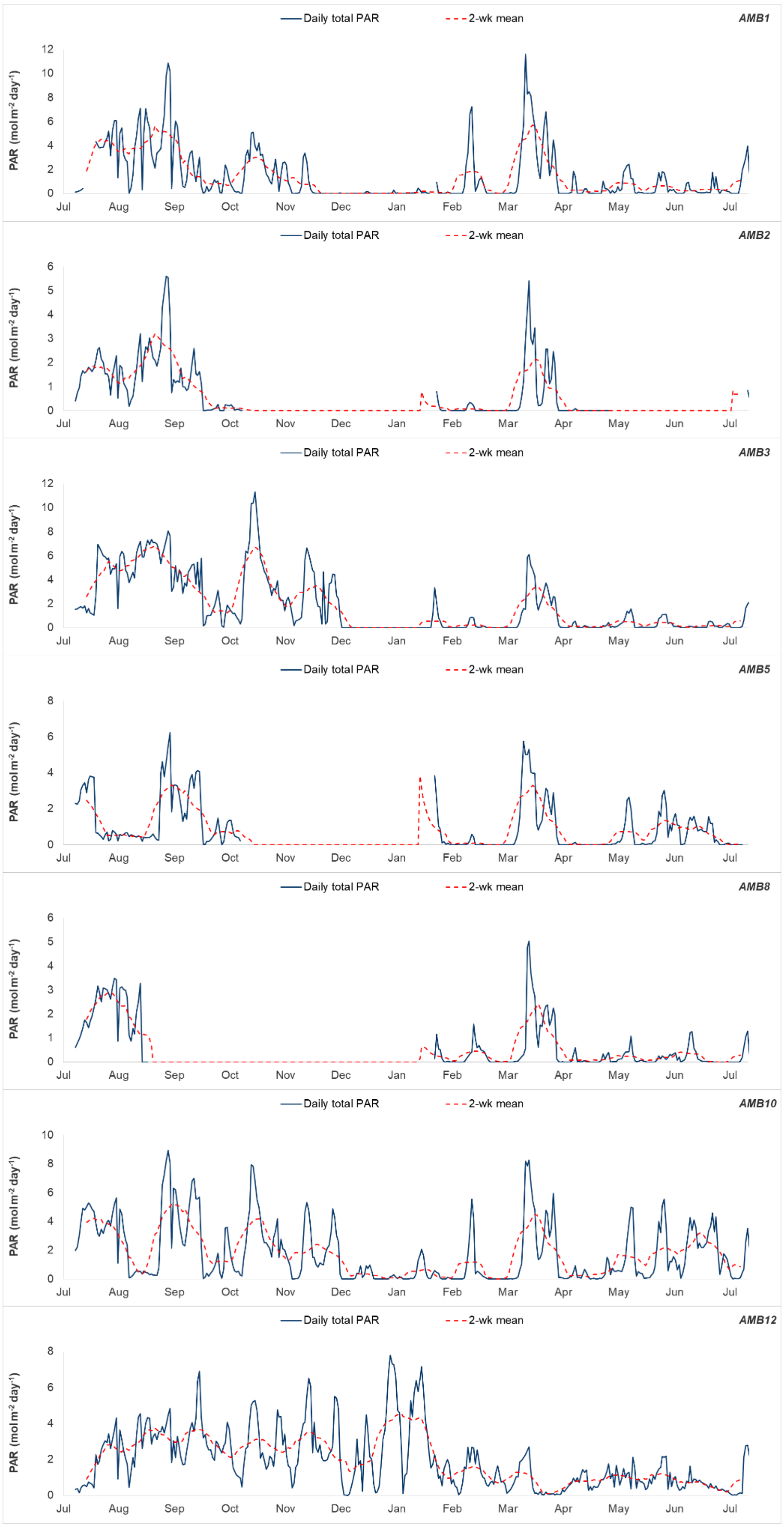


Figure 3.22 Time series of daily PAR (mol m^{-2} day^{-1}) from July 2018 to July 2019. Daily PAR is plotted in blue and a 2-week moving average of daily PAR is plotted in red.

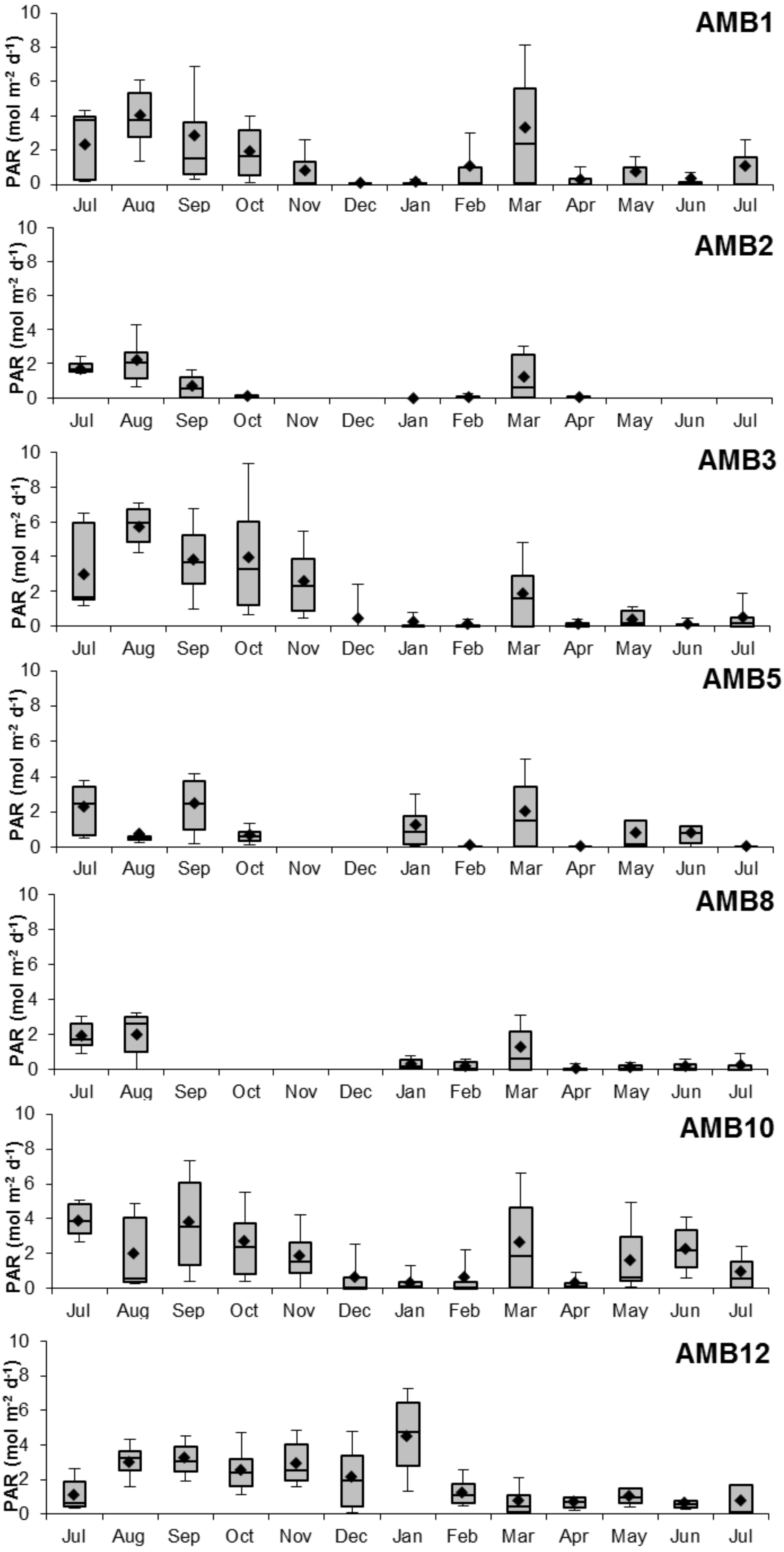


Figure 3.23 Monthly boxplots of total daily PAR (mol m^{-2} day^{-1}) from July 2018 to July 2019. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

3.3.6 Similarities in patterns of PAR among sites

There are moderate correlations ($R^2 > 0.5$) between the benthic PAR at 8 of 21 site pairwise comparisons (Figure 3.24). The strongest associations ($R^2 > 0.65$) were between AMB2 and AMB3, 2 and 8, 3 and 8, as well as 5 and 10. AMB12 was not correlated with any other of the sites. This analysis assists in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region.

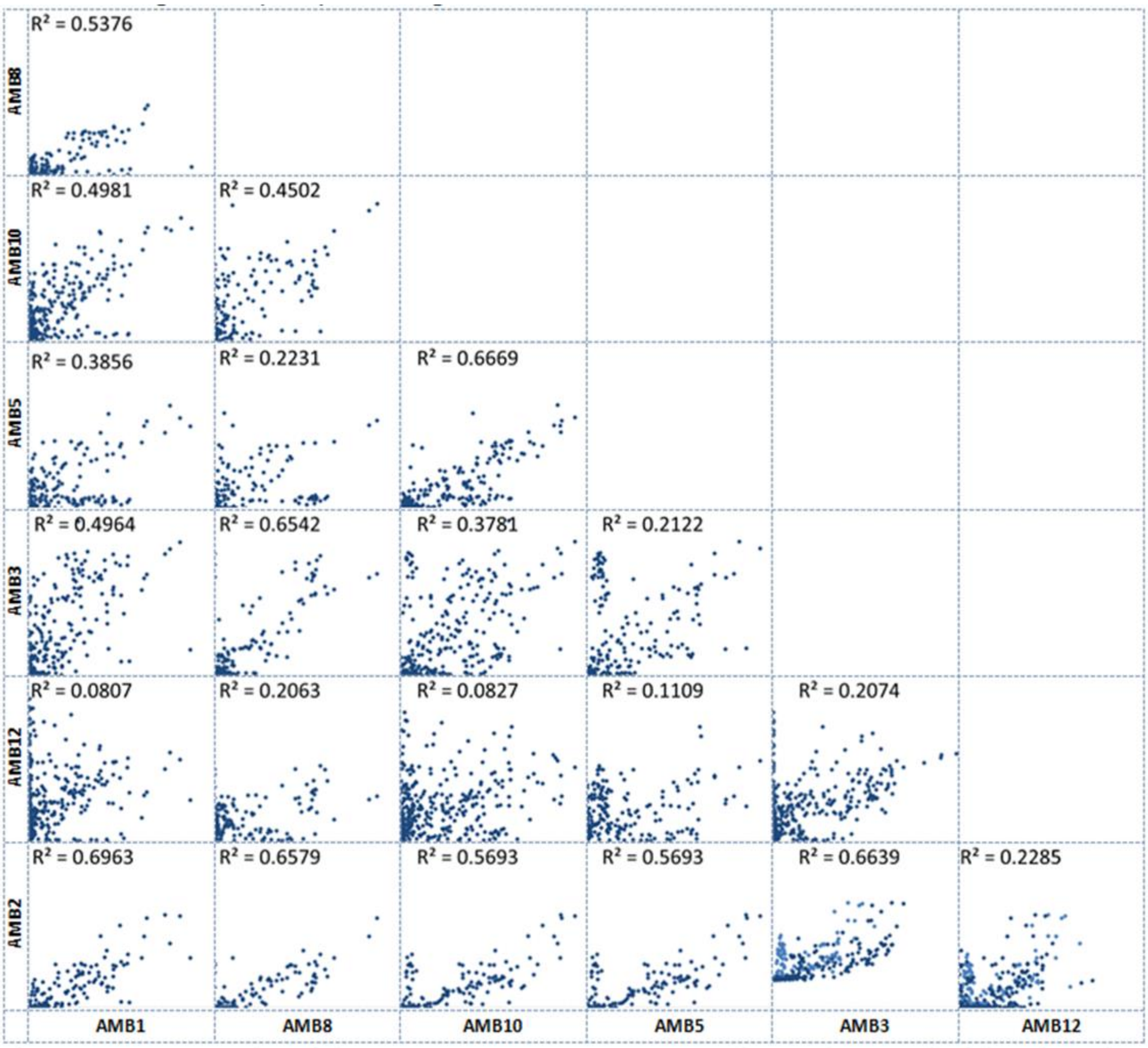


Figure 3.24 Scatterplots of the pairwise comparisons among sites indicating the strength of the relationships between patterns of daily PAR. R^2 values are presented for each comparison

3.3.7 Annual site comparison

Comparison of the data 2014-2019 provides a perspective of trends in the monitored environment. Weather can induce small variations between years, but consistent differences between sites suggest characteristic differences in aquatic environments.

RMS water height

RMS water height values are expected to change each year if there are changes to the locations where data was located or a change in weather events for the year. RMS values in 2018-2019 largely reflected the differences observed in previous years (Figure 3.25). Slight differences in RMS are most likely due to variation in weather between years.

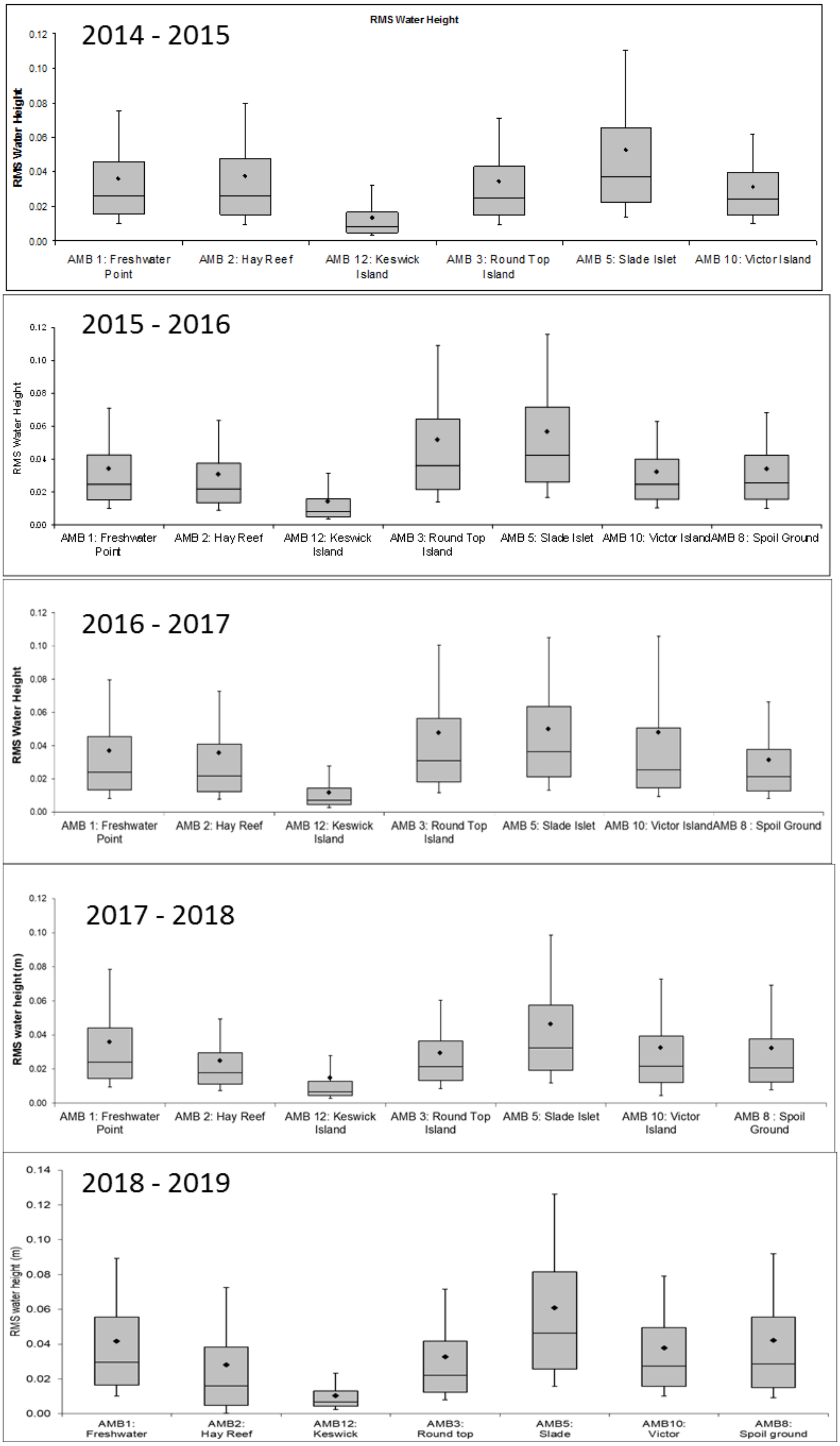


Figure 3.25 Annual summaries of RMS water height (m) from 2014-2019. Note that the y-axis scale is different for 2018-2019.

NTUe/SSC

Differences in SSC between sites are largely consistent between years (Figure 3.26). AMB12 and AMB3 consistently had the lowest SSC, while AMB1, AMB2, and AMB10 typically had high SSC. Large SSC events during later years, such as Tropical Cyclone Debbie in 2017, are likely causes for the increased variance compared to the 2014-2015 year.

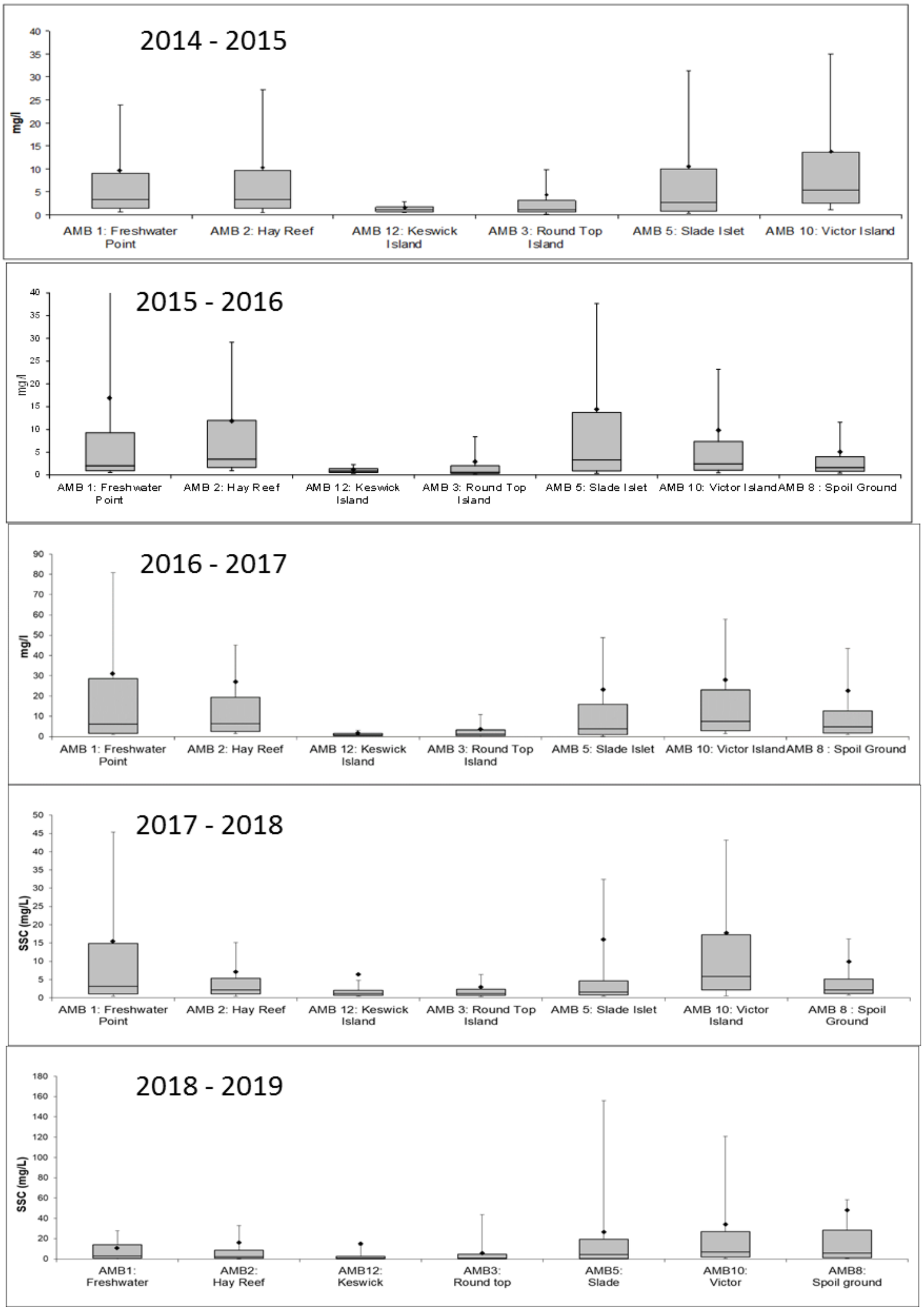


Figure 3.26 Annual summaries of suspended sediment concentration (SSC) from 2014-2019. Note that different scales are used between years.

Deposition rate

A similar pattern of deposition rates between sites occurred in 2018-2019 compared to previous years, although the upper quartiles were substantially higher (Figure 3.27). In 2017-2018, a small increase in mean deposition was observed at AMB5, but there was no overall trend of increasing or decreasing deposition rates across all sites. Further analysis and 2019-2020 data are required to determine what influenced the higher deposition rates in 2018-2019.

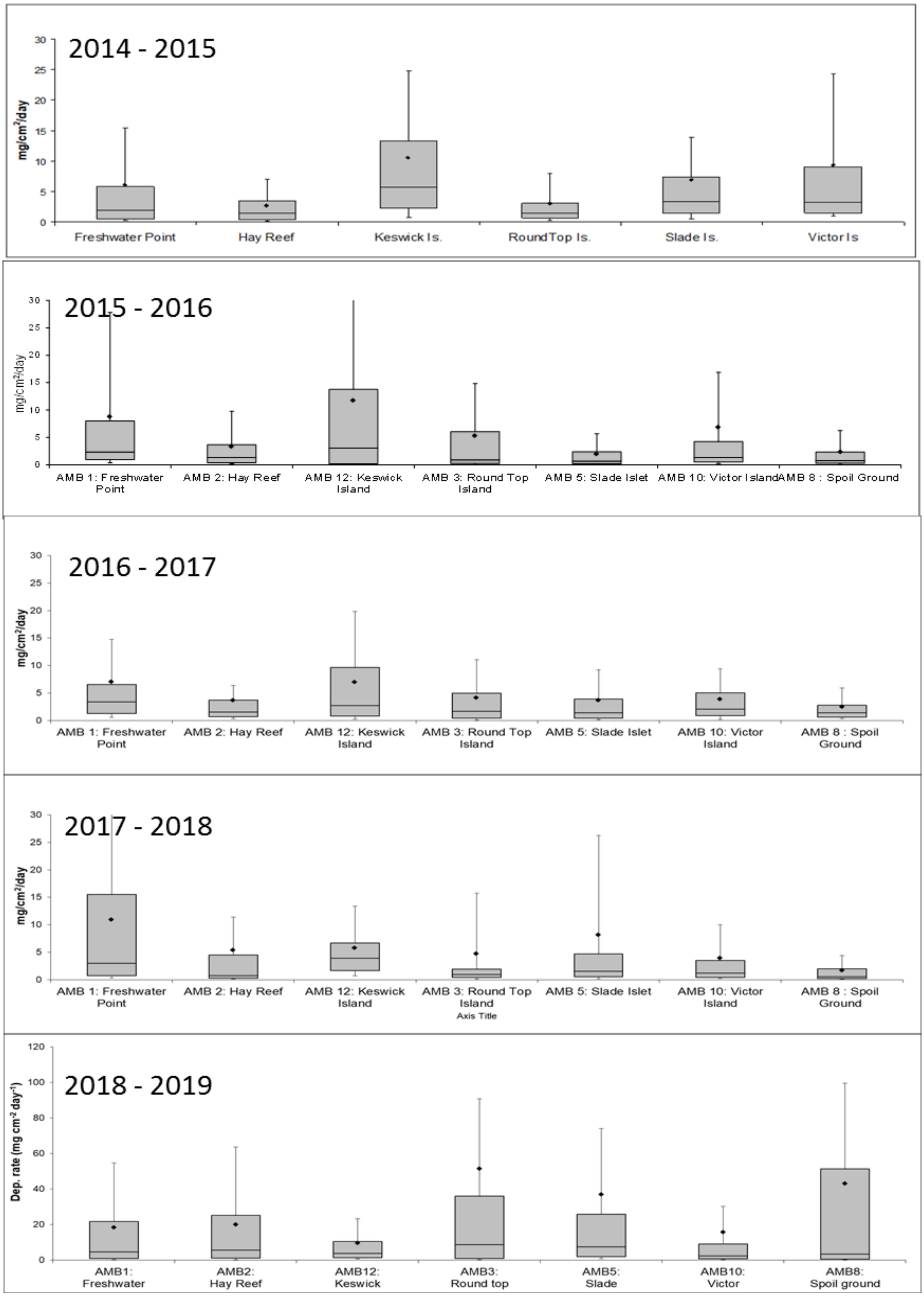


Figure 3.27 Annual summaries of daily deposition (mg cm^{-2} day^{-1}) from 2014-2019. Note that different scales are used between years.

3.3.8 Seasonal variation: wet vs dry

A comparison of wet and dry season water quality (2014-2019) suggests that the wet season coincides with increased suspended sediments, increased sediment deposition, and decreased irradiance at some sites. Temperatures were higher in the wet season at all sites. No clear seasonal pattern was observed for RMS across all sites.

Sites AMB1, AMB2, AMB5, and AMB10 exhibit strong seasonal differences, including increased SSC (Figure 3.29) and decreased PAR (Figure 3.31). AMB8 had higher suspended sediments, but similar PAR, in the wet season, possibly because this site is at 17 m and PAR is limited by depth. Interestingly, a different subset of sites (AMB3, AMB10, AMB12) exhibited seasonal differences in sediment deposition, with higher sediment deposition rates observed during the wet season (Figure 3.30).

RMS water height

Wet seasons are associated with large storms, wind and rain. It is often assumed that there is a large difference in wave energy between the wet and dry seasons in the Mackay region, but the combined data from 2014-2019 indicate that there is not a large difference in RMS between seasons (Figure 3.28, all years). For 2018-2019, there was slightly higher median and upper quartile RMS during the wet season at multiple sites (AMB1, 2, 3, 8, 10).

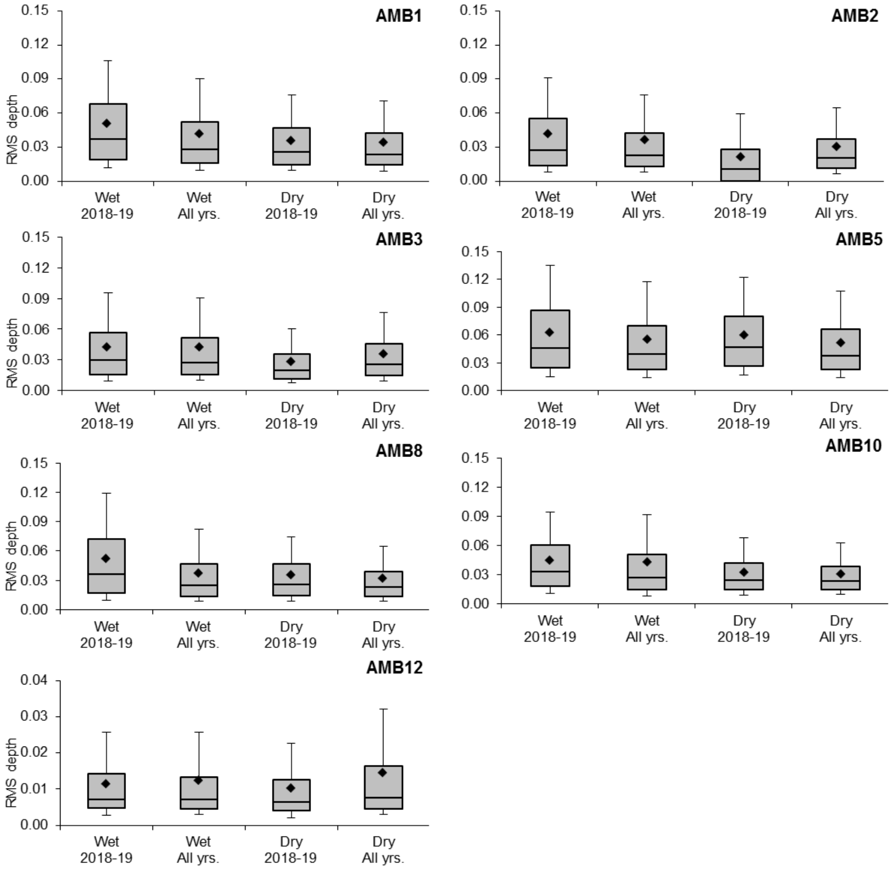


Figure 3.28 RMS water height box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2018-2019) or all available wet seasons (2014-2019). Note that a different scale is used for AMB12 compared to the other sites.

SSC

For most sites, suspended sediment concentrations (SSC) were higher during the wet season (Figure 3.29). At AMB1, 2, 5, 8, and 10, median and upper quartile SSC increased by at least 50 % during the wet season relative to dry season (All years). However, AMB 3 and 12 did not show elevated SSC during the wet season. The seasonal effect on SSC is further supported by higher mean and 90th percentiles during the wet season, indicating that high turbidity events were more extreme than in the dry season.

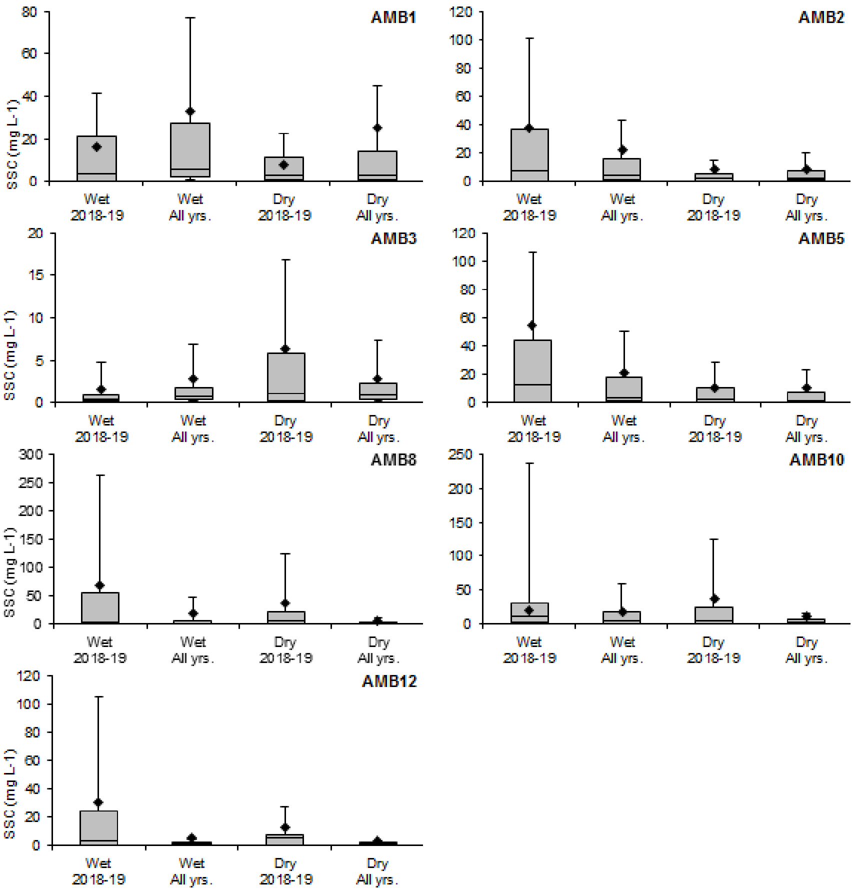


Figure 3.29 Suspended sediment concentration (SSC) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2018-2019) or all available wet seasons (2014-2019). Note that different scales are used for different sites.

2hr deposition rate

Across all monitoring years, median and upper quartile sediment deposition rates in the wet season were two times higher at four sites (AMB2, 3, 10, 12), approximately equal at one site (AMB5), and slightly lower at two sites (AMB1, AMB8; Figure 3.30).

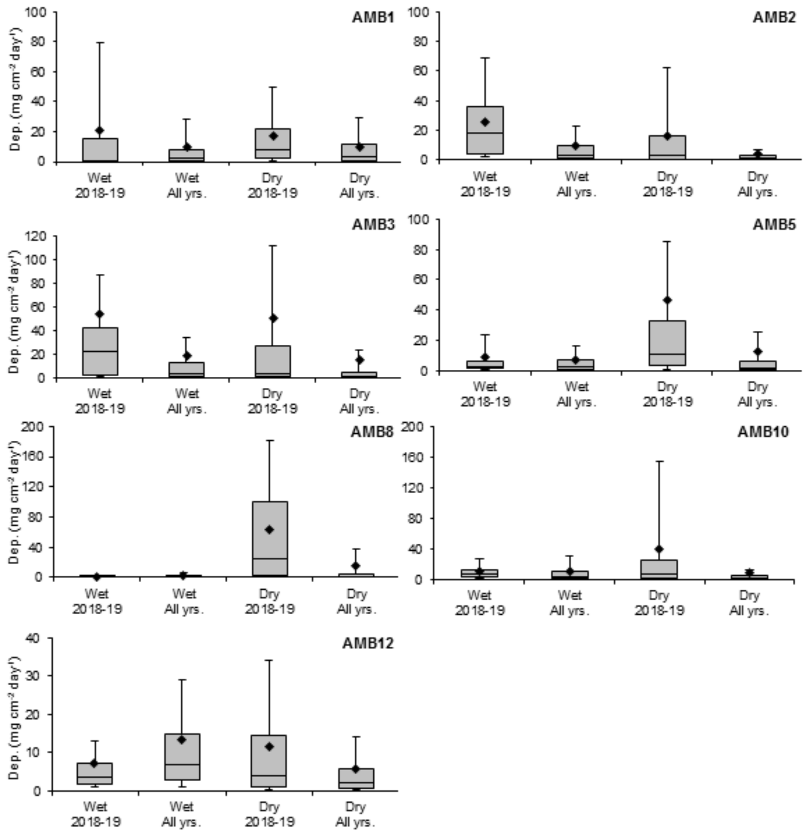


Figure 3.30 Sediment deposition rates (mg cm^{-2} day^{-1}) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2018-2019) or all available wet seasons (2014-2019). Note that different scales are used for different sites.

Total daily PAR

Even though day length increases in the wet season, four sites had reduced photosynthetically available radiation (PAR; Figure 3.31). Median and upper quartile PAR were lower in the wet season for four of seven sites (AMB1, AMB2, AMB5, AMB10). Two sites had similar PAR between seasons (AMB3, AMB8), and one site had higher PAR in the wet season (AMB12). This suggests that higher SSC (Figure 3.29) and/or more cloud cover could be responsible for reduced benthic PAR during the wet season.

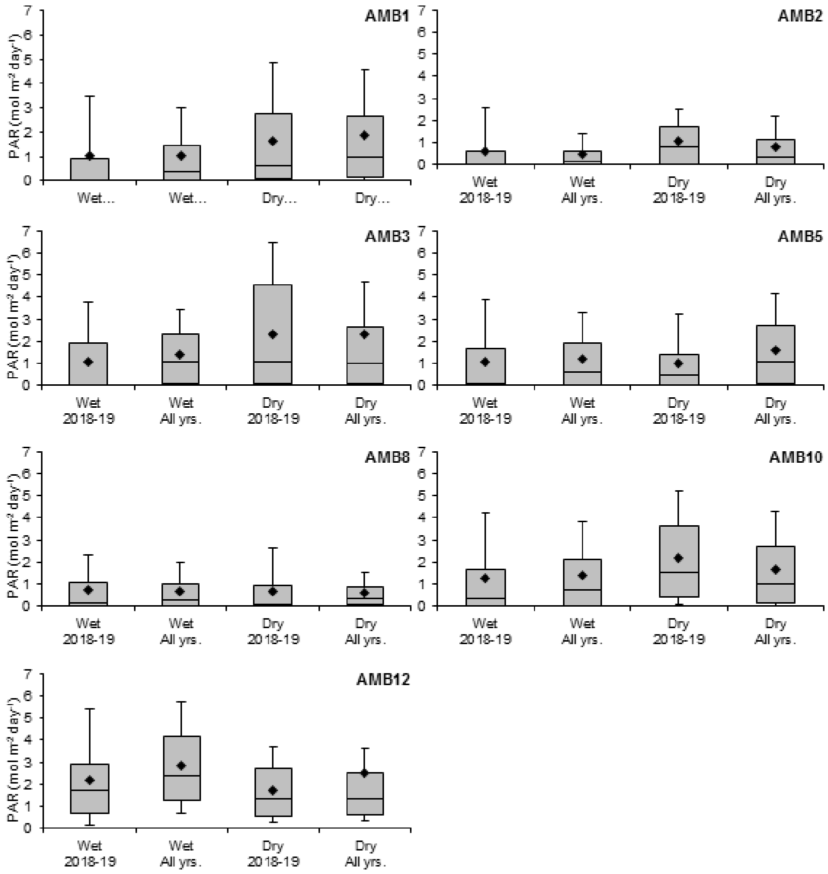


Figure 3.31 Photosynthetically available radiation (mol m^{-2} day^{-1}) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2018-2019) or all available wet seasons (2014-2019).

Water temperature

Median temperatures during the wet season (28-29 °C) are notably higher than in the dry season (22-24 °C; Figure 3.32).

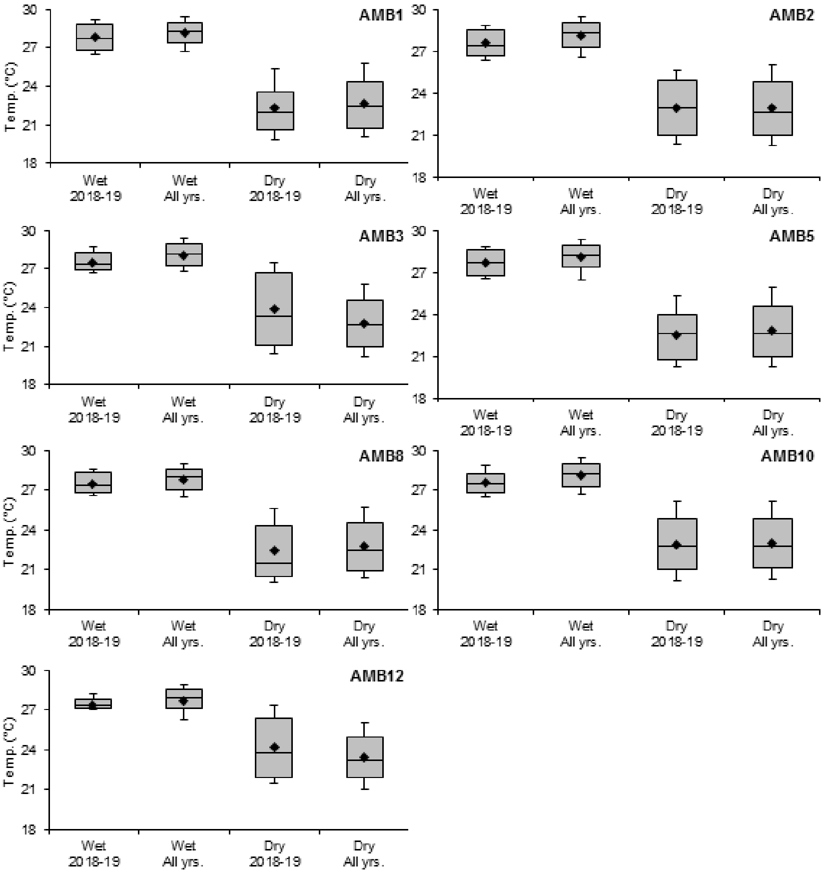
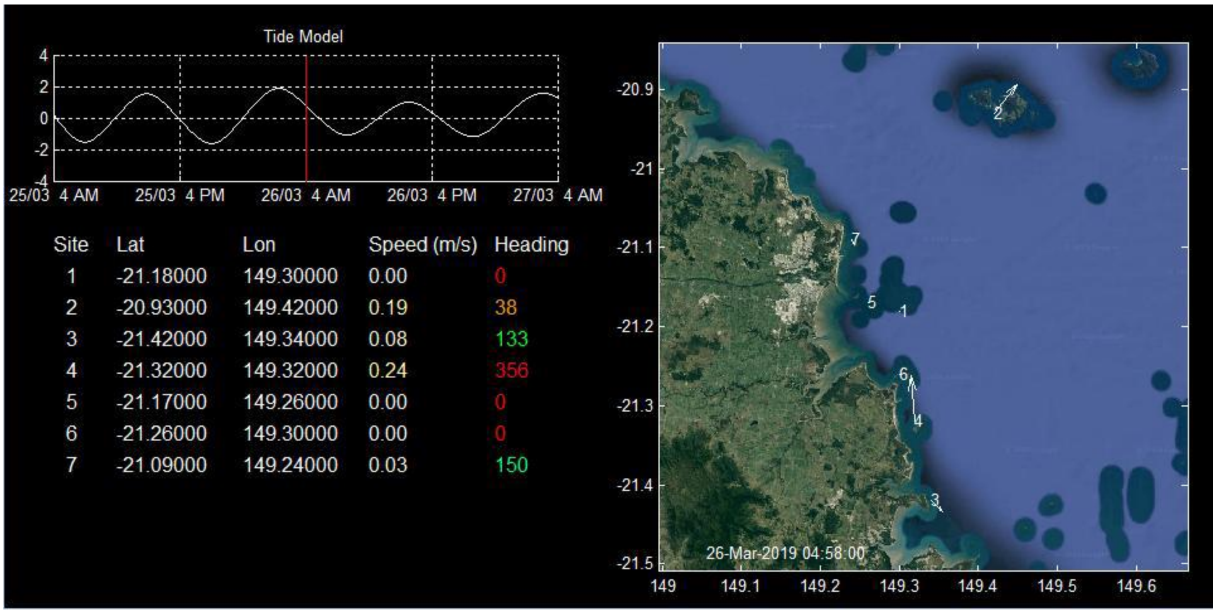


Figure 3.32 Temperature (°C) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2018-2019) or all available wet seasons (2014-2019).

3.3.9 Current meter

The current meter data indicates the prominent current direction and velocity at each site. Data shows that coastal current, tidal current or a combination of both influence current direction and magnitude. The figures below display the current meter data in current rose and average current speed rose diagrams. The current rose diagrams provide a visual representation of relative prominence of current velocity and direction. The average current speed rose diagrams displays the average current speed in every direction. Presented together these diagrams highlight the prominent direction of current and the average velocity of the current in this direction. A short and long animation illustrating how the current speed and direction changes over time at each site are accessible to view via sharepoint (Figure 3.33). Links to the videos are provided in Appendix A4.



Site	Lat	Lon	Speed (m/s)	Heading
1	-21.18000	149.30000	0.00	0
2	-20.93000	149.42000	0.19	38
3	-21.42000	149.34000	0.08	133
4	-21.32000	149.32000	0.24	356
5	-21.17000	149.26000	0.00	0
6	-21.26000	149.30000	0.00	0
7	-21.09000	149.24000	0.03	150

Figure 3.33 Example screengrab from current speed and direction animations

AMB 1: Freshwater Point

The current at AMB1 ranges from NW to SE (Figure 3.34) and low average velocities ranging from 0.05 m s^{-1} to 0.11 m s^{-1} (Figure 3.35). The predominant flow of current is along the coast in both directions at this site as expected from the dominant tidal currents.

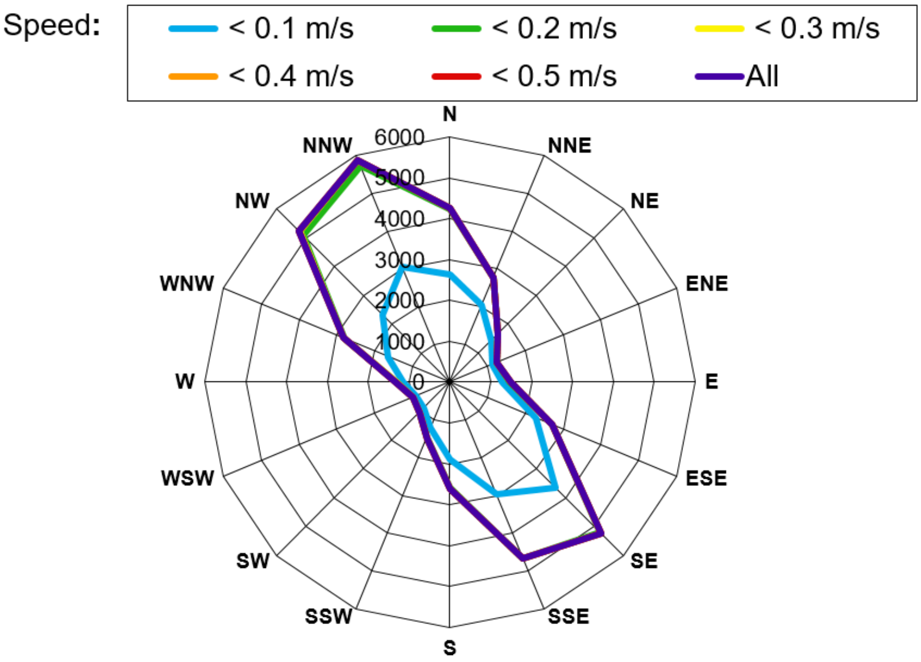


Figure 3.34 Current rose at AMB 1 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

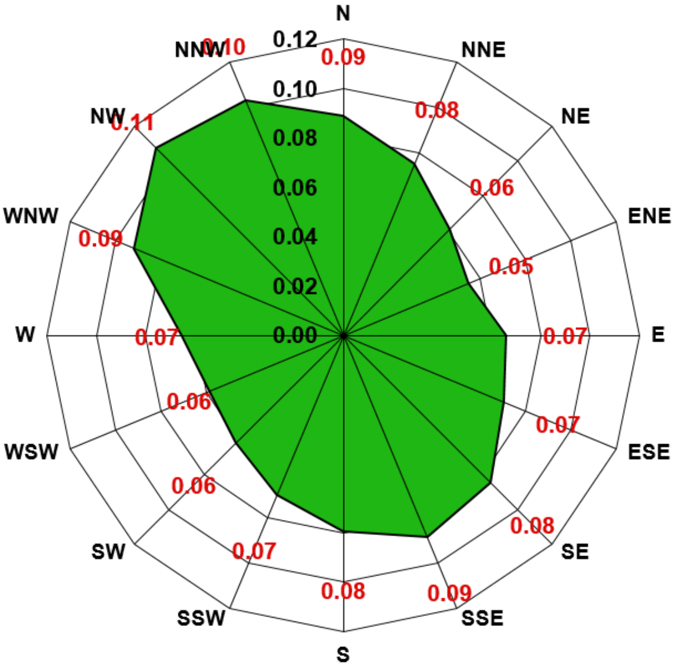


Figure 3.35 Average current speed at AMB1 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

AMB2

The current at AMB2 flows between NW and SE with fast current speeds of 0.27 and 0.30 m/s, respectively (Figure 3.36, Figure 3.37). Like AMB1, the predominant flow of current is along the coast in both directions at this site as expected from the dominant tidal currents.

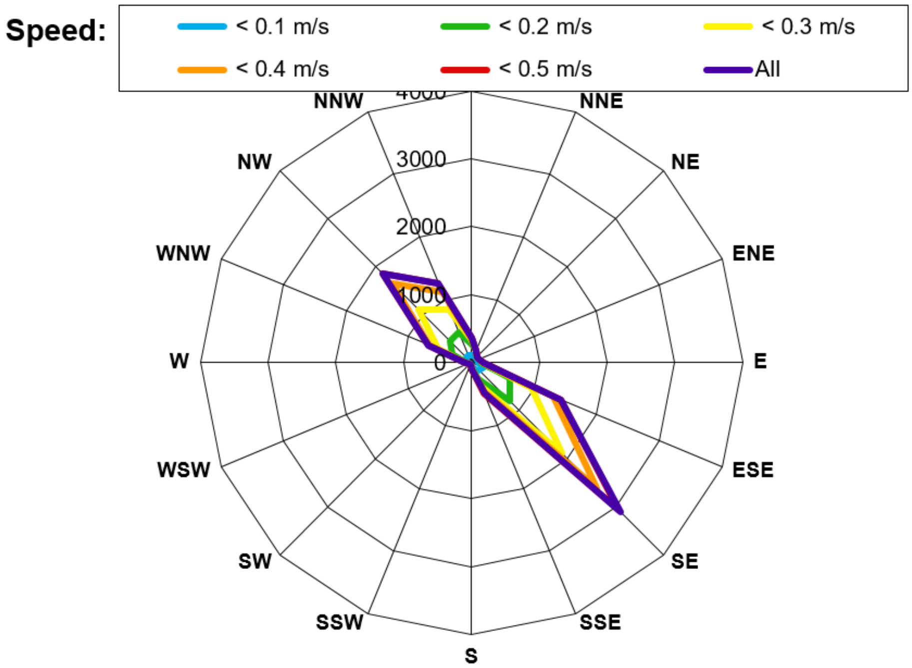


Figure 3.36 Current rose at AMB2 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

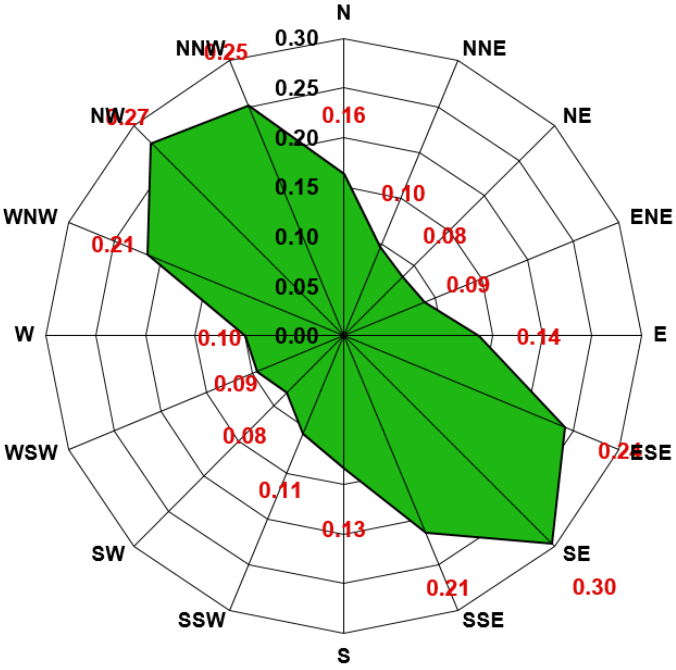


Figure 3.37 Average current speed at AMB2 from July 2018 to July 2019. The distance from origin indicates the average current speed (m/s) in each direction which is in red.

AMB3

The predominant current direction at AMB3 was NE (Figure 3.38). The fastest average current speeds were N (0.33 m s^{-1}) and S (0.31 m s^{-1}; Figure 3.39). The predominant NE direction is likely due to the position on the NW side of the island. The complicated current directions at AMB3 are likely due to the site moving during deployments.

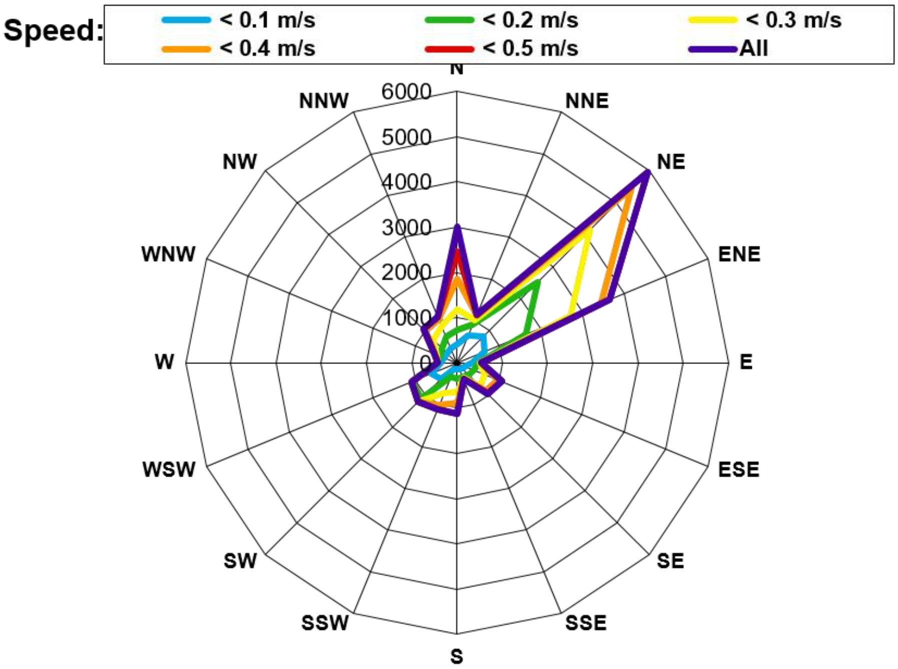


Figure 3.38 Current rose at AMB3 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

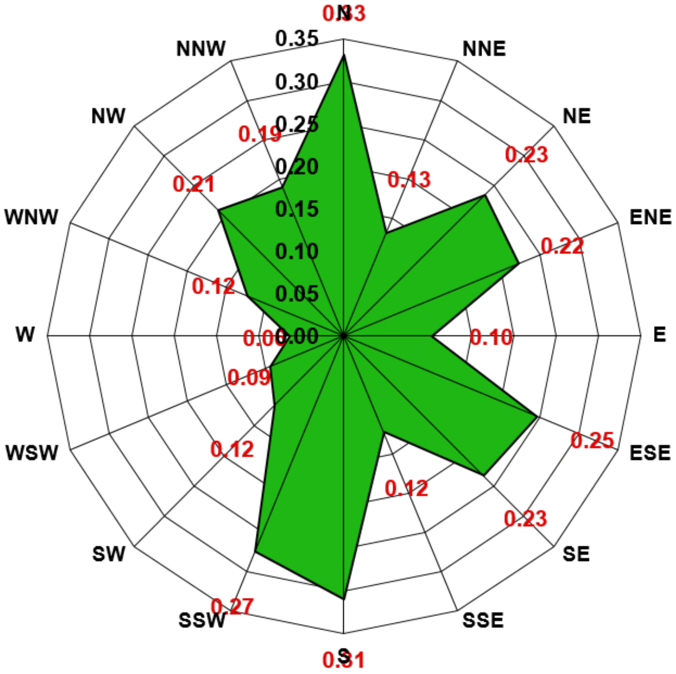


Figure 3.39 Average current speed at AMB3 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

AMB5

The prevailing current at Slade ranged from WSW to SW with an average speed of 0.15 m s^{-1} (Figure 3.40). In other directions, the average current speed was 0.10 m s^{-1} (Figure 3.41). This strong SW current flow is due to the monitoring site location being on the W side by Slade Island.

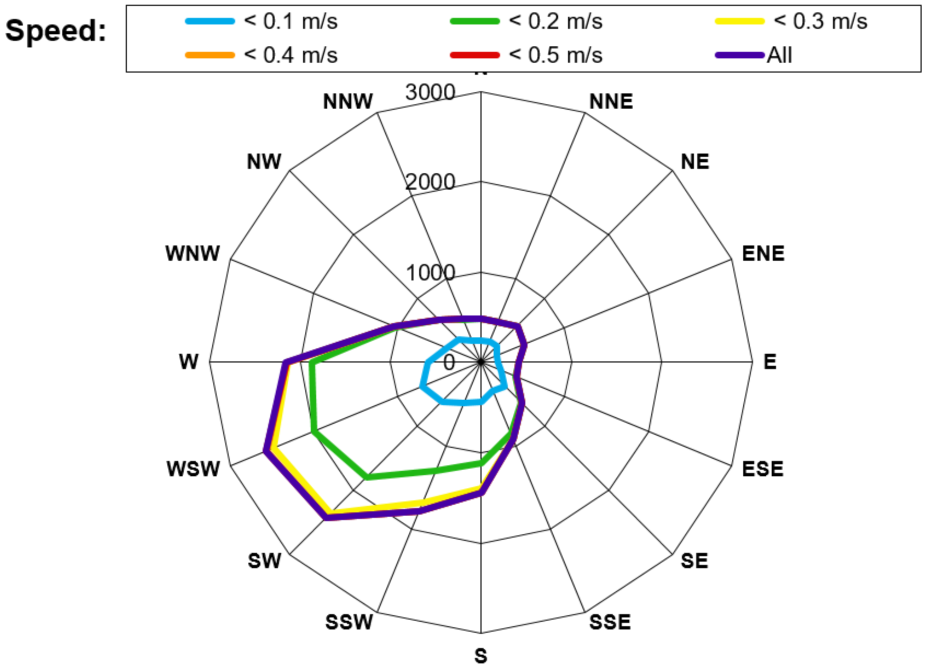


Figure 3.40 Current rose at AMB5 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

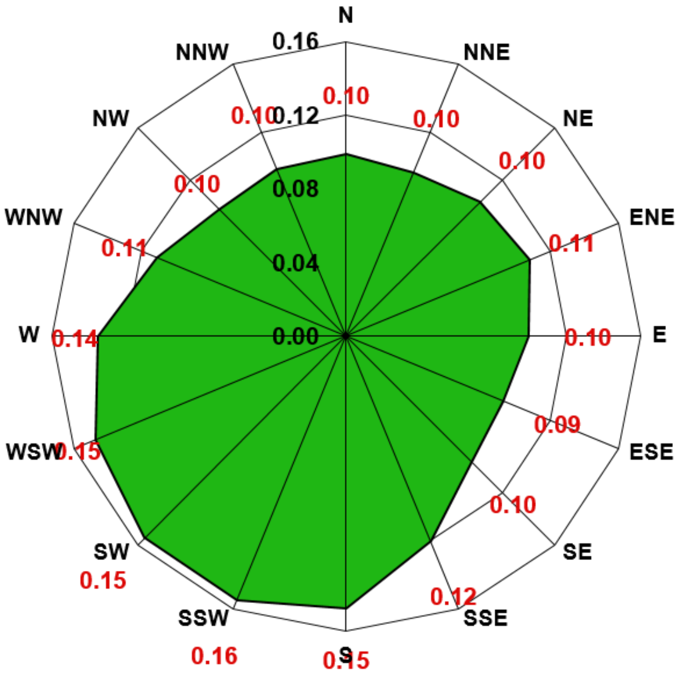


Figure 3.41 Average current speed at AMB5 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

AMB8

The current at the Spoil Grounds flowed predominantly to NNE and SSW indicating tidal currents with a change of direction between the ebb and flood tides (Figure 3.42). Average current speeds were 0.28 and 0.27 m s^{-1} towards the NNE and SSW, respectively (Figure 3.43). The currents at AMB8 run parallel with the coast indicating strong tidal influence on the recorded current data.

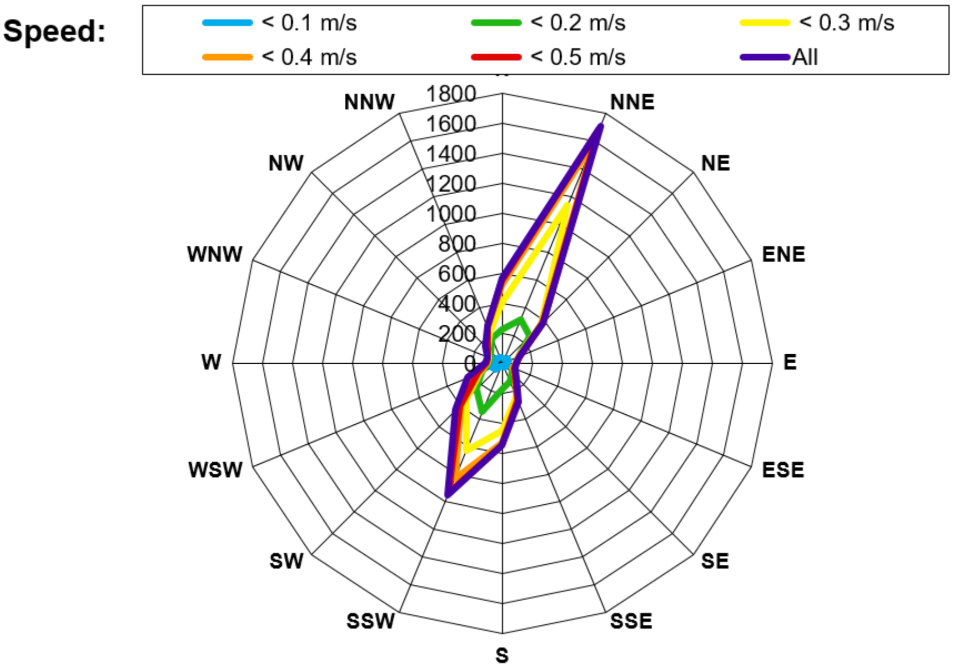


Figure 3.42 Current rose at AMB8 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

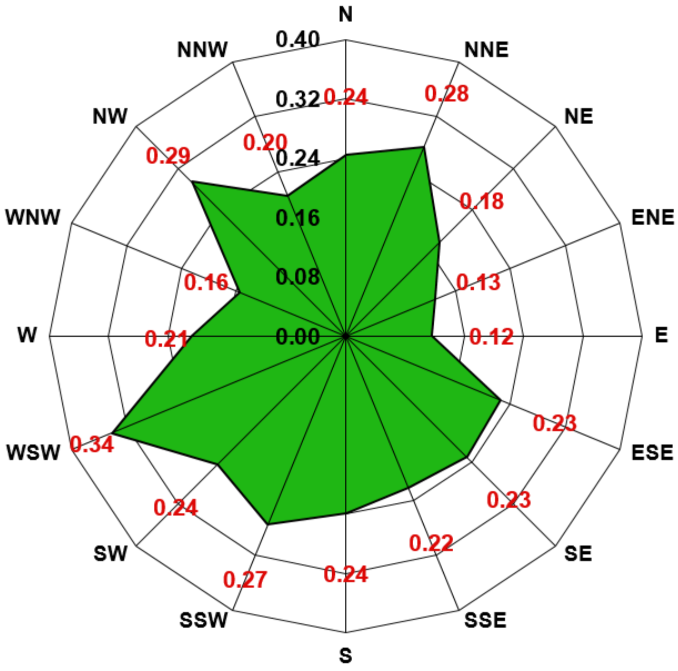


Figure 3.43 Average current speed at AMB8 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

AMB10

The current at Victor Island predominantly flows in the NW and SSW directions with average current speeds of 0.23 and 0.17 m s^{-1}, respectively (Figure 3.44, Figure 3.45). In other directions, current speeds average 0.13-0.17 m s^{-1}. The currents near AMB10 likely run along the coast, however the current at the site is affected by its location on the NW side of the island.

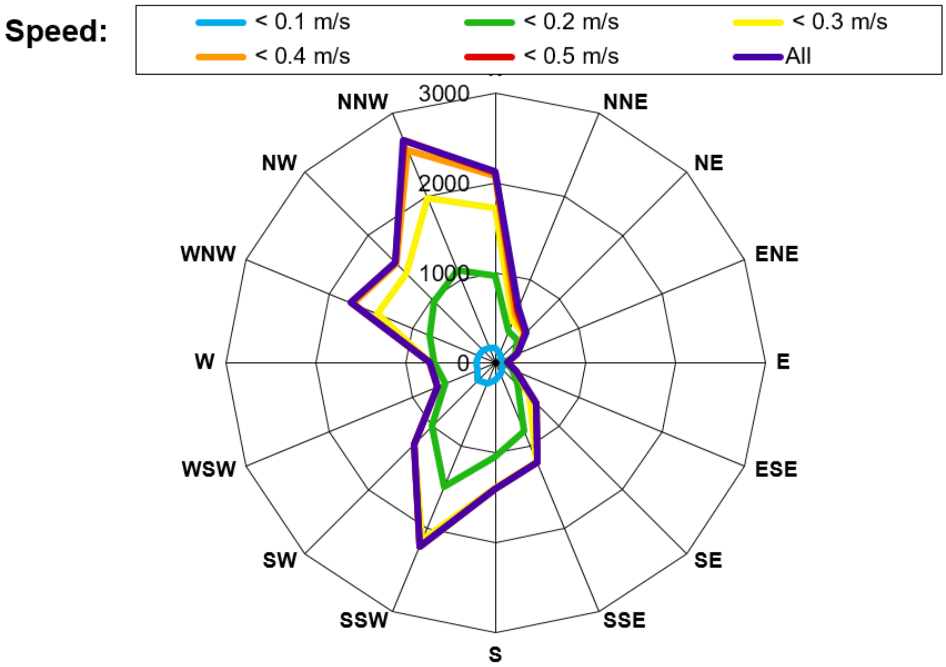


Figure 3.44 Current rose at AMB10 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

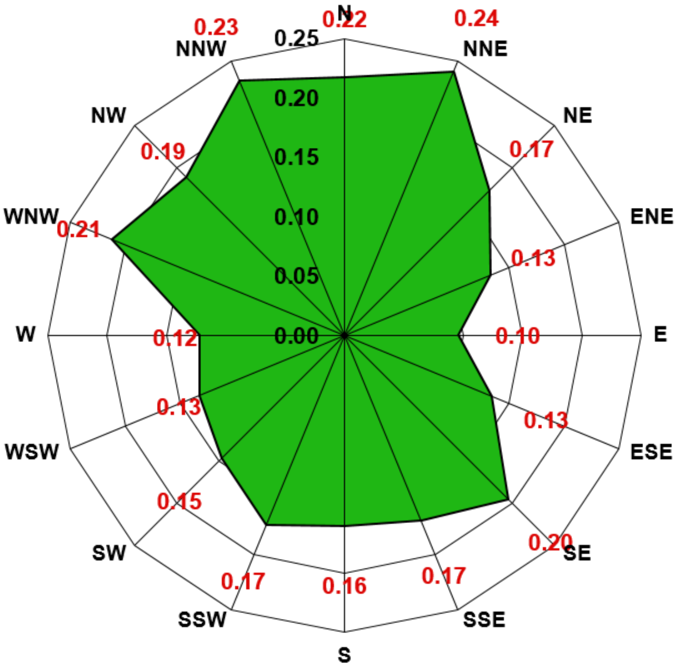


Figure 3.45 Average current speed at AMB10 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

AMB12

The current at Keswick Island flows predominantly in the NE direction with average velocity of 0.23 m s^{-1} (Figure 3.46, Figure 3.47).

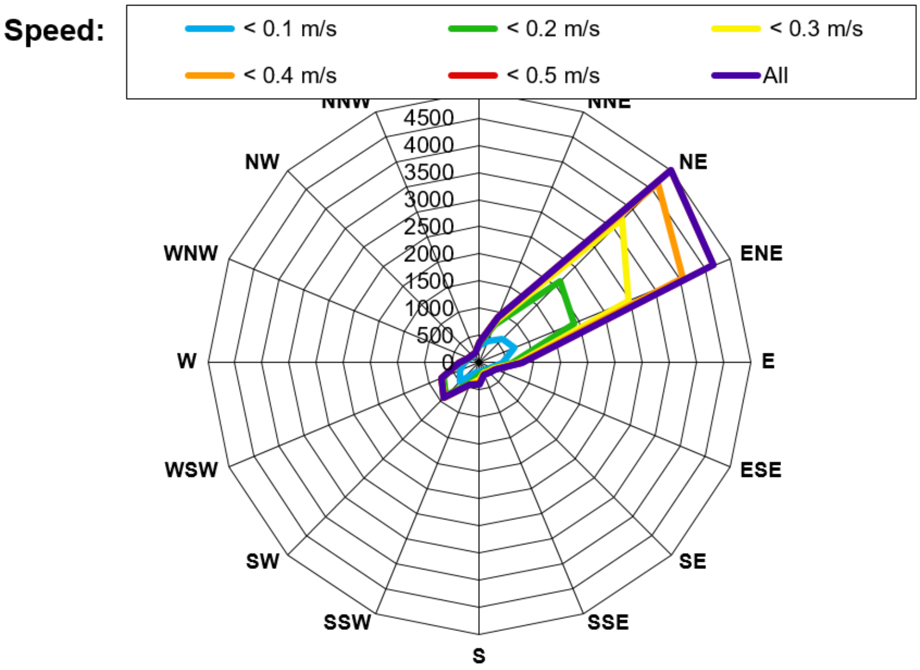


Figure 3.46 Current rose at AMB12 for the monitoring period July 2018 to July 2019. The distance from the origin indicates the count of currents in each direction while the coloured lines indicate counts of different current velocities.

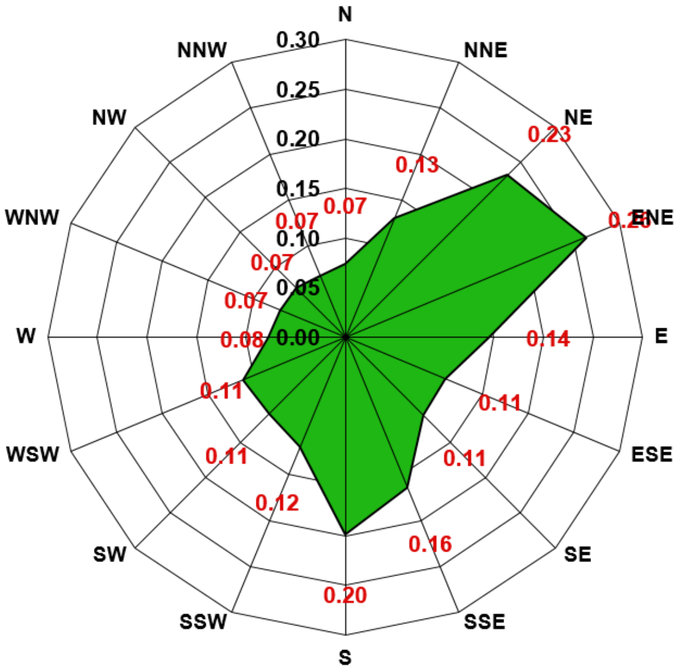


Figure 3.47 Average current speed at AMB12 from July 2018 to July 2019. The distance from origin indicates the average current speed (m s^{-1}) in each direction which is in red.

3.4 River Plumes

3.4.1 Site specific outputs

Freshwater Point (AMB 1)

A stepwise regression analysis was run against the Freshwater Point data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth, Sandy River discharge, and the NESW wind component explained 49 % of the SSC variability (Table 3.8). The relative importance analysis suggested that RMS of water depth is the most influential parameter on SSC (81 % of overall R^2), followed by Sandy River discharge (NWSE = 19 % of overall R^2, and NESW = 0.01 % of overall R^2; Figure 3.48). Partial effects plots (Figure 3.49) followed expected trends for SSC in relation to each environmental parameter selected in the model. Overall, an increase in SSC was observed with increases in the environmental predictors. The stronger the winds coming from the east (i.e. positive values for wind_NESW) the higher the SSC readings were. These results are similar to previous years, with the exception of Pioneer River discharge was an important parameter in the 2018/19 period.

Table 3.8 Statistical summary of the stepwise regression analysis to Freshwater Point in 2018/19

	Freshwater Point		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.31	4.62 – 6.00	**<0.001**
log(RMS)	1.15	0.99 – 1.31	**<0.001**
log(Sandy + 1)	0.12	0.05 – 0.18	**<0.001**
wind NESW	0.01	0.00 – 0.02	**0.037**
Observations	310		
R^2 / adjusted R^2	0.486 / 0.481		

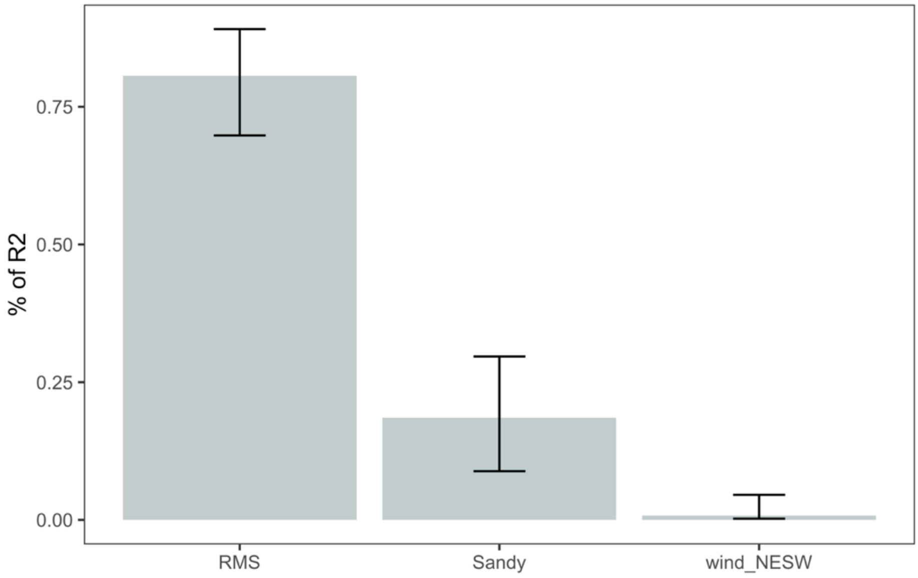


Figure 3.48 Freshwater Point bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95 % bootstrap confidence intervals, and % of r squared values are normalized to sum 100 %

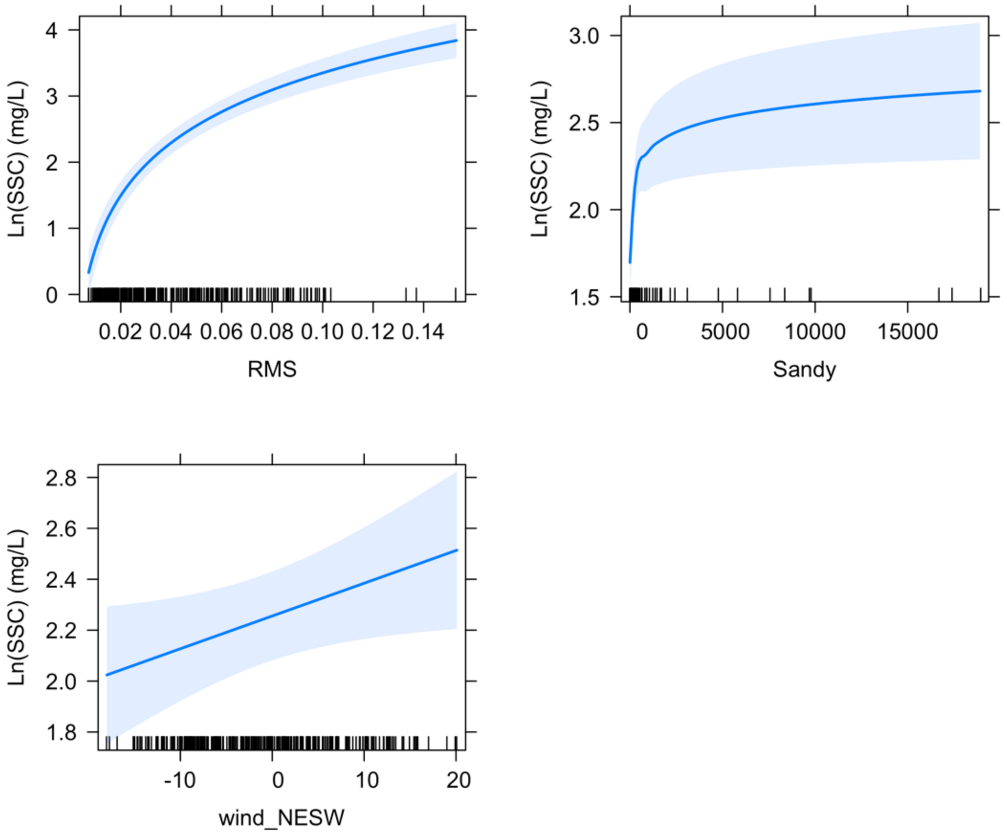


Figure 3.49 Partial effect plots for Freshwater Point parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

Hay Point Reef (AMB 2)

A stepwise regression analysis was run against the Hay Point Reef data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth, tide amplitude, and Pioneer River discharge explained 36 % of the SSC variability (Table 3.9). The relative importance analysis suggested that the NWSE wind component and Pioneer river discharge were the two most influential parameters on SSC (44 % and 40 % of overall R^2, respectively). RMS of water depth and tidal amplitude also contributed to SSC variability (11 and 5 % of overall R^2, respectively) (Figure 3.50). Partial effects plots (Figure 3.51) followed expected trends for SSC in relation to each environmental parameter selected in the model, except for RMS of water depth which showed SSC to decrease in relation to increasing RMS.

Table 3.9 Statistical summary of the stepwise regression analysis to Hay Point Reef data

	Hay Reef		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-5.71	-7.68 – -3.74	**<0.001**
log(RMS)	-0.29	-0.41 – -0.17	**<0.001**
log(Pioneer + 1)	0.55	0.37 – 0.73	**<0.001**
wind NWSE	-0.09	-0.12 – -0.06	**<0.001**
Amplitude	0.26	0.06 – 0.47	**0.014**
Observations	169		
R^2 / adjusted R^2	0.357 / 0.341		

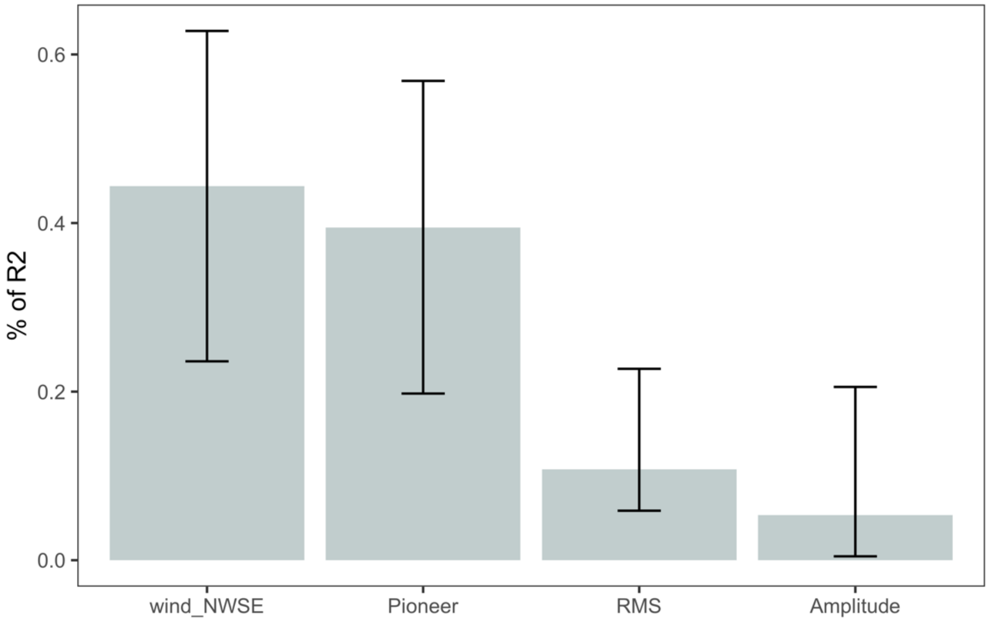


Figure 3.50 Hay Reef bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

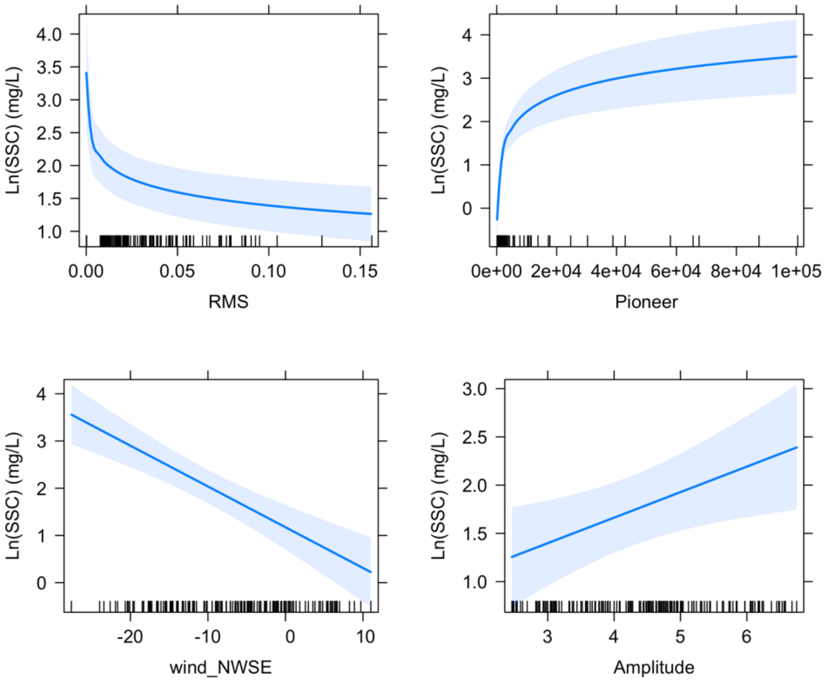


Figure 3.51 Partial effect plots for Hay Reef parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95 % CI and rug on x-axis stand for data density

Keswick Island (AMB 12)

A stepwise regression analysis was run against the Keswick Island data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth and tidal amplitude explained ~12 % of the SSC variability (Table 3.10). The relative importance analysis suggested that the RMS of water depth was the most influential parameter on SSC (68 % of overall R^2), while tidal amplitude accounted for 32 % of the overall R^2 (Figure 3.52). Partial effects plots (Figure 3.53) followed expected trends for SSC in relation to each environmental parameter selected in the model, showing a positive relationship between SSC and RMS of water depth and tidal amplitude. The results are similar to 2016/17, where only RMS of water depth and tidal amplitude were important in the SSC analysis at this site.

Table 3.10 Statistical summary of the stepwise regression analysis to Keswick Island data

		Keswick	
Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.29	0.86 – 1.71	**<0.001**
log(RMS)	0.19	0.12 – 0.27	**<0.001**
Amplitude	0.08	0.04 – 0.13	**0.001**
Observations	325		
R^2 / adjusted R^2	0.115 / 0.109		

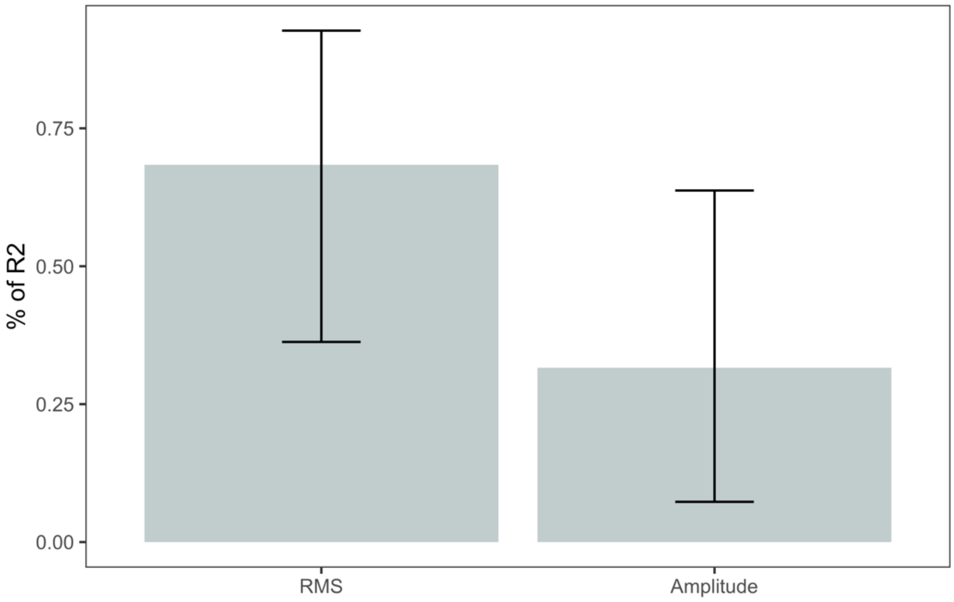


Figure 3.52 Keswick Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

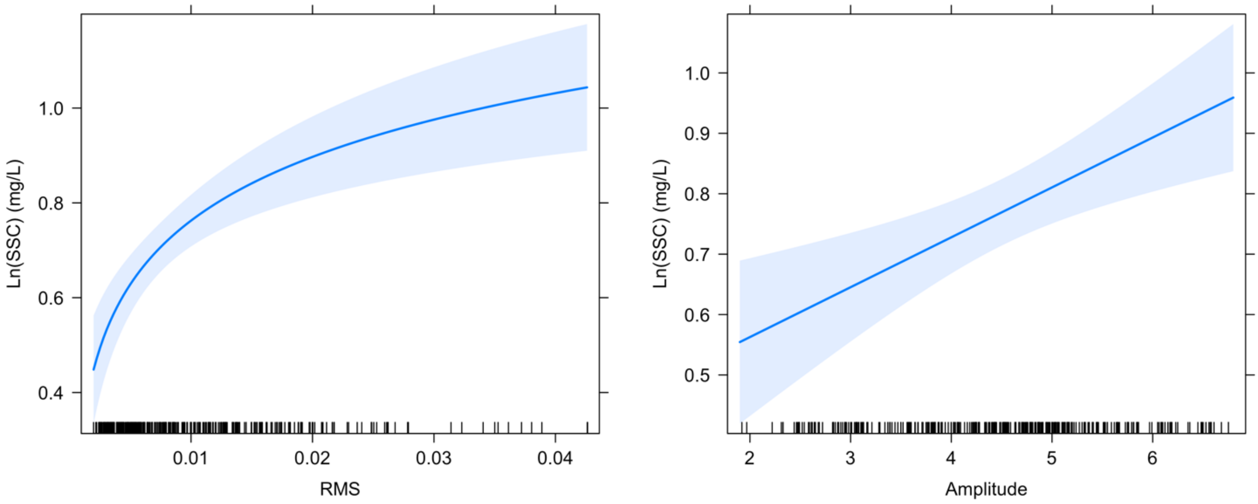


Figure 3.53 Partial effect plots for Keswick Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

Round Top Island (AMB 3)

A stepwise regression analysis was run against the Round Top Island data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth was the only factor influencing SSC, explaining 41 % of the variability (Table 3.11). Overall, an increase in SSC was observed with increases in RMS of water depth (Figure 3.54). These results differ from previous years where Pioneer River discharge, wind_NESW, and tidal amplitude were important factors in explaining variability in SSC.

Table 3.11 Statistical summary of the stepwise regression analysis to Round Top Island data

	Roundtop		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	2.66	2.28 – 3.04	**<0.001**
log(RMS)	0.52	0.42 – 0.62	**<0.001**
Observations	153		
R^2 / adjusted R^2	0.410 / 0.406		

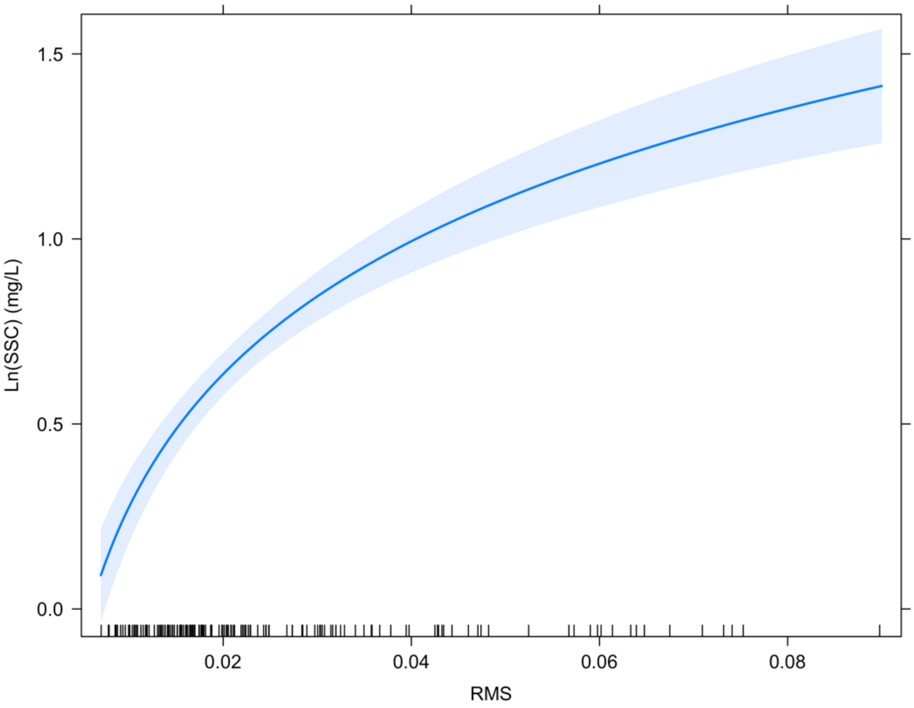


Figure 3.54 Partial effect plots for Round Top Island for RMS affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

Slade Islet (AMB 5)

A stepwise regression analysis was run against the Slade Islet data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth and Pioneer River discharge explained 45 % of the SSC variability (Table 3.12). The relative importance analysis suggested that RMS of water depth was the most influential parameter on SSC (74 % of overall R^2), while Pioneer River discharge accounted for the remaining 26 % of the overall R^2 (Figure 3.55). Overall, an increase in SSC was observed with increases in the environmental predictors (Figure 3.56).

Table 3.12 Statistical summary of the stepwise regression analysis to Slade Island data

	Slade		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.28	2.95 – 5.61	**<0.001**
log(RMS)	1.26	0.98 – 1.53	**<0.001**
log(Pioneer + 1)	0.24	0.13 – 0.36	**<0.001**
Observations	158		
R^2 / adjusted R^2	0.451 / 0.444		

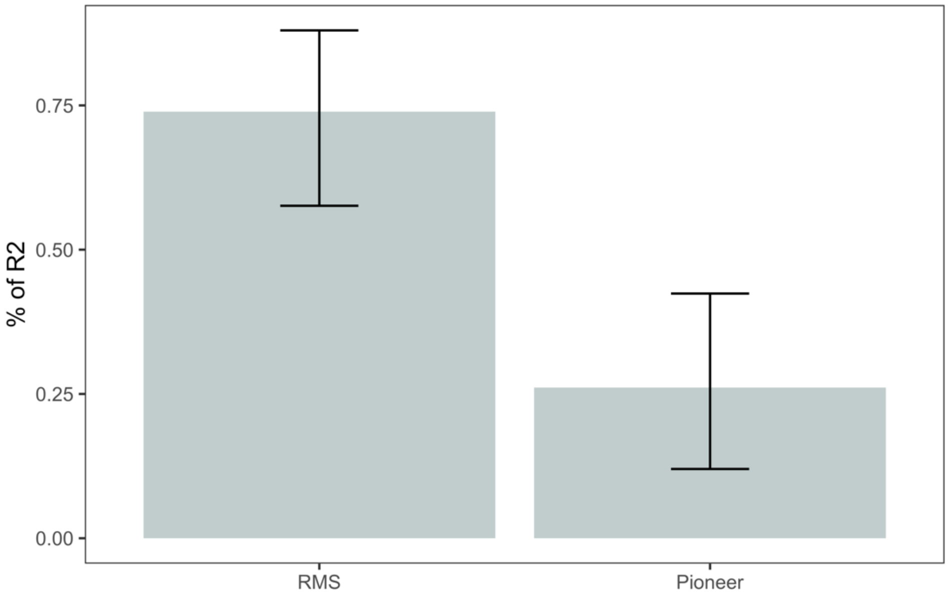


Figure 3.55 Slade Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95 % bootstrap confidence intervals, and % of r squared values are normalized to sum 100 %

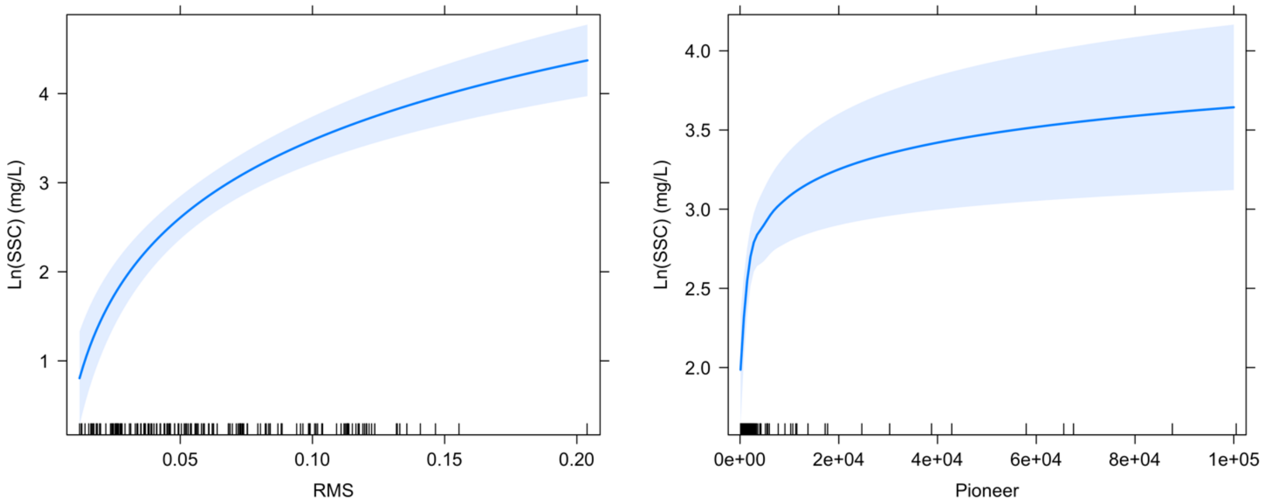
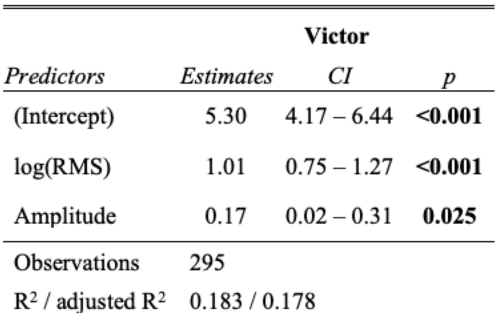


Figure 3.56 Partial effect plots for Slade Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95 % CI and rug on x-axis stand for data density

Victor Islet (AMB 10)

A stepwise regression analysis was run against the Victor Islet data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. RMS of water depth and tide amplitude together explained 18 % of the SSC variability (Table 3.13). The relative importance analysis suggested that RMS of water depth was the most influential parameter on SSC (92 % of the overall R^2), while tidal amplitude provided the remaining 8 % of the overall R^2 value (Figure 3.57). Partial effects plots (Figure 3.58) followed expected trends for SSC in relation to each environmental parameter selected in the model. Overall, an increase in SSC was observed with increases in the environmental predictors.

Table 3.13 Statistical summary of the stepwise regression analysis to Victor Island data



	Victor		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.30	4.17 – 6.44	**<0.001**
log(RMS)	1.01	0.75 – 1.27	**<0.001**
Amplitude	0.17	0.02 – 0.31	**0.025**
Observations	295		
R^2 / adjusted R^2	0.183 / 0.178		

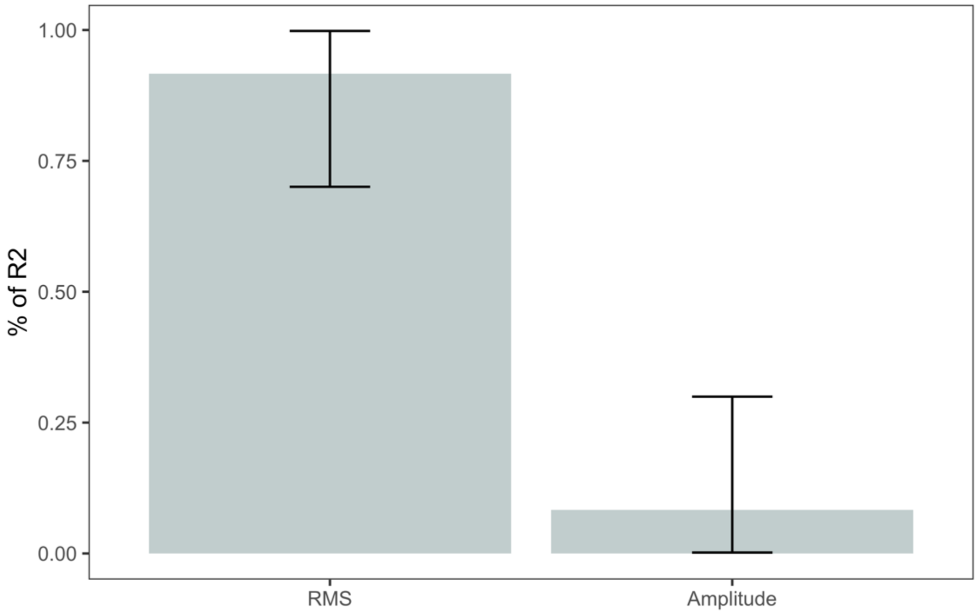


Figure 3.57 Victor Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95 % bootstrap confidence intervals, and % of r squared values are normalized to sum 100 %

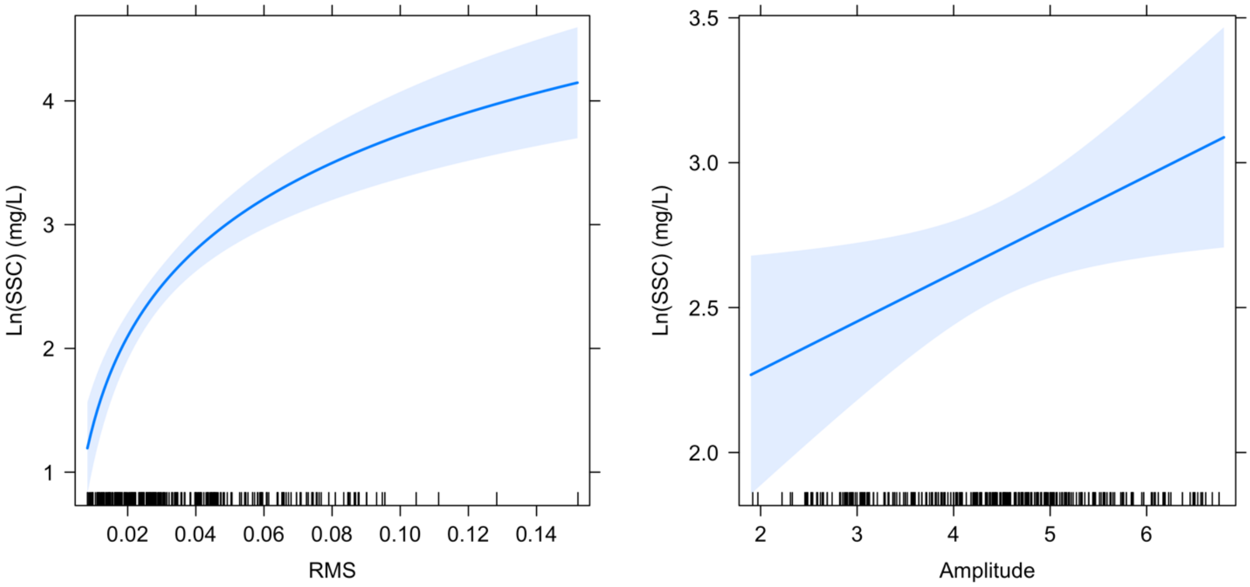


Figure 3.58 Partial effect plots for Victor Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95 % CI and rug on x-axis stand for data density

Relocation ground (AMB 8)

A stepwise regression analysis was run against the Relocation ground data to identify the appropriate variable selection, excluding autocorrelation and outliers, for the multiple regression analysis. The NWSE wind component and Pioneer River discharge explained 29 % of the SSC variability (Table 3.14). The relative importance analysis suggested that the NWSE wind component was the most influential parameter on SSC (66 % of overall R^2), while Pioneer River discharge was less important (34 % of the overall R^2) (

Figure **3.59**). Partial effects plots (Figure 3.60) show that there was an overall increase in SSC with increases in Pioneer River discharge, and a decrease in SSC with strong winds from the west (i.e. positive NWSE values).

Table 3.14 Statistical summary of the stepwise regression analysis to Relocation Ground data

	Relocation Grounds		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-1.77	-3.07 – -0.47	**0.008**
log(Pioneer + 1)	0.39	0.21 – 0.58	**<0.001**
wind NWSE	-0.11	-0.14 – -0.08	**<0.001**
Observations	205		
R^2 / adjusted R^2	0.293 / 0.286		

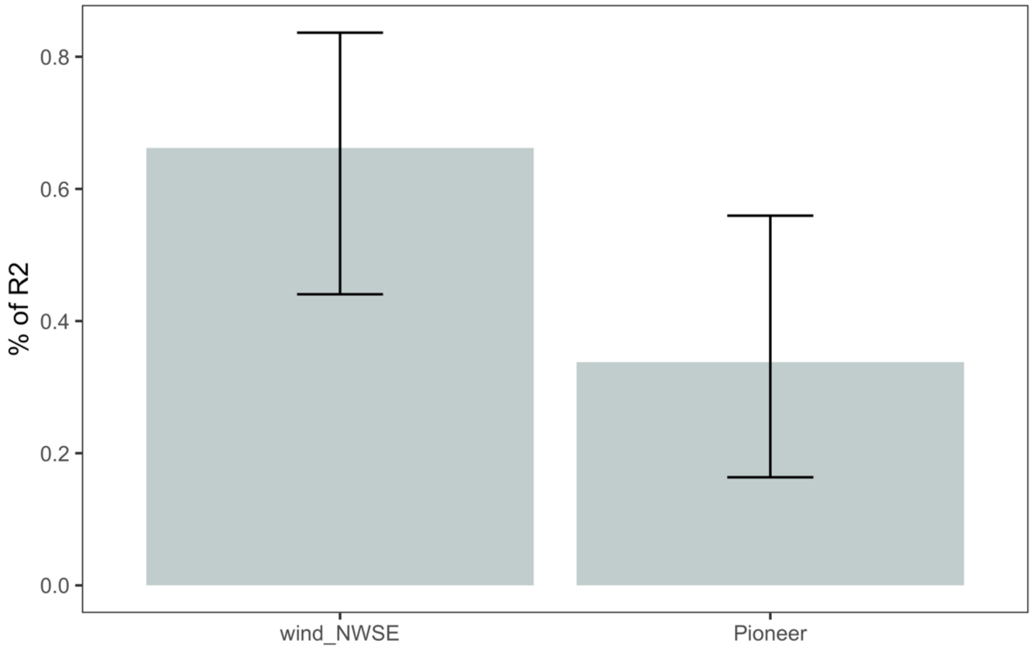


Figure 3.59 Spoil Grounds bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95 % bootstrap confidence intervals, and % of r squared values are normalized to sum 100 %

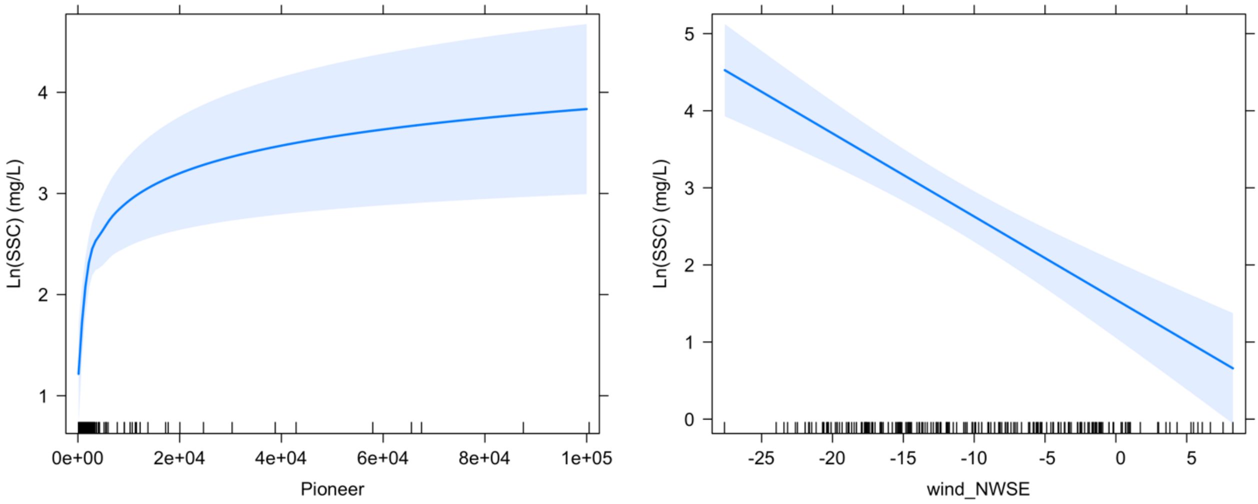


Figure 3.60 Partial effect plots for Relocation Ground parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

4.1.1 Climatic conditions

- An important factor to consider in interpreting data during this year of monitoring is that the 2018/19 wet season was average for the Mackay and Hay Point region.
- This highly inter-annual variability in rainfall supports the need for a long-term program, in order to fully characterise the conditions under different climatic patterns.
- Comparison of these data with future years will be important to characterise ambient water quality conditions. Care is needed with the analysis of long term data series, to ensure that underlying conditions are taken into consideration. The monitoring program to date has only had a single year where wet season rainfall was well above average.
- The wind speed and direction recorded at Mackay airport during the study period has been a useful inclusion in this assessment. The daily average wind speed and direction recorded at Mackay airport for the reporting period (2018/19) was, again, predominantly from the south east and south west. The strongest winds (>24km h^{-1}) were predominantly from the south east (more than 55% of the days).

4.1.2 Ambient water quality

- There continues to be a strong seasonal pattern for water temperature, with highest temperatures experienced during summer months, while winter months experience much cooler conditions. The amplitude in water temperature across the region between winter and summer is almost 10 °C, with typically less than 2 °C difference through the water column. This patter is consistent from year to year over the five years of this program.
- The water column profile for dissolved oxygen, temperature, electrical conductivity and pH continue to be well mixed, although there is a subtle oxycline with dissolved oxygen concentrations decreasing with depth.
- Turbidity was generally higher at the bottom horizon at all sites, contributing to a distinct separation of water horizons in the multivariate statistics. This pattern for turbidity is probably related to the bottom horizon proximal to the sea floor and the effects of remobilised sediments. The elevated turbidity in the bottom horizon becomes an important consideration when examining sensitive receptor habitats. Corals and seagrass habitats are sensitive to water clarity changes, therefore measuring bottom horizon turbidity is a very relevant component of this program; surface measurements for turbidity, or indeed suspended solid concentrations, might not be an entirely relevant measure when the objective is to protect and enhance sensitive benthic habitats.
- Particulate nitrogen and phosphorus are again elevated above guideline values throughout this reporting period, indeed the highest among all years that this program has been progressing. Elevated nutrient concentrations in coastal waters of the Mackay region is a concern and requires ongoing investigation in order to identify broader catchment landscape processes driving nutrient transport to the coastal ocean and enact effective management strategies.
- Chlorophyll-*a* concentrations continue to exceed regional guidelines, and are particularly high in summer months and when nutrient concentrations are also high.
- The species composition of phytoplankton and zooplankton communities differed primarily between years. In particular, the species composition of plankton communities were distinct in 2015 and 2016, while phytoplankton species composition was similar across surveys conducted in 2017-2019. For zooplankton, species composition in 2017 was distinct from highly similar communities in 2018 and 2019.

- Copper concentrations exceeded ANZECC 95 % protection guideline values at MKY_AMB2 in March 2019. All other metals in the ultra-trace suite were present at concentrations lower than guideline values, and/or lower than analytical detection limits.
- Ametryn, Atrazine, Diuron, and Hexaninone were detected at several monitoring sites, particularly during the wet season survey (March 2019). Diuron concentrations exceeded water quality objectives at three sites in March 2019, which could be a consequence of the high rainfall events experienced in February 2019.
- The database for the region continues to expand, with more data generated under various environmental conditions particularly given the increased monitoring frequency for particulate nutrients and chlorophyll-*a*.
- Discussions continue to integrate these data into the Mackay/Whitsunday regional water quality report card, and could be used to assist developing locally specific water quality objectives (WQOs) that are scheduled in the Environmental Protection Act (Queensland).

4.1.3 Sediment deposition and turbidity

- Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment (Orpin and Ridd 2012), and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week.
- Another important finding here was that deposition data did not indicate large deposits occurring at any of the monitored sites, and this is likely attributed to re-suspension of sediment by wave energy.
- The five year-long data set comparing wet and dry seasons shows little difference in SSC for the sites AMB 3 and 12, however there were differences for sites AMB 1, 2, 5, 8, 10, whereby means and medians were 50 % higher than in the dry season, however there was no discernible difference in wet and dry RMS wave height statistics.

4.1.4 Photosynthetically active radiation (PAR)

- Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles (Orpin and Ridd 2012), and rainfall events resulting from storms leading to increased catchment flows, and an input of suspended solids (Fabricius et al., 2013).
- Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter (Kirk 1985; Davis-Colley and Smith 2001). Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites and sites of closer proximity to one another were more similar than distant sites.
- While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations (Erftemeijer and Lewis 2006; Erftemeijer et al., 2012), the relationship between these two parameters is not always strong (Sofonia and Unsworth 2010). As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae and corals it is becoming more

useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.

- Overall there was little consistent difference between wet and dry season PAR levels. Four sites had decreased PAR during the wet season (AMB1, AMB2, AMB5, AMB10); two sites showed very little difference between wet and dry seasons (AMB3, AMB8); and one site (AMB12) showed an increase in median PAR of more than 80% in the wet season.

4.2 Recommendations

4.2.1 Data base repository

An electronic version of the ambient marine water quality database has been prepared as an annexure to this report. It currently comprises MS-Excel Workbooks containing raw data files including results for water chemistry (*in-situ* field measurements, nutrients, filterable metals, pesticides/herbicides), and all the continuous high frequency logger data files for sediment deposition, PAR, turbidity, water temperature, and RMS recorded during the period July 2014 and July 2018. This data base continues to be maintained by TropWATER personnel, with back up copy archived on the James Cook University network with restricted access.

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A1 CALIBRATION PROCEDURES

A1.1 Turbidity/Deposition Calibration

The turbidity and deposition sensors on each instrument are calibrated to a set of plastic optical standards that give consistent NTU return values. This enables the calculation of raw data values into NTU values. The NTU values can then be converted into SSC and ASSD values through the SSC calibration process. Deposition sensors are calibrated to give measurements in units of mg/cm^2 using the methodology outlined in Ridd *et al* (2001) and Thomas *et al* (2003). Instruments are calibrated every six months or after every deployment. Sediment samples are taken at each deployment site and used to determine sediment calibration coefficients used to account for variations in grain size and shape that can alter the implied SSC value.

A1.2 SSC Calibration

An instrument is placed in a large container (50 L) with black sides and the output is read on a computer attached to the logger. Saltwater is used to fill the container. Sediment from the study site is added to a small container of salt water and agitated. The water-sediment slurry is then added to the large container which is stirred with a small submerged pump. A water sample is taken and analysed for total suspended sediment (TSS) using standard laboratory techniques in the ACTFR laboratory at JCU which is accredited for these measurements. Approximately 6 different concentrations of sediment are used for each site. TSS is then plotted against the NTU reading from the logger for each of the different sediment concentrations. A linear correlation between NTU and SSC is then calculated. The correlations typically have an r^2 value equal to or greater than 0.9.

A1.3 Light Calibration

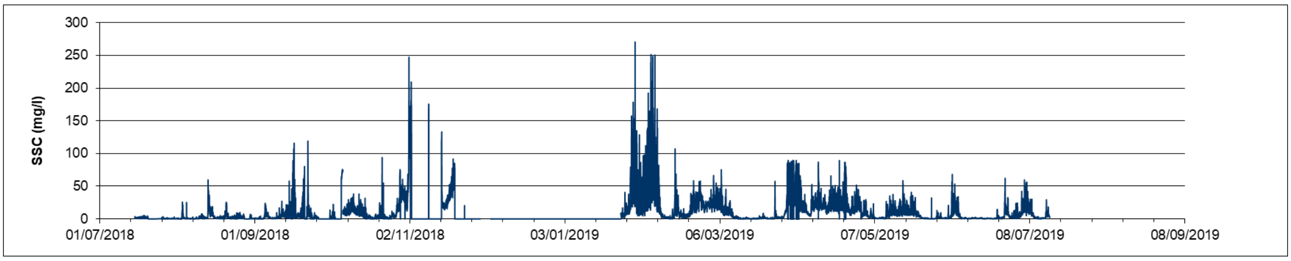
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration coefficient is used to ensure accurate reporting of PAR data. An in-field comparison between the logger light sensor and LICOR U250A is made on deployment of the instruments to ensure accurate reporting of the data. In field calibration of the nephelometer light sensor against the LICOR U250A at varying depth has been carried out to account for changes in sensitivity changes at depth.

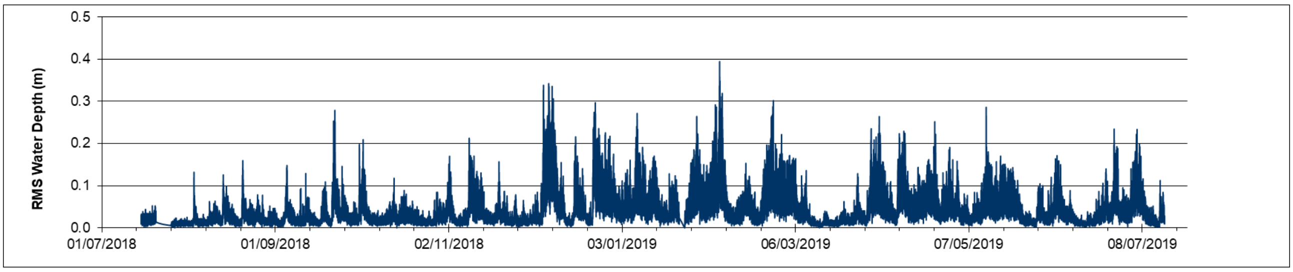
A1.4 Pressure Sensor Calibration

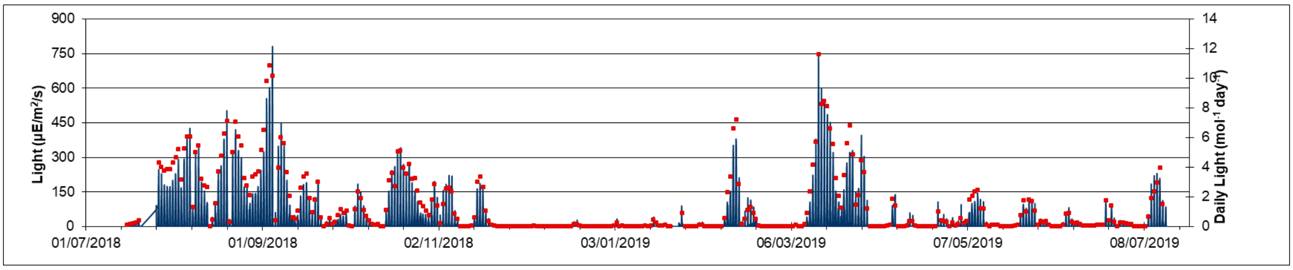
All pressure sensors are calibrated against a pressure gauge and the pressure is converted into depth in metres.

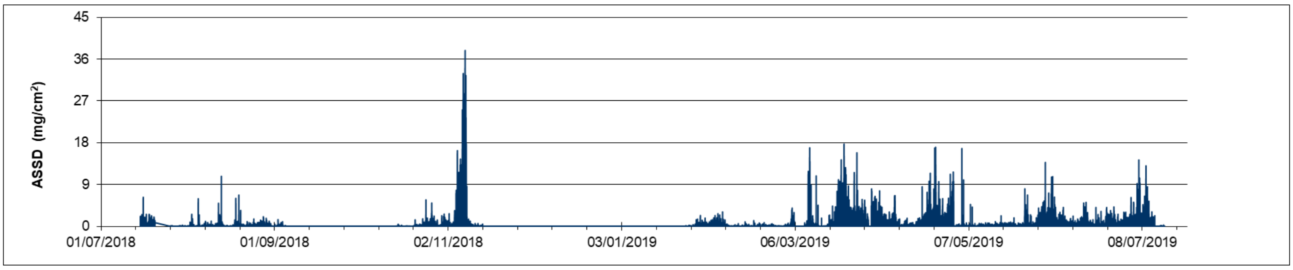
A2 TIME SERIES DATA

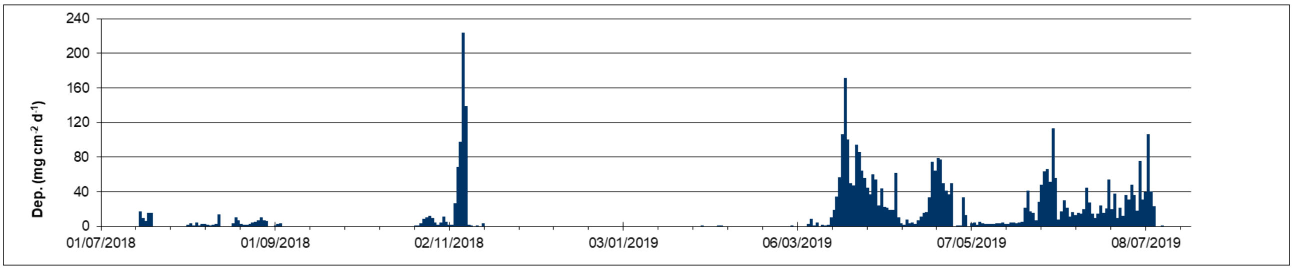
A2.1 AMB1: Freshwater Point

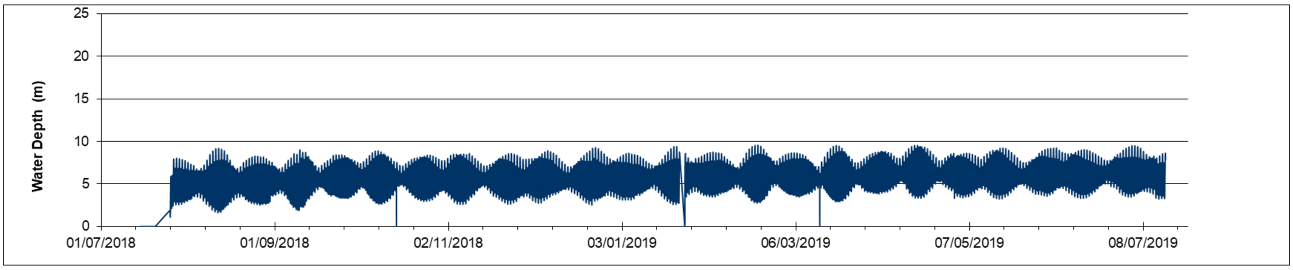


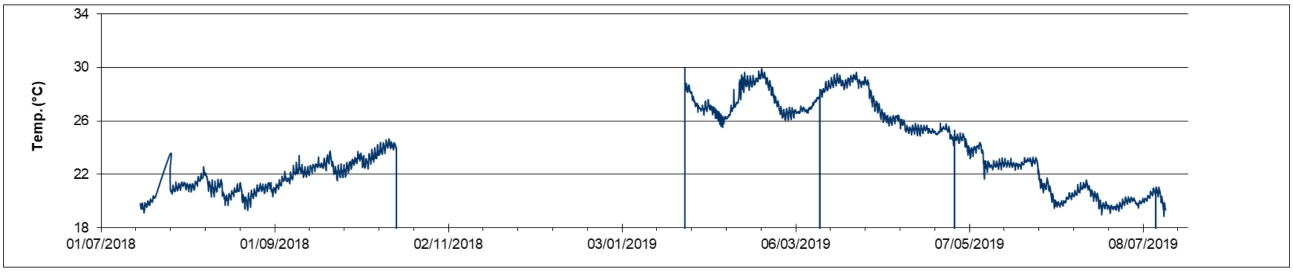












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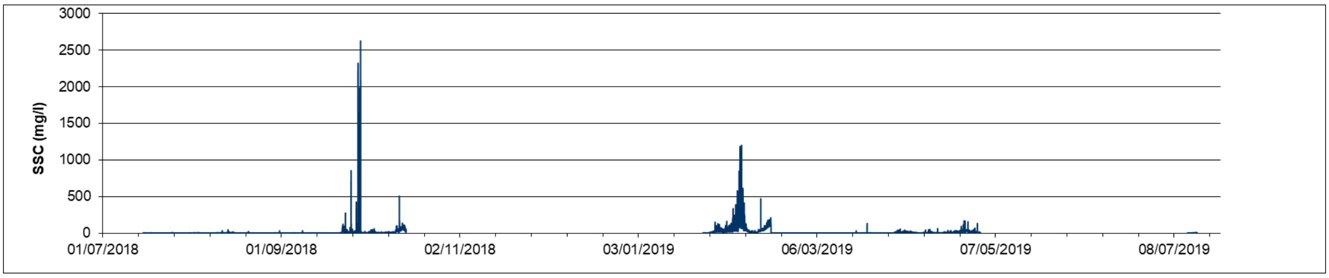
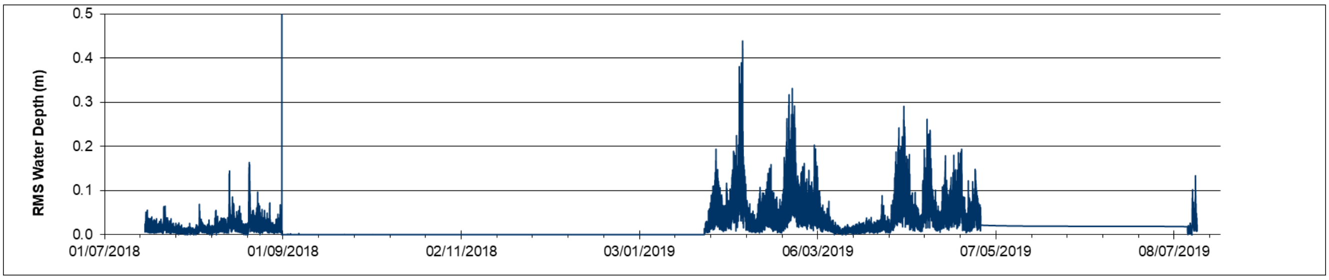
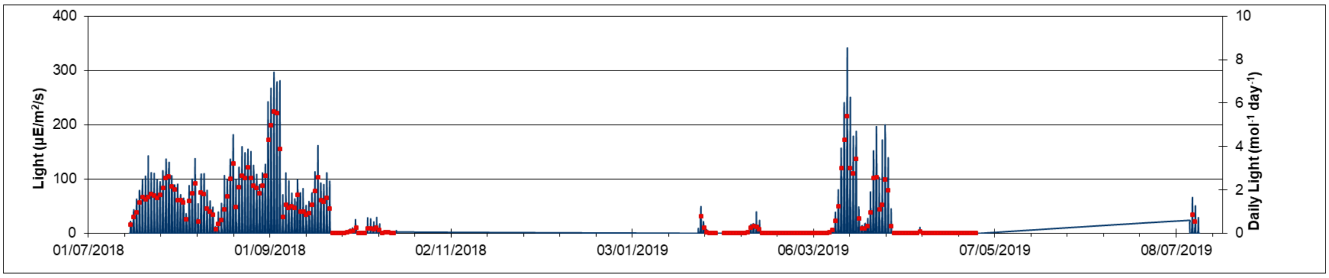
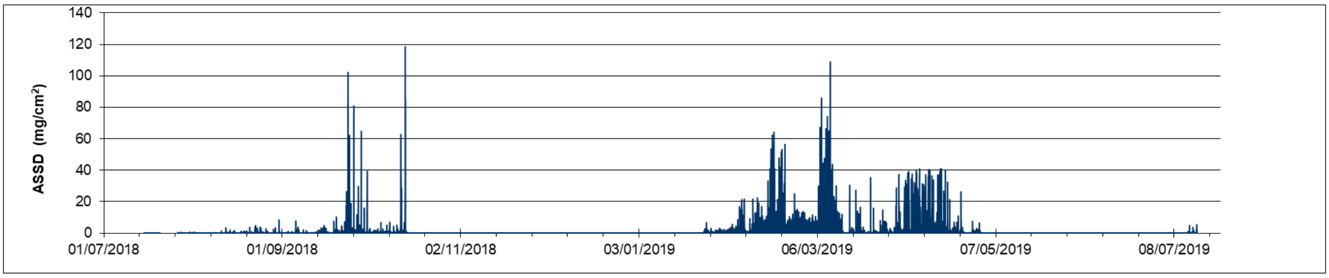
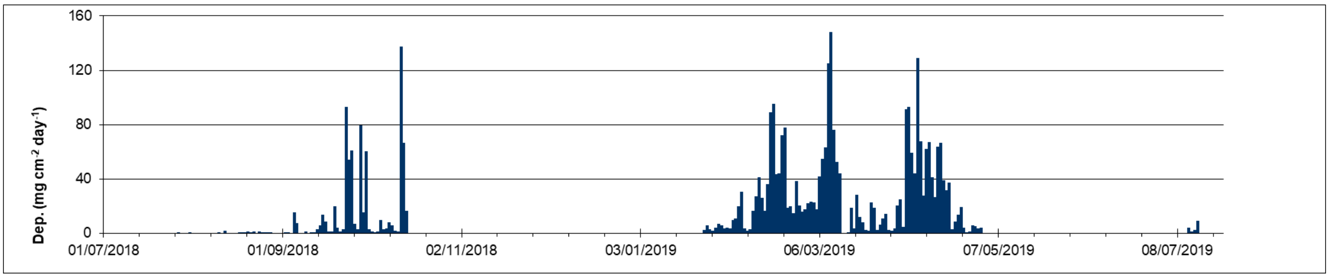
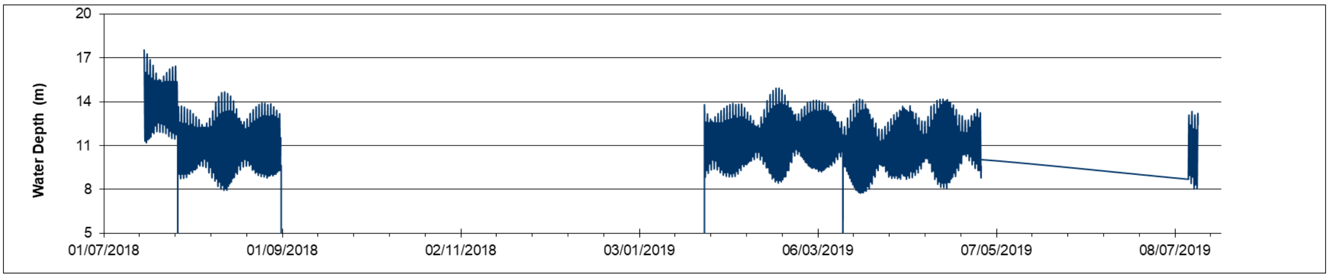


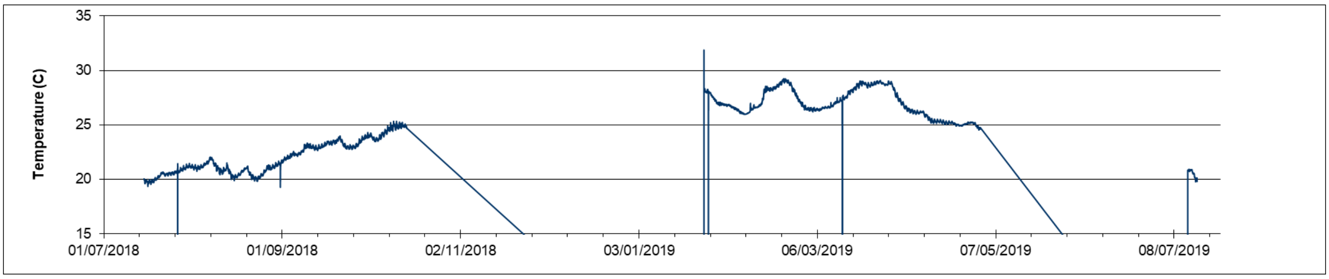




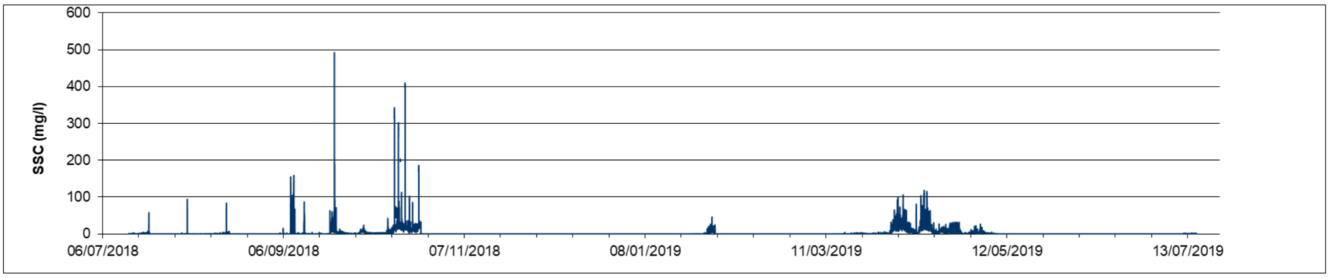


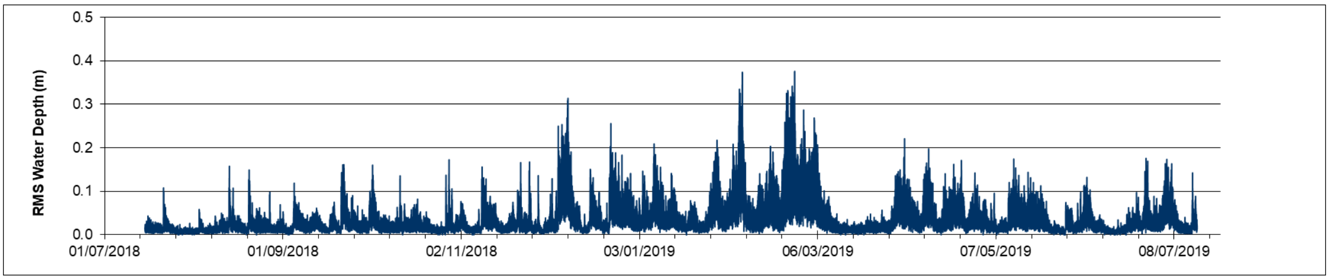


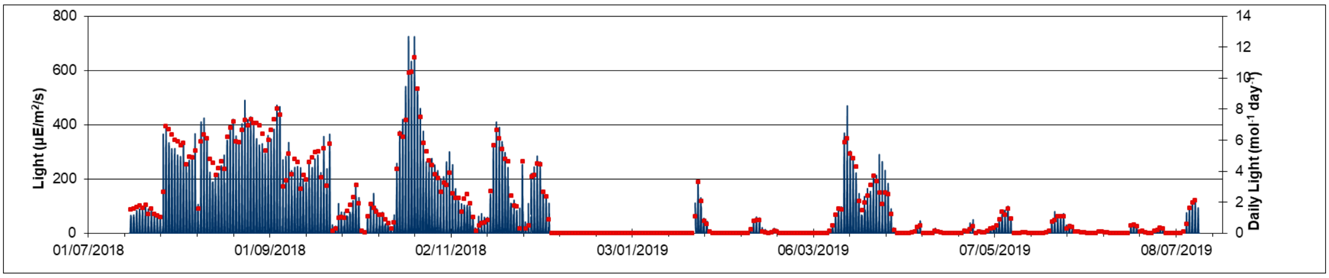


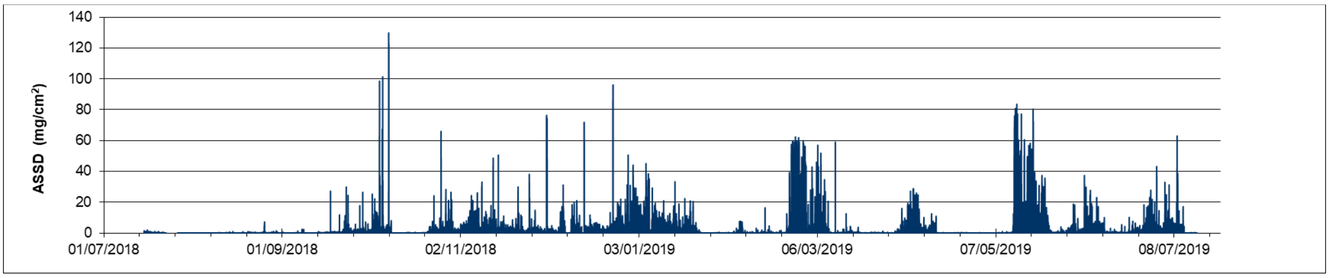


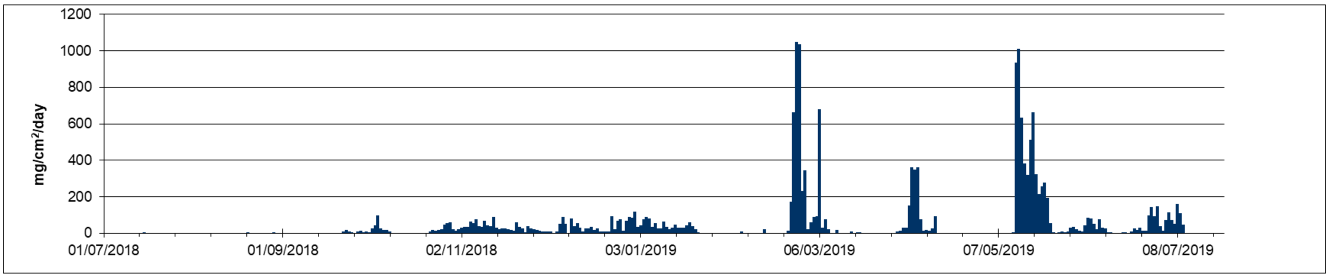
A2.3 AMB3: Round Top Island

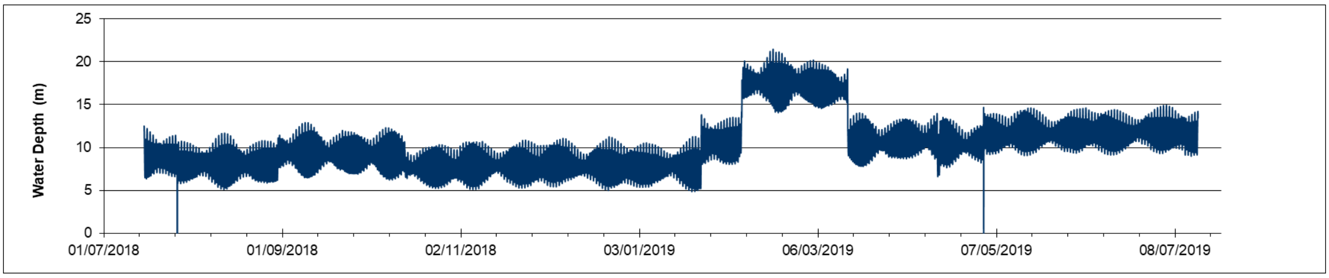


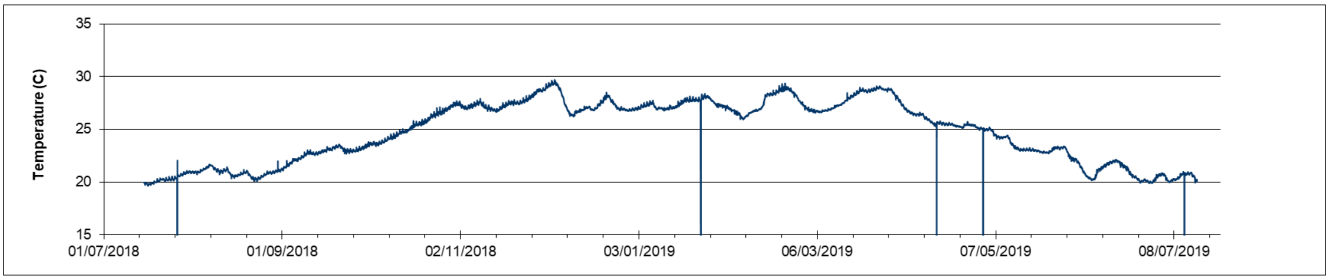












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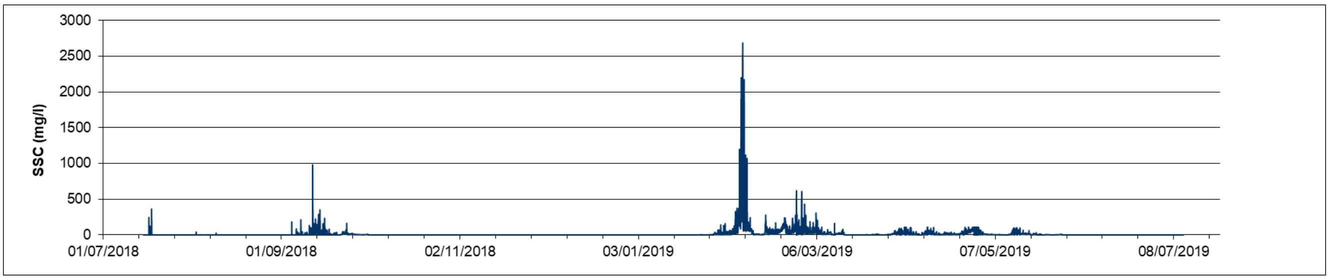

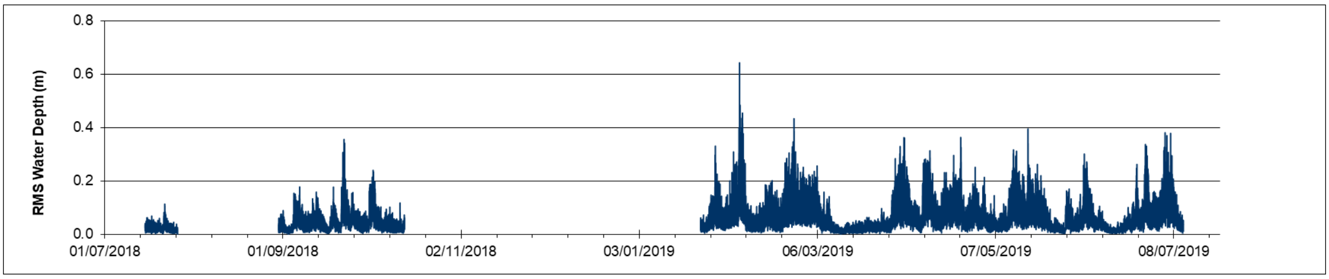

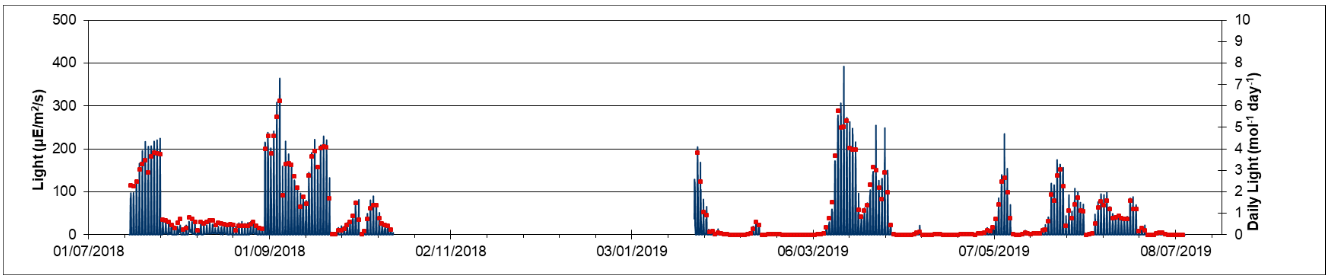

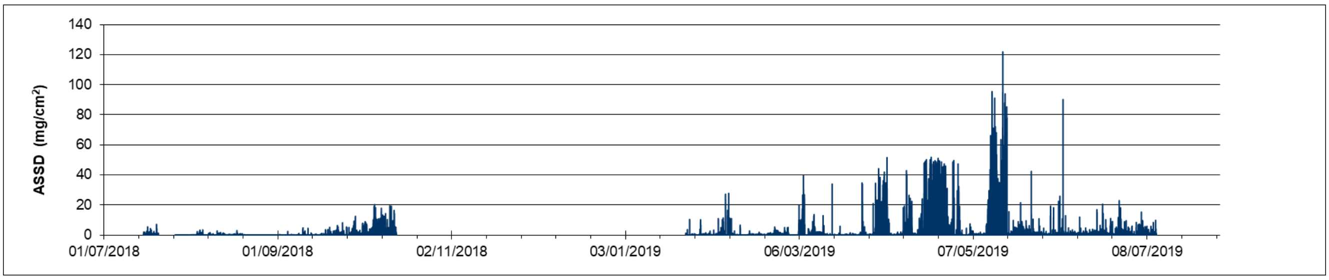

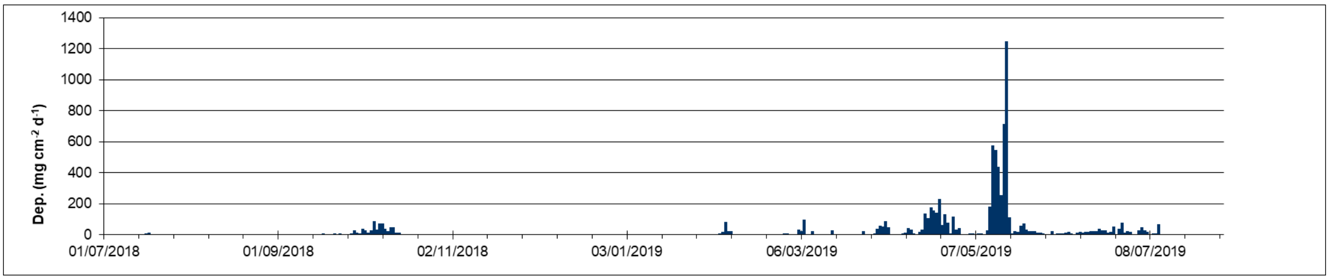

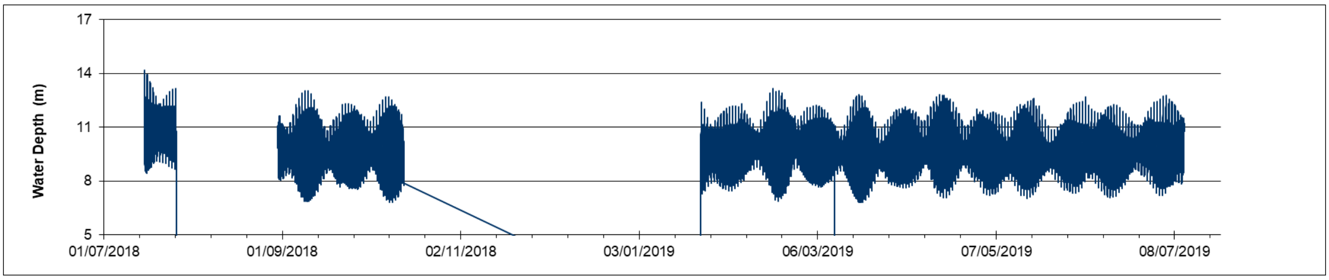

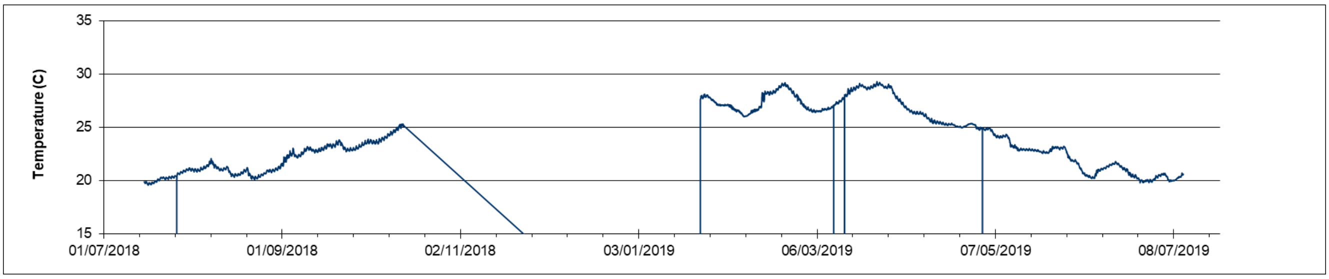

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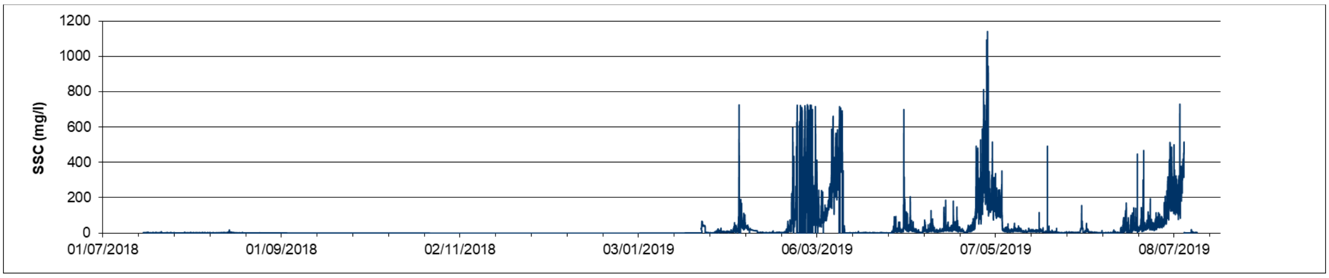

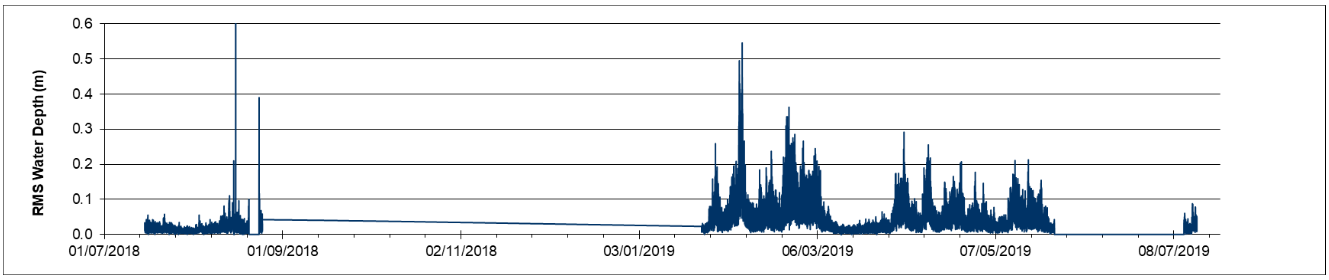

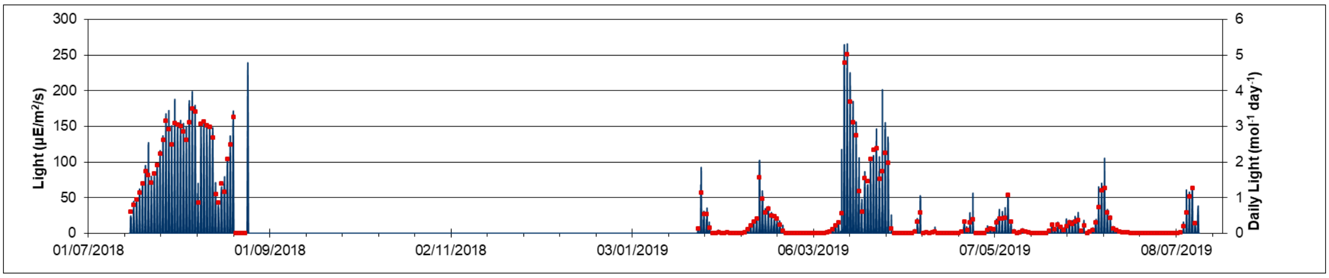
Light (µE/m²/s)
300
250
200
150
100
50
0
Daily Light (mol⁻¹ day⁻¹)
6
5
4
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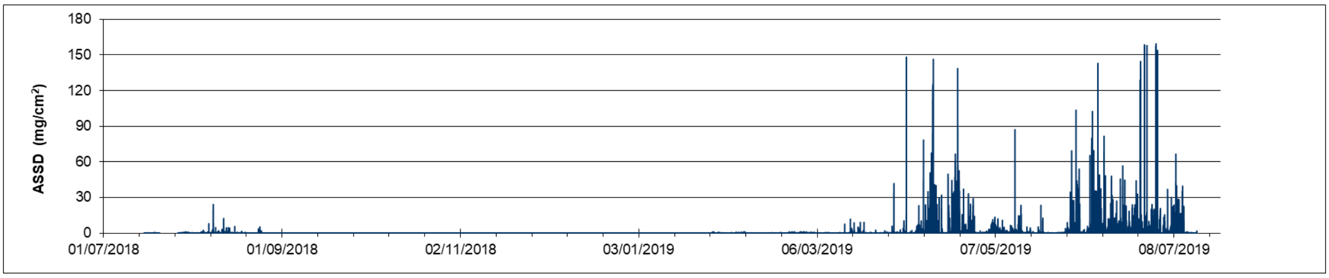
07/05/2019
08/07/2019


ASSD (mg/cm²)
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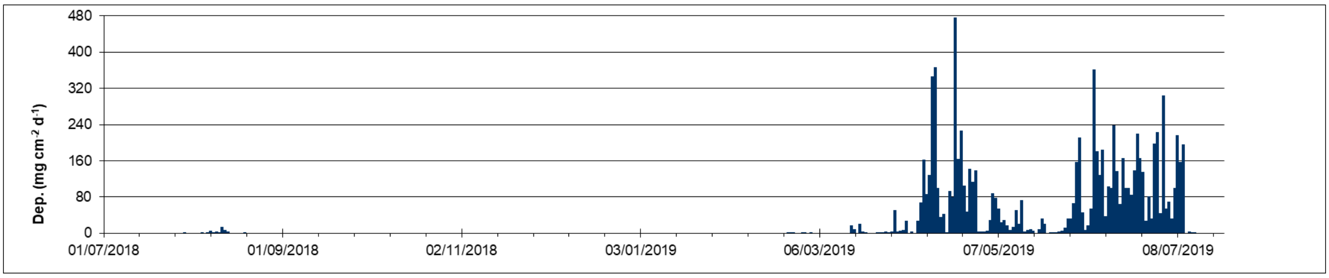
07/05/2019
08/07/2019


Dep. (mg cm⁻² d⁻¹)
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01/07/2018
01/09/2018
02/11/2018
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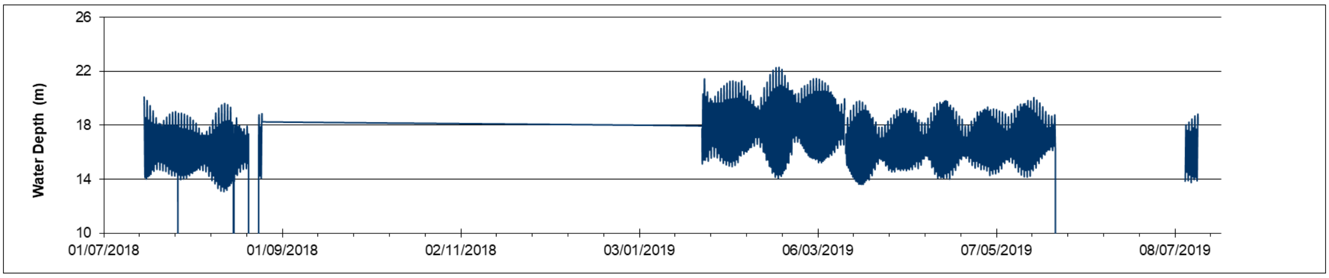
08/07/2019


Water Depth (m)
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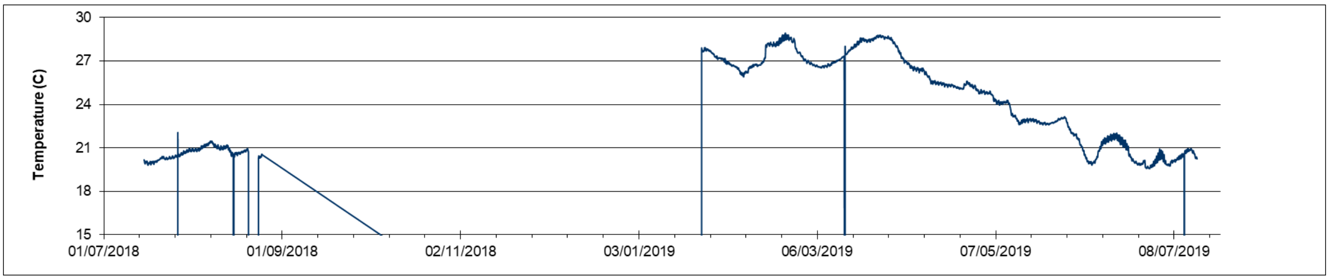
01/07/2018
01/09/2018
02/11/2018
03/01/2019
06/03/2019
07/05/2019
08/07/2019


Temperature (C)
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27
24
21
18
15
01/07/2018
01/09/2018
02/11/2018
03/01/2019
06/03/2019
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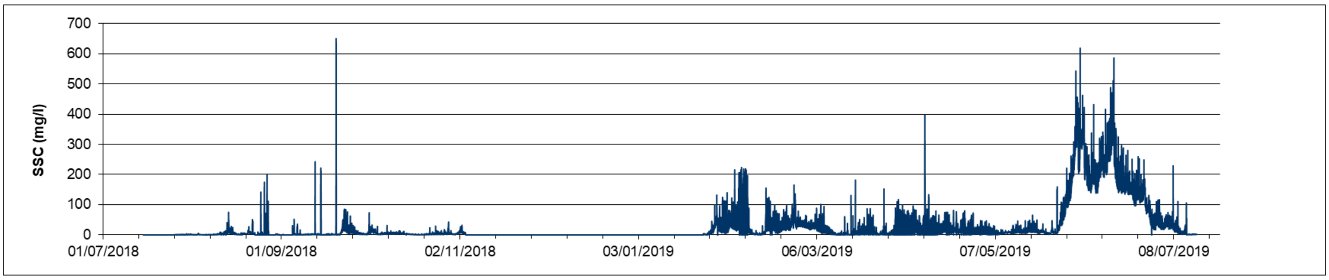
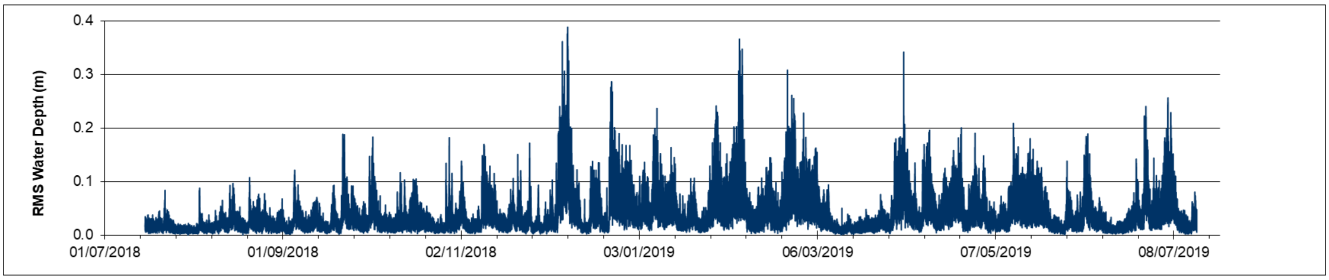
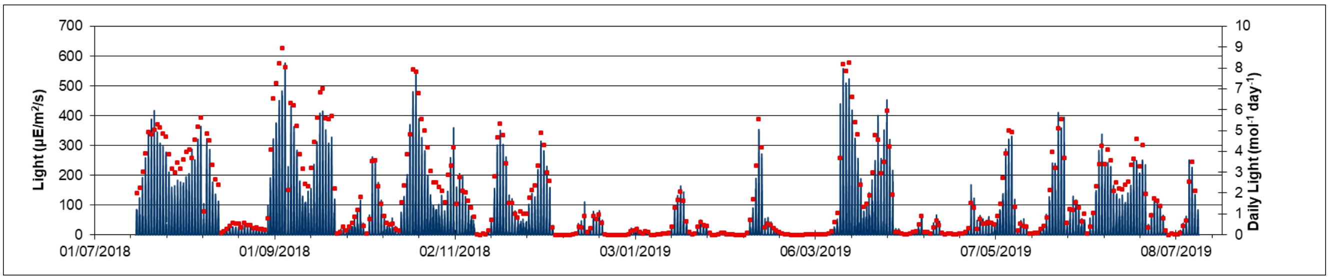
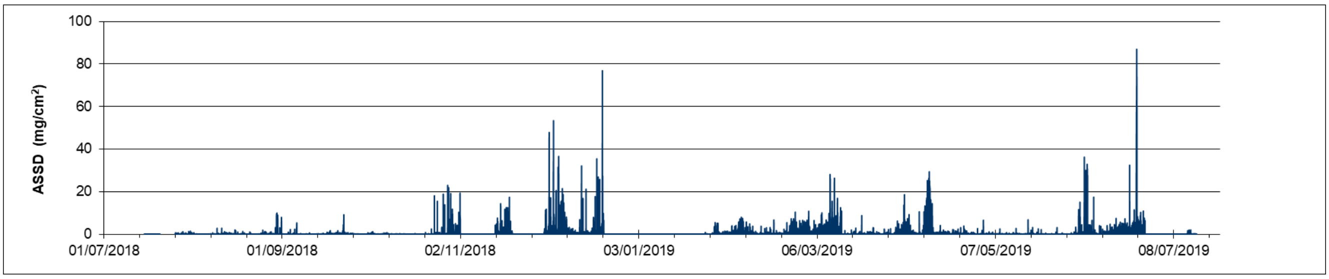
08/07/2019

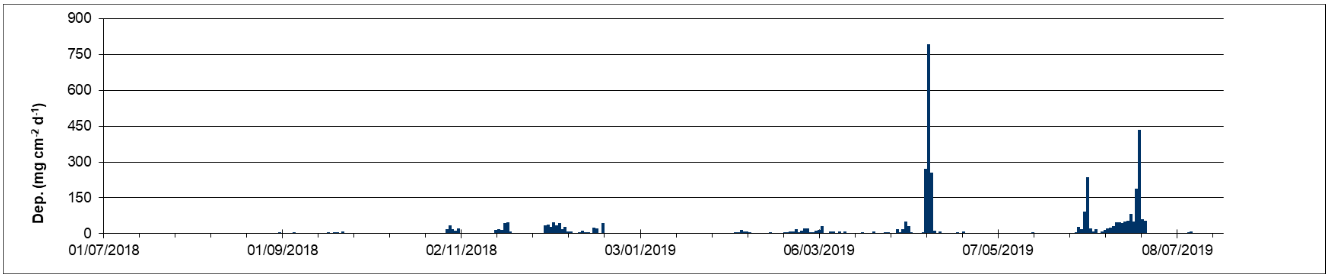
A2.6 AMB10: Victor Island

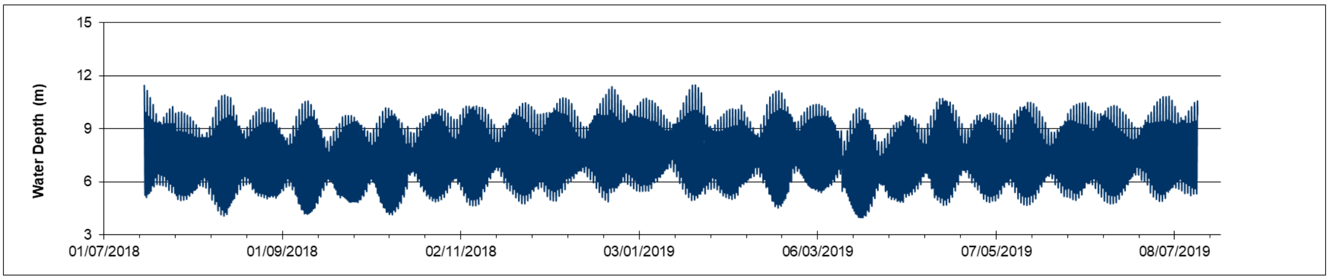


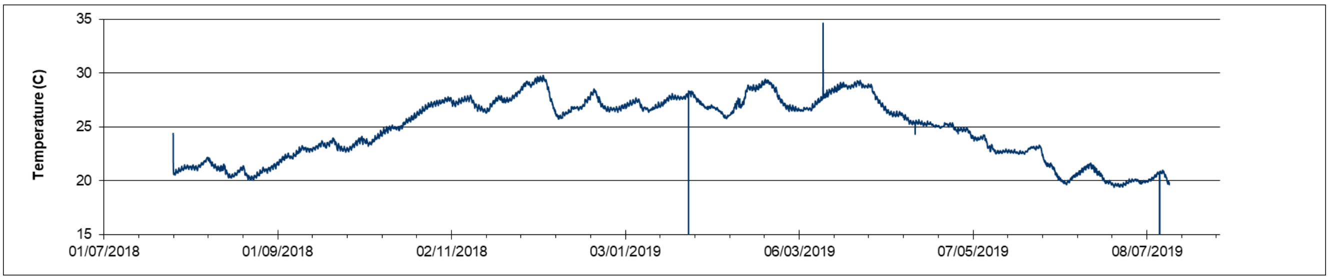




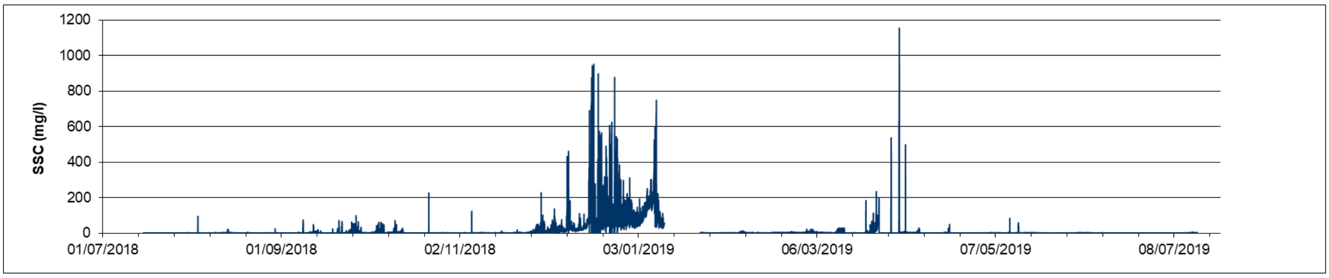


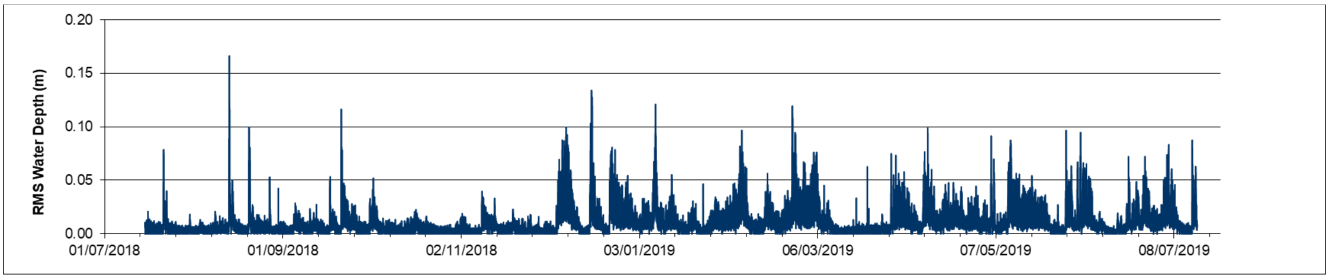


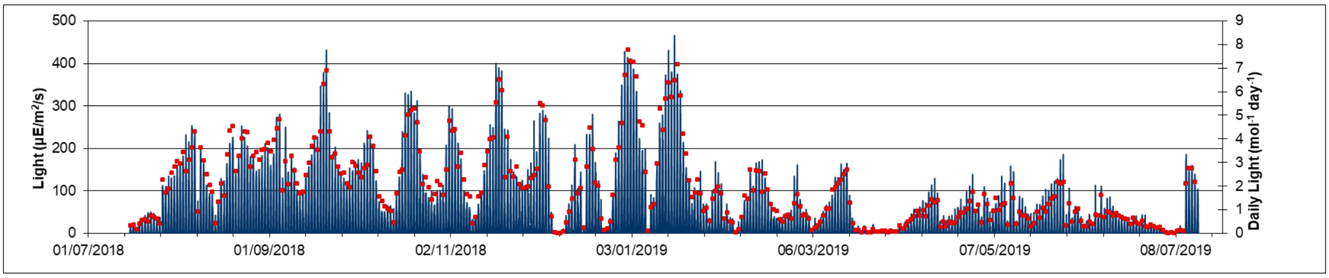


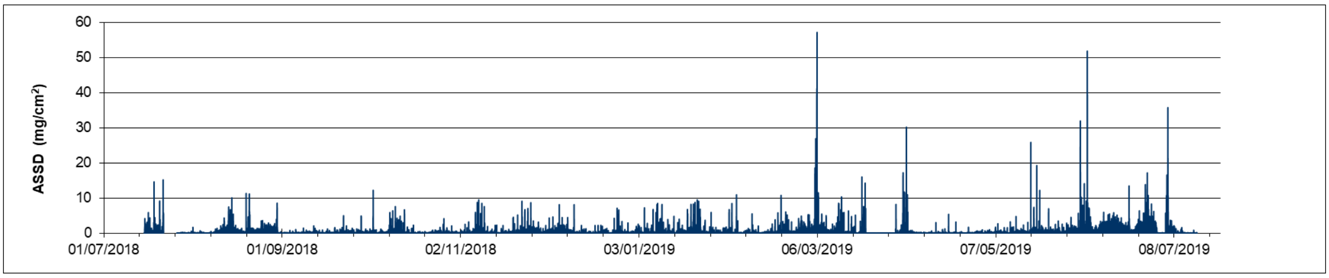


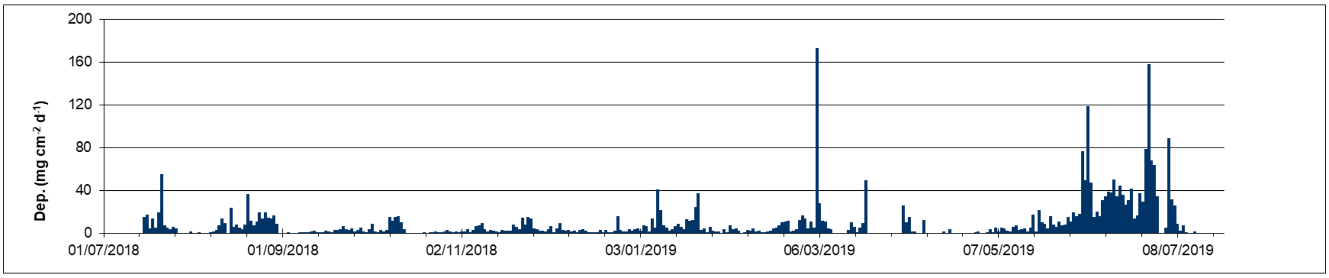
A2.7 AMB12: Keswick Island

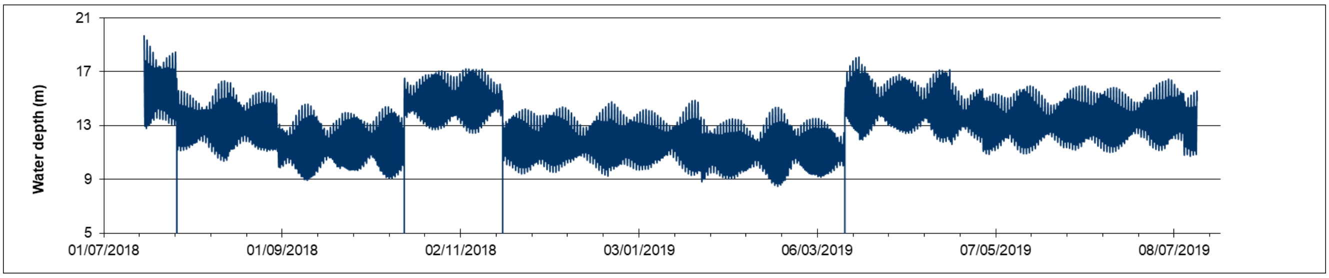


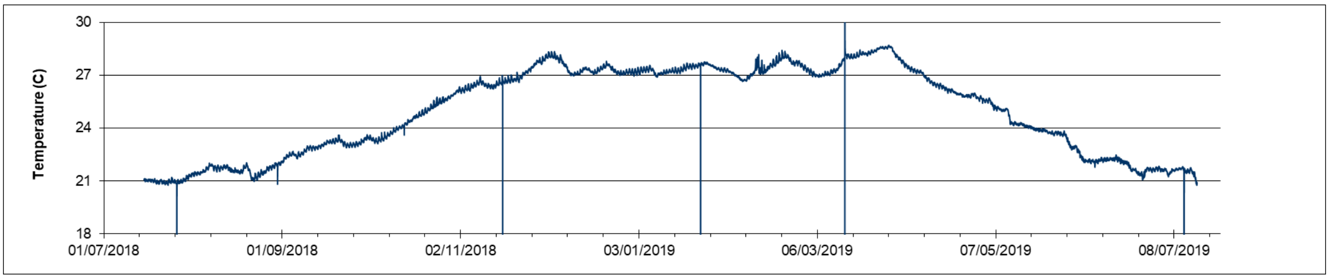









Water depth (m)
21
17
13
9
5
01/07/2018
01/09/2018
02/11/2018
03/01/2019
06/03/2019
07/05/2019
08/07/2019


Temperature (C)
30
27
24
21
18
01/07/2018
01/09/2018
02/11/2018
03/01/2019
06/03/2019
07/05/2019
08/07/2019

A3 SUMMARY OF MONTHLY STATISTICS

A3.1 AMB1: Freshwater Point

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.98	2.70	4.80	10.63	13.85		32.36	24.35	7.28	23.54	6.77	3.96	7.48
median	0.87	1.15	1.69	5.35	0.00		18.52	15.12	1.65	19.28	4.86	1.22	3.24
min	0.00	0.01	0.00	0.00	0.00		1.17	0.00	0.00	4.02	0.04	0.00	0.00
lower	0.30	0.52	0.28	1.18	0.00		9.04	4.83	0.51	14.38	1.14	0.72	1.21
upper	1.39	2.63	5.16	13.20	15.90		41.39	30.13	11.21	27.91	10.22	2.95	11.33
max	5.48	59.54	119.08	93.32	244.77		270.09	250.49	74.94	89.49	58.49	68.05	59.74
90th percentile	2.01	6.31	11.71	30.49	47.64		87.06	56.17	23.00	43.32	16.21	12.02	20.41
10th percentile	0.18	0.23	0.00	0.00	0.00		3.44	2.17	0.23	9.91	0.50	0.41	0.76
n	1668	4127	4317	4430	3946	0	946	4020	4458	4255	4451	4320	2012
St. Dev	0.79	4.76	9.35	14.62	32.57		36.11	30.95	10.41	14.82	6.88	7.01	8.82
St. Error	0.02	0.07	0.14	0.22	0.52		1.17	0.49	0.16	0.23	0.10	0.11	0.20

	Deposition 07/2018	Deposition 08/2018	Deposition 09/2018	Deposition 10/2018	Deposition 11/2018	Deposition 12/2018	Deposition 01/2019	Deposition 02/2019	Deposition 03/2019	Deposition 04/2019	Deposition 05/2019	Deposition 06/2019	Deposition 07/2019
Mean	6.60	3.98	2.42	4.21	44.18		0.38	0.27	37.19	30.71	9.75	29.54	32.48
median	3.21	2.73	2.71	2.05	3.49		0.34	0.20	19.55	21.89	4.26	20.44	31.15

min	0.11	0.03	0.00	0.02	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.30	2.01	1.94	0.41	1.87		0.11	0.16	1.68	8.58	2.98	15.26	5.38
upper	13.99	5.35	3.04	8.78	69.00		0.61	0.29	56.31	50.02	10.13	37.17	40.43
max	17.63	13.85	3.36	12.11	223.47		0.78	1.25	171.86	79.42	48.37	113.16	106.65
90th percentile	16.17	8.17	3.23	10.90	130.63		0.72	0.43	96.73	65.39	28.69	56.76	67.54
10th percentile	0.12	0.68	1.48	0.12	0.94		0.10	0.08	0.36	3.32	1.94	11.04	0.53
n	10	28	3	17	13	0	7	28	27	30	31	30	14
St. Dev	7.45	3.39	1.13	4.48	70.12		0.29	0.25	43.98	25.24	12.42	23.19	30.51
St. Error	2.36	0.64	0.65	1.09	19.45		0.11	0.05	8.46	4.61	2.23	4.23	8.15

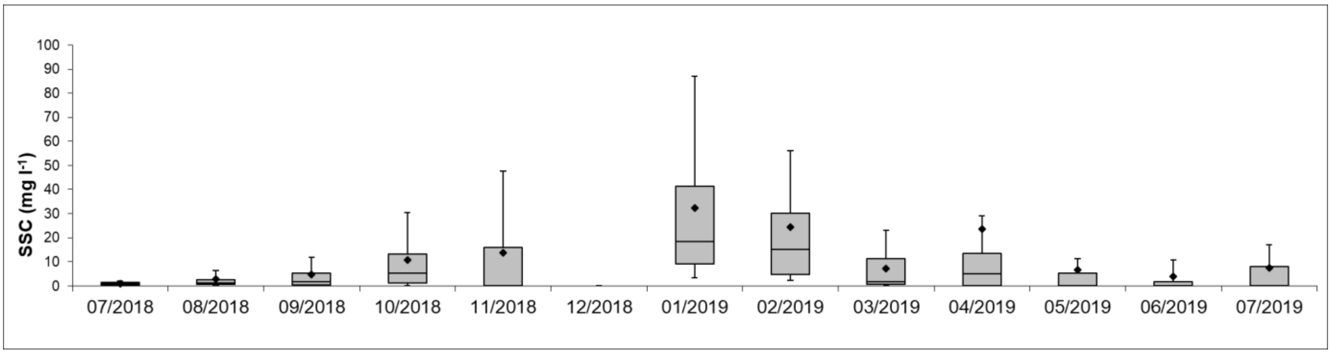
	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	RMS 04/2019	RMS 05/2019	RMS 06/2019	RMS 07/2019
Mean	0.01	0.02	0.03	0.03	0.03	0.07	0.06	0.07	0.03	0.06	0.04	0.04	0.04
median	0.01	0.02	0.02	0.02	0.02	0.05	0.05	0.05	0.02	0.06	0.04	0.03	0.03
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
lower	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.01	0.04	0.02	0.02	0.02
upper	0.02	0.03	0.04	0.03	0.04	0.09	0.07	0.09	0.04	0.08	0.06	0.05	0.06
max	0.05	0.16	0.28	0.21	0.21	0.34	0.27	0.39	0.22	0.26	0.28	0.23	0.23
90th percentile	0.02	0.04	0.06	0.05	0.07	0.14	0.10	0.13	0.07	0.11	0.08	0.07	0.09
10th percentile	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01
n	1678	4455	4320	4462	4244	4464	4186	4032	4462	4320	4463	4320	2014

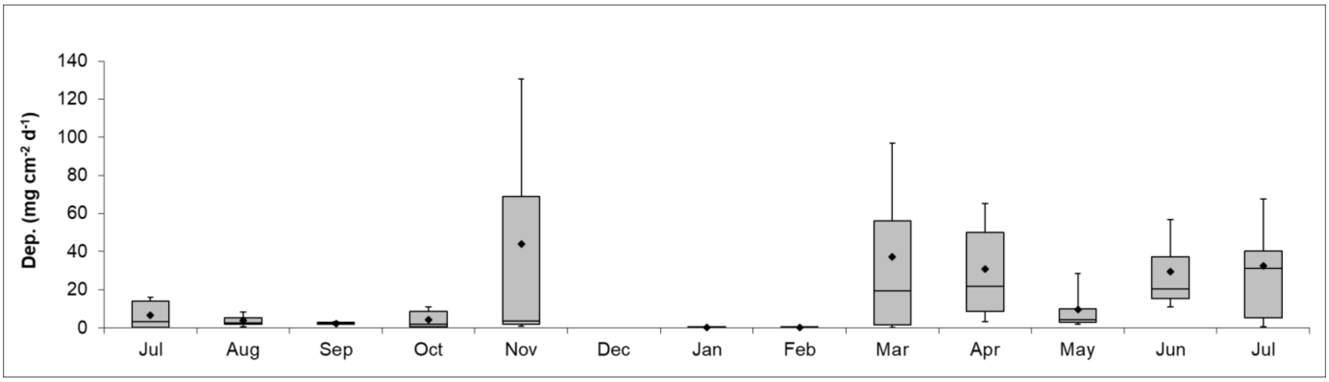
St. Dev	0.01	0.02	0.02	0.02	0.03	0.05	0.03	0.05	0.03	0.04	0.03	0.03	0.04
St. Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

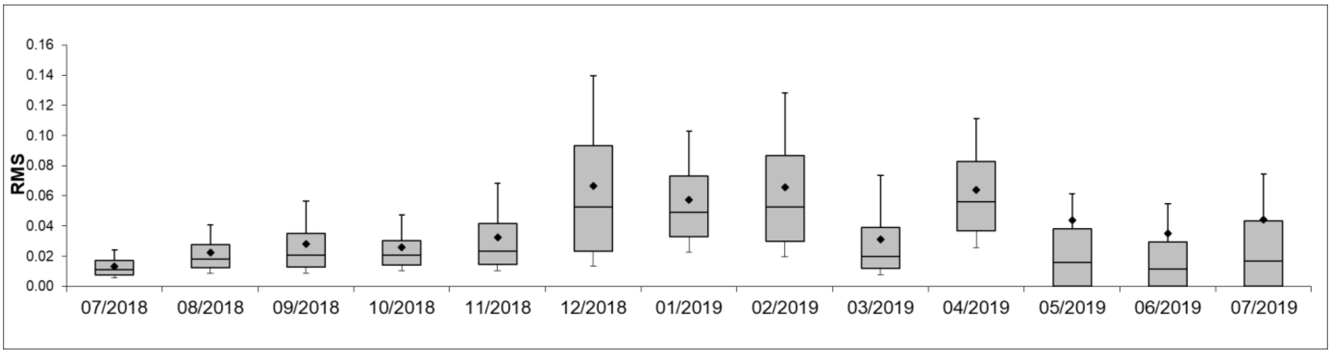
	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	20.49	20.89	22.31	23.61			27.65	27.75	27.97	25.84	23.28	20.28	20.20
median	20.71	20.89	22.36	23.58			27.50	27.42	28.34	25.53	22.94	20.25	20.12
min	19.12	19.30	20.60	22.41			26.65	25.52	26.07	24.65	21.59	18.97	19.49
lower	19.83	20.54	21.97	23.19			27.02	26.81	26.84	25.27	22.71	19.71	19.96
upper	21.10	21.24	22.70	24.11			28.23	28.92	28.92	26.26	23.95	20.84	20.43
max	23.53	22.57	23.76	24.67			29.89	29.92	29.64	28.83	25.31	21.75	21.06
90th percentile	21.27	21.58	23.03	24.28			28.59	29.22	29.17	27.08	24.59	21.16	20.74
10th percentile	19.61	20.15	21.52	22.90			26.90	26.31	26.62	25.11	22.57	19.53	19.83
n	1678	4455	4320	1935	0	0	948	4032	4454	4320	4453	4320	2005
St. Dev	0.67	0.55	0.59	0.54			0.65	1.14	1.05	0.80	0.78	0.63	0.34
St. Error	0.02	0.01	0.01	0.01			0.02	0.02	0.02	0.01	0.01	0.01	0.01

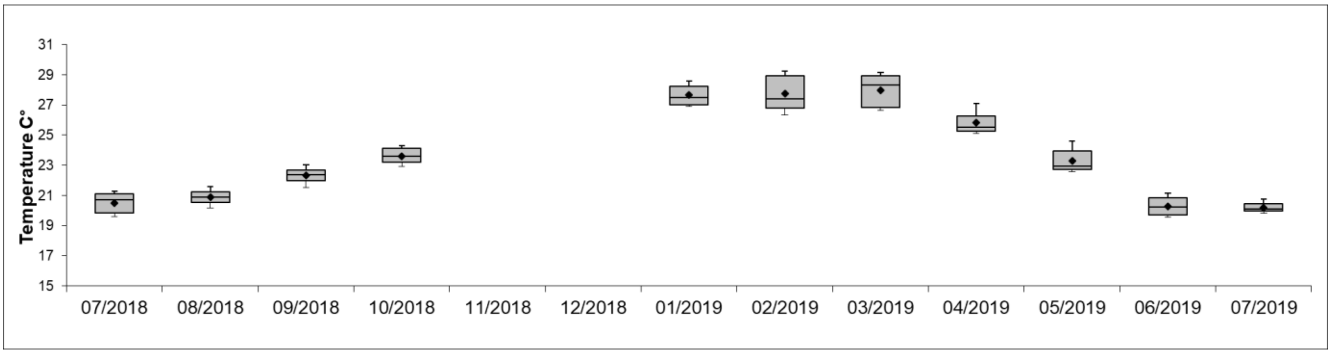
	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light

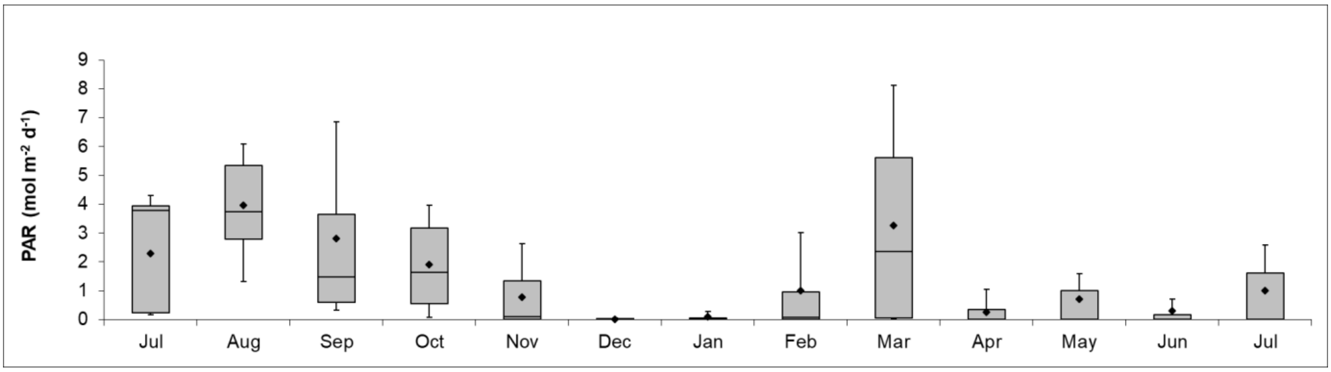
	07/2018	08/2018	09/2018	10/2018	11/2018	12/2018	01/2019	02/2019	03/2019	04/2019	05/2019	06/2019	07/2019
Mean	2.30	3.96	2.81	1.91	0.78	0.02	0.09	1.00	3.27	0.26	0.70	0.31	1.00
median	3.79	3.74	1.49	1.63	0.09	0.00	0.03	0.08	2.37	0.02	0.23	0.16	0.21
min	0.11	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.24	2.78	0.61	0.56	0.00	0.00	0.01	0.00	0.06	0.00	0.08	0.08	0.01
upper	3.93	5.35	3.64	3.17	1.33	0.01	0.05	0.97	5.61	0.35	1.24	0.32	1.82
max	4.32	7.11	10.87	5.11	3.37	0.17	0.91	7.22	11.62	1.85	2.45	1.76	3.96
90th percentile	4.31	6.09	6.86	3.96	2.63	0.06	0.28	3.02	8.12	1.05	1.82	0.87	2.79
10th percentile	0.17	1.33	0.32	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
n	11	31	30	31	30	31	28	28	31	30	31	30	14
St. Dev	1.99	1.95	3.10	1.57	1.10	0.04	0.19	1.90	3.23	0.48	0.81	0.41	1.32
St. Error	0.60	0.35	0.57	0.28	0.20	0.01	0.04	0.36	0.58	0.09	0.15	0.08	0.35


SSC (mg l⁻¹)
0
10
20
30
40
50
60
70
80
90
100
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Dep. (mg cm⁻² d⁻¹)
0
20
40
60
80
100
120
140
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul


RMS
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Temperature C°
15
17
19
21
23
25
27
29
31
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


PAR (mol m⁻² d⁻¹)
0
1
2
3
4
5
6
7
8
9
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

A3.2 AMB2: Hay Reef

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.86	1.69	15.04	1.09			0.04	83.97	0.45	9.02			2.24
median	0.67	1.02	1.25	8.91			11.18	40.96	0.10	5.12			10.85
min	0.00	0.00	0.00	0.00			8.84	8.20	0.00	0.00			8.04
lower	0.45	0.58	0.57	5.10			10.06	20.81	0.02	2.86			9.40
upper	1.06	1.84	4.40	26.90			12.27	95.78	0.28	9.75			12.10
max	9.97	44.71	2624.75	500.08			13.79	1199.16	132.28	165.66			13.34
90th percentile	1.67	3.64	13.31	57.47			12.68	169.48	0.74	19.75			12.88
10th percentile	0.25	0.33	0.17	3.79			9.51	13.08	0.00	1.60			8.86
n	2441	4139	4319	1905	0	0	923	2448	2491	4245	0	0	344
St. Dev	0.68	2.48	144.05	28.63			1.22	128.79	3.92	12.79			1.51
St. Error	0.01	0.04	2.19	0.66			0.04	2.60	0.08	0.20			0.08

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	0.33	0.52	15.45	18.50			4.30	28.75	28.82	35.58			2.58
median	0.24	0.37	3.15	3.21			3.99	20.06	18.32	27.45			2.27
min	0.04	0.03	0.00	0.00			0.00	0.00	0.00	0.00			0.52
lower	0.05	0.15	0.84	1.47			2.84	10.34	4.25	5.51			1.86
upper	0.49	0.73	14.84	9.29			5.84	39.03	38.40	61.27			3.14
max	0.84	1.77	93.15	137.23			6.82	95.43	148.43	129.18			4.01

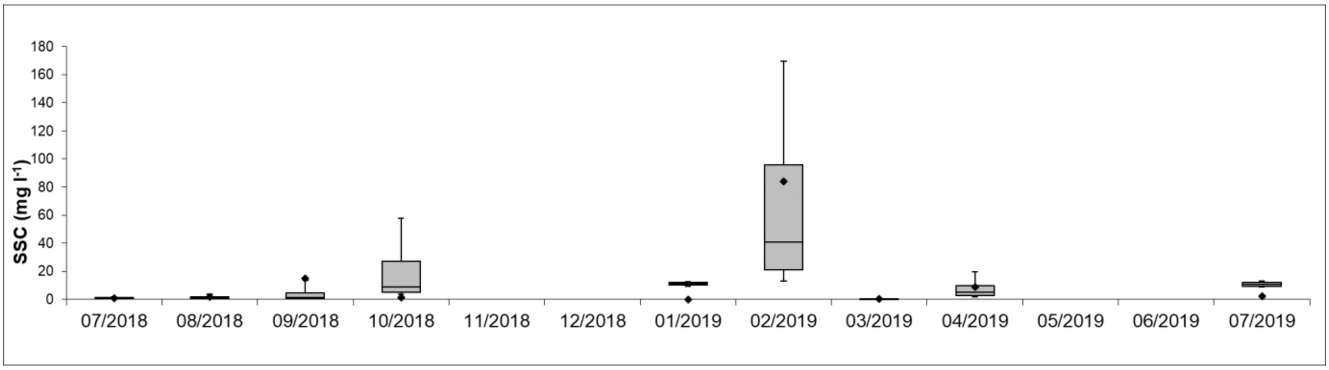
90th percentile	0.70	1.22	60.44	51.50			6.28	73.80	64.58	70.26			3.66
10th percentile	0.05	0.06	0.24	1.14			2.24	3.54	2.09	3.54			1.62
n	5	27	30	14	0	0	7	28	30	30	1	0	3
St. Dev	0.34	0.47	25.89	38.20			1.89	26.35	35.60	32.99			1.31
St. Error	0.15	0.09	4.73	10.21			0.71	4.98	6.50	6.02			0.75

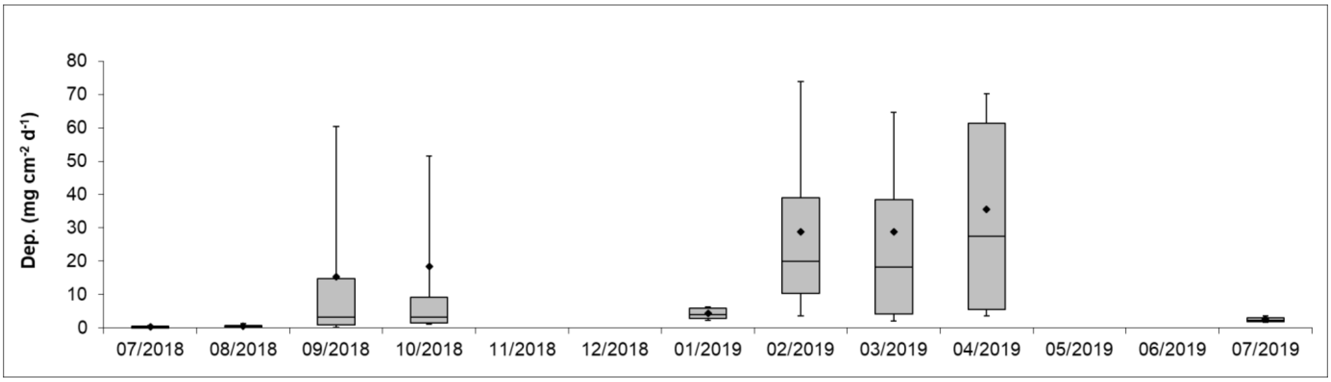
	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	RMS 04/2019	RMS 05/2019	RMS 06/2019	RMS 07/2019
Mean	0.013	0.019	0.000	0.000			0.041	0.061	0.024	0.058			0.019
median	0.011	0.015	0.000	0.000			0.034	0.047	0.015	0.050			0.013
min	0.000	0.000	0.000	0.000			0.004	0.004	0.000	0.004			0.000
lower	0.008	0.009	0.000	0.000			0.019	0.027	0.009	0.031			0.008
upper	0.017	0.023	0.000	0.000			0.055	0.078	0.029	0.075			0.023
max	0.065	3.853	0.003	0.000			0.194	0.439	0.202	0.291			0.102
90th percentile	0.023	0.034	0.000	0.000			0.080	0.121	0.056	0.106			0.043
10th percentile	0.005	0.006	0.000	0.000			0.012	0.017	0.007	0.021			0.005
n	2445	4463	4320	1920	0	0	923	4031	4455	4320	0	0	344
St. Dev	0.007	0.059	0.000	0.000			0.029	0.049	0.023	0.036			0.017
St. Error	0.000	0.001	0.000	0.000			0.001	0.001	0.000	0.001			0.001

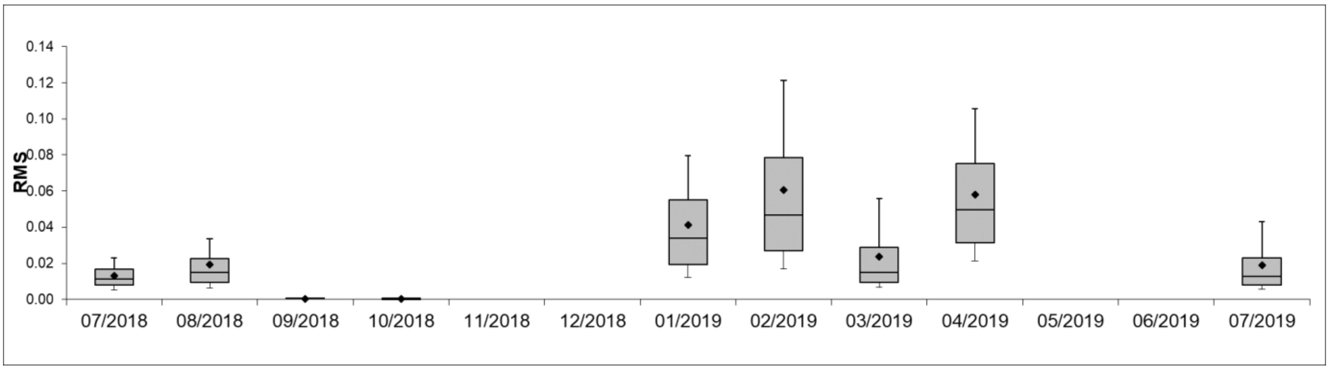
	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	20.48	20.89	22.96	24.39			27.53	27.39	27.70	25.79			20.74
median	20.54	20.97	23.01	24.49			27.53	26.95	27.77	25.34			20.80
min	19.35	19.32	21.53	23.47			26.77	25.96	26.19	24.70			20.46
lower	20.03	20.47	22.64	23.91			27.03	26.58	26.60	25.14			20.61
upper	20.83	21.22	23.37	24.85			27.98	28.31	28.73	26.23			20.86
max	21.46	22.05	24.30	25.33			31.66	29.24	29.08	28.68			20.92
90th percentile	21.13	21.46	23.65	24.98			28.10	28.84	28.86	27.16			20.88
10th percentile	19.79	20.20	22.13	23.67			26.94	26.13	26.43	25.01			20.52
n	2445	4464	4320	1920	0	0	918	4031	4448	4320	0	0	329
St. Dev	0.48	0.48	0.56	0.51			0.50	1.01	1.01	0.88			0.14
St. Error	0.01	0.01	0.01	0.01			0.02	0.02	0.02	0.01			0.01

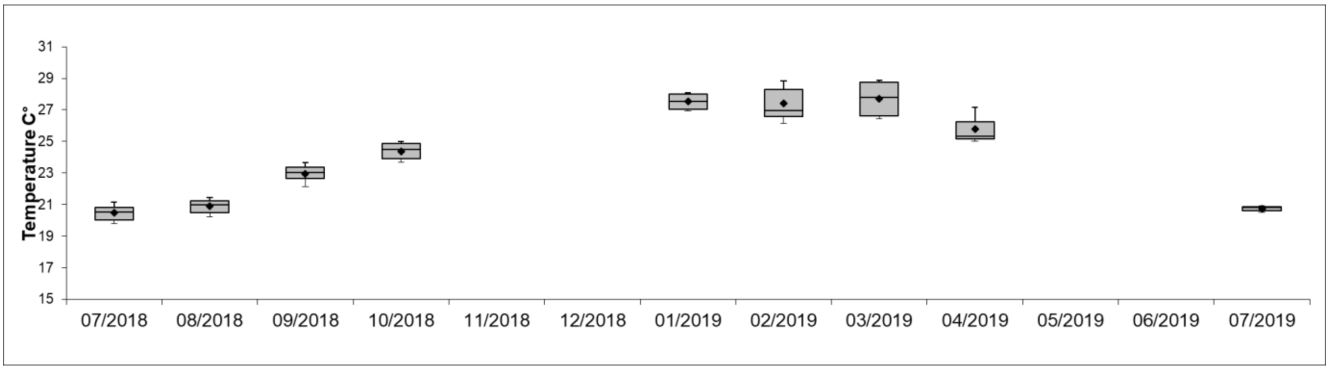
	Light 07/2018	Light 08/2018	Light 09/2018	Light 10/2018	Light 11/2018	Light 12/2018	Light 01/2019	Light 02/2019	Light 03/2019	Light 04/2019	Light 05/2019	Light 06/2019	Light 07/2019
Mean	1.67	2.20	0.73	0.08			0.00	0.04	1.25	0.01			

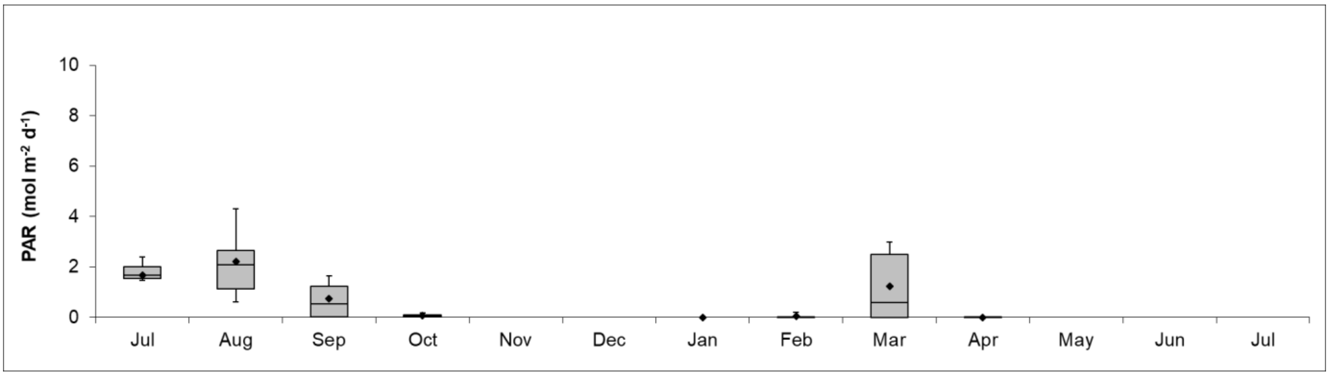
median	1.66	2.09	0.55	0.06			0.00	0.00	0.58	0.00			
min	0.40	0.19	0.00	0.01			0.00	0.00	0.00	0.00			
lower	1.53	1.13	0.03	0.02			0.00	0.00	0.00	0.00			
upper	2.01	2.65	1.23	0.11			0.00	0.01	2.51	0.00			
max	2.62	5.60	2.59	0.24			0.00	0.34	5.41	0.09			
90th percentile	2.40	4.31	1.64	0.19			0.00	0.21	3.00	0.01			
10th percentile	1.46	0.61	0.01	0.01			0.00	0.00	0.00	0.00			
n	17	31	30	7	0	0	5	28	31	24	0	0	0
St. Dev	0.47	1.44	0.74	0.09			0.00	0.10	1.49	0.02			
St. Error	0.11	0.26	0.13	0.03			0.00	0.02	0.27	0.00			


SSC (mg l⁻¹)
180
160
140
120
100
80
60
40
20
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Dep. (mg cm⁻² d⁻¹)
80
70
60
50
40
30
20
10
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


RMS
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Temperature C°
31
29
27
25
23
21
19
17
15
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


PAR (mol m⁻² d⁻¹)
10
8
6
4
2
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

A3.3 AMB3: Round Top Island

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.59	0.68	3.21	13.88			3.92		0.59	12.48	2.54		1.07
median	0.38	0.34	0.00	3.60			0.49		0.46	7.93	1.67		1.01
min	0.00	0.00	0.00	0.23			0.00		0.04	0.00	0.00		0.46
lower	0.13	0.22	0.00	1.61			0.08		0.27	3.63	0.95		0.83
upper	0.65	0.61	1.21	12.98			6.57		0.72	16.80	3.21		1.23
max	56.95	93.79	490.17	409.38			45.88		6.34	117.91	26.68		2.88
90th percentile	0.91	1.08	6.03	23.62			12.69		1.10	27.56	5.28		1.47
10th percentile	0.05	0.15	0.00	1.04			0.00		0.16	1.29	0.54		0.70
n	1812	2767	4320	2833	0	0	1065	0	2251	4277	1139	0	499
St. Dev	2.13	3.23	15.30	40.35			6.19		0.54	14.04	2.71		0.35
St. Error	0.05	0.06	0.23	0.76			0.19		0.01	0.21	0.08		0.02

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	1.06	0.96	3.43	22.14	35.02	37.87	34.91	115.15	49.27	52.00	194.40	33.66	59.55
median	0.51	0.67	1.15	16.79	29.23	27.67	30.90	1.11	2.00	1.75	7.41	21.81	48.93
min	0.00	0.02	0.01	0.07	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.04	0.09	0.40	4.49	21.70	10.38	8.66	0.63	1.32	0.61	0.53	7.46	3.86

upper	1.37	1.12	4.09	27.24	40.77	64.71	47.16	10.82	23.06	29.56	308.49	42.99	100.71
max	3.94	5.11	17.55	99.37	89.61	91.77	120.02	1050.50	678.00	362.16	1013.06	141.97	159.60
90th percentile	3.02	2.32	10.20	54.15	64.64	85.96	75.57	362.40	89.88	171.62	636.93	85.92	139.96
10th percentile	0.02	0.04	0.04	0.57	15.98	8.67	0.37	0.51	0.66	0.39	0.18	2.38	0.19
n	10	30	30	24	30	30	30	28	30	30	30	30	14
St. Dev	1.38	1.22	4.73	24.04	20.28	30.18	29.76	294.09	135.91	108.85	291.06	35.71	56.29
St. Error	0.43	0.22	0.86	4.91	3.70	5.51	5.43	55.58	24.81	19.87	53.14	6.52	15.04

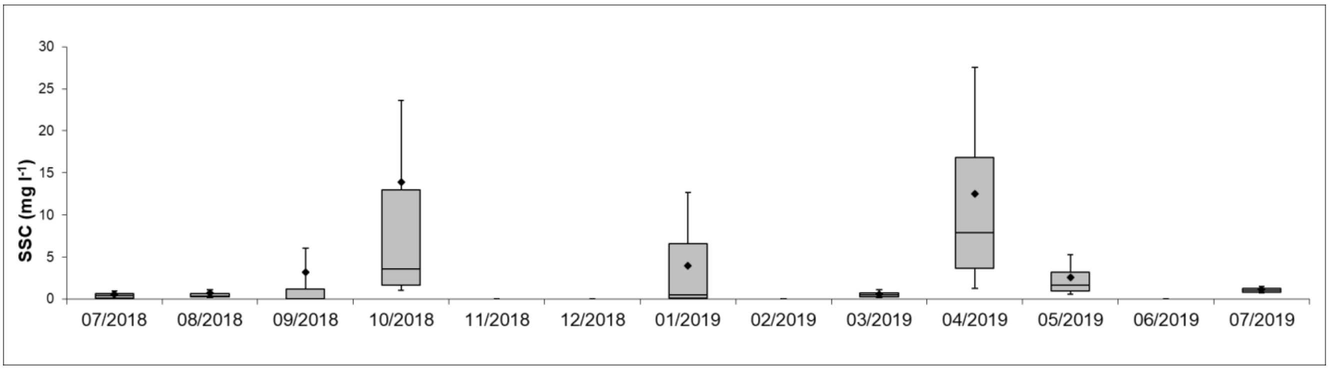
	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	RMS 04/2019	RMS 05/2019	RMS 06/2019	RMS 07/2019
Mean	0.01	0.02	0.02	0.02	0.02	0.05	0.04	0.07	0.03	0.05	0.03	0.02	0.03
median	0.01	0.01	0.02	0.02	0.02	0.04	0.03	0.06	0.02	0.04	0.02	0.02	0.02
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.04	0.01	0.02	0.01	0.01	0.01
upper	0.01	0.02	0.03	0.03	0.03	0.07	0.05	0.09	0.04	0.06	0.04	0.03	0.04
max	0.11	0.16	0.16	0.17	0.17	0.31	0.22	0.37	0.29	0.22	0.17	0.18	0.17
90th percentile	0.02	0.03	0.04	0.04	0.05	0.10	0.08	0.14	0.09	0.08	0.06	0.05	0.07
10th percentile	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01
n	2433	4461	4320	4459	4244	4464	4443	4032	4460	4317	4455	4320	2014
St. Dev	0.01	0.01	0.02	0.02	0.02	0.04	0.03	0.05	0.04	0.03	0.02	0.02	0.03

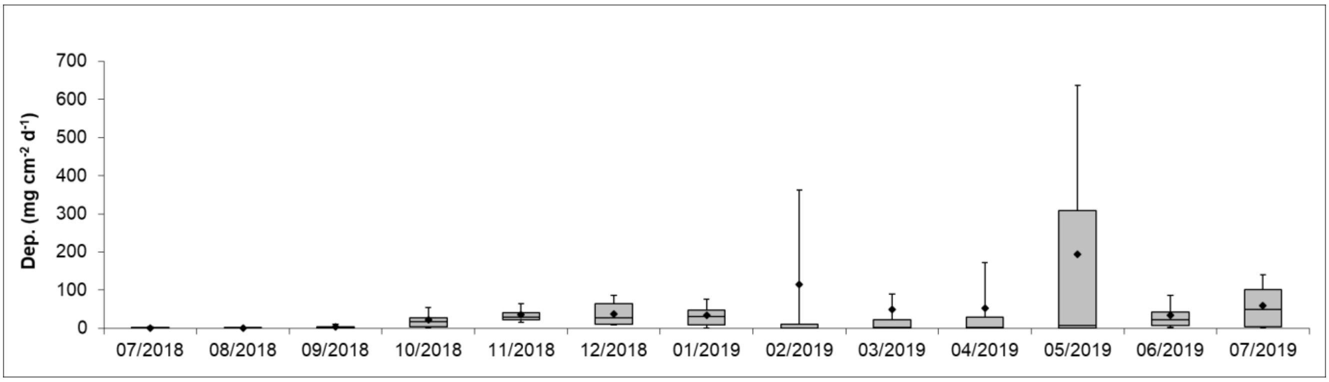
St. Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

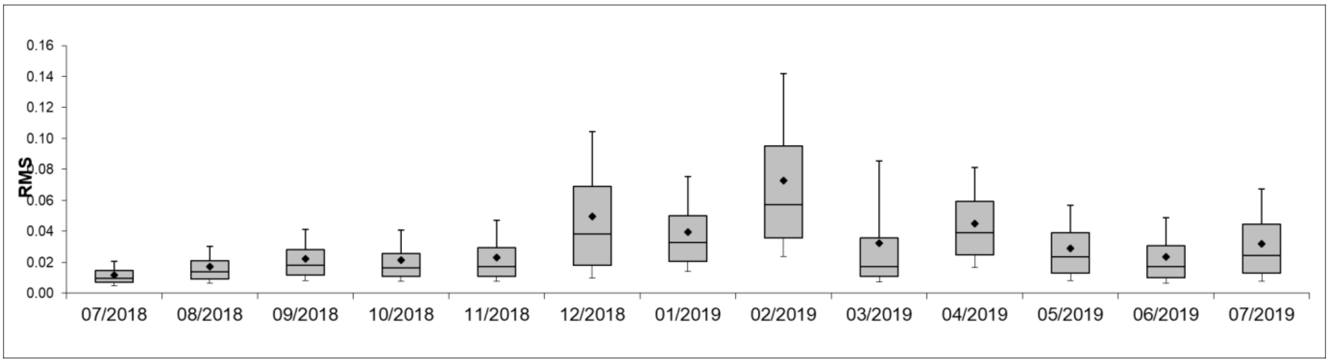
	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	20.32	20.88	22.73	25.29	27.46	27.50	27.40	27.53	27.81	26.07	23.63	21.10	20.50
median	20.24	20.91	22.89	25.27	27.38	27.07	27.33	27.25	27.83	25.64	23.24	21.20	20.59
min	19.62	20.03	21.07	23.36	26.63	26.20	26.76	25.92	26.56	25.12	22.70	19.88	19.96
lower	20.02	20.66	22.45	24.17	27.08	26.83	27.05	26.74	26.92	25.40	23.00	20.32	20.24
upper	20.64	21.09	23.12	26.42	27.64	28.06	27.72	28.40	28.70	26.48	24.28	21.80	20.73
max	21.98	21.97	23.81	27.69	28.85	29.70	28.38	29.37	29.11	28.67	25.20	22.85	20.98
90th percentile	20.91	21.28	23.33	26.98	28.30	29.17	27.95	28.79	28.81	27.53	24.98	22.07	20.81
10th percentile	19.83	20.42	21.79	23.69	26.91	26.67	26.92	26.33	26.74	25.28	22.85	20.08	20.13
n	2433	4461	4320	4459	4244	4464	4429	4032	4460	4312	4446	4320	2000
St. Dev	0.38	0.32	0.57	1.22	0.51	0.92	0.38	0.93	0.86	0.89	0.78	0.78	0.27
St. Error	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

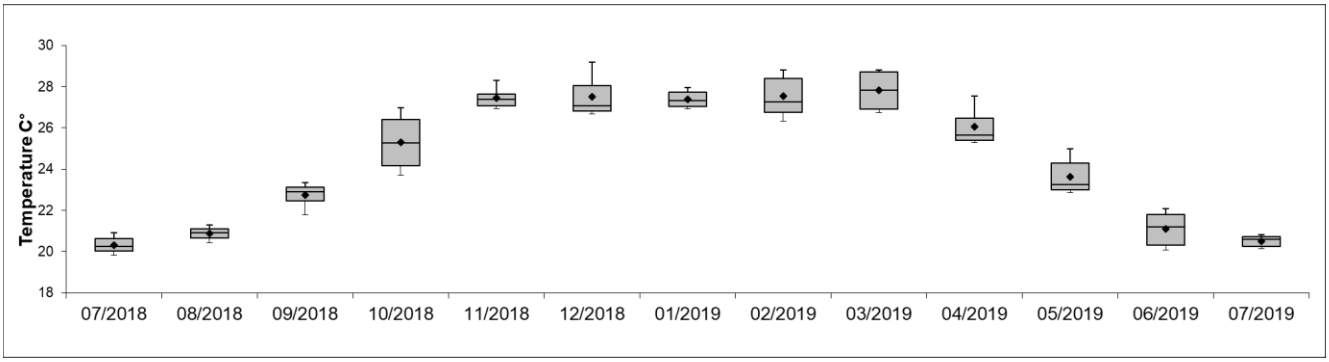
	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light

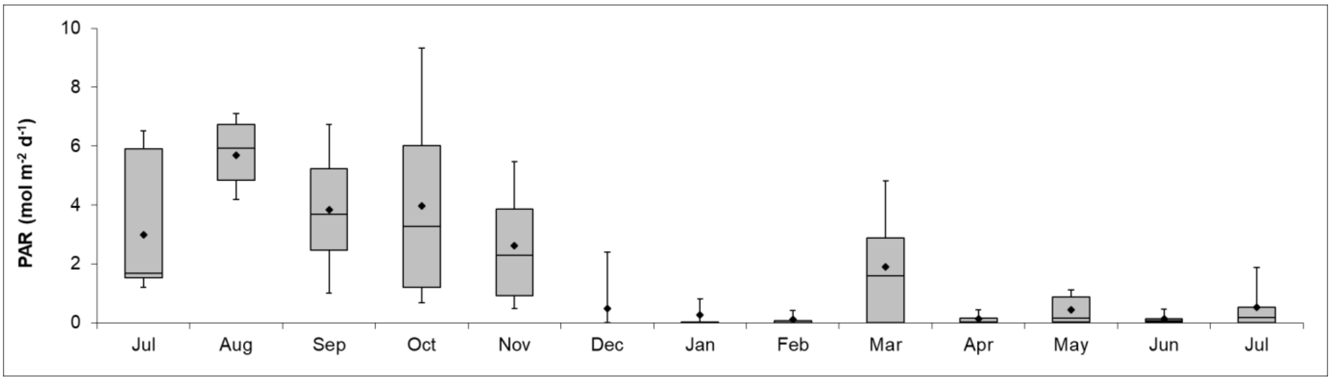
	07/2018	08/2018	09/2018	10/2018	11/2018	12/2018	01/2019	02/2019	03/2019	04/2019	05/2019	06/2019	07/2019
Mean	3.00	5.69	3.83	3.96	2.61	0.48	0.26	0.12	1.91	0.14	0.43	0.13	0.53
median	1.68	5.92	3.68	3.28	2.30	0.00	0.00	0.01	1.60	0.02	0.16	0.08	0.18
min	1.06	1.59	0.17	0.07	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	1.54	4.84	2.46	1.20	0.92	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00
upper	5.92	6.73	5.23	6.02	3.87	0.00	0.00	0.08	2.87	0.16	0.89	0.13	0.53
max	6.93	7.36	8.05	11.33	6.66	4.48	3.34	0.86	6.10	1.23	1.58	0.54	2.14
90th percentile	6.51	7.10	6.73	9.32	5.47	2.40	0.82	0.42	4.83	0.43	1.12	0.46	1.87
10th percentile	1.21	4.19	1.01	0.67	0.48	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
n	17	31	30	31	30	31	31	28	31	30	31	30	14
St. Dev	2.29	1.29	2.14	3.30	1.91	1.24	0.72	0.26	1.91	0.25	0.50	0.17	0.78
St. Error	0.56	0.23	0.39	0.59	0.35	0.22	0.13	0.05	0.34	0.05	0.09	0.03	0.21


SSC (mg l-1)
30
25
20
15
10
5
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Dep. (mg cm-2 d-1)
700
600
500
400
300
200
100
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


RMS
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Temperature C°
30
28
26
24
22
20
18
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


PAR (mol m-2 d-1)
10
8
6
4
2
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

A3.4 AMB5: Slade Island

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	1.12	0.38	10.84				4.60	110.39	17.70	22.62	9.33		
median	0.29	0.30	1.24				1.35	40.02	3.16	13.09	4.13		
min	0.00	0.00	0.00				0.00	1.20	0.00	0.00	0.00		
lower	0.16	0.19	0.24				0.42	14.04	0.00	6.46	1.16		
upper	0.45	0.42	6.56				5.15	91.00	24.18	28.97	10.18		
max	357.29	39.72	974.14				140.17	2677.49	430.13	109.94	109.62		
90th percentile	0.66	0.59	22.20				10.89	194.65	49.08	60.01	21.05		
10th percentile	0.09	0.00	0.00				0.19	5.60	0.00	3.42	0.00		
n	2429	1948	4320	0	0	0	1101	4002	4456	4215	4088	0	0
St. Dev	11.87	1.22	37.59				10.20	270.64	32.38	24.33	15.31		
St. Error	0.24	0.03	0.57				0.31	4.28	0.49	0.37	0.24		

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	4.51	1.92	4.46	42.96			1.06	8.12	12.79	61.14	146.32	20.28	17.39
median	3.37	1.52	2.75	36.38			0.90	2.96	3.73	40.36	23.03	17.24	13.38
min	0.06	0.03	0.02	0.01			0.03	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.43	0.89	0.65	29.57			0.25	1.55	1.48	8.30	9.09	9.90	6.13
upper	7.60	2.35	5.89	51.13			1.64	6.08	19.45	103.26	93.63	23.15	26.86

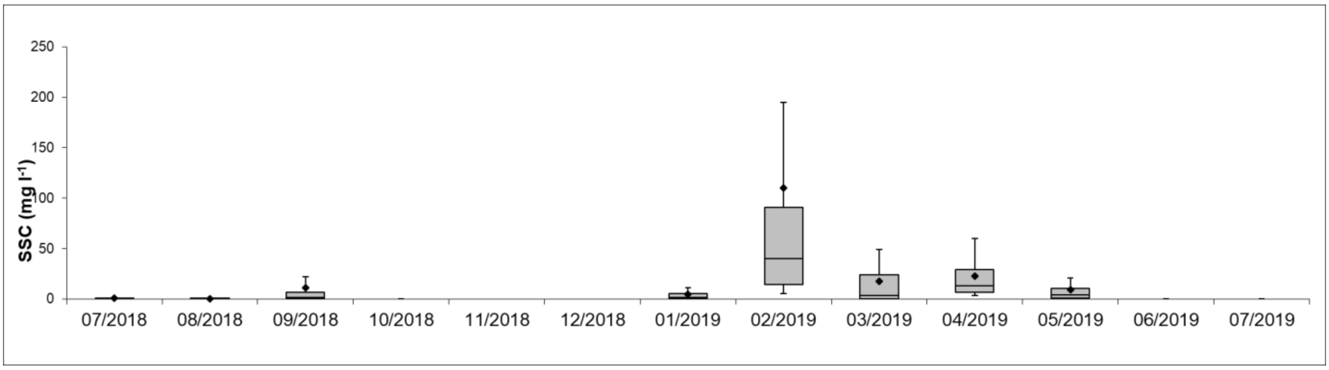
max	12.08	6.41	26.54	89.02			2.57	85.09	98.00	231.29	1250.19	80.06	48.27
90th percentile	11.39	4.24	10.69	74.74			2.05	21.01	29.21	144.27	545.24	36.68	31.57
10th percentile	0.23	0.18	0.15	17.54			0.24	0.67	1.09	2.12	6.38	5.41	5.23
n	7	19	30	13	0	0	8	28	22	30	31	30	10
St. Dev	5.05	1.73	5.60	23.42			0.88	16.44	21.81	61.93	280.53	15.95	14.72
St. Error	1.91	0.40	1.02	6.50			0.31	3.11	4.65	11.31	50.39	2.91	4.65

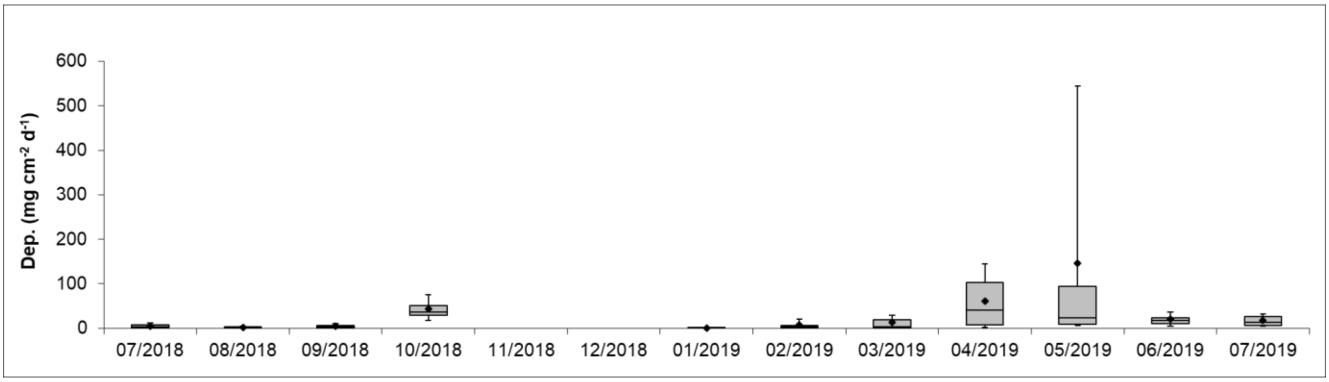
	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	04/2019	05/2019	06/2019	07/2019
Mean	0.02	0.03	0.05	0.04			0.06	0.09	0.04	0.09	0.06	0.05	0.09
median	0.02	0.03	0.04	0.03			0.05	0.07	0.03	0.08	0.05	0.04	0.08
min	0.00	0.01	0.00	0.01			0.00	0.01	0.00	0.01	0.00	0.00	0.01
lower	0.02	0.02	0.02	0.02			0.03	0.05	0.02	0.05	0.03	0.02	0.05
upper	0.03	0.04	0.06	0.05			0.08	0.11	0.05	0.11	0.09	0.07	0.12
max	0.11	0.08	0.35	0.24			0.33	0.64	0.26	0.36	0.39	0.34	0.38
90th percentile	0.04	0.05	0.09	0.09			0.12	0.17	0.10	0.15	0.13	0.11	0.17
10th percentile	0.01	0.02	0.01	0.02			0.02	0.03	0.01	0.04	0.02	0.01	0.03
n	1630	228	4320	1776			1102	4032	4463	4320	4463	4320	1440
St. Dev	0.01	0.01	0.03	0.03			0.04	0.06	0.04	0.05	0.05	0.04	0.06
St. Error	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.00	0.00	0.00

	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp	Temp				
	07/2018	08/2018	09/2018	10/2018	11/2018	12/2018	01/2019	02/2019	03/2019	04/2019	05/2019	06/2019	07/2019
Mean	20.34	20.92	22.91	24.22			27.57	27.48	27.86	25.95	23.48	20.89	20.29
median	20.28	20.95	22.94	24.08			27.61	27.26	28.10	25.52	23.09	20.95	20.32
min	19.57	20.07	21.36	23.45			27.02	26.00	26.42	24.84	22.53	19.79	19.89
lower	19.96	20.60	22.70	23.69			27.17	26.61	26.76	25.25	22.87	20.32	20.06
upper	20.75	21.17	23.23	24.70			27.85	28.31	28.80	26.46	24.17	21.44	20.49
max	21.19	22.07	23.89	25.31			28.12	29.20	29.30	28.64	25.01	22.51	20.71
90th percentile	20.99	21.41	23.47	25.12			27.98	28.81	28.95	27.46	24.83	21.78	20.59
10th percentile	19.75	20.39	22.29	23.55			27.09	26.27	26.56	25.07	22.71	20.00	20.01
n	2443	4451	4320	1776			1096	4032	4452	4320	4458	4320	1440
St. Dev	0.45	0.38	0.46	0.57			0.34	0.95	0.99	0.91	0.78	0.66	0.22
St. Error	0.01	0.01	0.01	0.01			0.01	0.01	0.01	0.01	0.01	0.01	0.01

	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light	Light
	07/2018	08/2018	09/2018	10/2018	11/2018	12/2018	01/2019	02/2019	03/2019	04/2019	05/2019	06/2019	07/2019
Mean	2.23	0.73	2.43	0.66			1.23	0.06	1.97	0.03	0.78	0.80	0.03
median	2.46	0.49	2.46	0.60			0.89	0.00	1.52	0.00	0.20	0.80	0.00

min	0.30	0.20	0.02	0.01			0.03	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.66	0.41	0.99	0.36			0.15	0.00	0.03	0.00	0.05	0.21	0.00
upper	3.45	0.60	3.75	0.88			1.76	0.02	3.41	0.01	1.50	1.18	0.04
max	3.82	4.62	6.26	1.37			3.84	0.58	5.76	0.46	3.04	1.74	0.10
90th percentile	3.77	0.72	4.17	1.35			3.02	0.14	5.01	0.03	2.49	1.54	0.09
10th percentile	0.52	0.27	0.19	0.17			0.08	0.00	0.00	0.00	0.01	0.00	0.00
n	17	31	30	12			7	28	31	30	31	30	10
St. Dev	1.38	0.97	1.72	0.46			1.43	0.14	1.87	0.09	1.00	0.56	0.04
St. Error	0.33	0.17	0.31	0.13			0.54	0.03	0.34	0.02	0.18	0.10	0.01


SSC (mg l⁻¹)
250
200
150
100
50
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Dep. (mg cm⁻² d⁻¹)
600
500
400
300
200
100
0
07/2018
08/2018
09/2018
10/2018
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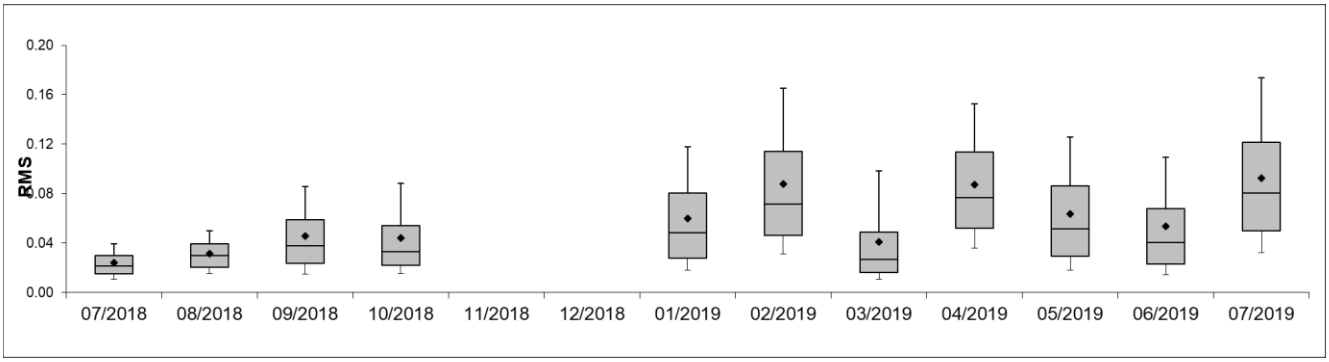
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


RMS
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0.16
0.12
0.08
0.04
0.00
07/2018
08/2018
09/2018
10/2018
11/2018
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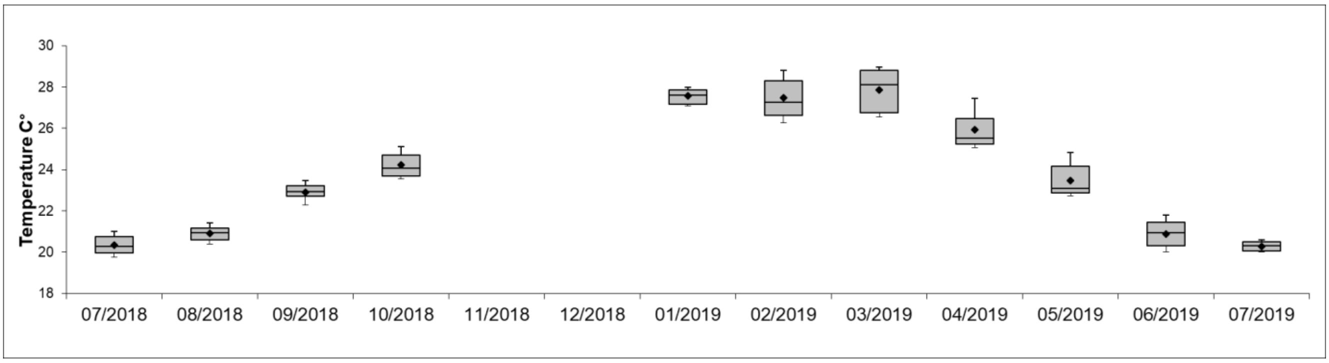
05/2019
06/2019
07/2019


Temperature C°
30
28
26
24
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18
07/2018
08/2018
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11/2018
12/2018
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02/2019
03/2019
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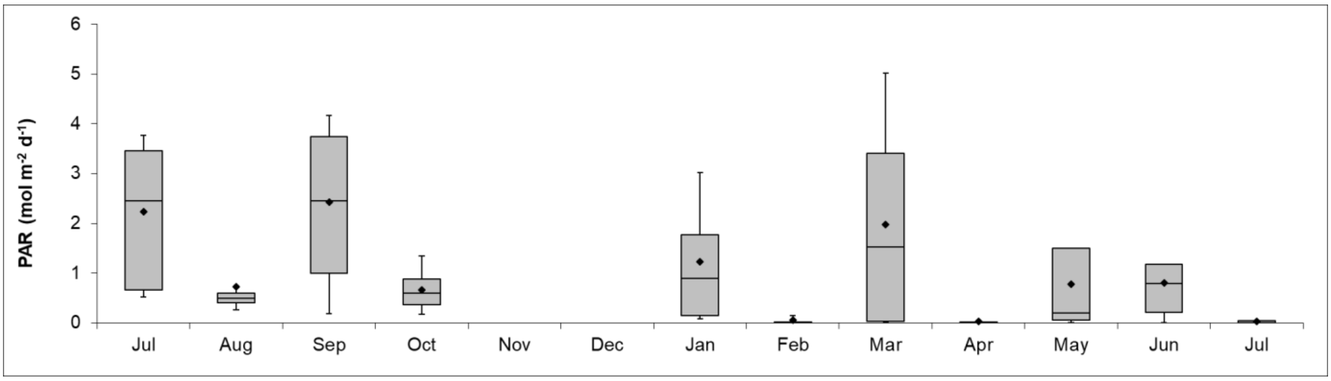
06/2019
07/2019


PAR (mol m-2 d-1)
0
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Jul
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A3.5 AMB8: Spoil Ground

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.75	1.05					11.05	31.83	117.47	27.69	68.13	16.47	169.26
median	0.53	0.82					2.96	6.48	1.56	15.19	10.33	4.22	133.73
min	0.00	0.03					0.00	0.00	0.00	1.30	0.51	0.44	1.15
lower	0.35	0.51					0.53	2.23	0.41	9.85	4.99	1.95	50.34
upper	0.93	1.26					11.30	20.98	195.76	25.16	102.68	22.96	273.38
max	7.78	17.87					66.69	718.93	725.73	697.91	1138.00	467.48	727.51
90th percentile	1.55	1.96					40.16	72.36	396.18	52.06	207.74	47.26	362.68
10th percentile	0.23	0.32					0.15	1.05	0.14	5.00	1.80	0.95	14.87
n	2447	2904	0	0	0	0	1046	3808	4219	4320	4458	4320	1682
St. Dev	0.65	0.95					16.71	83.02	175.52	46.40	126.05	26.73	133.69
St. Error	0.01	0.02					0.52	1.35	2.70	0.71	1.89	0.41	3.26

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	0.47	2.84					0.38	0.66	2.82	102.03	20.98	119.41	100.74
median	0.38	1.93					0.27	0.33	0.81	74.64	9.76	101.92	62.58
min	0.06	0.00					0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.14	0.95					0.18	0.10	0.43	12.95	4.46	57.52	10.73
upper	0.49	3.45					0.48	0.90	2.91	136.82	29.05	166.01	186.64

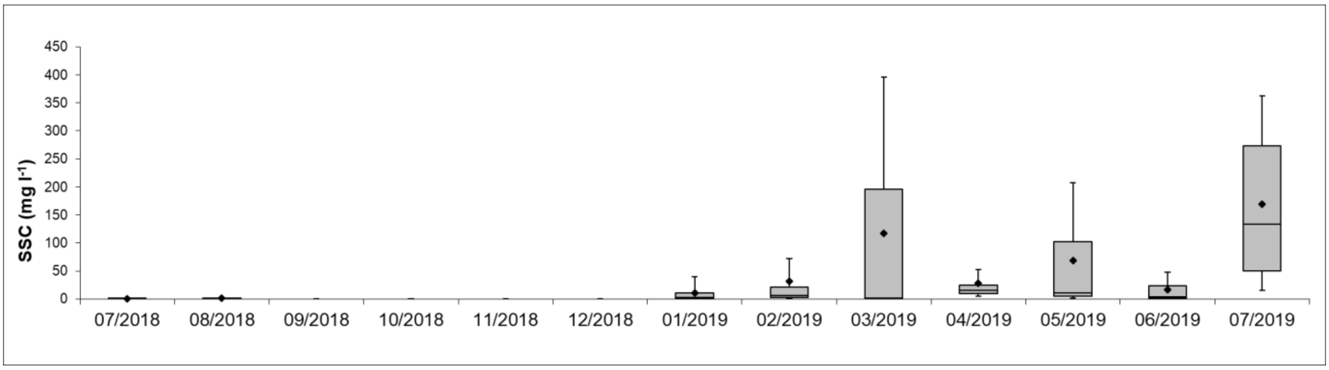
max	1.95	13.23					1.03	2.78	20.21	475.86	87.86	362.49	305.16
90th percentile	0.91	6.10					0.72	1.76	4.98	238.01	55.24	212.58	221.78
10th percentile	0.08	0.45					0.11	0.01	0.07	3.05	1.60	31.44	1.84
n	17	17	0	0	0	0	8	28	30	30	31	30	14
St. Dev	0.48	3.25					0.31	0.78	4.86	117.50	24.16	80.02	100.99
St. Error	0.12	0.79					0.11	0.15	0.89	21.45	4.34	14.61	26.99

	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	RMS 04/2019	RMS 05/2019	RMS 06/2019	RMS 07/2019
Mean	0.014	0.021					0.042	0.078	0.032	0.054	0.041		0.019
median	0.013	0.016					0.032	0.061	0.018	0.047	0.034		0.017
min	0.000	0.000					0.000	0.007	0.000	0.006	0.003		0.001
lower	0.008	0.010					0.018	0.038	0.011	0.031	0.022		0.011
upper	0.018	0.024					0.055	0.101	0.035	0.069	0.054		0.025
max	0.057	3.338					0.258	0.545	0.265	0.291	0.213		0.088
90th percentile	0.024	0.036					0.091	0.151	0.081	0.097	0.078		0.034
10th percentile	0.006	0.007					0.012	0.025	0.007	0.021	0.015		0.007
n	2447	2918	0	0	0	0	1048	4032	4351	4320	3810	0	505
St. Dev	0.007	0.063					0.033	0.059	0.035	0.033	0.027		0.012
St. Error	0.000	0.001					0.001	0.001	0.001	0.001	0.000		0.001

	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	20.33	20.89					27.50	27.36	27.63	26.00	23.44	20.84	20.33
median	20.30	20.90					27.54	27.11	27.58	25.52	23.01	20.88	20.29
min	19.80	20.29					27.11	25.90	26.53	24.90	22.58	19.56	19.74
lower	20.08	20.70					27.23	26.66	26.85	25.32	22.79	19.99	20.07
upper	20.53	21.09					27.71	28.19	28.48	26.50	24.16	21.61	20.64
max	22.02	21.47					27.92	28.93	28.79	28.46	25.02	22.62	20.96
90th percentile	20.78	21.24					27.81	28.52	28.62	27.48	24.77	21.91	20.84
10th percentile	19.96	20.55					27.18	26.28	26.64	25.15	22.69	19.82	19.85
n	2447	2918	0	0	0	0	1039	4032	4345	4320	4464	4320	2001
St. Dev	0.29	0.26					0.25	0.85	0.80	0.90	0.80	0.84	0.35
St. Error	0.01	0.00					0.01	0.01	0.01	0.01	0.01	0.01	0.01

	Light 07/2018	Light 08/2018	Light 09/2018	Light 10/2018	Light 11/2018	Light 12/2018	Light 01/2019	Light 02/2019	Light 03/2019	Light 04/2019	Light 05/2019	Light 06/2019	Light 07/2019
Mean	1.94	2.03					0.36	0.24	1.28	0.08	0.15	0.22	0.24
median	1.75	2.61					0.15	0.03	0.61	0.01	0.07	0.06	0.00

min	0.60	0.00					0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	1.41	0.99					0.08	0.00	0.00	0.00	0.01	0.01	0.00
upper	2.63	3.04					0.54	0.42	2.17	0.06	0.22	0.31	0.26
max	3.16	3.49					1.15	1.58	5.03	0.59	1.07	1.27	1.28
90th percentile	3.06	3.24					0.79	0.62	3.11	0.32	0.41	0.59	0.90
10th percentile	0.89	0.00					0.01	0.00	0.00	0.00	0.00	0.00	0.00
n	17	23	0	0	0	0	7	28	31	30	31	30	14
St. Dev	0.84	1.26					0.42	0.37	1.47	0.15	0.22	0.34	0.43
St. Error	0.20	0.26					0.16	0.07	0.26	0.03	0.04	0.06	0.11


SSC (mg l⁻¹)
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200
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100
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07/2018
08/2018
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11/2018
12/2018
01/2019
02/2019
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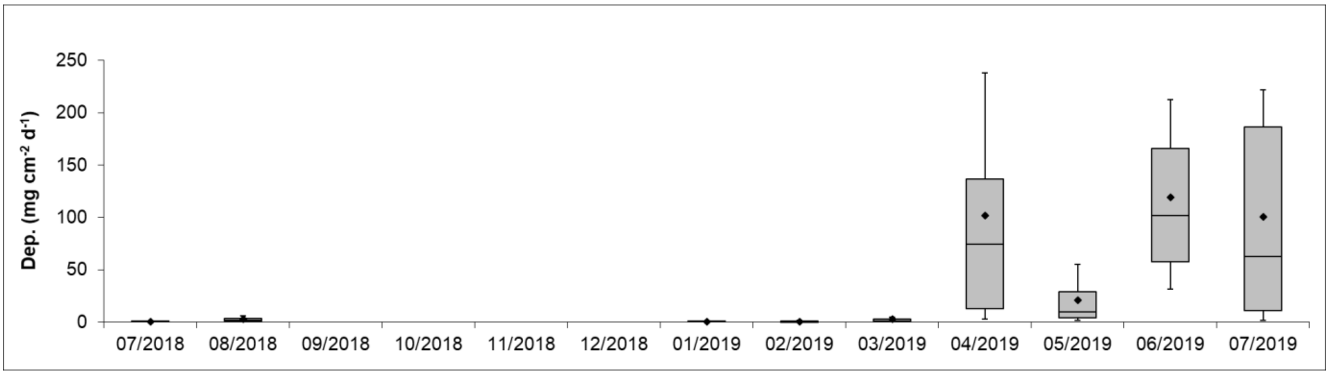
Dep. (mg cm⁻² d⁻¹)
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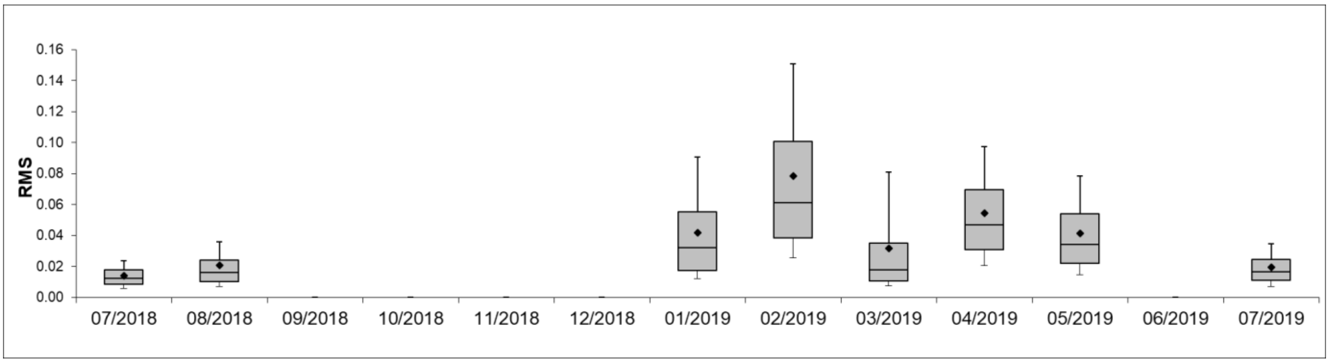
05/2019
06/2019
07/2019


RMS
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0.12
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0.08
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06/2019
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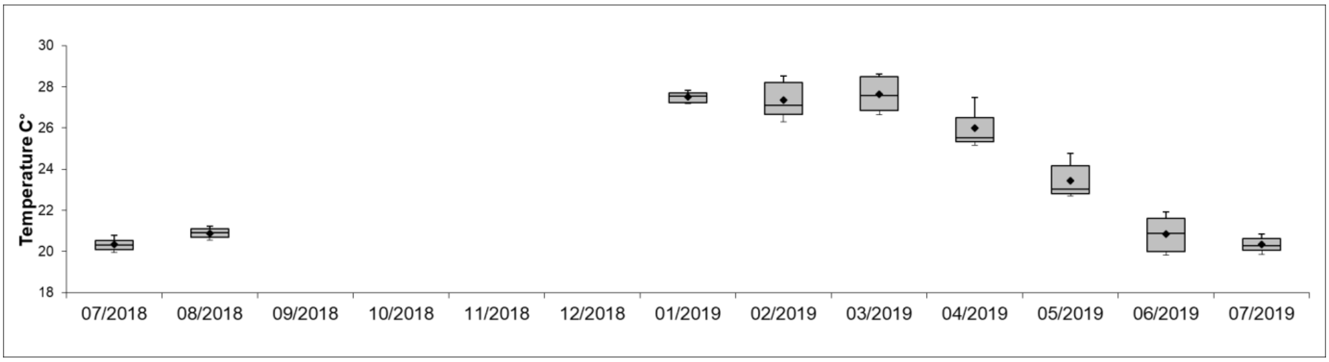
Temperature C°
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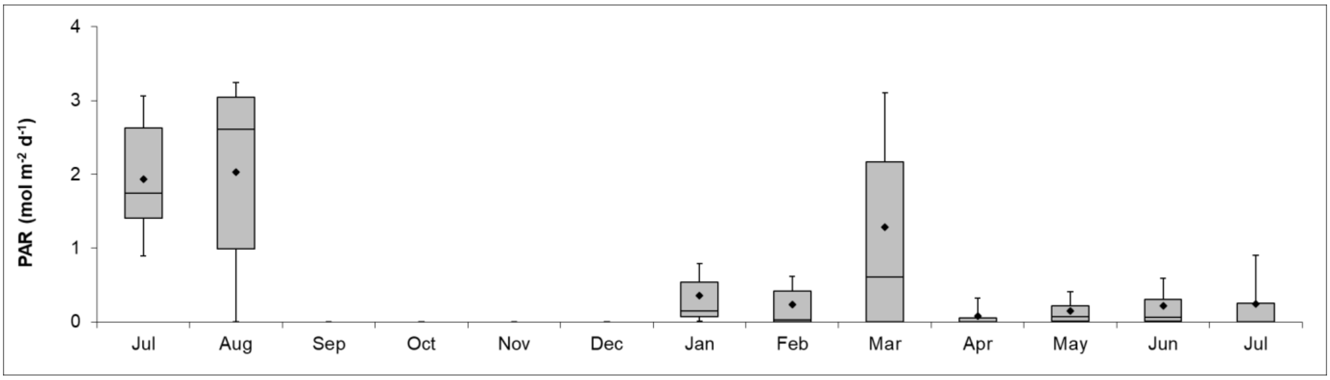
04/2019
05/2019
06/2019
07/2019


PAR (mol m^{-2} d^{-1})
4
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0
Jul
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A3.6 AMB10: Victor Is.

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.71	4.14	6.10	4.25	8.48		18.63	34.08	10.30	19.34	15.65	194.25	23.46
median	0.61	1.34	1.24	3.02	6.67		11.82	25.40	3.29	13.53	8.53	180.76	21.62
min	0.00	0.00	0.00	0.05	2.95		0.00	0.04	0.00	0.00	0.00	0.00	0.58
lower	0.43	0.44	0.37	1.82	5.14		2.54	10.63	1.31	7.63	5.38	139.63	5.98
upper	0.83	4.14	3.56	5.12	9.47		32.61	44.14	15.09	24.02	14.87	241.60	34.30
max	3.74	198.44	646.23	73.56	31.78		131.94	218.87	181.55	393.14	220.62	610.41	228.94
90th percentile	1.18	8.45	13.08	8.29	15.65		44.02	76.74	30.50	40.85	32.26	315.36	47.99
10th percentile	0.29	0.00	0.00	0.98	4.29		1.14	3.25	0.69	4.06	2.74	102.15	1.26
n	907	4127	4315	4462	432	0	932	3935	4364	3343	4460	4320	2013
St. Dev	0.49	10.98	24.09	4.50	5.17		18.61	33.91	14.19	21.35	22.19	82.64	21.00
St. Error	0.02	0.17	0.37	0.07	0.25		0.61	0.54	0.21	0.37	0.33	1.26	0.47

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	0.72	1.02	1.83	3.31	24.93	19.99	1.66	5.67	6.96	51.18	1.32	61.09	4.99
median	0.51	0.56	0.57	0.47	19.18	17.22	1.15	3.84	4.34	4.32	0.98	30.66	4.41
min	0.22	0.01	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.00
lower	0.23	0.20	0.20	0.15	15.23	4.83	0.45	2.29	1.57	2.39	0.61	17.11	2.78
upper	0.77	1.02	2.84	1.12	32.90	33.20	2.56	7.63	9.59	10.40	1.92	54.48	6.92

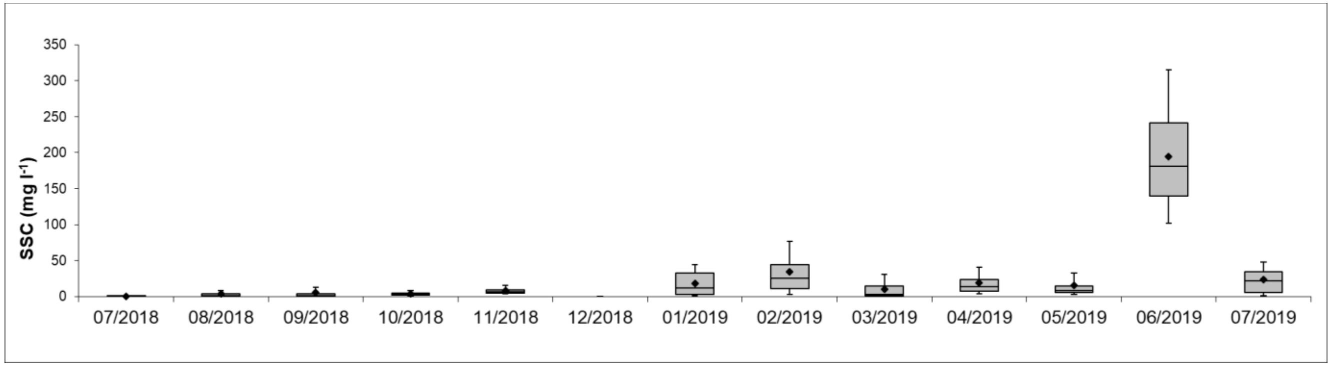
max	1.88	7.21	10.50	35.04	48.98	46.60	4.21	18.79	32.33	792.79	5.12	432.86	9.43
90th percentile	1.44	2.16	4.92	13.06	45.60	44.52	3.58	11.05	15.08	71.34	2.60	130.73	8.42
10th percentile	0.22	0.13	0.14	0.08	12.95	3.31	0.24	1.62	0.62	1.56	0.44	4.57	1.80
n	5	29	30	31	7	21	6	28	30	30	31	27	3
St. Dev	0.69	1.51	2.63	7.77	15.09	15.85	1.60	4.63	7.70	154.69	1.07	91.71	4.17
St. Error	0.31	0.28	0.48	1.40	5.70	3.46	0.65	0.87	1.41	28.24	0.19	17.65	2.41

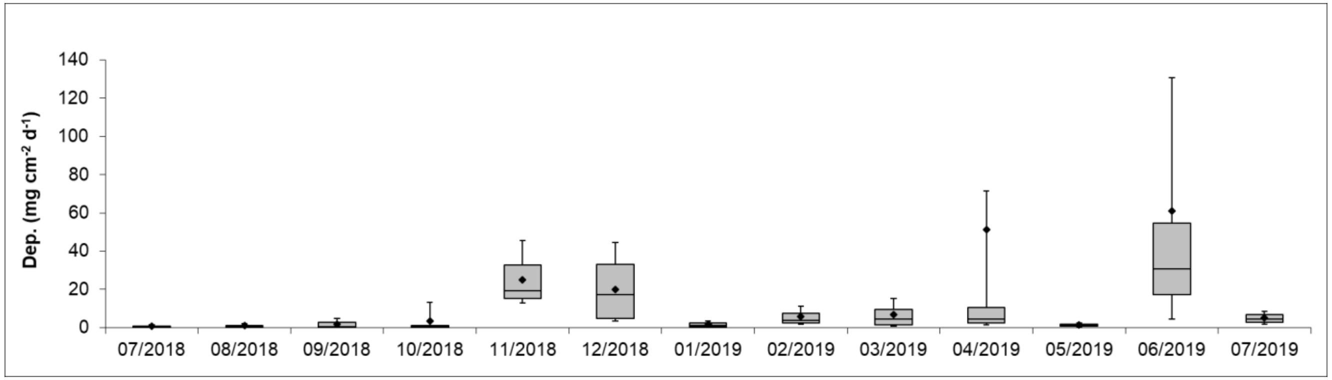
	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	04/2019	05/2019	06/2019	07/2019
Mean	0.014	0.020	0.027	0.027	0.030	0.059	0.048	0.063	0.028	0.054	0.040	0.033	0.046
median	0.012	0.018	0.022	0.021	0.023	0.047	0.040	0.051	0.018	0.047	0.034	0.025	0.035
min	0.000	0.000	0.002	0.003	0.003	0.003	0.005	0.004	0.000	0.004	0.002	0.002	0.002
lower	0.008	0.011	0.014	0.014	0.014	0.022	0.026	0.031	0.011	0.031	0.020	0.015	0.019
upper	0.018	0.025	0.034	0.034	0.040	0.081	0.061	0.082	0.034	0.070	0.055	0.040	0.062
max	0.084	0.107	0.188	0.183	0.172	0.388	0.241	0.365	0.228	0.341	0.208	0.240	0.253
90th percentile	0.023	0.035	0.050	0.052	0.061	0.125	0.087	0.123	0.063	0.096	0.077	0.065	0.095
10th percentile	0.006	0.008	0.010	0.010	0.010	0.013	0.017	0.020	0.008	0.021	0.013	0.009	0.012
n	2447	4450	4320	4463	4244	4464	4459	4032	4462	4319	4462	4320	2015
St. Dev	0.007	0.012	0.020	0.019	0.023	0.048	0.031	0.045	0.025	0.031	0.027	0.027	0.036
St. Error	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.001

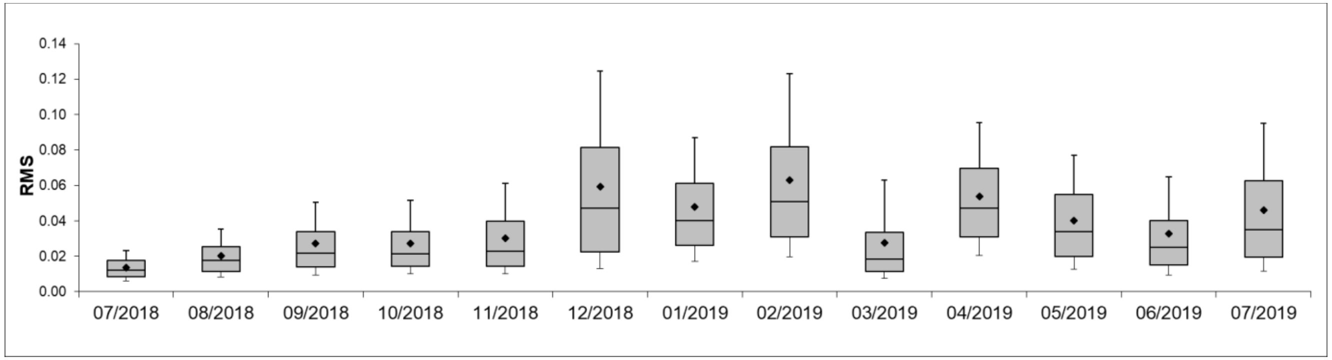
	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	21.07	21.04	22.96	25.54	27.56	27.34	27.30	27.60	27.89	25.84	23.35	20.48	20.20
median	21.10	21.07	23.00	25.38	27.50	26.86	27.28	27.37	28.21	25.44	23.05	20.44	20.09
min	20.54	20.05	21.45	23.22	26.30	25.75	26.37	25.78	26.46	24.35	22.19	19.40	19.72
lower	20.88	20.64	22.70	24.52	27.15	26.60	26.88	26.75	26.79	25.22	22.71	19.85	19.95
upper	21.25	21.35	23.34	26.86	27.81	28.06	27.68	28.65	28.78	26.28	24.00	21.12	20.43
max	24.41	22.18	24.10	27.81	29.25	29.79	28.35	29.44	34.55	28.63	24.98	22.25	20.99
90th percentile	21.33	21.62	23.61	27.33	28.74	29.31	27.91	29.04	28.94	27.20	24.67	21.47	20.74
10th percentile	20.71	20.39	22.16	23.71	26.67	26.23	26.70	26.20	26.60	25.05	22.60	19.65	19.87
n	908	4450	4320	4463	4244	4464	4454	4032	4462	4319	4462	4320	2004
St. Dev	0.28	0.47	0.54	1.31	0.67	1.09	0.46	1.08	0.97	0.85	0.77	0.69	0.33
St. Error	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01

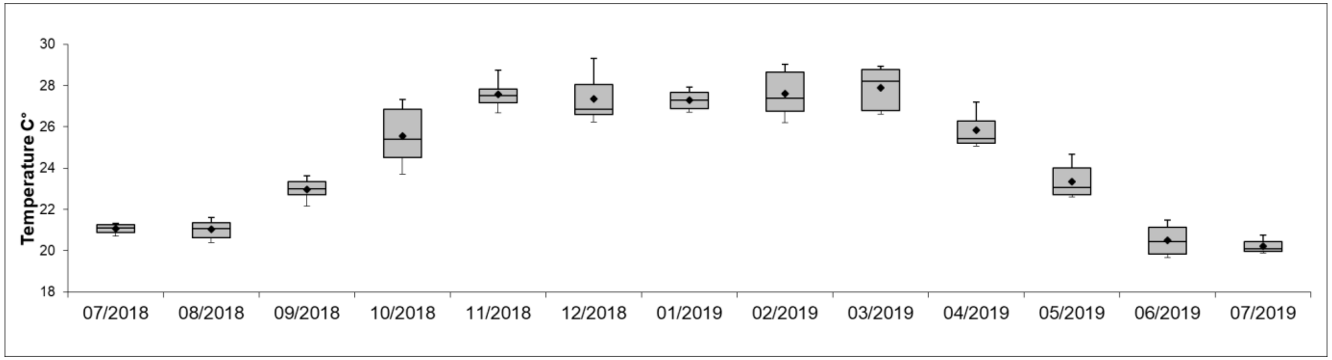
	Light 07/2018	Light 08/2018	Light 09/2018	Light 10/2018	Light 11/2018	Light 12/2018	Light 01/2019	Light 02/2019	Light 03/2019	04/2019	05/2019	06/2019	07/2019
Mean	3.90	2.05	3.86	2.75	1.87	0.66	0.36	0.64	2.68	0.33	1.66	2.25	0.96
median	3.87	0.58	3.55	2.35	1.52	0.03	0.13	0.07	1.89	0.12	0.60	2.19	0.55
min	1.99	0.08	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.00

lower	3.16	0.34	1.34	0.81	0.90	0.00	0.04	0.00	0.03	0.05	0.43	1.19	0.06
upper	4.87	4.04	6.07	3.72	2.66	0.66	0.40	0.38	4.66	0.33	2.98	3.37	1.56
max	5.28	6.54	8.95	7.94	5.32	4.90	2.07	5.55	8.26	1.91	5.55	4.60	3.52
90th percentile	5.07	4.85	7.36	5.54	4.23	2.57	1.30	2.19	6.63	0.95	4.94	4.12	2.41
10th percentile	2.69	0.26	0.38	0.42	0.04	0.00	0.00	0.00	0.02	0.02	0.09	0.63	0.03
n	17	31	30	31	30	31	31	28	31	30	31	30	14
St. Dev	1.05	2.07	2.79	2.19	1.48	1.27	0.55	1.39	2.75	0.48	1.80	1.30	1.11
St. Error	0.25	0.37	0.51	0.39	0.27	0.23	0.10	0.26	0.49	0.09	0.32	0.24	0.30


SSC (mg l⁻¹)
350
300
250
200
150
100
50
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Dep. (mg cm⁻² d⁻¹)
140
120
100
80
60
40
20
0
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


RMS
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
02/2019
03/2019
04/2019
05/2019
06/2019
07/2019


Temperature C°
30
28
26
24
22
20
18
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
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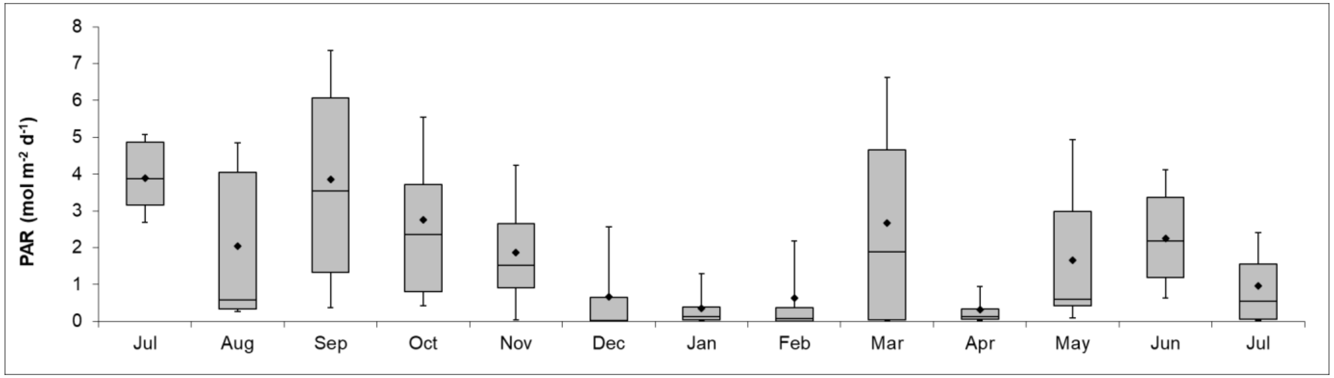
03/2019
04/2019
05/2019
06/2019
07/2019


PAR (mol m-2 d-1)
8
7
6
5
4
3
2
1
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

A3.7 AMB12: Keswick Island

	SSC 07/2018	SSC 08/2018	SSC 09/2018	SSC 10/2018	SSC 11/2018	SSC 12/2018	SSC 01/2019	SSC 02/2019	SSC 03/2019	SSC 04/2019	SSC 05/2019	SSC 06/2019	SSC 07/2019
Mean	0.34	0.70	2.52	1.68	1.97	79.01	121.43	1.68	7.33	5.72	0.96	0.91	1.54
median	0.27	0.37	0.44	0.29	0.16	36.59	97.99	1.16	1.97	0.00	0.76	0.73	1.26
min	0.00	0.00	0.00	0.00	0.00	0.00	25.88	0.00	0.00	0.00	0.00	0.16	0.38
lower	0.17	0.21	0.19	0.00	0.00	15.84	69.20	0.55	0.62	0.00	0.35	0.50	0.90
upper	0.39	0.73	1.05	1.13	0.96	104.53	155.70	2.24	4.22	2.64	1.10	1.20	1.97
max	2.99	93.35	97.79	223.75	223.75	950.99	732.11	13.00	529.57	1148.58	82.07	4.39	6.19
90th percentile	0.58	1.29	5.54	3.25	3.58	200.68	204.17	3.86	15.13	4.04	1.57	1.76	2.64
10th percentile	0.12	0.12	0.06	0.00	0.00	3.73	49.64	0.29	0.00	0.00	0.12	0.37	0.67
n	806	4138	4318	4461	4243	4464	1584	4020	3722	2751	4452	1728	508
St. Dev	0.31	2.07	7.13	6.07	7.95	108.69	80.07	1.65	23.34	52.41	2.49	0.57	0.94
St. Error	0.01	0.03	0.11	0.09	0.12	1.63	2.01	0.03	0.38	1.00	0.04	0.01	0.04

	Dep. 07/2018	Dep. 08/2018	Dep. 09/2018	Dep. 10/2018	Dep. 11/2018	Dep. 12/2018	Dep. 01/2019	Dep. 02/2019	Dep. 03/2019	Dep. 04/2019	Dep. 05/2019	Dep. 06/2019	Dep. 07/2019
Mean	9.56	8.98	1.93	3.87	4.67	2.98	10.91	4.67	16.78	3.62	6.42	42.70	14.86
median	5.20	7.74	1.30	1.75	3.13	2.32	6.80	3.22	5.09	0.57	4.93	35.15	3.94
min	0.16	0.34	0.19	0.15	0.43	0.00	0.10	0.05	0.00	0.06	0.03	0.27	0.02
lower	1.67	1.32	0.75	0.93	2.03	1.20	4.18	1.80	3.38	0.41	2.65	19.81	0.40
upper	14.15	13.63	2.82	3.45	6.61	3.22	12.73	5.62	11.08	1.72	8.03	48.80	21.37

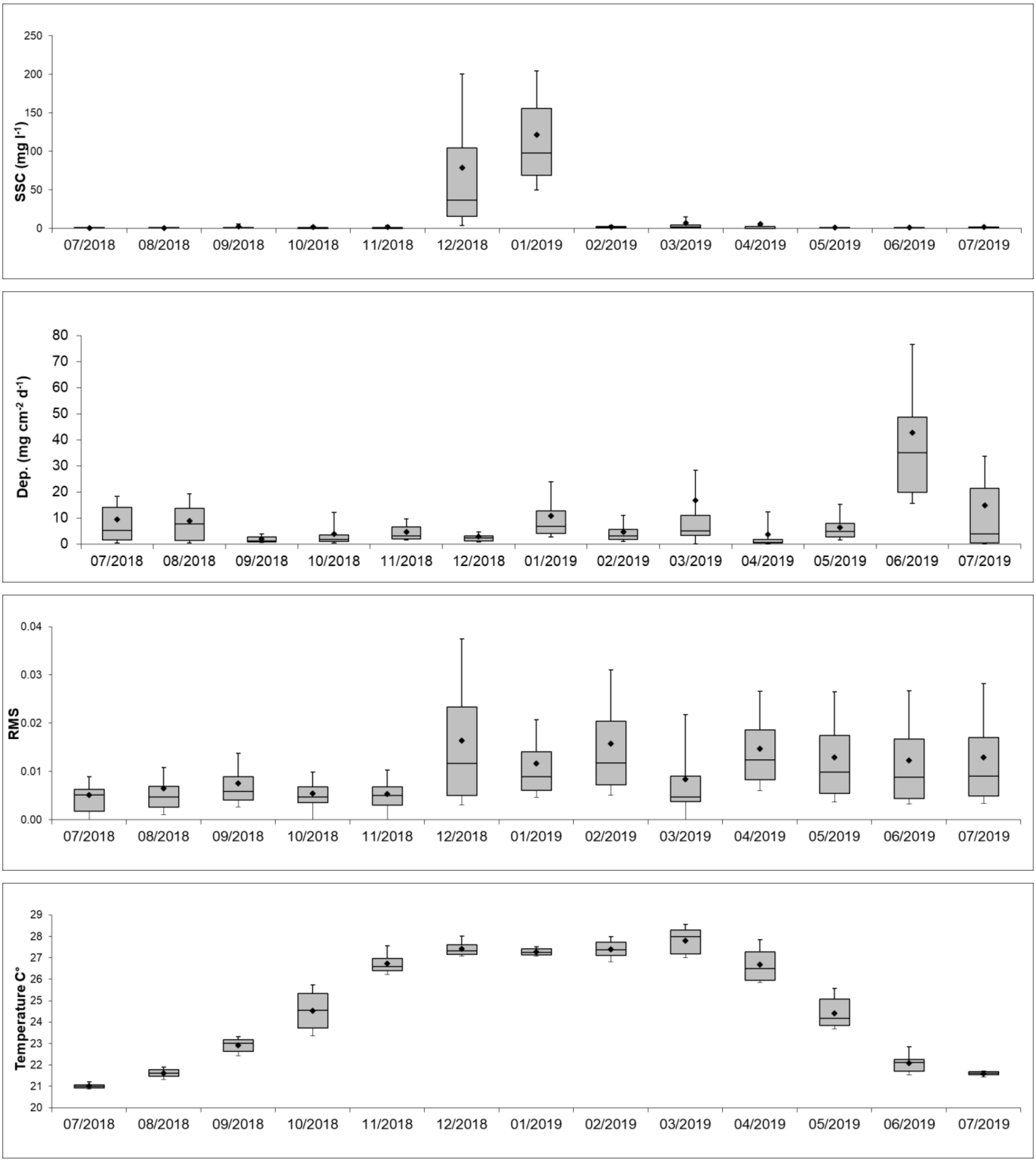
max	55.23	36.94	6.91	15.77	15.57	15.77	40.90	16.36	172.91	26.23	21.35	158.31	89.01
90th percentile	18.29	19.31	3.99	12.18	9.66	4.62	23.84	11.01	28.25	12.33	15.31	76.73	33.68
10th percentile	0.39	0.45	0.54	0.37	1.51	0.81	2.80	0.93	0.09	0.21	1.50	15.68	0.25
n	17	30	30	29	30	31	23	28	21	22	30	30	14
St. Dev	13.31	8.53	1.64	4.89	4.05	3.05	10.65	4.13	37.53	6.64	5.27	32.19	24.58
St. Error	3.23	1.56	0.30	0.91	0.74	0.55	2.22	0.78	8.19	1.42	0.96	5.88	6.57

	RMS 07/2018	RMS 08/2018	RMS 09/2018	RMS 10/2018	RMS 11/2018	RMS 12/2018	RMS 01/2019	RMS 02/2019	RMS 03/2019	RMS 04/2019	RMS 05/2019	RMS 06/2019	RMS 07/2019
Mean	0.005	0.007	0.008	0.005	0.005	0.016	0.012	0.016	0.008	0.015	0.013	0.012	0.013
median	0.005	0.005	0.006	0.005	0.005	0.012	0.009	0.012	0.005	0.012	0.010	0.009	0.009
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
lower	0.002	0.003	0.004	0.004	0.003	0.005	0.006	0.007	0.004	0.008	0.005	0.004	0.005
upper	0.006	0.007	0.009	0.007	0.007	0.023	0.014	0.020	0.009	0.019	0.017	0.017	0.017
max	0.079	0.166	0.116	0.051	0.039	0.134	0.121	0.119	0.076	0.099	0.096	0.095	0.087
90th percentile	0.009	0.011	0.014	0.010	0.010	0.037	0.021	0.031	0.022	0.027	0.027	0.027	0.028
10th percentile	0.000	0.001	0.003	0.000	0.000	0.003	0.005	0.005	0.000	0.006	0.004	0.003	0.003
n	2443	4464	4320	4464	4243	4464	3310	4032	4462	4320	4459	4320	2014
St. Dev	0.006	0.009	0.007	0.004	0.004	0.016	0.010	0.013	0.010	0.009	0.011	0.011	0.012
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

	Temp 07/2018	Temp 08/2018	Temp 09/2018	Temp 10/2018	Temp 11/2018	Temp 12/2018	Temp 01/2019	Temp 02/2019	Temp 03/2019	Temp 04/2019	Temp 05/2019	Temp 06/2019	Temp 07/2019
Mean	21.02	21.62	22.92	24.53	26.73	27.42	27.28	27.40	27.81	26.69	24.41	22.09	21.60
median	20.99	21.62	23.00	24.55	26.59	27.31	27.26	27.36	27.98	26.50	24.16	22.12	21.61
min	19.82	20.84	22.04	23.11	25.53	26.96	26.89	26.65	26.88	25.67	23.23	21.06	21.23
lower	20.93	21.48	22.64	23.71	26.39	27.15	27.14	27.11	27.19	25.95	23.84	21.71	21.54
upper	21.08	21.79	23.18	25.33	26.97	27.61	27.41	27.73	28.30	27.28	25.06	22.25	21.69
max	21.45	22.11	23.62	26.15	28.01	28.34	27.69	28.41	30.74	28.56	25.83	23.40	21.83
90th percentile	21.21	21.89	23.32	25.73	27.56	28.01	27.52	27.98	28.56	27.85	25.56	22.84	21.72
10th percentile	20.87	21.31	22.42	23.35	26.22	27.07	27.07	26.82	27.01	25.83	23.68	21.52	21.44
n	2443	4464	4320	4464	4243	4464	3310	4032	4462	4320	4459	4320	2003
St. Dev	0.14	0.23	0.34	0.88	0.47	0.35	0.17	0.41	0.59	0.77	0.70	0.45	0.11
St. Error	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00

	Light 07/2018	Light 08/2018	Light 09/2018	Light 10/2018	Light 11/2018	Light 12/2018	Light 01/2019	Light 02/2019	Light 03/2019	Light 04/2019	Light 05/2019	Light 06/2019	Light 07/2019
Mean	1.16	3.03	3.28	2.60	2.98	2.18	4.55	1.27	0.79	0.73	1.10	0.65	0.78
median	0.61	3.27	3.03	2.39	2.55	1.93	4.74	1.13	0.46	0.70	0.98	0.60	0.14

min	0.16	0.45	1.71	0.47	0.43	0.00	0.10	0.05	0.03	0.06	0.32	0.27	0.02
lower	0.44	2.56	2.50	1.64	1.95	0.48	2.77	0.63	0.13	0.36	0.64	0.40	0.07
upper	1.90	3.64	3.89	3.19	4.05	3.35	6.43	1.78	1.12	0.98	1.48	0.78	1.65
max	3.04	4.54	6.91	5.28	6.52	6.71	7.77	2.69	2.70	1.75	2.18	1.63	2.78
90th percentile	2.66	4.31	4.50	4.72	4.84	4.80	7.25	2.55	2.12	1.37	2.11	0.93	2.58
10th percentile	0.36	1.58	1.94	1.13	1.57	0.08	1.31	0.49	0.07	0.20	0.41	0.30	0.03
n	17	31	30	31	30	31	23	28	30	30	31	30	14
St. Dev	0.99	1.04	1.25	1.30	1.49	1.92	2.27	0.78	0.83	0.45	0.57	0.31	1.11
St. Error	0.24	0.19	0.23	0.23	0.27	0.34	0.47	0.15	0.15	0.08	0.10	0.06	0.30


SSC (mg l⁻¹)
250
200
150
100
50
0
Dep. (mg cm⁻² d⁻¹)
80
70
60
50
40
30
20
10
0
RMS
0.04
0.03
0.02
0.01
0.00
Temperature C°
29
28
27
26
25
24
23
22
21
20
07/2018
08/2018
09/2018
10/2018
11/2018
12/2018
01/2019
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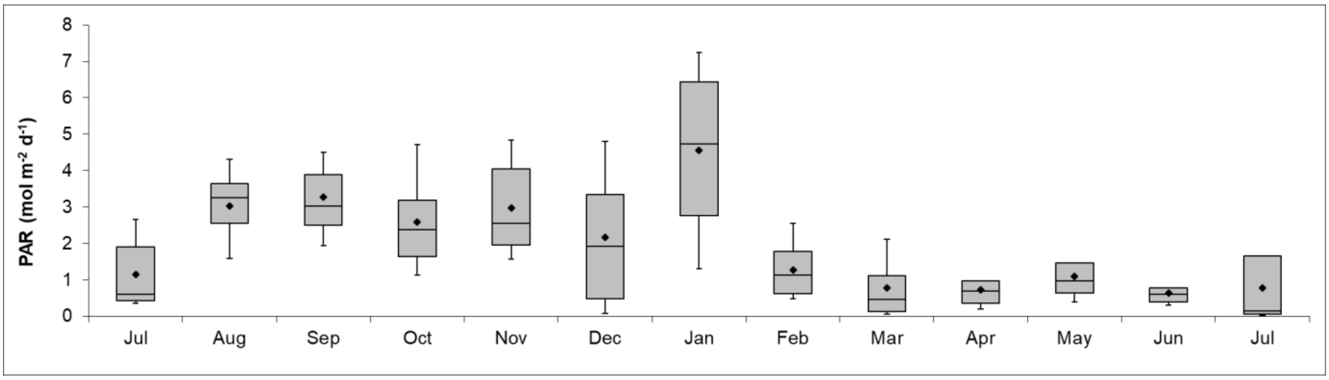
04/2019
05/2019
06/2019
07/2019


PAR (mol m⁻² d⁻¹)
0
1
2
3
4
5
6
7
8
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul

A4 MAROTTE CURRENT METER ANIMATIONS

Link to short video:

https://jamescookuniversity-my.sharepoint.com/:v:/r/personal/rachael_macdonald_jcu_edu_au/Documents/NQBP%20Ambient%20Marine%20Water%20Quality%20Monitoring%20Program/Mackay/Marotte%20video/Mackay_cm2018-2019_short.avi?csf=1&e=PwHH2H

Link to long video:

https://jamescookuniversity-my.sharepoint.com/:v:/r/personal/rachael_macdonald_jcu_edu_au/Documents/NQBP%20Ambient%20Marine%20Water%20Quality%20Monitoring%20Program/Mackay/Marotte%20video/Mackay_cm2018-2019_long.avi?csf=1&e=mNaJ5k

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ATSIP Building
James Cook University
Townsville Qld 4811

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Fax: 07 4781 5589
Email: TropWATER@jcu.edu.au

Web: www.jcu.edu.au/tropwater/