Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program

(July 2017 – July 2018)

Nathan Waltham, Christina Buelow, James Whinney, Rachael Macdonald and Alex Olsen

Report No. 18/18

November 2018

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A Report for North Queensland Bulk Ports Corporation

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SUMMARY POINTS

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 2017/18 wet season rainfall across the study was within the 10^{th} percentile of the distribution of total annual wet season rainfall recorded in the region (1910 to 2018). For the entire ambient marine monitoring period, the total rainfall at Plane Creek Sugar Mill (17 km linear from Hay Point) was 892 mm, with 39% recorded during February 2018. Rainfall in the region contributed to short flow pulse river flow that were generally not sufficient to create notable discharge to the marine environment. This contrasts the previous wet season (2016/17) where rainfall was within the 90^{th} percentile of historical records.
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 (>24km/hr) were predominantly from the south east (more than 45% 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 6wkly 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 (Zeu:Z) ranged between 9 and 100% of the water column at sites, suggesting that optical water clarity on survey days were generally good.
4. Turbidity was generally low at the water surface horizon, and increased with water depth. This pattern is probably related to the bottom horizon being 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, such as corals and seagrass that are sensitive to water clarity changes. 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 benthic habitats.

5. Particulate nutrient concentrations exceeded relevant guidelines for the region. Chlorophyll-*a* concentrations were also regularly elevated above the relevant guideline, particularly so during April 2018 – probably in response to elevated available nutrient concentrations during these months. Continuing elevated nutrients and chlorophyll-*a* concentrations in the region highlights persistent local sources contributing to these concentrations (i.e. runoff from local farms or urban centres).
6. Ultra-trace heavy metals are non-detectable a factor probably reflecting the low rainfall. Atrazine, Diuron, and Hexaninone were detected at several coastal sites, particularly during the wet season survey (April 2018).
7. 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.
8. 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 regularly exceeds relevant water quality guidelines at all sites, indicating that the development of local water quality guidelines is prudent.
3. The four year-long data set comparing wet and dry seasons shows little difference in SSC for the sites AMB 3, 8 10 and 12, however, there were differences for sites AMB1, 2 and 5. At AMB 1, 2 and 5 wet season means and medians were approximately twice that of dry season values. There was no discernible difference between wet and dry RMS wave height values, which indicates that the increase in turbidity at these inshore sites is not likely to be due to an increase in wave activity.
4. Fine-scale patterns of photosynthetically active radiation (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, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids. The multivariate predictive NTUe/SSC model did not provide a clear prediction of these events and may be better applied to data from future dredge campaigns.
5. 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.

6. 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.
7. 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. Most sites showed no difference between wet and dry, while AMB 1 and 2, showed increases of mean and median values of more than 40% during the dry season and AMB 12 showed a decrease in mean and median values of more than 60%.

Recommendations

1. The program this reporting period included seven monitoring sites, which has allowed us to continue characterising water quality in the Mackay region. It is recommended that these same seven 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 kilometres 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.

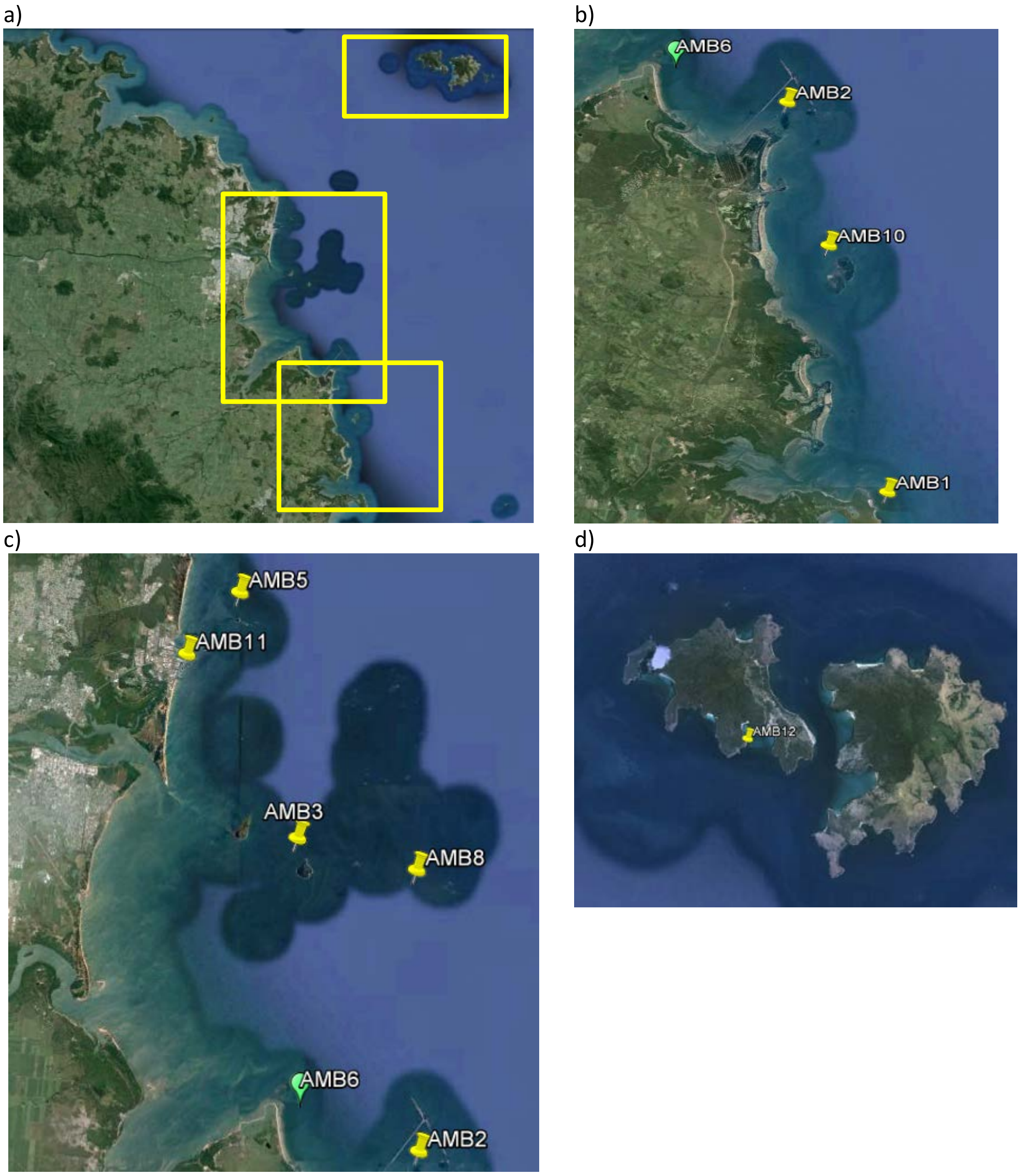


Figure 1.1 Locations of the marine water quality monitoring program sites during 2017/18 program. AMB6 is PAR logger only

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	1	-21.42	149.34	Yes	Yes
Hay Reef	2	-21.26	149.30	Yes	Yes
Round Top Island	3b	-21.17	149.26	Yes	Yes
Slade Island	5	-21.09	149.24	Yes	Yes
Dudgeon Point	6b	-21.24	149.25	Yes	Yes
Spoil Grounds	8	-21.18	149.30	Yes	Yes
Victor Island	10	-21.32	149.32	Yes	Yes
Mackay Harbour	11	-21.11	149.22	Yes	
Keswick Island	12	-20.93	149.42	Yes	Yes

1.3 Rainfall and river flows

To date, the total wet season rainfall within the study area is low, within the 10th percentile of the distribution of total annual wet season rainfall recorded in the region (Figure 1.2). However, the exception was (2016/17) rainfall which was in the 5th percentile for wet season totals, mostly influenced by Tropical Cyclone Debbie, where over 1,100mm of rainfall was recorded in several days. The influence of rainfall and therefore catchment flow can clearly change from year to year, which highlights precisely the reason and necessity for long term commitment to ambient marine monitoring programs.

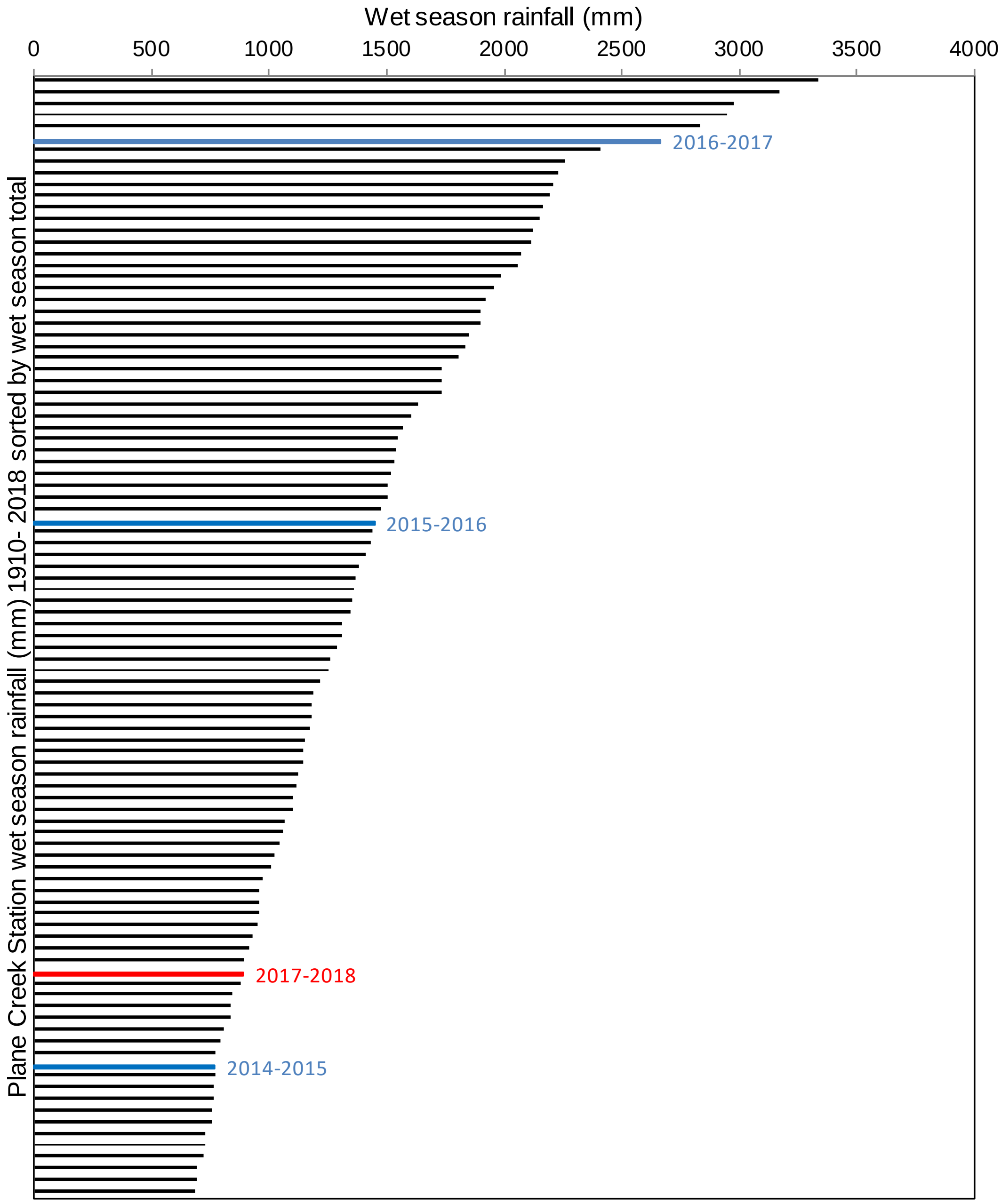


Figure 1.2 BOM wet season (Nov – March) rainfall data for Plane Creek Sugar Mill (station number: 33059) ranked in order of decreasing total rainfall (mm). Blue bars show total rainfall over the past few years, and the red bar represents the 2017/18 ambient marine water quality monitoring period

The example hydrograph for Pioneer River (Figure 1.3) shows more frequent rainfall events during 2016/17 in comparison the 2017/18 reporting period, despite Cyclone Iris that came close to crossing through the study area in early April 2018 (Figure 1.4). In March 2017, tropical cyclone Debbie caused a large peak in river flow (Figure 1.4).

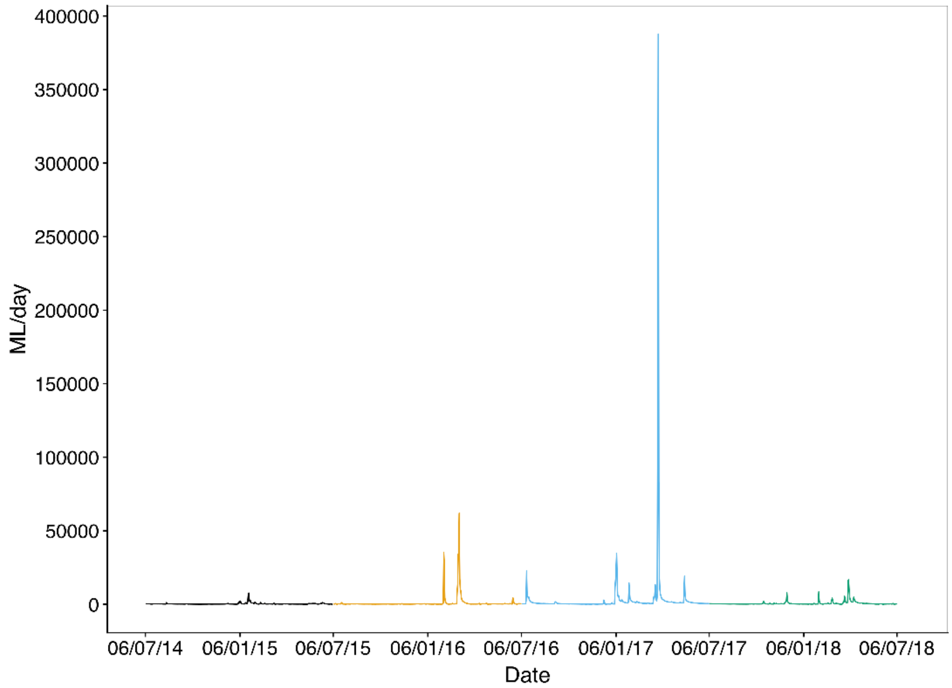


Figure 1.3 Flow (Megalitres/day) recorded for Pioneer River. Line colour indicates monitoring period: black = July2014 – July 2015, orange = July 2015 – July 2016, blue = July 2016 – July 2017, and green = July 2017 – July 2018

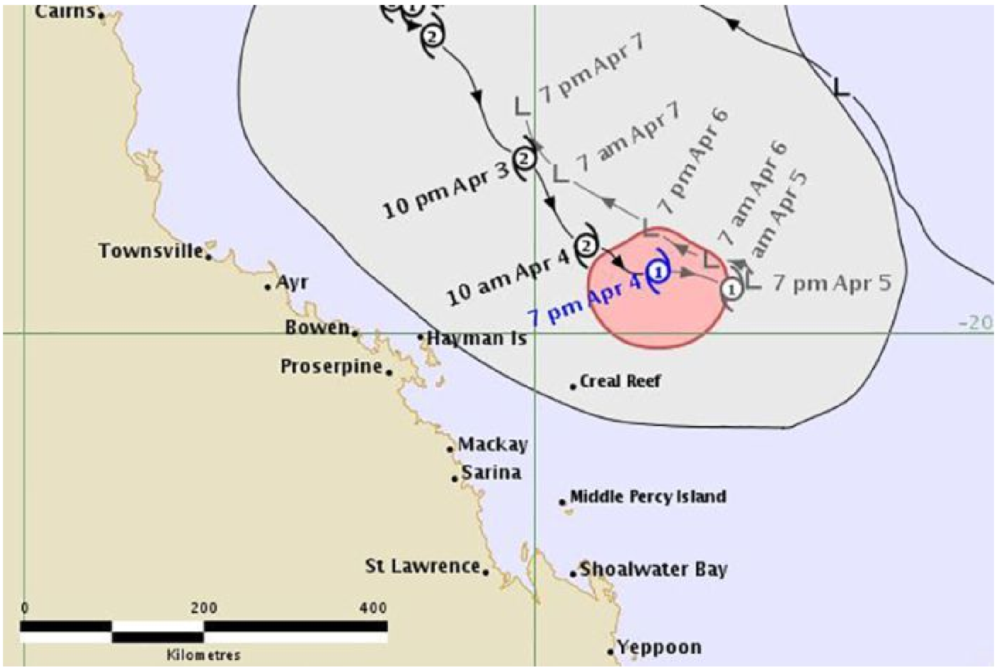


Figure 1.4 Tropical Cyclone Iris passing Mackay 4 April 2018

1.4 Wind for Mackay Airport

The daily average wind speed and direction recorded at Mackay airport for the reporting period (2017/18) is predominantly from the south east and south west, with more than 45% of the days reaching more than 24km/hr (Figure 1.5). The higher percentage of days with winds greater than 24km/hr in 2016/17 compared to previous years may be linked to the passing of tropical cyclone Debbie. However, 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 2017/18).

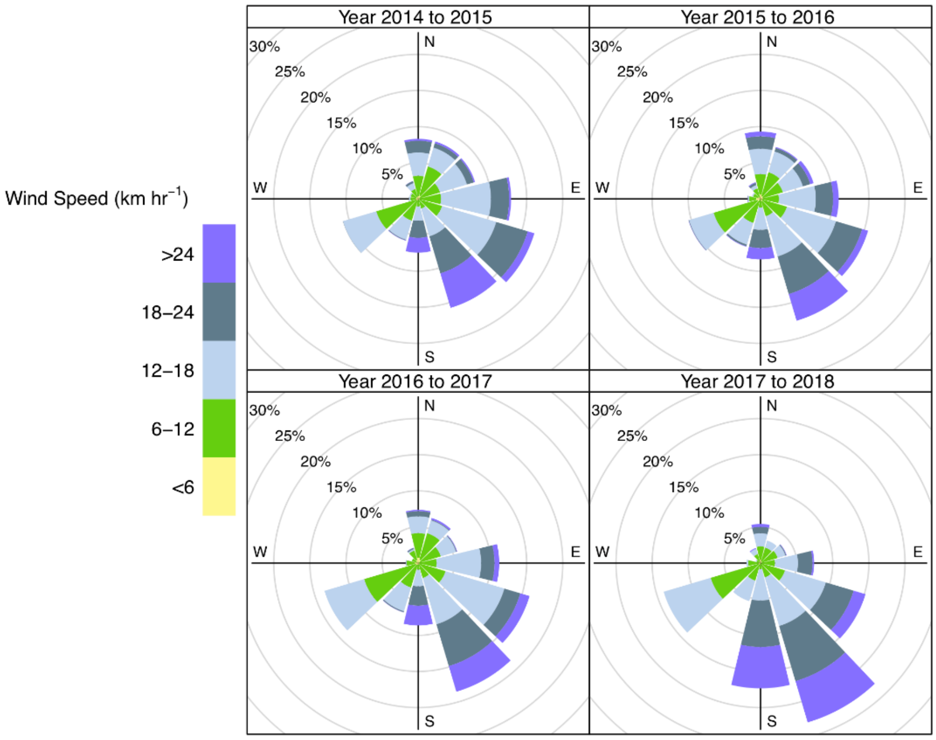


Figure 1.5 Daily average wind direction and strength recorded in Mackay airport from July 2017 to July 2018

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 2017 and July 2018. These data are part of a longer term commitment to monitor and characterise receiving water quality conditions, 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 6wk basis (Table 2.1) over the 12 month project from a research vessel. At each site, a calibrated multiprobe is used to measure water temperature, salinity, dissolved oxygen (%), pH, and turbidity (Figure 2.1). In addition to spot measurements, secchi disk depth is recorded, as a measure of the optical clarity of the water column, along with light attenuation using a LiCor meter. These field *in-situ* measurements are recorded at three depth horizons: a) surface (0.25m); b) mid-depth; and c) bottom horizon. 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*; and
- 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.

Figure 2.1 TropWATER staff conducting field water quality sampling

Table 2.1 Summary of instrument maintenance and water quality surveys completed during the 2017/18 reporting period

Date	Nutrients, Chloro	Metals, herbicides	Plankton	Logger maintenance
July 2017	Yes	-	Yes	Yes
September 2017	Yes	-	Yes	Yes
October 2017	Yes	-	Yes	Yes
December 2017	Yes	-	Yes	Yes
February 2018	Yes	-	Yes	Yes
April 2018	Yes	Yes	-	Yes
June 2018	Yes	-	-	Yes
July 2018	Yes	-	-	Yes

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e., DERM 2009b; APHA 2005; 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 posterior 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 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 after collection. Filters are then wrapped in aluminium foil and frozen. Pigment determinations from acetone extracts of the filters were completed using spectrophotometry, method described in 'Standard Methods for the Examination of Water and Wastewater, 10200 H. Chlorophyll'.

Water samples are 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 phosphorus and total filterable nitrogen and phosphorus are analysed simultaneously using nitrogen and phosphorous methods after alkaline persulphate digestion, following methods as presented in 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method' and in 'Standard Methods for the Examination of Water and Wastewater, 4500-P F. Automated Ascorbic Acid Reduction Method'. Nitrate, Nitrite and Ammonia were analysed using the methods 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method', 'Standard Methods for the Examination of Water and Wastewater, 4500-NO2- B.

Colorimetric Method', and 'Standard Methods for the Examination of Water and Wastewater, 4500-NH3 G. Automated Phenate Method', respectively. Filterable Reactive Phosphorous is analysed following the method presented in 'Standard Methods for the Examination of Water and Wastewater, 4500-P F. Automated Ascorbic Acid Reduction Method'. Filterable heavy metals, and herbicides are analysed by Australian Laboratory Service (ALS).

For all water quality plots, boxes are 20th and 80th quantile, centre line is median, 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 survey vessel for approximately 100 m. The boat speed is reduced to approximately 6kts, with a GPS point taken at the start and end of each plankton tow. At the end of each plankton tow, the nets are retrieved, and the contents retained in the plastic jar attached to the net was immediately transferred to preservation containers. Samples were identified 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 seven sites 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.

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 (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 *x* 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 re-suspension 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 (see 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/day. 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 Dn is the *n*th 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 10m 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 in a bolt that protrudes from the instrument and gives sensitive temperature measurements.

a) b)

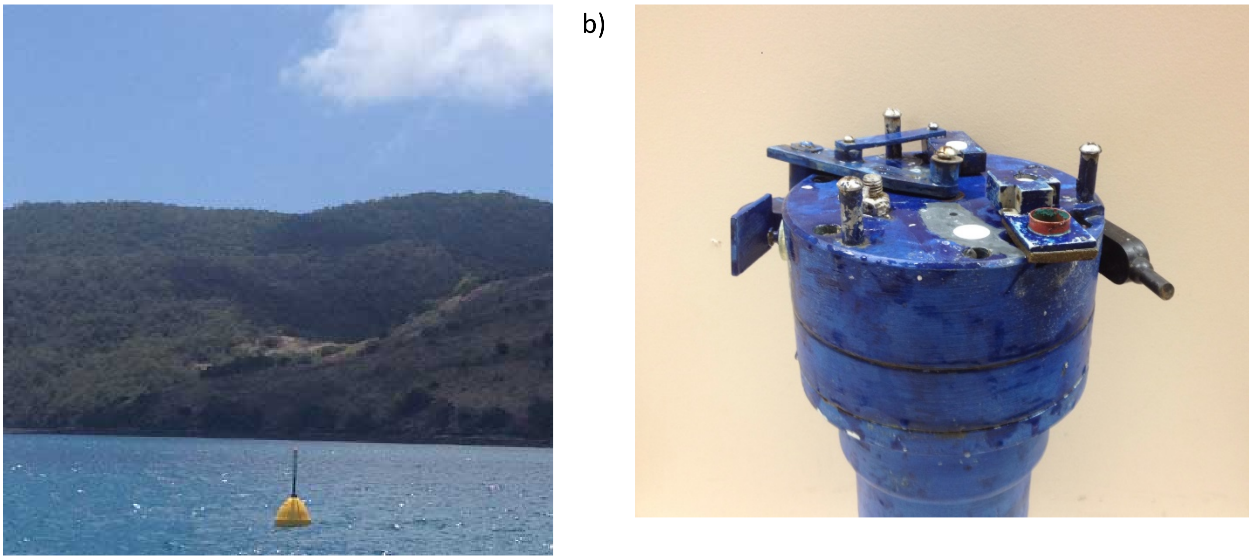


Figure 2.3 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

2.3.5 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 photons m^2/day) 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.

a)

b)

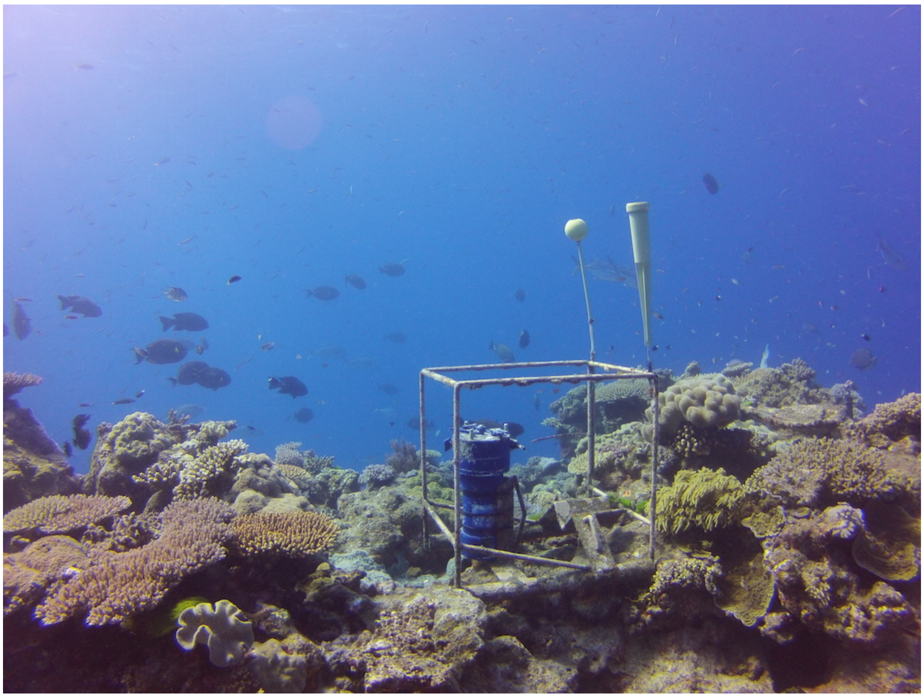


Figure 2.4 a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte at Moore Reef. Image courtesy of Eric Fisher

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. Mean daily wind was calculated from 8 daily readings decomposed into NE-SW (wind_NESW) and NW-SE (wind_NWSE) components. 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 2017 and July 2018 water temperature ranged between 20 and 30^{o}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.

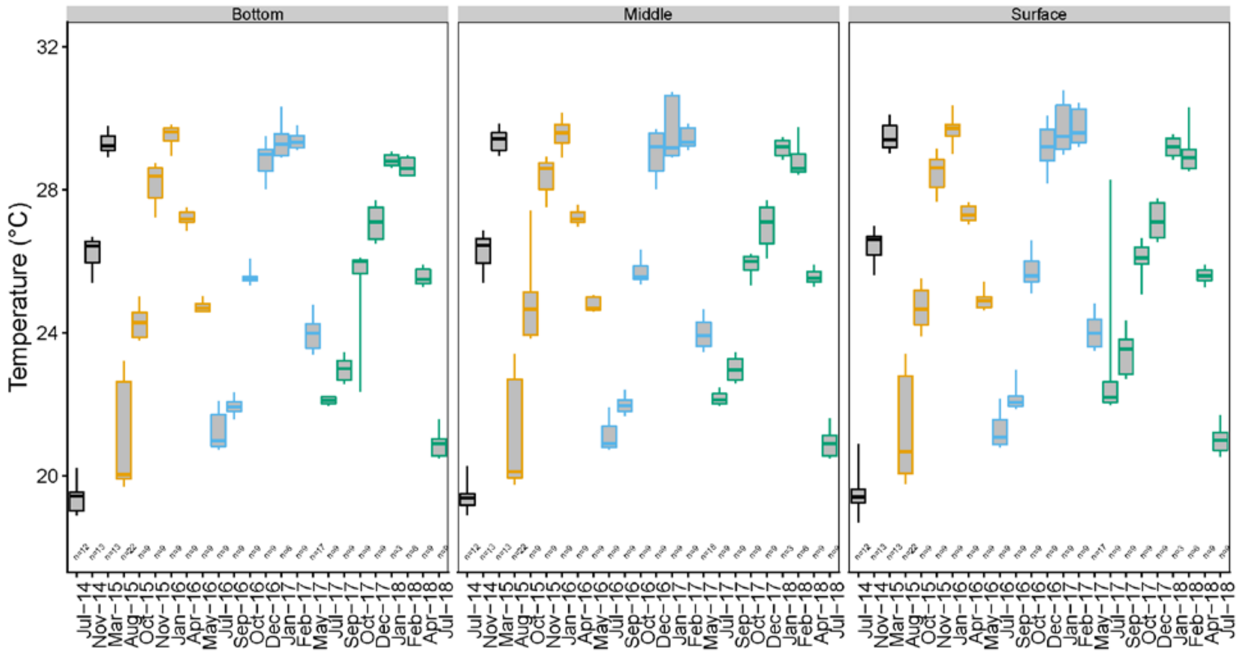
Electrical conductivity (EC) was stable across all sites, with little evidence of changing conditions through the water column (Figure 3.2). Overall EC has remained between 51 mS/cm and 57 mS/cm, generally indicating oceanic conditions. However, during the present reporting period, salinity (ppt) was 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 115% (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 with dissolved oxygen levels similar along the depth profile.

Field pH measurements were stable across sites and depths primarily ranging between 8.0 and 8.3 (Figure 3.4). However, samples collected in August 2015 and April 2016 were more acidic (< 7.9) and samples collected in May and July 2016 were more alkaline (> 8.3), although still within expected range for marine waters (ANZECC, 2000). Similar to the 2016-2017 monitoring period, pH levels were relatively stable during 2017-2018.

Field turbidity measurements typically ranged between <1 to 55 NTU, with notable exceptions in November 2014 where turbidity was higher (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 16m (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 (Zeu: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.

A)



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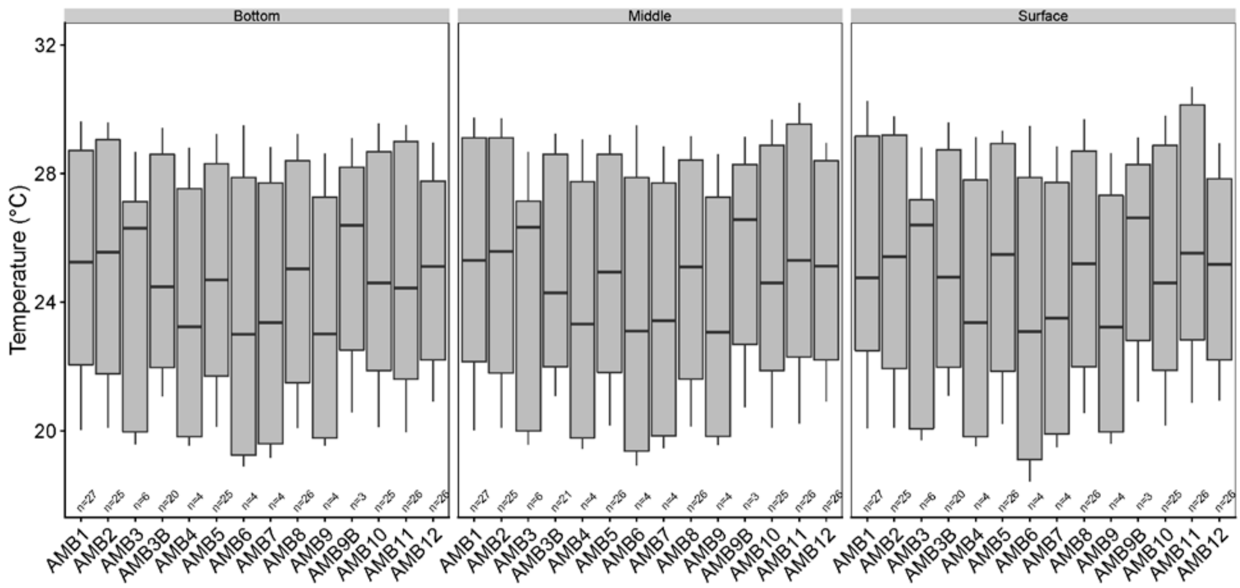


Figure 3.1 Water temperature box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four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

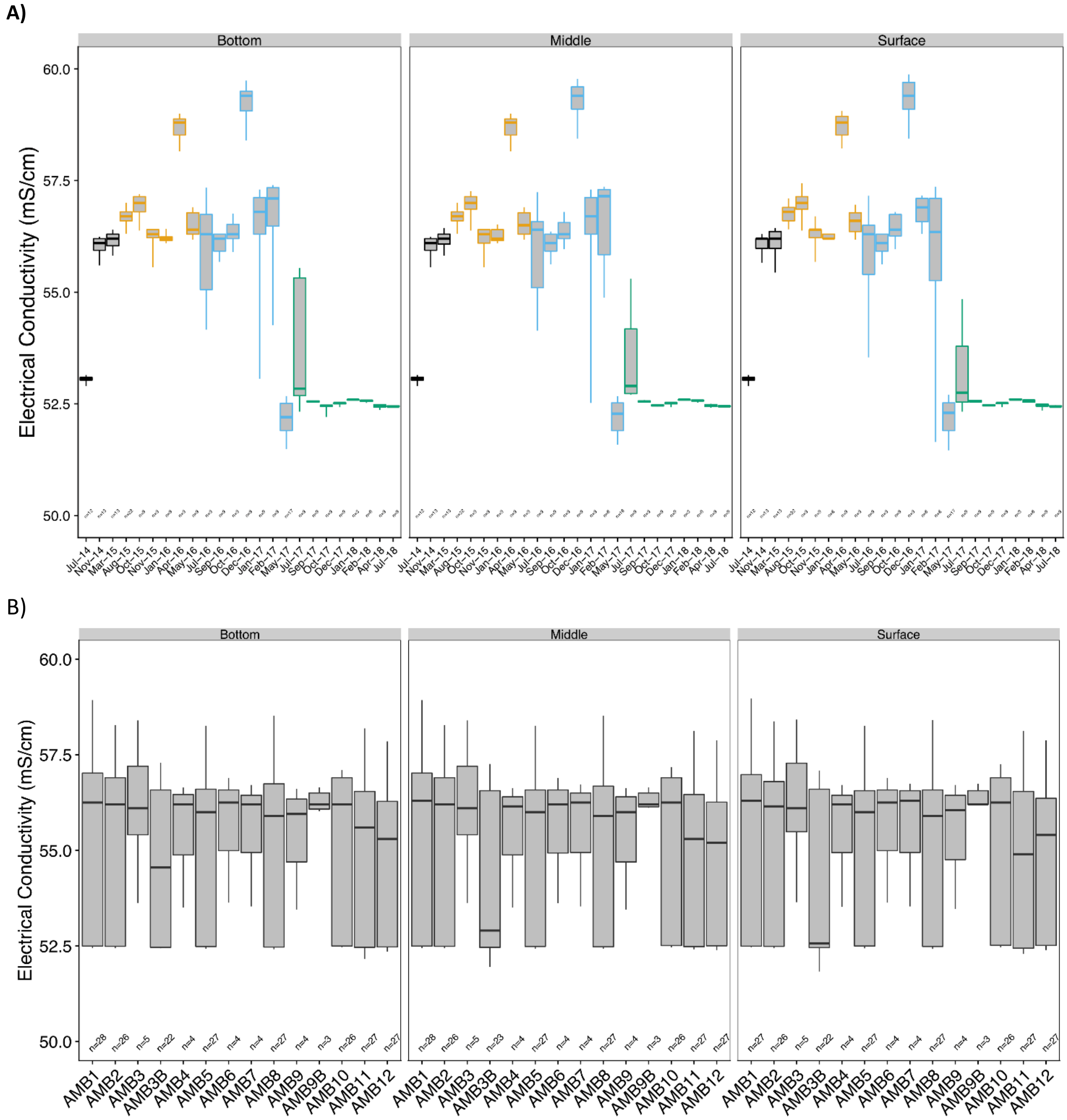
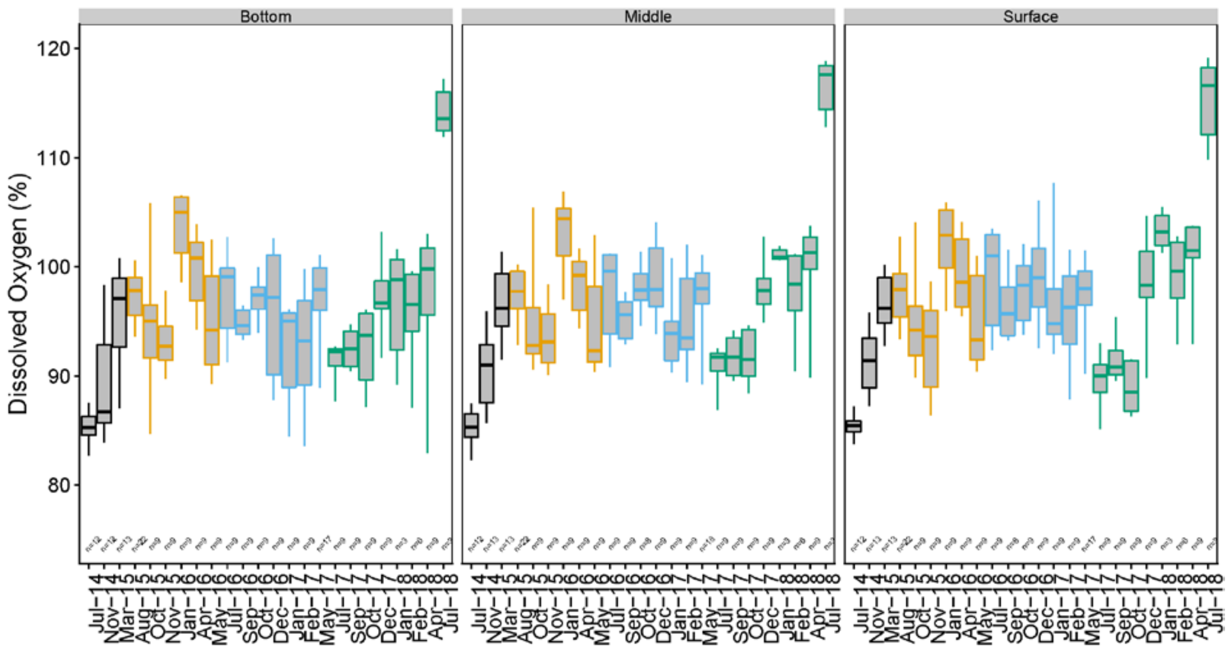


Figure 3.2 Salinity box plots recorded: (a) three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling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

A)



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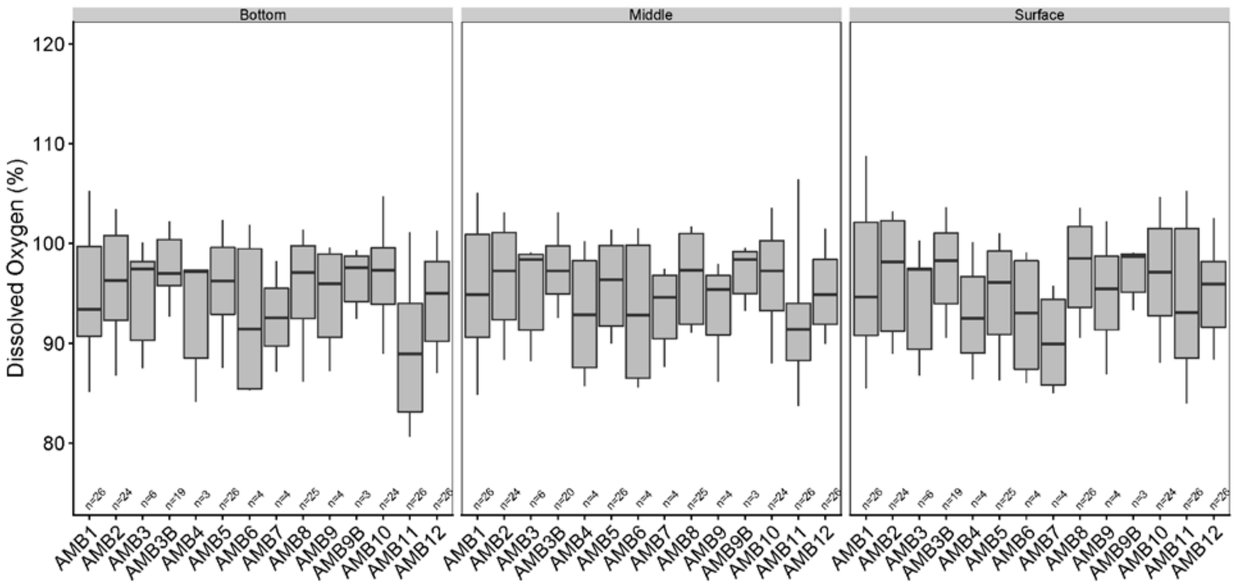
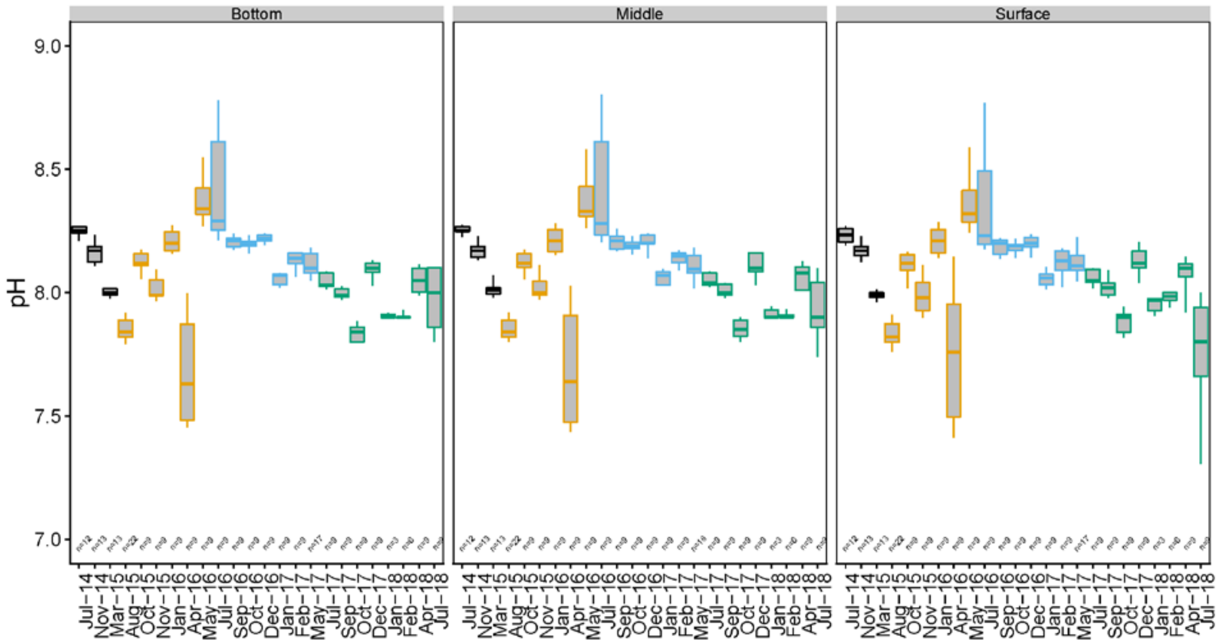


Figure 3.3 Dissolved oxygen box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four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

A)



B)

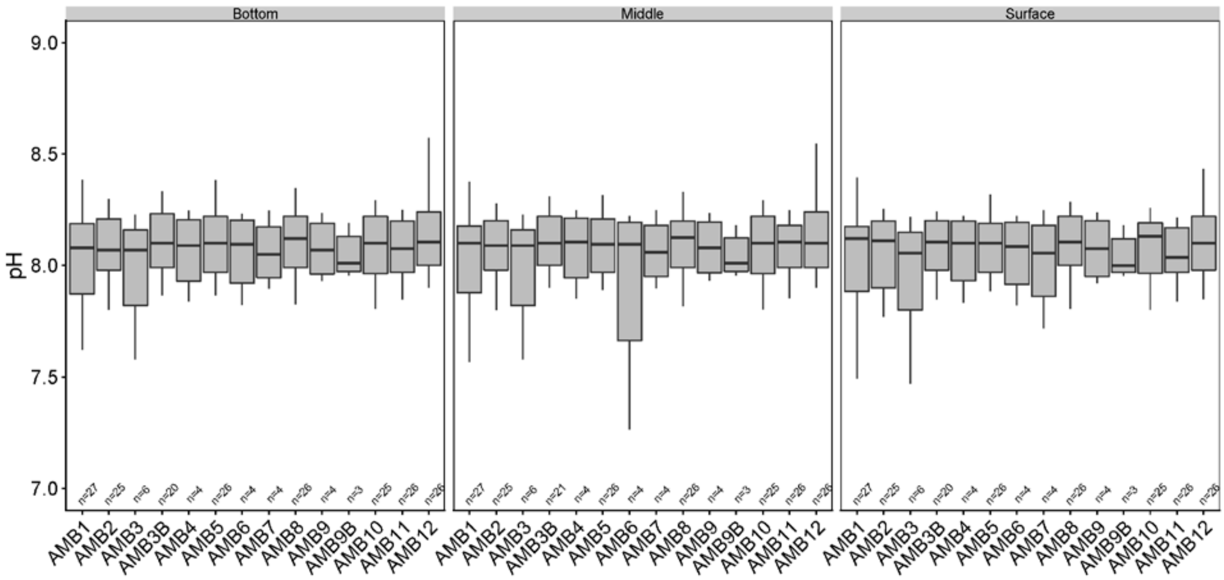
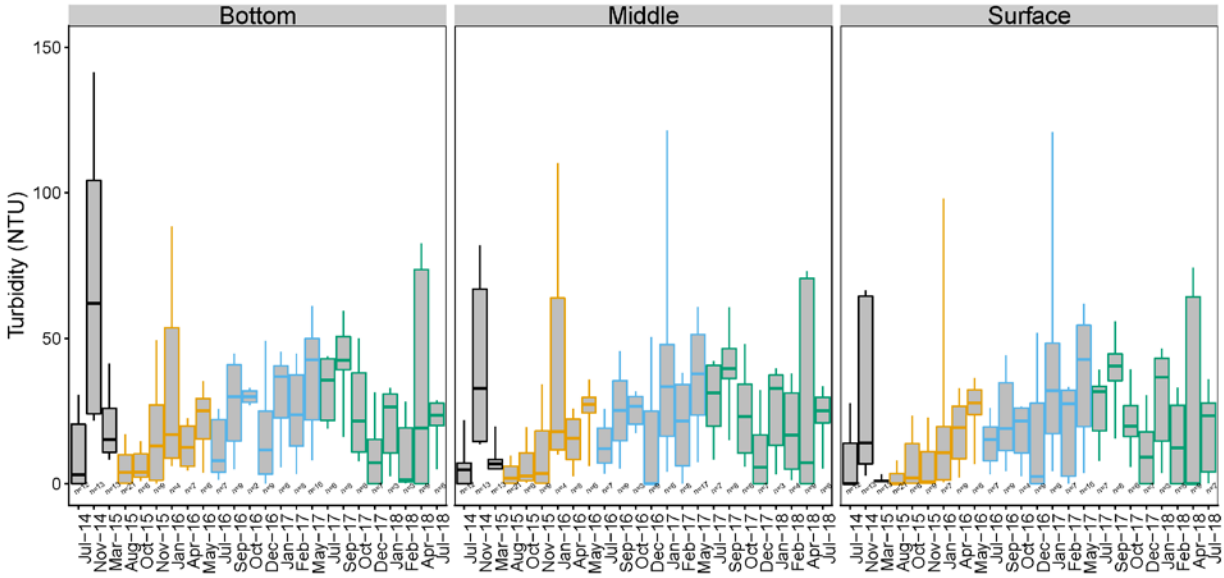


Figure 3.4 pH box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling periods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

A)



B)

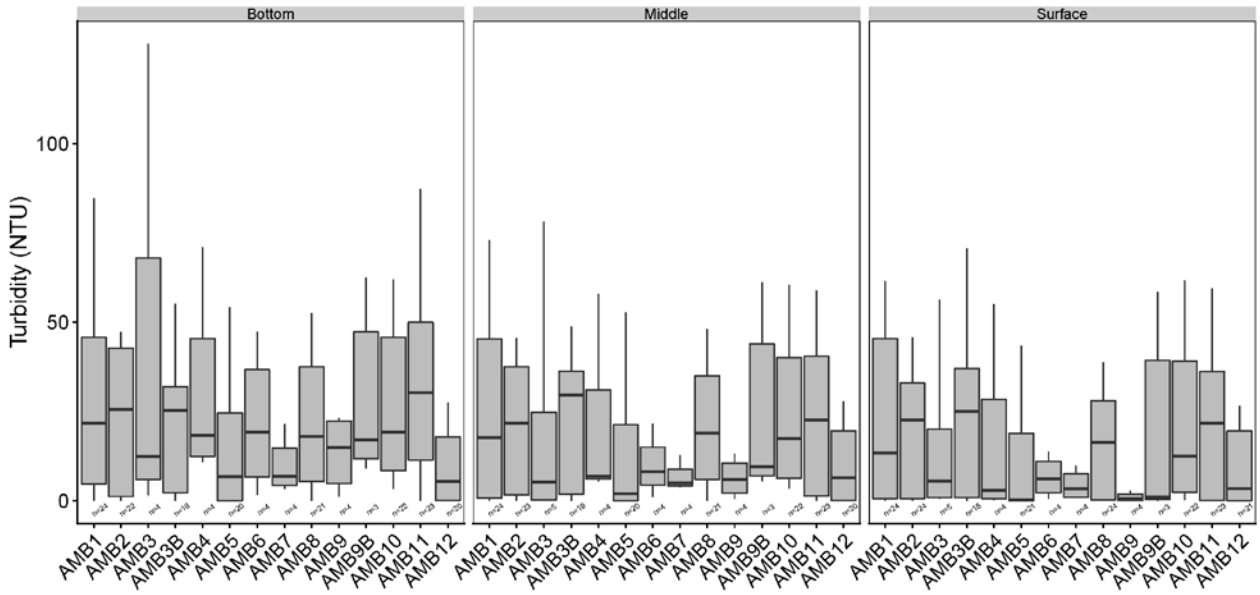
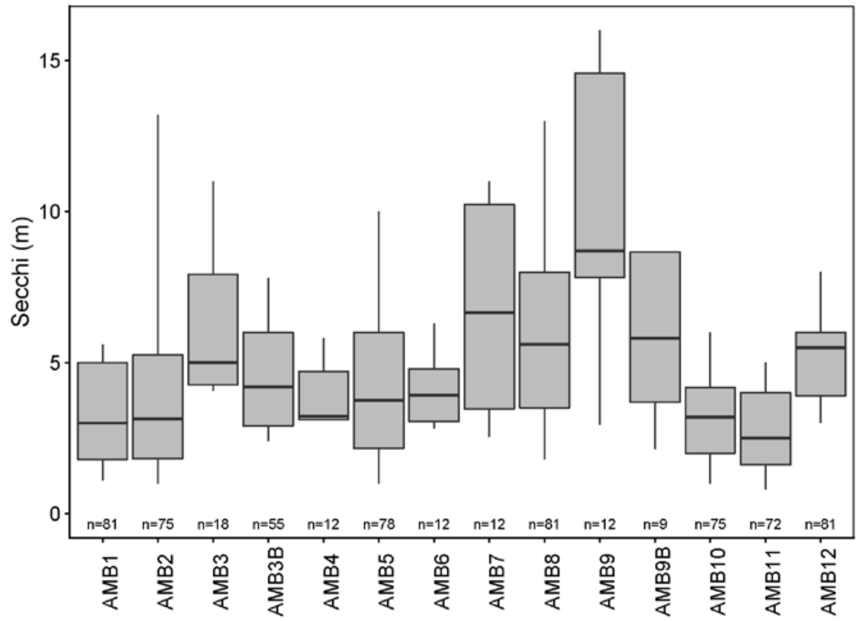


Figure 3.5 Turbidity box plots recorded: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling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

A)



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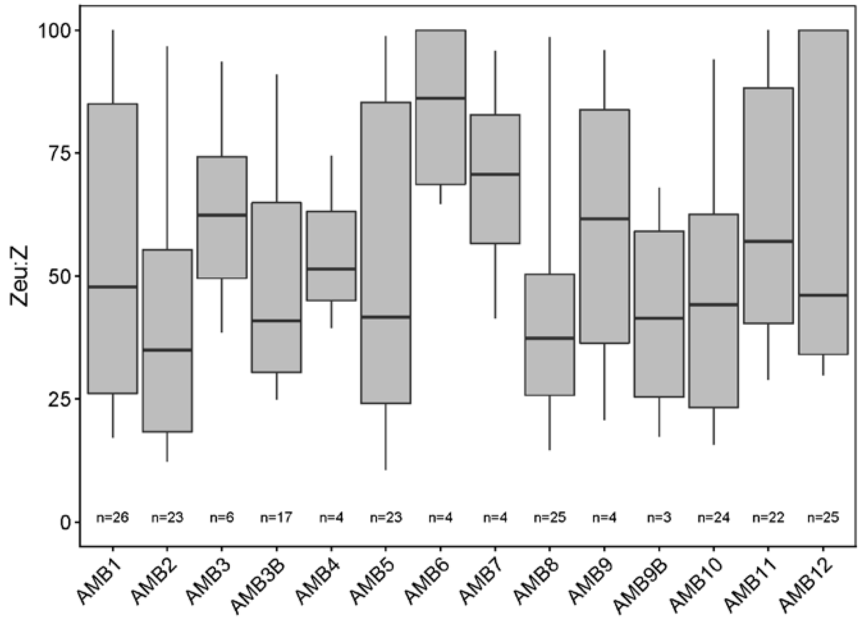


Figure 3.6 (A) Water secchi disk depth for all sites (surveys pooled for all monitoring periods 2014-2018); and (b) light attention depth to depth ratio (Zeu:Z) for sites (surveys pooled for all monitoring periods 2014-2018)

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, 2009). Particulate nitrogen concentrations continue to exceed the guideline (Figure 3.7a). Despite high concentrations during certain months, PN is generally similar across all sites (Figure 3.7b).

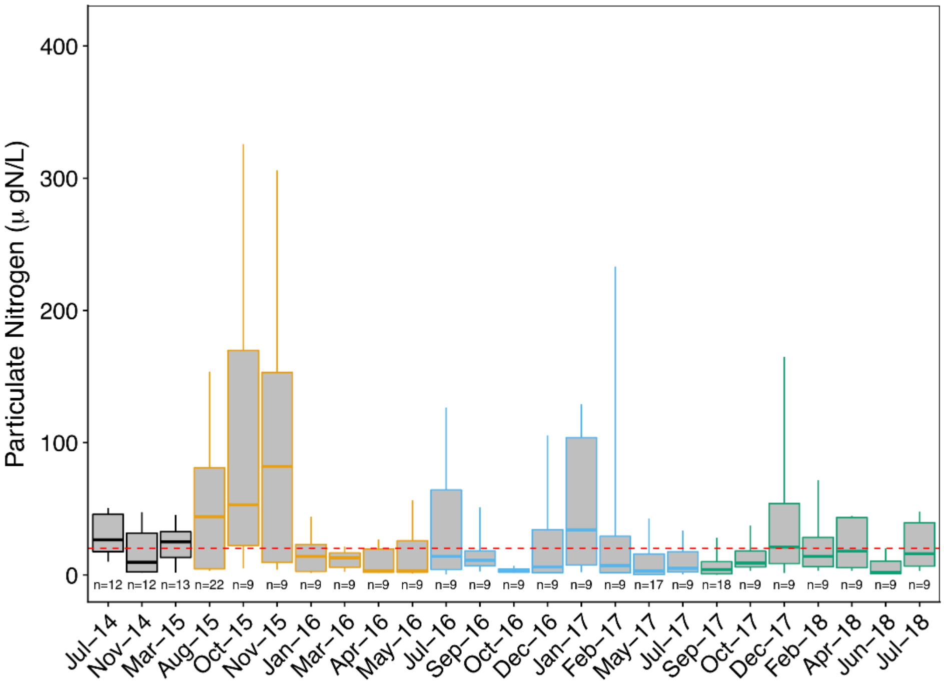
High concentrations of PN might be associated with the contribution from local land use activities, whereby despite low rainfall (see Figure 1.3), there would be still some base flow from rivers and local rainfall that is known to contribute to nutrient loadings to coastal regions (Brodie et al. 2012; 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., 2016).

Particulate phosphorus concentrations continue to be variable from survey to survey and site to site with no apparent seasonal pattern (Figure 3.8). April 2018 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) continues to record the highest concentrations, which might related to local urban stormwater runoff (Figure 3.8B).

Chlorophyll-*a* concentrations were generally elevated above the guidelines (Figure 3.9). This has been a trend since the program commenced. Over all four monitoring periods (2014-2018) Chlorophyll-*a* concentrations were highest at AMB6B and AMB11 (Figure 3.9B).

Relationships between nutrient levels (i.e. PN, PP, Chlor-a, and Phaeophytin-a) across all sites and sampling periods were positive but weak (correlation coefficients (r) ranged between 0.12 – 0.37; Figure 3.10). Principal components analysis was used to further explore patterns in nutrient levels among sites, showing 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 sites with relatively high nutrient, chlorophyll-a and phaeophytin-a levels (Figure 3.11).

A)



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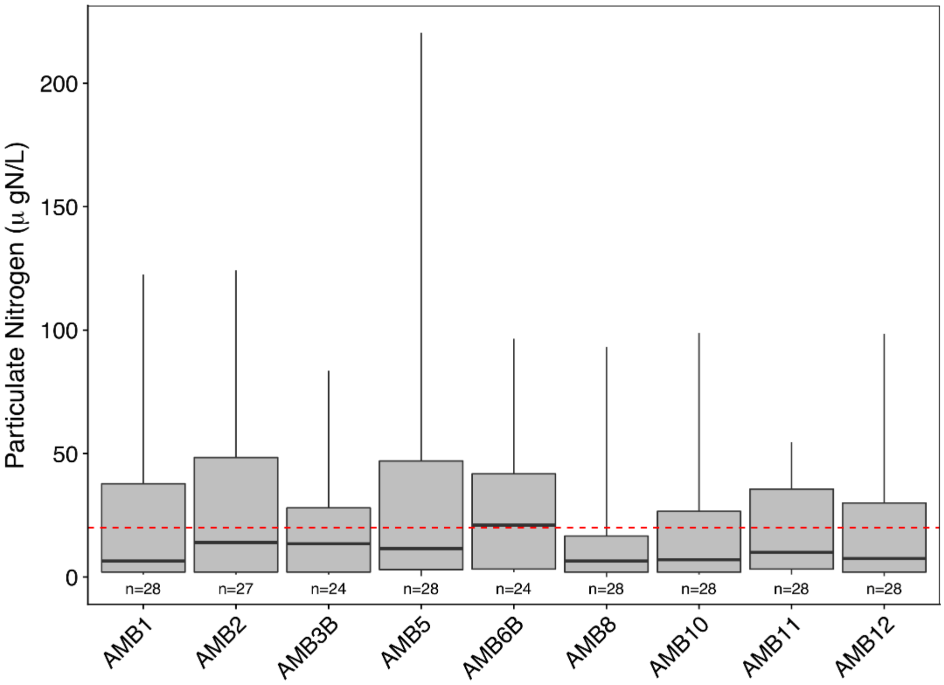
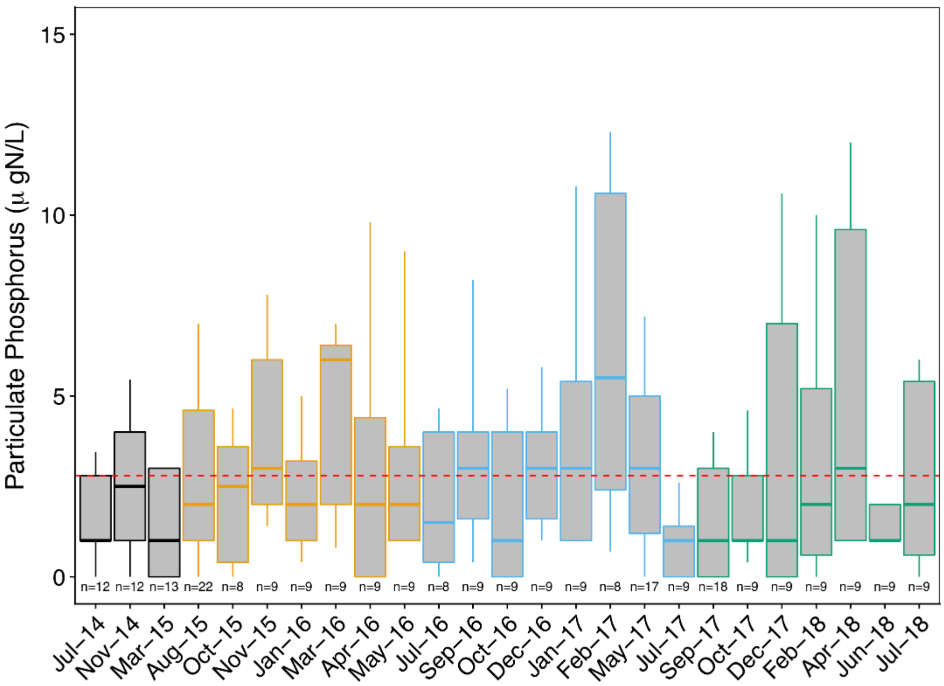


Figure 3.7 Particulate nitrogen box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling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

A)



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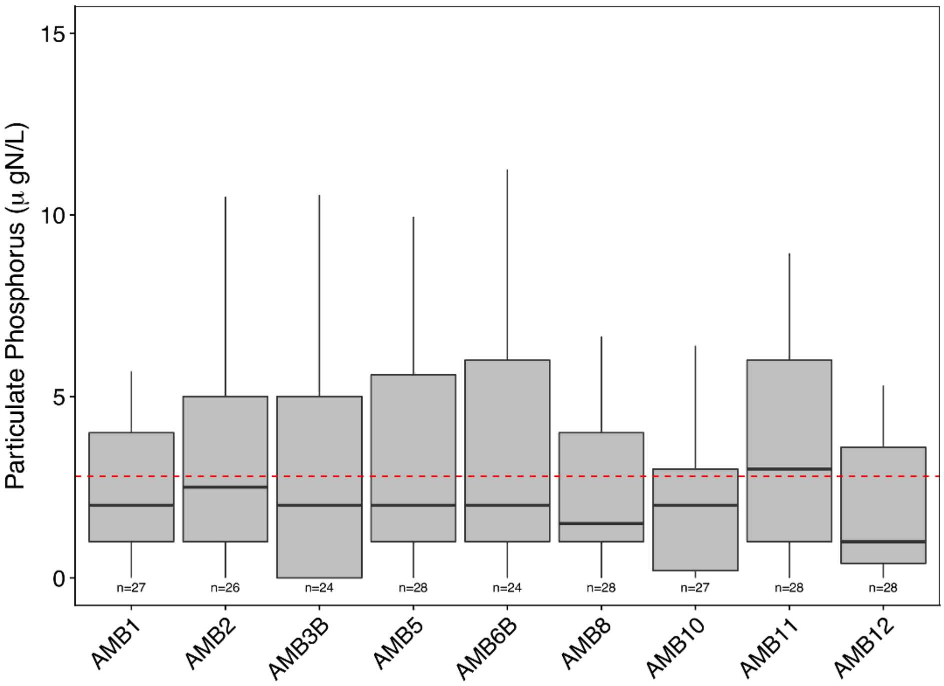
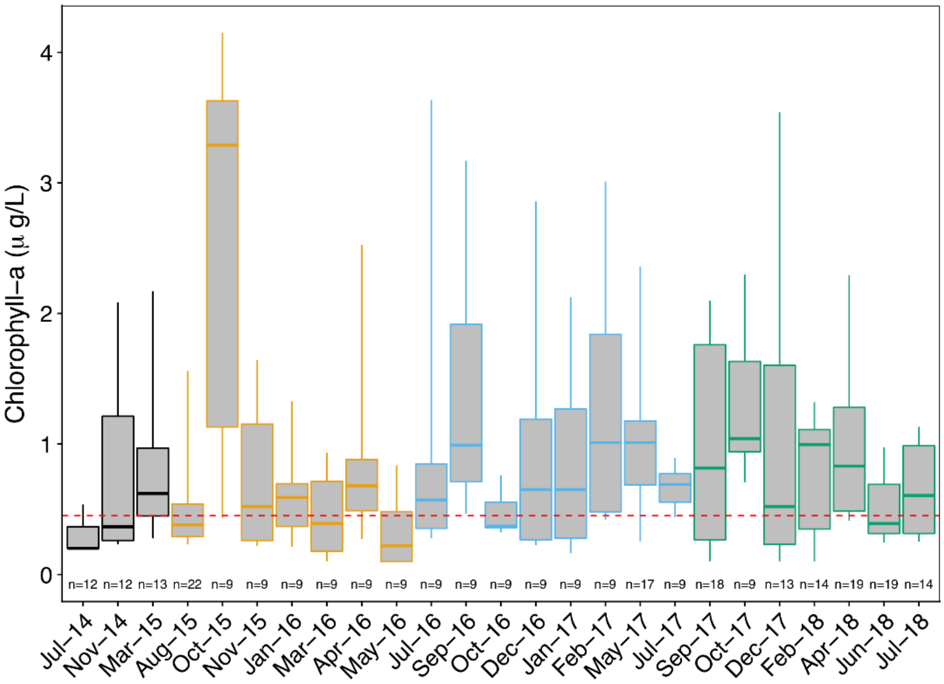


Figure 3.8 Particulate phosphorus box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and

green = 2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2018)

A)



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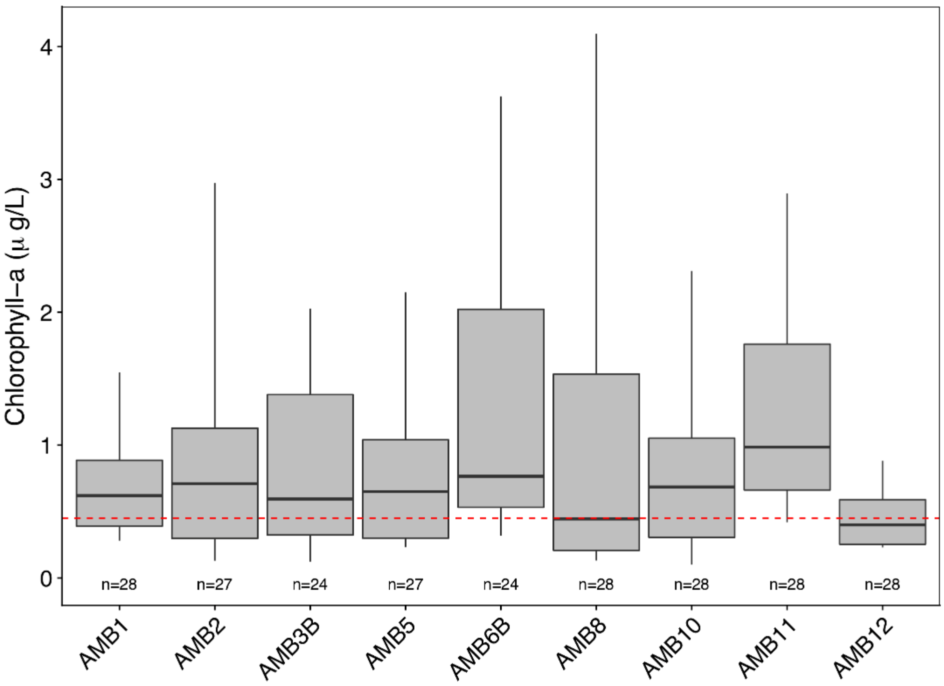


Figure 3.9 Chlorophyll-*a* box plots: (a) the three depth horizons during each survey (sites pooled) where colour indicates monitoring period: black = 2014/2015, orange = 2015/2016, blue = 2016/2017; and green =

2017/2018; and (b) the three depth horizons for each site (pooled across all four sampling periods during 2014-2018)

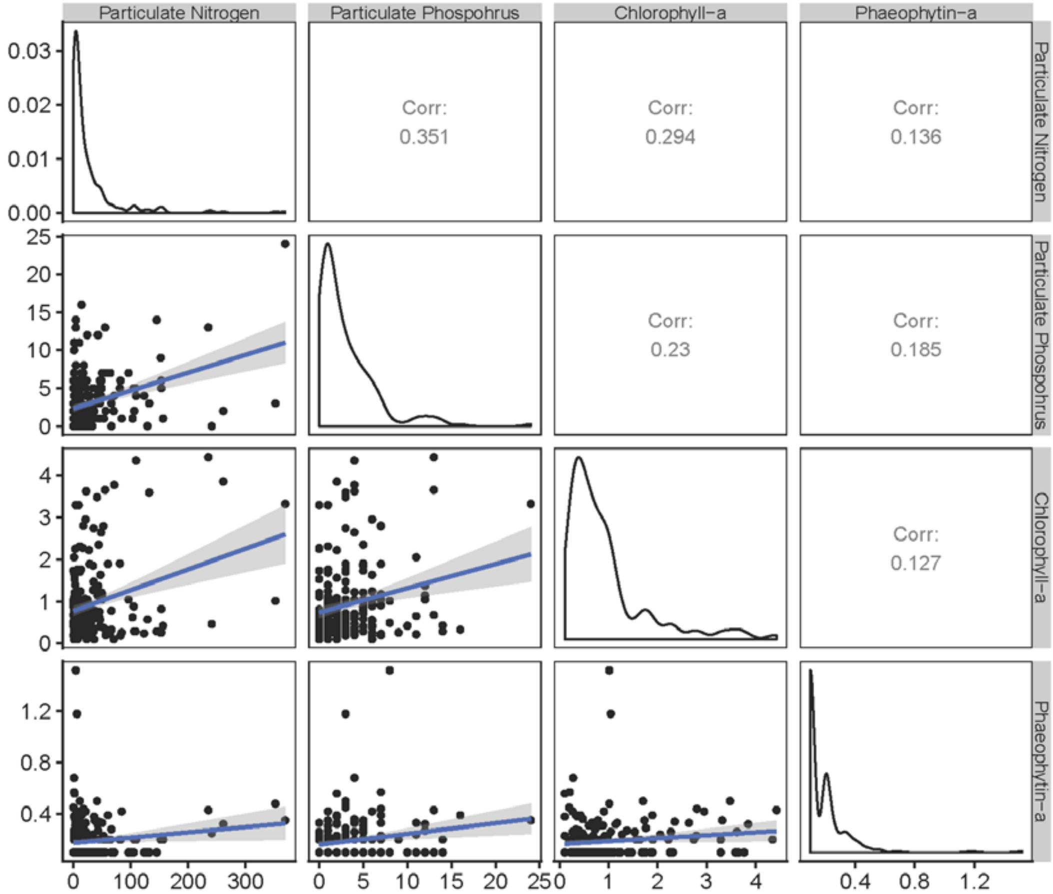


Figure 3.10 Scatterplot of nutrient relationships at pooled across all sites and surveys. Lines of best fit with 95% confidence intervals are displayed in blue, and correlation coefficients are shown in corresponding plots. Density plots show the distribution of the data.

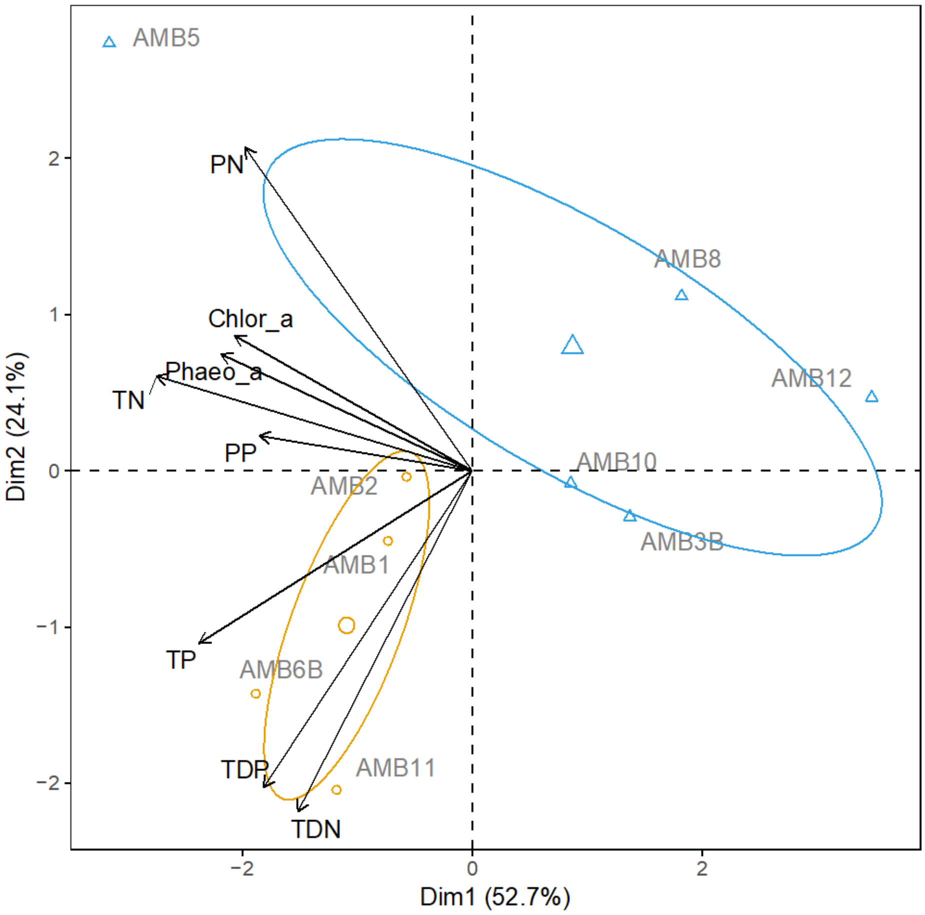


Figure 3.11 Principal components analysis (PCA) exploring relationships between nutrients (red vectors) and sites (blue = offshore, orange = coastal) with 95% confidence interval ellipses surrounding offshore and coastal groups. Nutrient labels are abbreviated as follows: PP = Particulate Phosphorus, 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 = 76.8%.

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). Most of the filterable metals continue to be undetectable above the Limit of Reporting (LOR), the exception is arsenic (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 for As (V) and 2.3 µg/L 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
	Unit	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
	LOR	-	0.2	1	0.2	0.5	0.1	5
	ANZECC	-	5.5	1.3	4.4	70	1.4	15
Jul-14	Mean	1.5	<0.2	<1	0.3	<0.5	<0.1	<5
	Min	1.3	<0.2	<1	0.2	<0.5	<0.1	<5
	Max	1.6	<0.2	2	0.3	<0.5	<0.1	<5
Nov-14	Mean	1.3	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	0.8	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.5	<0.2	1	<0.2	<0.5	<0.1	<5
Mar-15	Mean	1.7	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.9	<0.2	2	<0.2	<0.5	<0.1	<5
Aug-15	Mean	1.2	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	1.1	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.3	<0.2	1	<0.2	<0.5	<0.1	<5
Nov-15	Mean	1.7	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.9	<0.2	<1	<0.2	<0.5	<0.1	<5
Mar-16	Mean	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.7	<0.2	1	<0.2	<0.5	<0.1	<5
Dec-16	Mean	1.7	<0.2	<1	<0.2	<0.5	3.3	<5
	Min	1.6	<0.2	<1	<0.2	<0.5	2.6	<5
	Max	1.9	<0.2	<1	<0.2	0.6	5.2	<5
May-17	Mean	1.6	<0.2	<1	<0.2	<0.5	<0.1	<5
	Min	1.4	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	1.8	<0.2	<1	<0.2	0.7	<0.1	<5
Apr-18	Mean	1.8	<0.2	<1	<0.2	<0.5	<0.1	5
	Min	1.5	<0.2	<1	<0.2	<0.5	<0.1	<5
	Max	2	<0.2	<1	<0.2	0.5	<0.1	7
Overall	Mean	1.6	<0.2	1	0.1	0.6	0.5	2.8
	Min	0.8	<0.2	<1	<0.2	<0.5	<0.1	2.5
	Max	2	<0.2	2	0.25	0.7	3.3	7

3.1.4 Water pesticides and herbicides

The major pesticide and herbicide concentrations were not detected above the limit of reporting (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 (LOD unchanged since 2008). During this reporting period, Hexaninone, Diuron and Atrazine were again detected, and probably represent catchment land use in the local area, which 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.

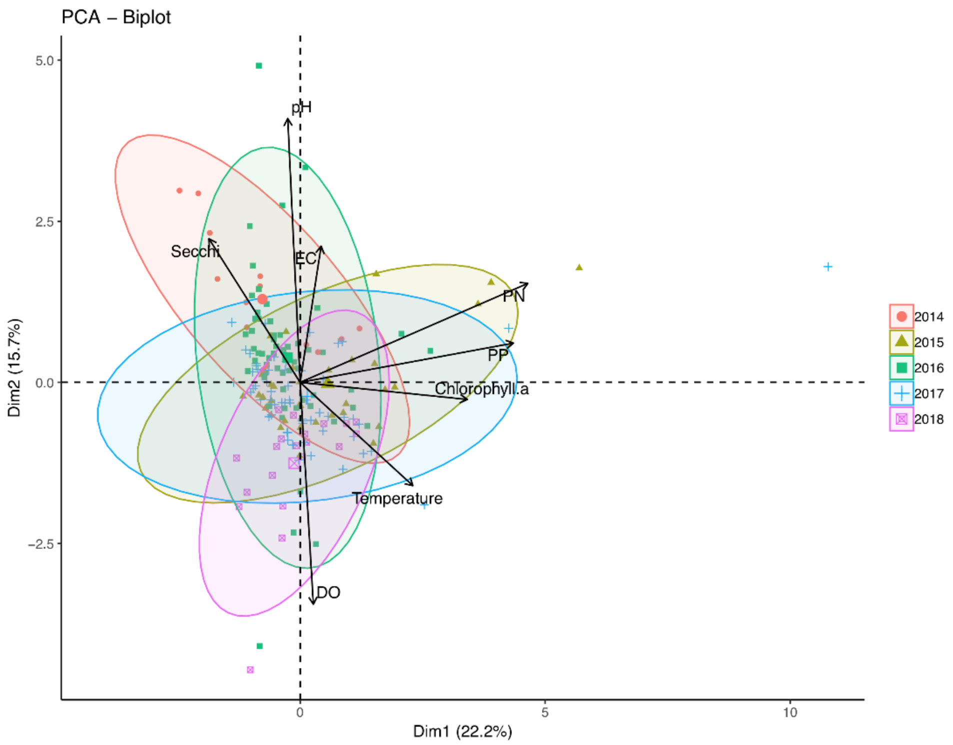
Table 3.2 Summary (average) statistics for pesticides/herbicides recorded at all sites during the program (all values are µg/L). Values are pooled across sites for each survey and compared to the Water Quality Guidelines for the Great Barrier Reef Marine Park (GBRMPA, 2010) 95% protection level. Mackay-Whitsunday 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

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 3.10). Electrical conductivity (EC) and pH are negatively correlated with dissolved oxygen (DO), and these variables are not associated with any yearly (Figure 3.10A) or 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, 22.2%), and increasing values of these parameters are weakly associated with wet season (Figure 3.10B). Higher temperatures are also associated with wet season (Figure 3.10B).

A)



B)

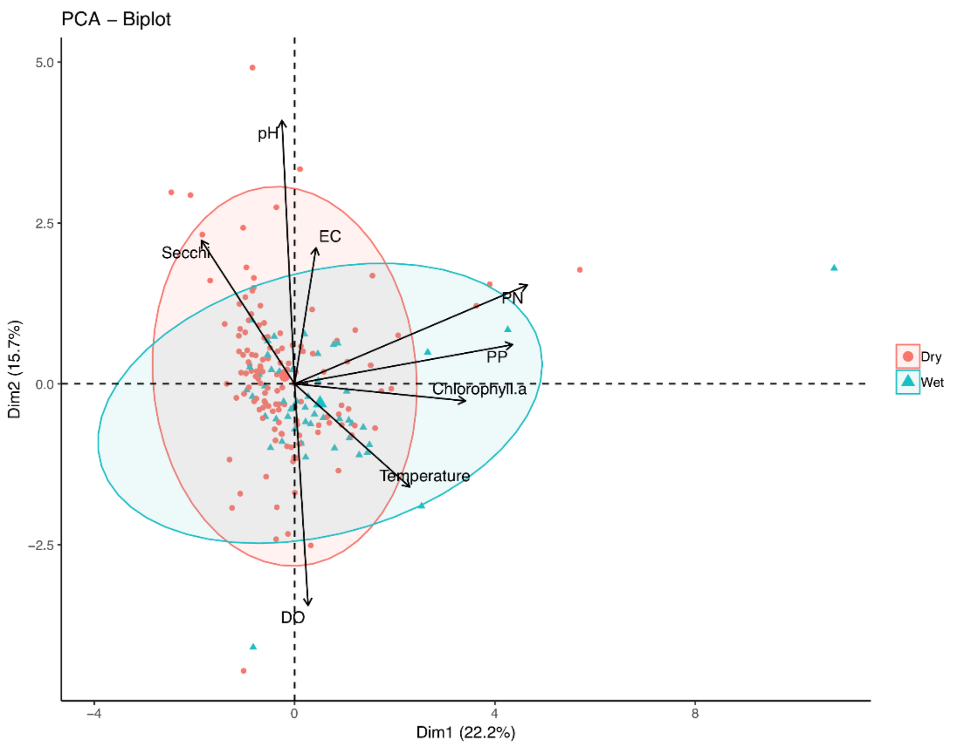


Figure 3.10 Principal components analysis (PCA) exploring relationships between nutrients and physiochemical parameters (black vectors) and monitoring sites. The 95% confidence interval ellipses show overall differences between: A) sites grouped by year and B) sites grouped by season. Vector labels are 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 = 37.9%

3.2 Plankton communities

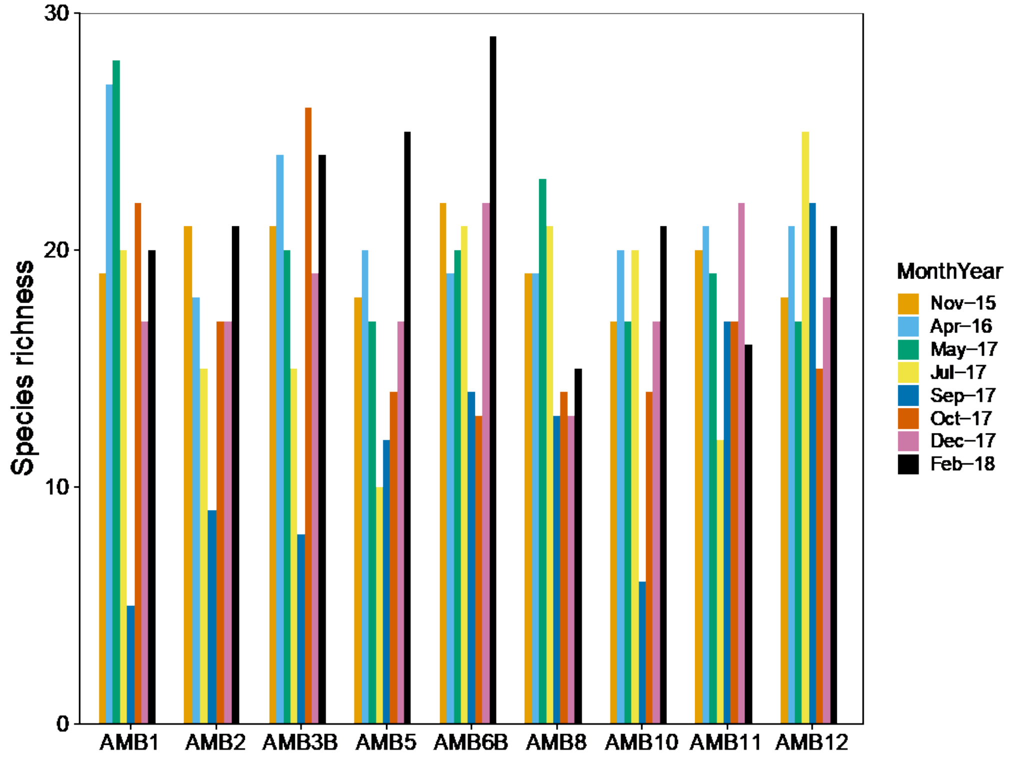
3.2.1 Diversity and abundance

A total of 82 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*. Freshwater Point (AMB 6) had the highest phytoplankton species richness in February 2018 (29 species), and the lowest species richness in September 2017 (4 species) (Figure 3.11a). 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 3.11b).

A total of 52 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 Point (AMB 6B) had the highest diversity of zooplankton species in November 2015 (19 species), while Hay Point (AMB 2) and Keswick island (AMB 12) both had the lowest zooplankton species diversity (4 species) in July 2017 and April 2016, respectively (Figure 3.12a). 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 3.12b).

Overall, the species composition of plankton communities showed high similarity across surveys throughout November 2015-February 2018, with the exception of November 2015 and April 2016 communities (Figure 3.13 & 3.14). This suggests that there is inter-annual variability in plankton species composition. The phytoplankton community also demonstrated seasonal variability, with dry season species composition (May, July, and September 2017) relatively distinct from wet season months (December and February 2018; Figure 3.14).

A)



B)

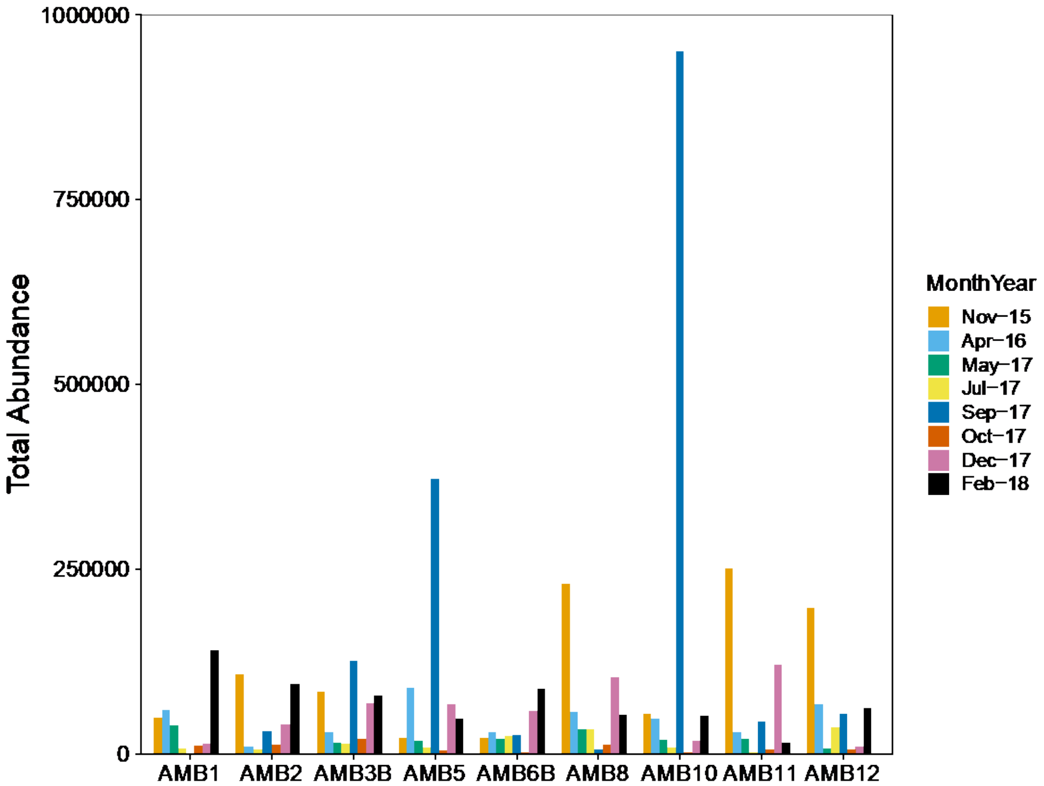
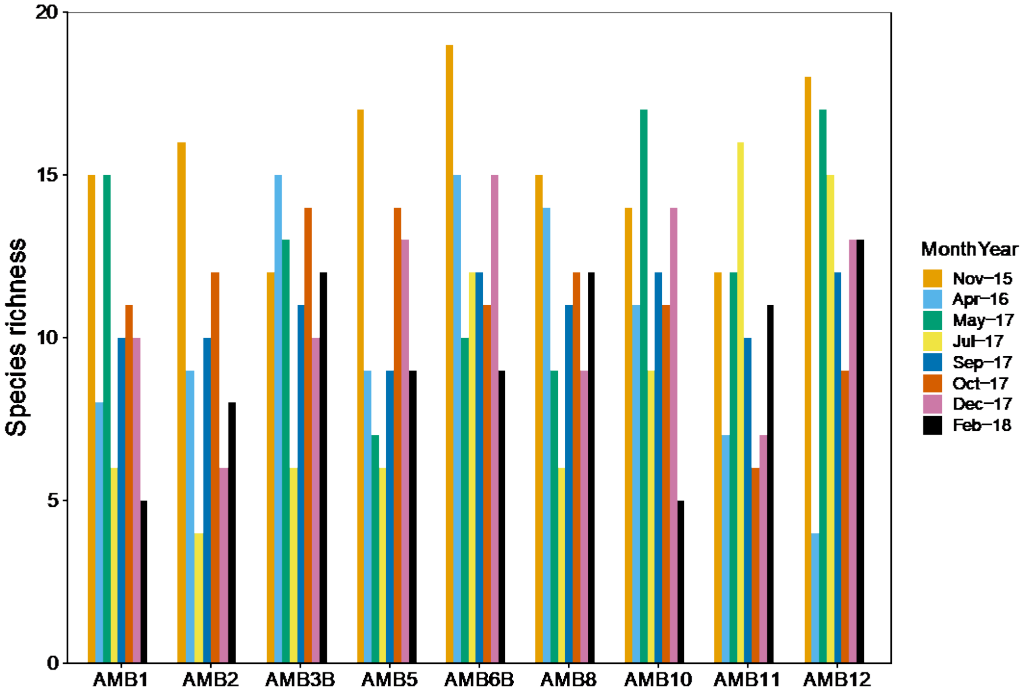


Figure 3.11 a) Species richness of phytoplankton; and b) total abundance of phytoplankton at each site for each survey

A)



B)

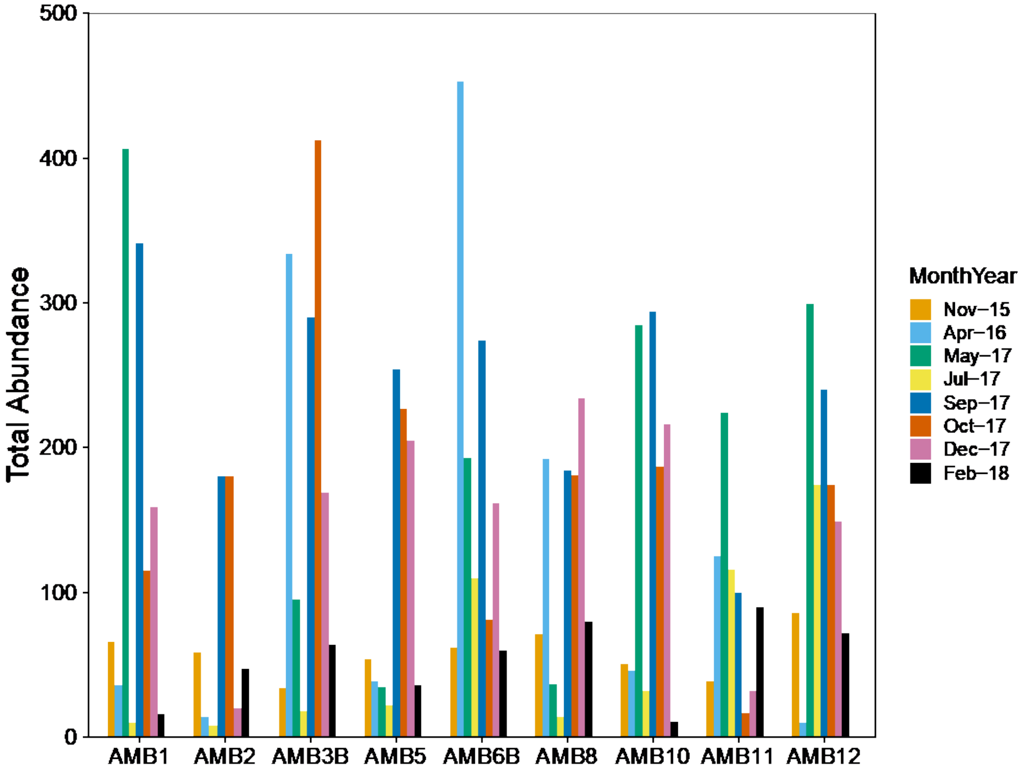


Figure 3.12 a) Species richness of zooplankton and b) total abundance of zooplankton at each site during the following survey periods: November 2015, April 2016, May 2017, July 2017, September 2017, and October 2017, December 2017, and February 2018

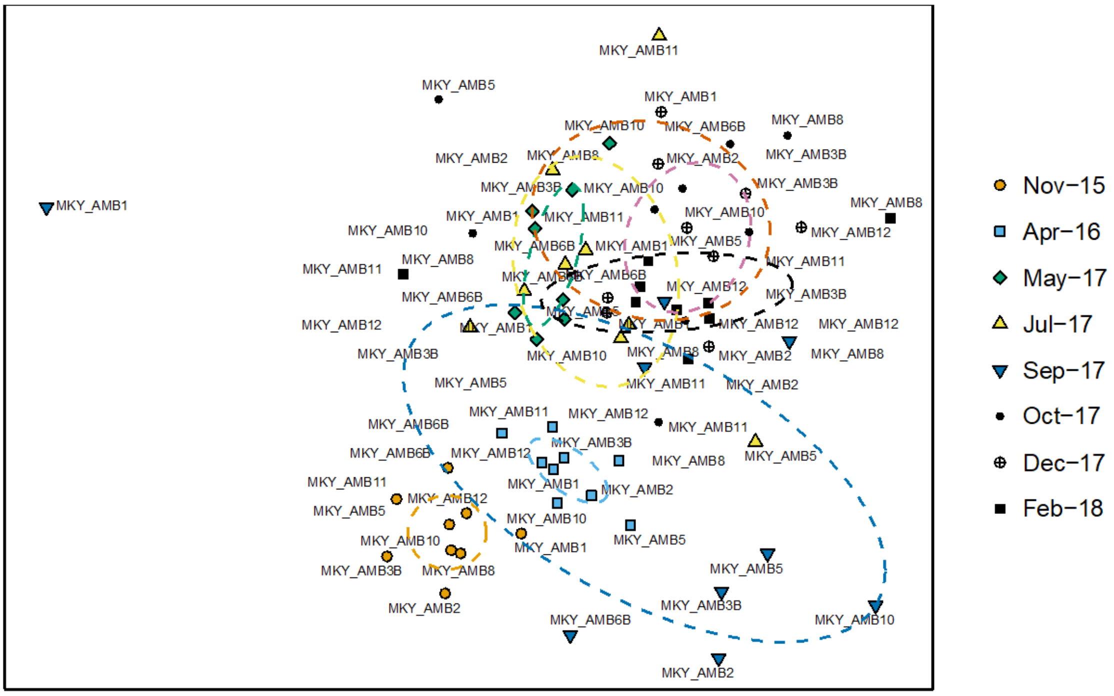


Figure 3.13 Non-dimensional ordination plot for phytoplankton collected during six survey periods throughout 2015-2018. Dashed lines represent 95% confidence interval ellipses for each survey period. Data has been squared root transformed on the Bray Curtis distance matrix (stress = 0.23, Clarke and Gorley 2006)

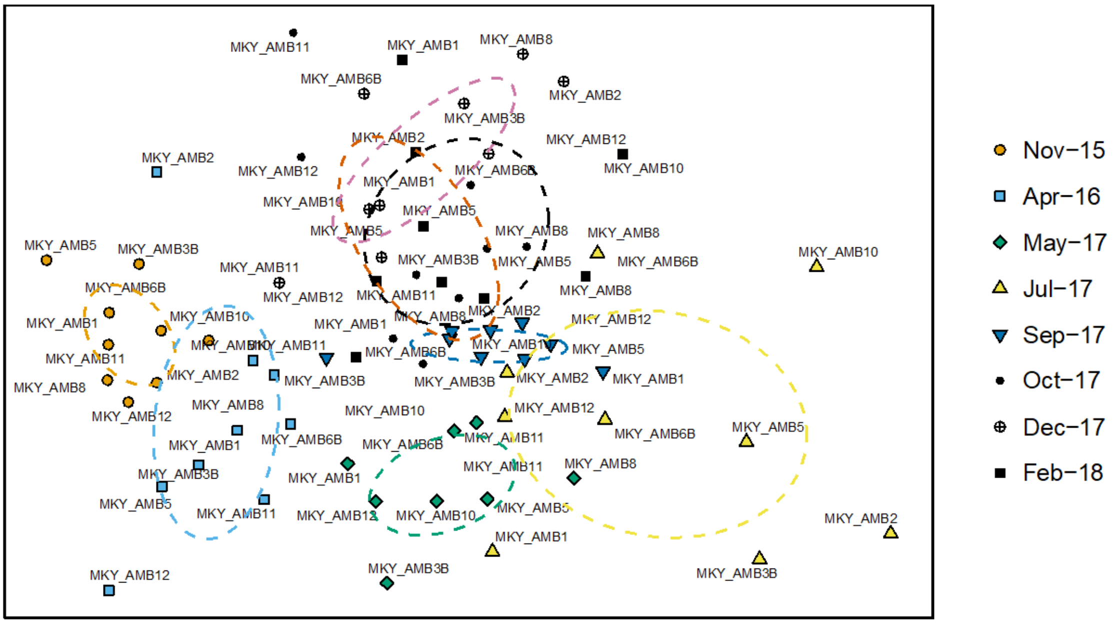


Figure 3.14 Non-dimensional ordination plot for zooplankton collected during six survey periods throughout 2015-2018. Dashed lines represent 95% confidence interval ellipses for each survey period. Data has been squared root transformed on the Bray Curtis distance matrix (stress = 0.22, Clarke and Gorley 2006)

3.3 Multiparameter water quality logger

Data is presented throughout the text (and in attached appendices) in a time series format, monthly and yearly statistical summaries. The box plots provide a visual representation of the descriptive statistics for RMS water height (m), Suspended Sediment Concentration (SSC, mg/L), deposition rate (mg cm^{-2} day^{-1}), water temperature (C°), and PAR (mol m^{-2} day^{-1}). In the box plots, the central diamonds represent the mean value, the central line represents the median value and the central box represents the range of the middle two quartiles. The vertical bars represent the range of the 90 thile and 10 thile data points.

3.3.1 RMS water height

RMS water height values are mostly driven by weather events and this is evident in the data as peaks in RMS water heights are observed at the same times at all sites over the survey year. Variation in the magnitude of RMS water height values during peak events and during non-event periods differs among sites due to differences in water depth and site exposure to wave energy. The RMS water height data from this survey year shows the sites can be categorised into three groups. Figure 3.15 provides a box plot of the yearly statistics of RMS at sites and this offers an effective visual representation of the three categories described below. Table 3.3 summaries the same yearly statistics from the box plot.

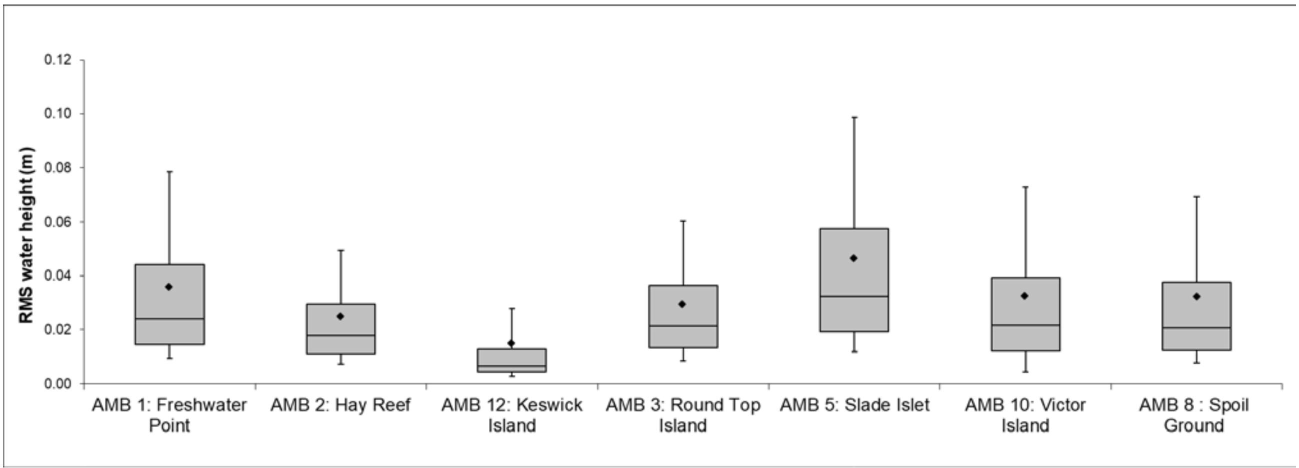


Figure 3.15 Box plot of RMS water height (m) at the seven sites for the monitoring period from July 2017 to July 2018

Table 3.3 Summary of RMS water height (m) statistics at the seven sites for the monitoring period from July 2017 to July 2018

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 12: Keswick Island	AMB 3: Round Top Island	AMB 5: Slade Island	AMB 10: Victor Island	AMB 8: Spoil Ground
Mean	0.036	0.025	0.015	0.030	0.047	0.033	0.032
Median	0.024	0.018	0.007	0.021	0.032	0.022	0.021
Minimum	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower quartile	0.015	0.011	0.004	0.013	0.019	0.012	0.012
Upper quartile	0.044	0.030	0.013	0.036	0.058	0.039	0.038
Maximum	0.427	0.320	2.678	0.288	1.295	0.631	2.326
90th percentile	0.078	0.049	0.028	0.060	0.098	0.073	0.069
10th percentile	0.010	0.007	0.003	0.009	0.012	0.005	0.008
n	50844	35946	52500	36061	45274	50529	45423
St. Dev	0.035	0.024	0.041	0.026	0.046	0.036	0.038
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The lowest value RMS category consisted only of Keswick Island (AMB 12). This site had much lower RMS values than all other sites with a median RMS water height of 0.015 m and the lowest variance in RMS values (10th percentile = 0.003 m, 90th percentile = 0.028 m). 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.

Freshwater Point (AMB 1), Hay Reef (AMB 2), Round Top Island (AMB 3), the spoil grounds (AMB 8), and Victor Island (AMB 10) can be categorised in the middle RMS water height group, with median RMS values ranging from 0.018 m to 0.024 m. As mentioned in the methodology, RMS water height is a proxy for wave energy or wave shear stress at the ocean floor (Macdonald 2015). This is important to note as the Hay Reef (AMB 2), Round Top Island (AMB 3) and spoil grounds (AMB 8) are more exposed locations than Freshwater Point (AMB 1) and Victor Island (AMB 10); yet because these locations are deeper the wave shear stress on the ocean floor is very similar to the more protected, yet much shallower Freshwater Point (AMB 1) and Victor Island (AMB 10). This information illustrates that these sites are directly influenced by very similar wave shear stress and therefore differences between sites needs to be attributed to other parameters such as current, depth and benthic geology.

Slade Island (AMB 5) had the highest median RMS value of 0.033 m, compared to the six other sites. Slade Island (AMB 5) was not a very shallow site (mean depth of 8.95 m) yet we attribute its relatively high RMS water height values to exposure to wave energy in its vicinity.

The RMS water height time series data (which can be found in the appendix) shows that large peaks occur throughout the year. Comparing sites reveals these peaks to primarily occur at the same times across all sites. These synchronised peaks are due to weather driven wave events being the strongest driver of wave shear stress on the ocean floor. Different sites show weather driven wave events at different magnitudes in the RMS data due to variations in site exposure and water depth.

Figures 3.16 provides an example of when weather driven wave energy in combination with tide are evident in the RMS data for Freshwater Point (AMB 1) during the reporting period. Figure 3.16 shows large spikes in RMS water height at the start and middle of the displayed period. These spikes are the result of weather driven wave events and are followed by periods where RMS water height falls to its background value as the weather events pass. Comparing the 12-point averaged trend line with the water depth data shows a similar periodicity in the RMS water height and water depth data. It is interesting to note that a reduction in water depth does align with the periodic peaks in RMS water height and it is thought that other factors such as current and changes in the sites exposure at different tides alters the wave dynamics of the site.

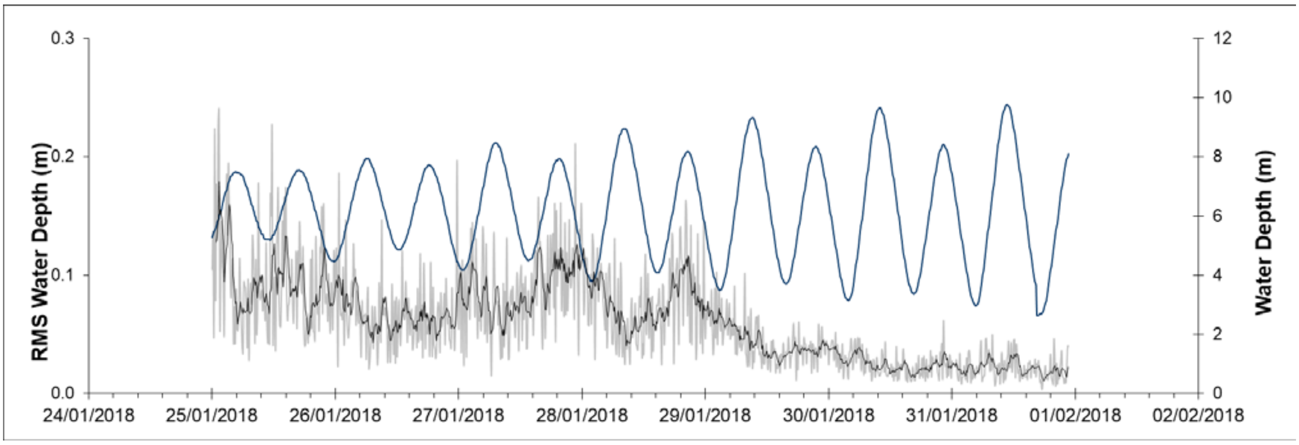


Figure 3.16 Freshwater (AMB 1) RMS water height (gray), 12 point moving average RMS trend line (black) and water depth (blue). Data shows periodic wave events followed by calmer periods throughout January 2018

3.3.2 NTUe/SSC

The NTUe/SSC time series data at each site (seen in the appendix) follows a typical pattern of low background values with recurring peak events. These peak events occurred at the same times at each site and coincide with peaks in RMS water height. This is a typical pattern as identified in past reports (Waltham et al. 2015 and 2016) and is similar to data collected in coastal locations in north Queensland by the James Cook University Marine Geophysics group (Ridd et al., 2001). Yearly statistical values and individual peak values differ between sites. These differences are the result of variation in influencing factors such as RMS water height, site depth, benthic geology, hydrodynamics and proximity to river mouths. Figure 3.17 provides a box plot of the yearly statistics of SSC values at sites, while Table 3.4 summaries the same yearly statistics.

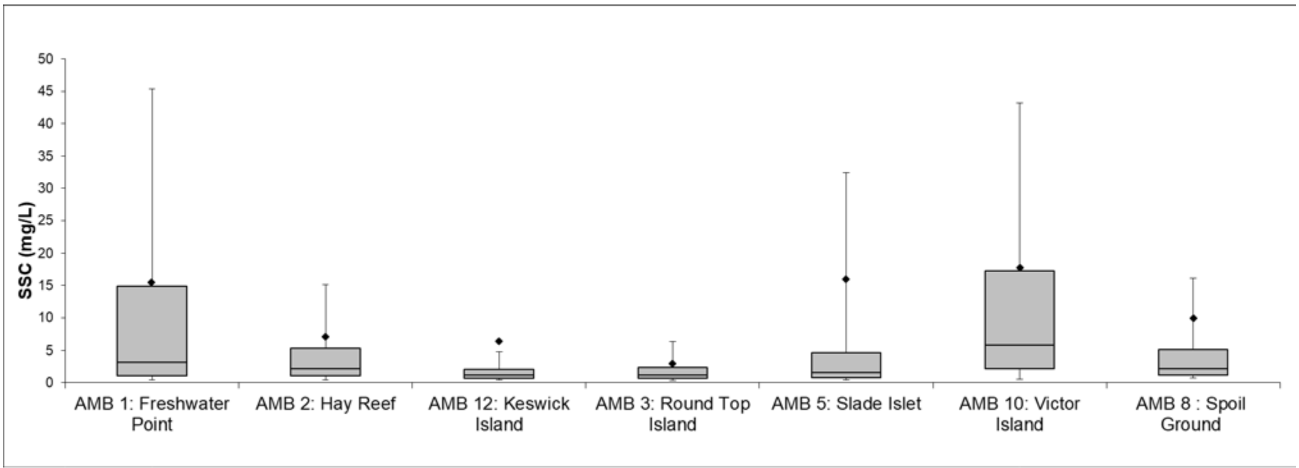


Figure 3.17 Box plot of SSC (mg/L) at the seven sites for the monitoring period from July 2017 to July 2018

Table 3.4 Summary of SSC (mg/L) statistics at the seven sites for the monitoring period from July 2017 to July 2018

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 12: Keswick Island	AMB 3: Round Top Island	AMB 5: Slade Island	AMB 10: Victor Island	AMB 8: Spoil Ground
Mean	15.47	7.17	6.42	2.93	15.96	17.80	9.94
Median	3.13	2.20	1.13	1.19	1.53	5.83	2.19
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lower quartile	1.08	1.07	0.64	0.65	0.72	2.19	1.15
Upper quartile	14.87	5.37	2.07	2.36	4.69	17.23	5.16
Maximum	428.99	326.65	3203.96	233.49	1163.42	1538.95	682.15
90th percentile	45.33	15.16	4.81	6.39	32.39	43.22	16.09
10th percentile	0.46	0.43	0.38	0.36	0.38	0.47	0.68
n	42417	24592	46931	31777	35579	40268	33955
St. Dev	32.75	17.36	52.91	6.87	61.06	40.99	32.72
St. Error	0.16	0.11	0.24	0.04	0.32	0.20	0.18

Of the seven sites, two (Keswick Island AMB 12 and Round Top Island AMB 3) had median SSC values below 1.2 mg/L and the least variance in NTUe/SSC. Site specific factors such as sediment size and type as well as wave shear stress (RMS water height) are major influences on NTUe/SSC and this is the likely attributing feature. Site AMB 3 Round Top Island showed the second lowest median (1.13 mg/L) and lowest variance between 10th and 90th percentiles (10th percentile = 0.38 mg/L, 90th percentile = 4.81 mg/L) values in NTUe/SSC. This is due to: a) the site being sheltered from the trade south east weather systems which could result in less re-suspension of sediments by wave energy; b) coarser sediment at this site being less easily resuspended, and c) the sites position on the mid-shelf GBR exposes it to cleaner oceanic water. Although Round Top Island (AMB 3) had the second highest RMS water height data from the survey year, which would suggest high re-suspension of local sediment, the sediment at this site is coarse and not easily resuspended.

The inshore sites, Freshwater Point (AMB 1), Hay Reef (AMB 2), Slade Island (AMB 5) and Victor Island (AMB 10) had higher median NTUe/SSC with greater variance. These sites are considered open ocean sites, however, in contrast inshore coastal currents are high in suspended solids from surrounding shallow water where re-suspension of sediment dominates the environment (Macdonald et al. 2013). 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.

3.3.3 Deposition

Deposition of sediment is a natural process occurring in all coastal marine waters. Suspended sediment naturally deposits in environments where the systems energy is not sufficient to keep it suspended. Deposition of sediment in a marine environment is of interest to environmental monitoring studies when it changes from its natural state. The Water Quality Guidelines for the Great Barrier Reef Marine Park (2010) references De'ath and Fabricius 2008 in noting that 10 mg cm^{-2} day^{-1} sedimentation is valid in areas of coarse sediment, but that where sediments are smaller and of high organic content the trigger limits need to be lower. The guidelines set the sedimentation 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}. The statistical summary of the daily average deposition rates for each site are presented in Figure 3.18 as box plots and summarised in Table 3.5.

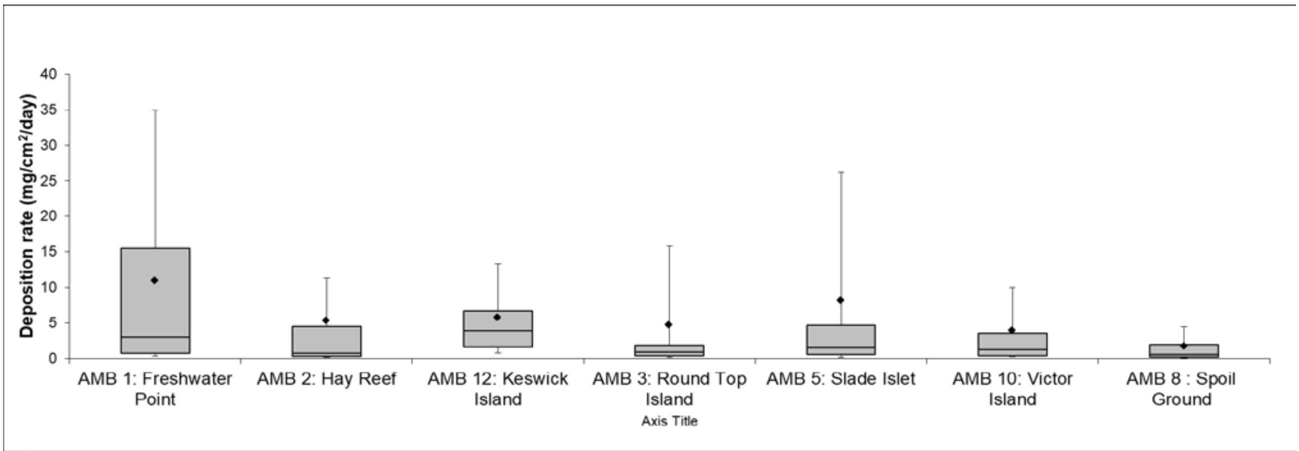


Figure 3.18 Box plot of two-hourly deposition rate (mg/cm^2/day) at the seven sites for the monitoring period from July 2017 to July 2018

Table 3.5 Summary of two-hourly deposition rate (mg/cm^2/day) statistics at the seven sites for the monitoring period from July 2017 to July 2018

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 12: Keswick Island	AMB 3: Round Top Island	AMB 5: Slade Island	AMB 10: Victor Island	AMB 8: Spoil Ground
Mean	10.98	5.42	5.85	4.75	8.23	3.99	1.74
Median	3.01	0.77	3.88	0.93	1.53	1.23	0.56
Minimum	0.05	0.04	0.03	0.03	0.00	0.00	0.00

Lower quartile	0.75	0.28	1.64	0.39	0.57	0.41	0.20
Upper quartile	15.49	4.48	6.71	1.91	4.68	3.51	1.98
Maximum	96.79	120.66	70.56	71.07	103.52	40.84	20.73
90th percentile	34.93	11.37	13.39	15.78	26.23	10.01	4.42
10th percentile	0.32	0.13	0.74	0.14	0.17	0.22	0.10
n	197	150	280	295	234	193	192
St. Dev	16.59	15.14	7.11	10.89	17.66	7.14	3.04
St. Error	1.18	1.24	0.42	0.63	1.15	0.51	0.22

The data indicates that Freshwater Point (AMB 1) and Slade Island (AMB 5) had the greatest deposition with means of 10.98 and 8.23 mg cm^{-2} day^{-1}, respectively; and median daily average deposition rates of 3.01 and 3.88 mg cm^{-2} day^{-1}, respectively. Again, it is suggested that the median rather than the mean values be used in analysis to provide an un-skewed value of the data. The median daily average deposition rate ranged from 0.77-1.53 mg cm^{-2} day^{-1} at the five other sites. These values may be more easily visualised by calculating them into the thickness of the sediment deposited. For example, using the relationship between density, mass and volume: a 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}.

It can be seen in the time series deposition data (see appendix) that deposition tends to peak following high RMS water height events but with a lag so that peak deposition occurs at a time when RMS water height has decreased to near background levels. An explanation for this lag is that as waves resuspend sediment, little deposition is expected because the energy in the system will keep the sediment in suspension. It is only when waves decrease and there is no longer enough energy in the system to keep the same quantity of sediment in suspension that deposition begins to occur.

3.3.4 Water temperature

The statistical summary of the water temperature for each site are presented in Figure 3.19 as box plots and summarised in Table 3.6. Like past Port of Hay Point and Mackay ambient marine water quality monitoring reports, water temperature data matched closely among all sites. Seasonal changes in water temperature were apparent, with the mean monthly temperature peaking between December and March at approximately 28.3-28.9 °C (Figure 3.22); 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 20.7-21.9 °C. 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).

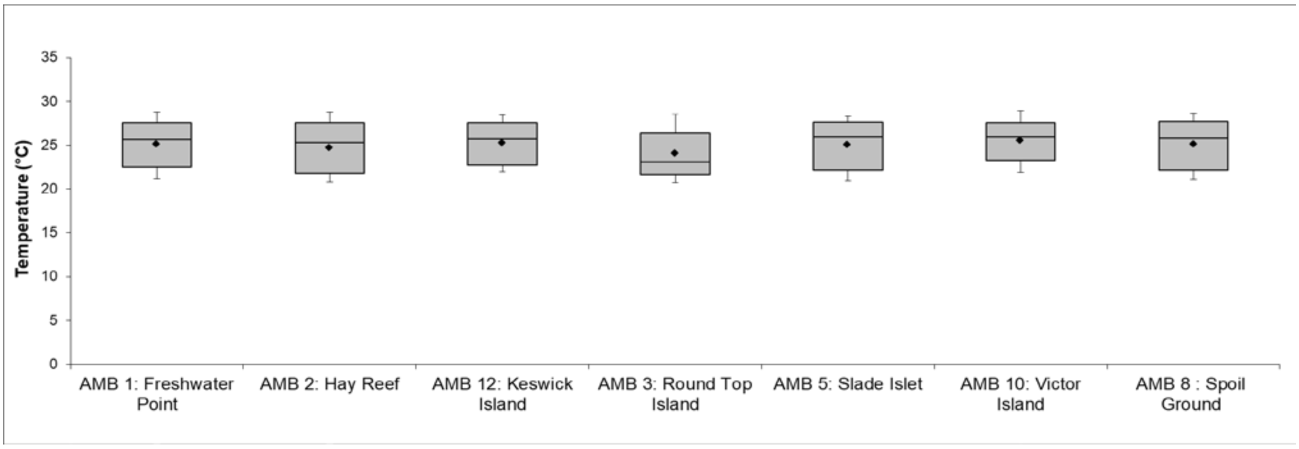


Figure 3.19 Box plot of the water temperature (°C) at the seven sites for the monitoring period from July 2017 to July 2018

Table 3.6 Summary of water temperature (°C) statistics at the seven sites for the monitoring period from July 2017 to July 2018

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 12: Keswick Island	AMB 3: Round Top Island	AMB 5: Slade Island	AMB 10: Victor Island	AMB 8: Spoil Ground
Mean	25.18	24.76	25.29	24.15	25.09	25.59	25.16
Median	25.69	25.29	25.77	23.09	25.95	25.97	25.84
Minimum	18.91	19.81	19.89	19.61	17.96	20.88	20.02
Lower quartile	22.53	21.80	22.70	21.65	22.13	23.25	22.14
Upper quartile	27.59	27.56	27.55	26.40	27.65	27.57	27.69
Maximum	33.74	30.76	29.62	30.26	29.99	31.64	29.86
90th percentile	28.78	28.78	28.42	28.52	28.29	28.91	28.62
10th percentile	21.14	20.79	21.98	20.72	20.91	21.88	21.07
n	50846	35946	52500	36061	45274	44295	45423
St. Dev	2.84	3.07	2.41	2.96	2.86	2.50	2.88
St. Error	0.01	0.02	0.01	0.02	0.01	0.01	0.01

3.3.5 Photosynthetically active radiation (PAR)

Benthic photosynthetically active radiation (PAR) was monitored at the seven sites from July 2017 to July 2018. The statistical summary of the PAR for each site are presented in Figure 3.20 as box plots and summarised in Table 3.7. Levels of benthic PAR at sites were strongly influenced by water depth with a general trend of lower mean PAR values occurring at deeper sites (e.g. AMB 8), while higher levels were more regularly measured at shallower sites (e.g. AMB 12), with the exception of Hay Reef (AMB 2), which has the lowest mean and median PAR values most likely due to its high suspended sediment levels.

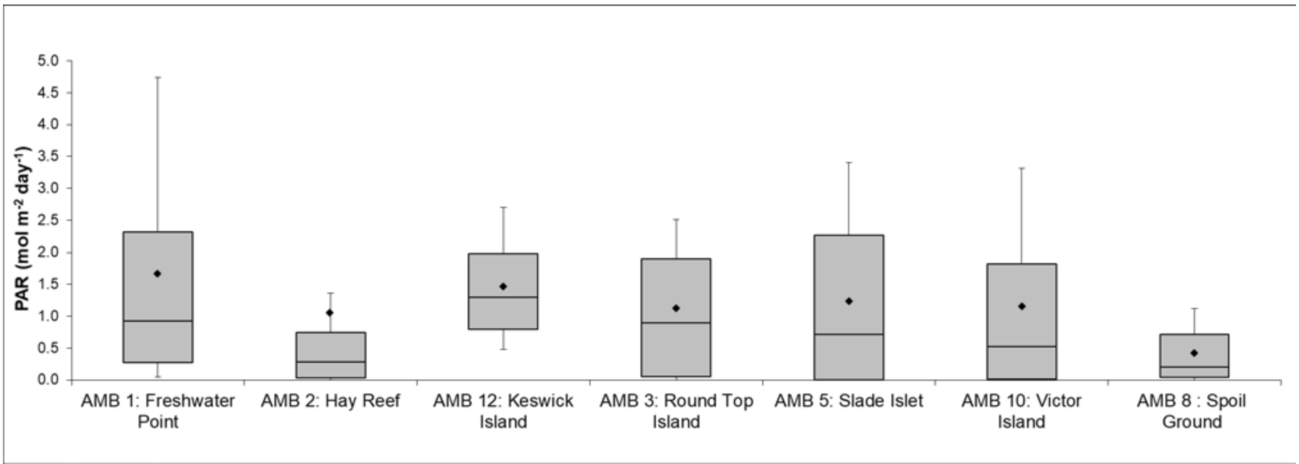


Figure 3.20 Box plot of the daily PAR (mol m^{-2} day^{-1}) at the seven sites for the monitoring period from July 2017 to July 2018

Table 3.7 Summary of daily PAR (mol m^{-2} day^{-1}) statistics at the seven sites for the monitoring period from July 2017 to July 2018

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 12: Keswick Island	AMB 3: Round Top Island	AMB 5: Slade Island	AMB 10: Victor Island	AMB 8: Spoil Ground
Mean	1.67	1.06	1.47	1.13	1.24	1.16	0.42
Median	0.93	0.29	1.29	0.89	0.72	0.53	0.20
Minimum	0.00	0.00	0.10	0.00	0.00	0.00	0.00
Lower quartile	0.27	0.03	0.79	0.06	0.01	0.02	0.04

Upper quartile	2.32	0.74	1.98	1.90	2.26	1.82	0.72
Maximum	8.93	142.22	4.67	4.20	5.68	6.01	2.31
90th percentile	4.74	1.36	2.70	2.51	3.40	3.31	1.13
10th percentile	0.05	0.00	0.47	0.00	0.00	0.00	0.00
n	354	244	363	255	315	366	310
St. Dev	1.92	9.09	0.90	1.04	1.42	1.44	0.47
St. Error	0.10	0.58	0.05	0.07	0.08	0.08	0.03

Using these above summary statistics and graphical representations of the full time series data (Figure 3.21) and monthly variational data (Figure 3.22) per site, we describe trends and temporal differences among sites and investigate possible drivers of significant decreases in PAR.

Benthic PAR was highly variable within sites throughout the year, with peaks and troughs occurring both regularly and intermittently over time. Semi-regular oscillations between low and high PAR levels were overridden by larger episodic events caused by storm or rainfall events. Investigating the monthly variation among sites shows a period of decreased daily PAR levels from October 2017 to November 2017 and January 2018 to February 2018, with a local peak of daily PAR at December 2017 across all sites. This reduction is less pronounced at Keswick Island, which is located 26 km from the mainland. This is similar to the pattern of greater daily PAR levels seen in the previous year (Waltham et al. 2015), from July 2015 through to December 2016 at the same sites.

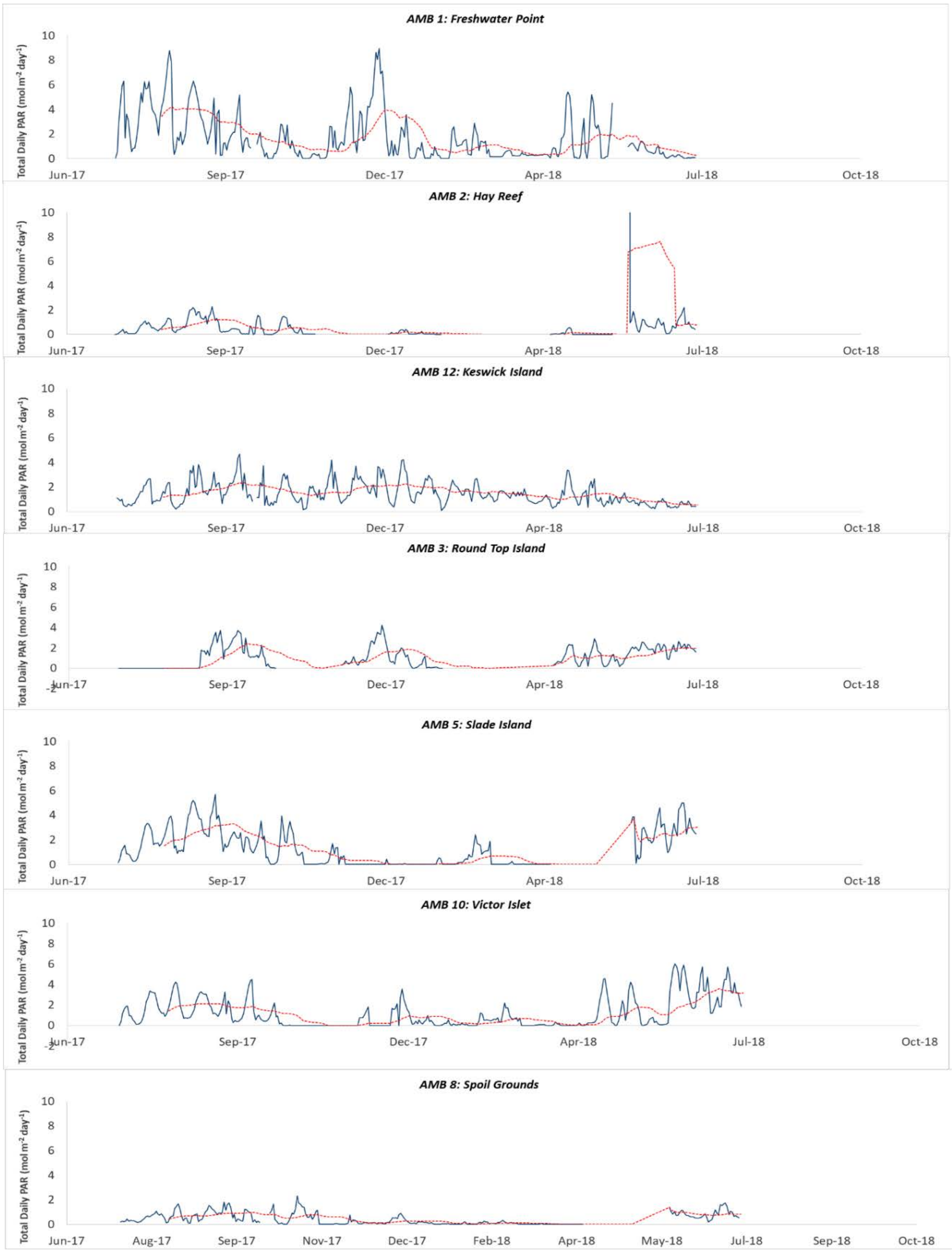


Figure 3.21 Time series of mean total daily PAR mol m^{-2} day^{-1} recorded at all sites for the monitoring period from July 2017 to July 2018

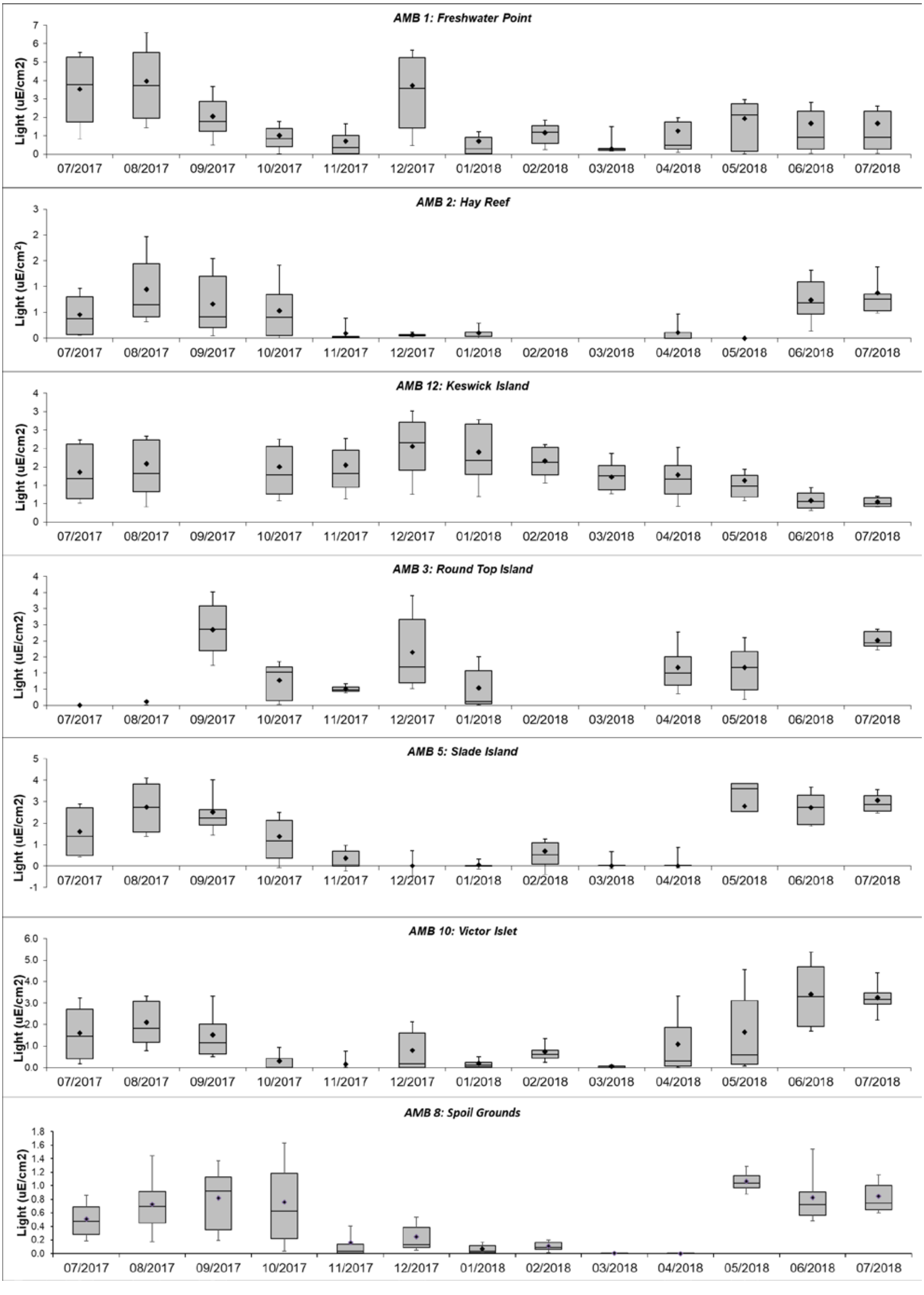


Figure 3.22 Monthly boxplots illustrating the variation in total daily PAR (mol photons m-2 day-1) at the seven representative sites throughout the monitoring period from July 2017 to July 2018

3.4.1 Similarities in patterns of PAR among sites

As sites were located at various depths below the lowest astronomical tide datum (LAT), direct comparisons of PAR among sites are not statistically valid. Therefore, the similarity in patterns of PAR over time among different sites was compared by plotting total daily PAR to examine the strength of the relationship using pairwise comparisons (Figure 3.23). The strength of the linear relationship between sites was measured using an R^2 value shown on each pairwise scatterplot.

Figure 3.23 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

Relationships in patterns of benthic PAR are found among distant coastal sites that were located in similar environments (e.g. Relocation spoil ground and Slade Islet, R^2 = 0.5818, which are both located on the northern sides of islands). As was found in previous reports, Keswick Island exhibited the least similarities among other coastal sites with very weak relationships in pairwise comparisons. Except for with Freshwater Point in this report, which also had low similarities with all other sites. This analysis assists in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region.

3.4.2 Relationship between light attenuation and suspended solid concentrations

In sediment-rich coastal waters, the dominant physical process that reduces PAR light intensity is scattering, which if turbidity levels are high enough, can cause underwater light to become isotropic. Investigations into the light attenuation coefficient provides an insight into the dynamic relationship between suspended solid concentrations and PAR light intensities.

Absorption and scattering describe the attenuation of light through water by interacting in a nonlinear and complex fashion within the radiative transport equations (Mobley 1994). These equations cannot be solved analytically; however the diffuse attenuation coefficient (k_d) (averaged across the PAR waveband 400-700 nm) may be approximated in ocean waters by using Beer-Lambert's law (Gordon 1989; Dennison et al. 1993; Kirk 1994),

$$\boldsymbol{I_z = I_{z0} e^{-k_d(z-z_0)}}$$

where I_{z0} and I_z are the downward directed irradiances at an upper depth (z_0) and a lower depth (z) respectively, and k_d is the diffuse attenuation coefficient (averaged across the PAR waveband 400-700 nm) (Jerlov 1976; Kirk 1977). k_d is comprised of a component due to clear water and a component due to SSC.

Light attenuation and suspended sediment concentration (*SSC*) are examined for all seven sites. A general relationship is found, whereby as SSC increases, light levels decrease exponentially, as is well described by Beer-lambert's Law. An example of this relationship can be seen in Figure 3.24 where during periods of high SSC, light is attenuated and when SSC exceeds approximately 10 mg/L, light extinction occurs.

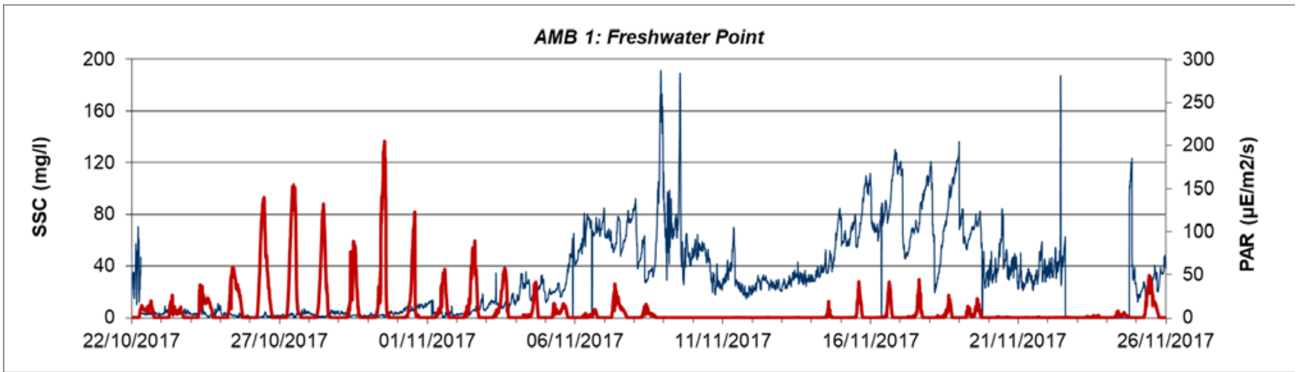


Figure 3.24 A typical example of the relationship between SSC and PAR light, showing light levels decreasing as SSC increases during October – November 2017 at Freshwater Point

3.4.3 Annual site comparison

Comparison of the 2014/2015, 2015/2016, 2016/2017 and 2017/2018 statistics provides a greater perspective of data trends in the monitored environment. Noting any differences or similarities in the statistics between the two years and discussing whether these observations are natural, a result of the monitoring method or indications of human influence on the environment leads to a more thorough understanding of the ecosystem. Results are expected to have small variations year to year due to natural variation in weather.

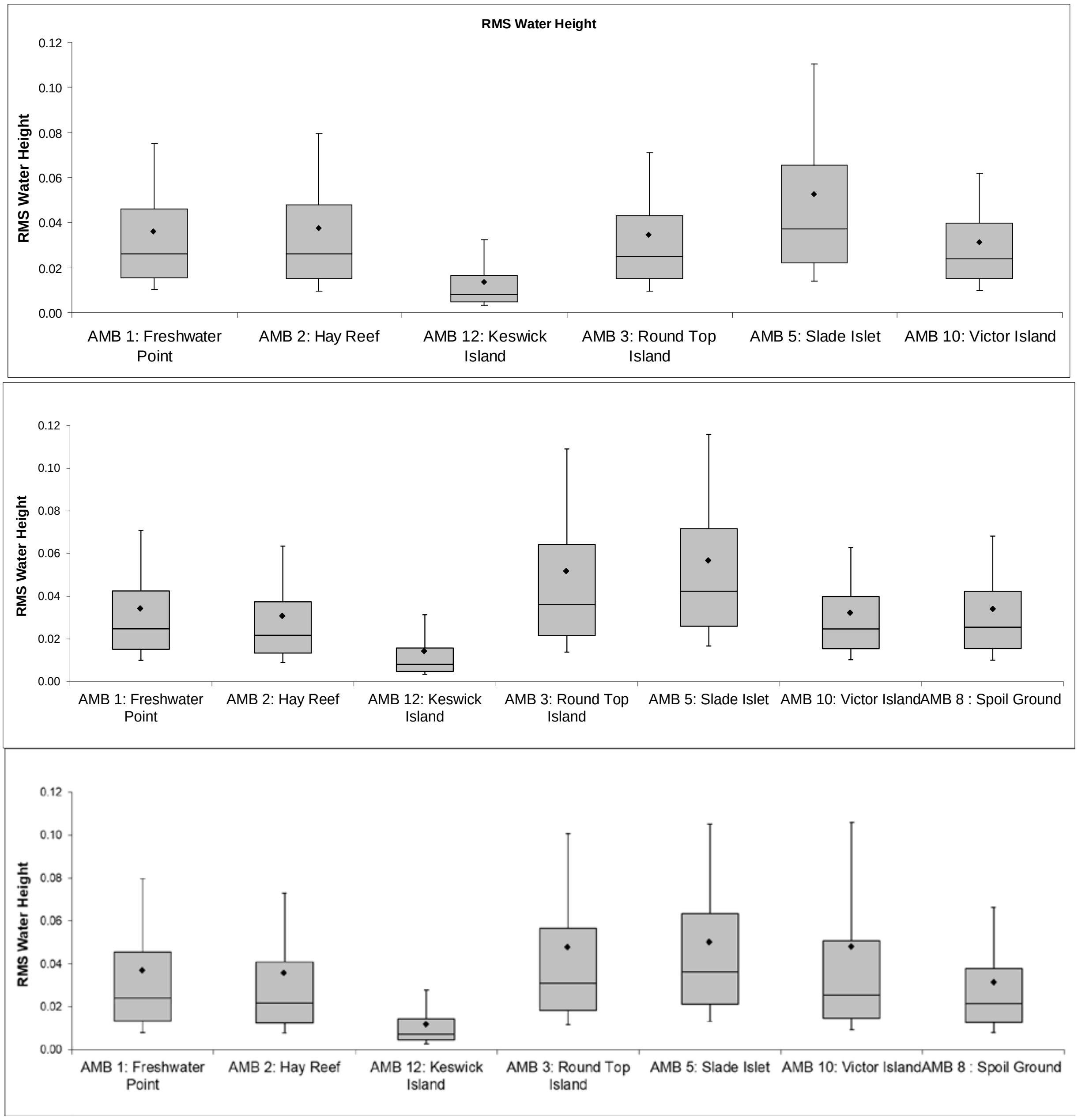
RMS water height

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. The figures below are box plots of RMS water height from 2014/2015, 2015/2016, 2016/2017 and 2017/2018 (Figure 3.25). Inspection of trends in the figures features very similar results between the years. As expected, sites with low RMS values in 2014/2015, 2015/2016 and 2016/2017 have remained low in 2017/2018 and the same for sites with high RMS water height values. Slight differences in the data are most likely the result of weather variances from year to year.

(a)

(b)

(c)



(d)

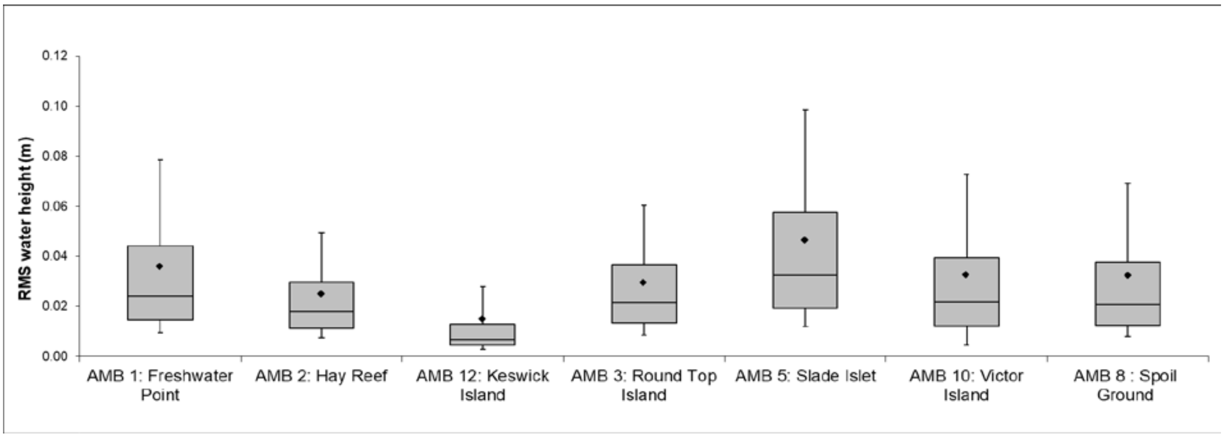
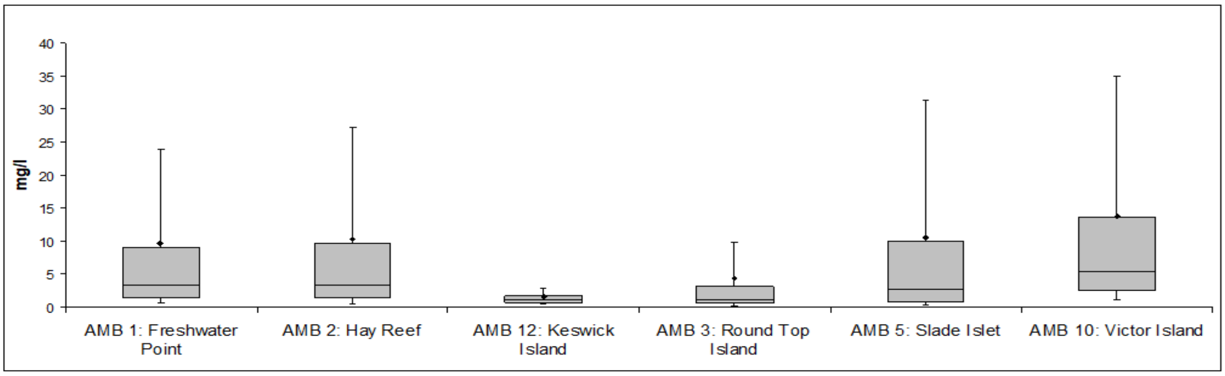


Figure 3.25 Comparison of RMS water height (m) boxplots at the seven deployment sites for (a) 2014/2015, (b) 2015/2016, (c) 2016/2017 and (d) 2017/2018

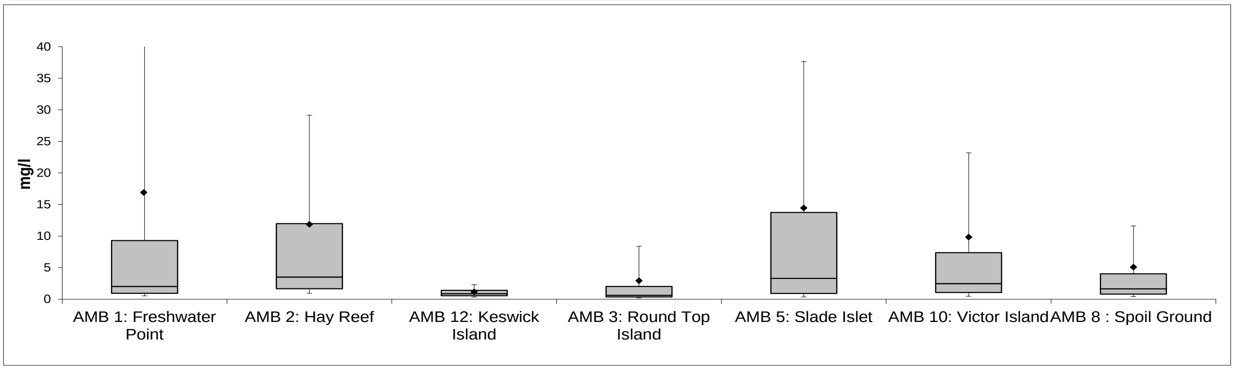
NTUe/SSC

SSC data show similar values across yearly statistical results (Figure 3.26). Keswick Island (AMB 12) and Round Top Island (AMB 3) SSC data depict very low values. Freshwater Point (AMB 1) data displayed much less variance in the first year, although the median has maintained consistency throughout the years. Large SSC events are present in the later years, such as Tropical Cyclone Debbie in 2017, are likely causes for the increased variance compared to the 2014/2015 year.

(a)



(b)



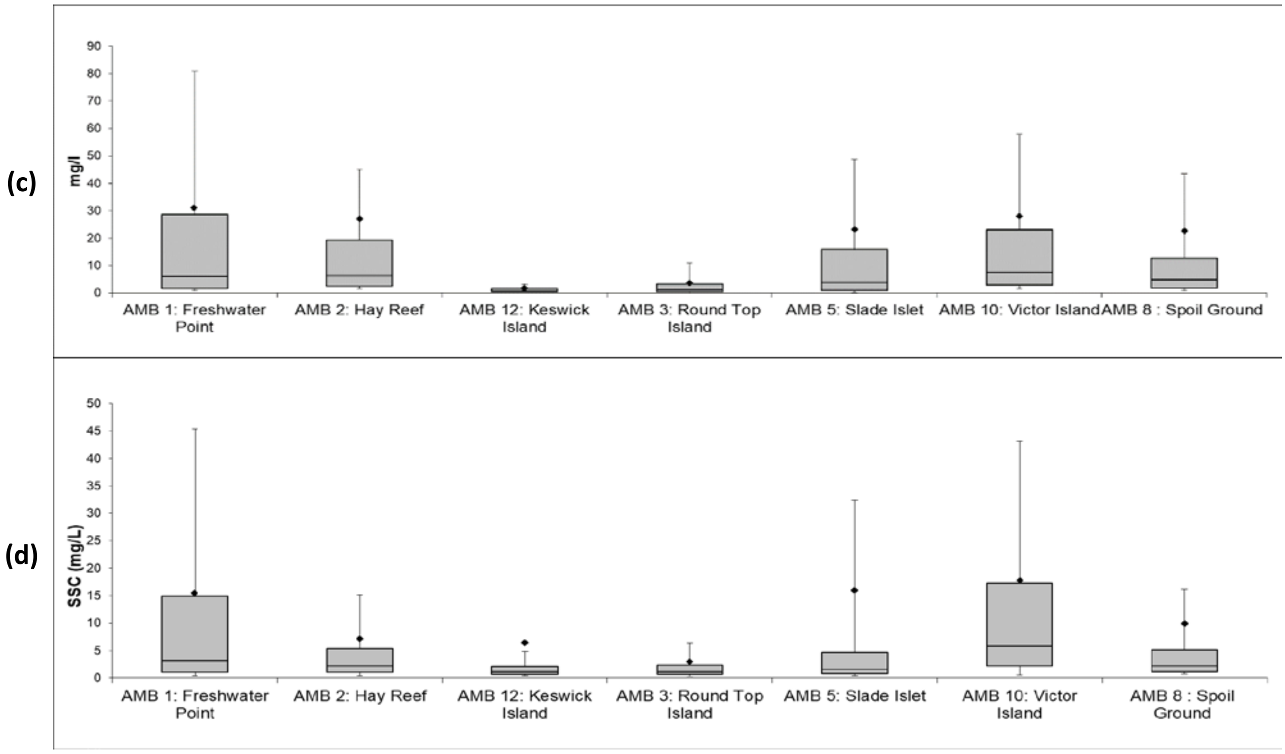
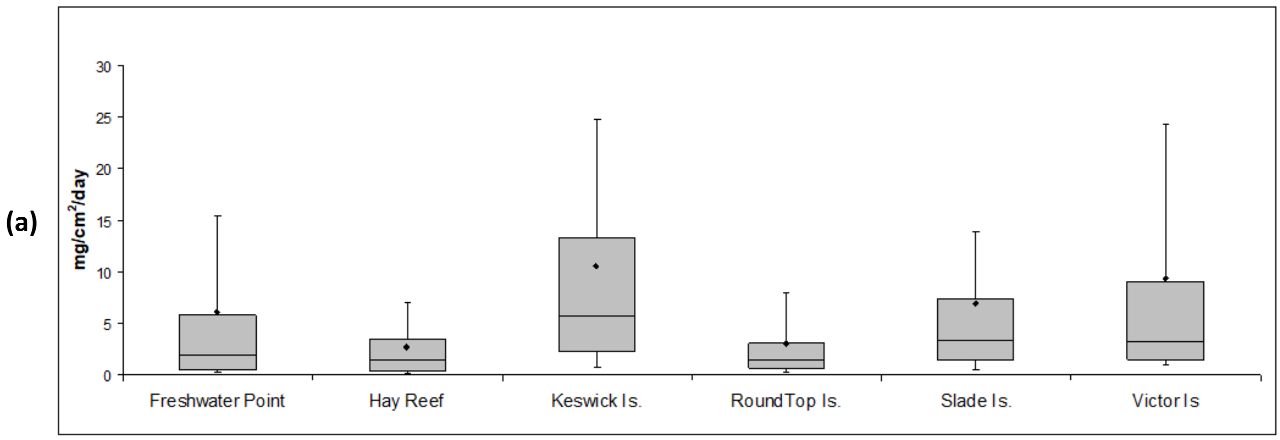


Figure 3.26 Comparison of SSC (mg/L) boxplots at the seven deployment sites for (a) 2014/2015, (b) 2015/2016, (c) 2016/2017 and (d) 2017/2018. Note the difference in scale on y-axis for (c) 2016/2017.

Deposition rate

Small variation in deposition rate is expected year to year and observed differences are likely the result of small changes in the environment (Figure 3.27). Slade Island (AMB 5) and Victor Island (AMB 10) showed higher deposition rates in the 2014/2015 year. The other sites show similar deposition values year to year. 2017/2018 saw a slight increase in the mean values for Slade Island. But there was no overall trend of increasing or decreasing deposition rates across all sites and further analysis is required before any relations between changes between the years at individual sites can be attributed to any influencing factors.



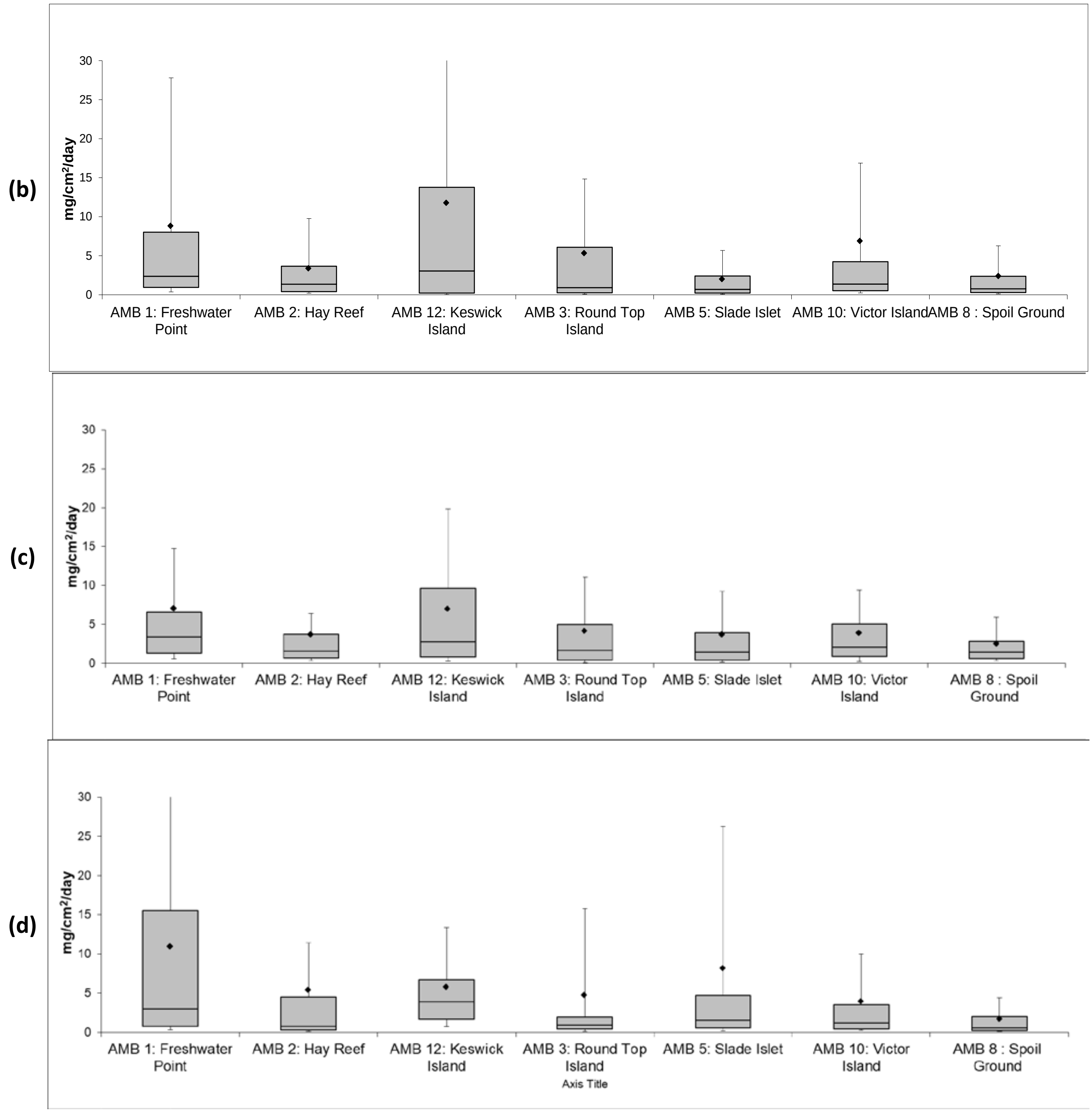


Figure 3.27 Comparison of two hourly deposition rate (mg/cm^2/day) boxplots at the seven deployment sites for (a) 2014/2015, (b) 2015/2016, (c) 2016/2017 and (d) 2017/2018

3.4.4 Seasonal variation: wet vs dry

Seasonal variation of all marine water properties is often assumed. The following comparison of wet and dry season statistics at all monitored sites from 2014-2018 shows there to be much less variation than many would expect.

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. The combined statistics from the 2014/2015, 2015/2016, 2016/2017 and 2017/2018 data sets show that this is not the case. There is an indiscernible difference in RMS water height data between the wet and dry season periods and this is clearly observed (Figure 3.28).

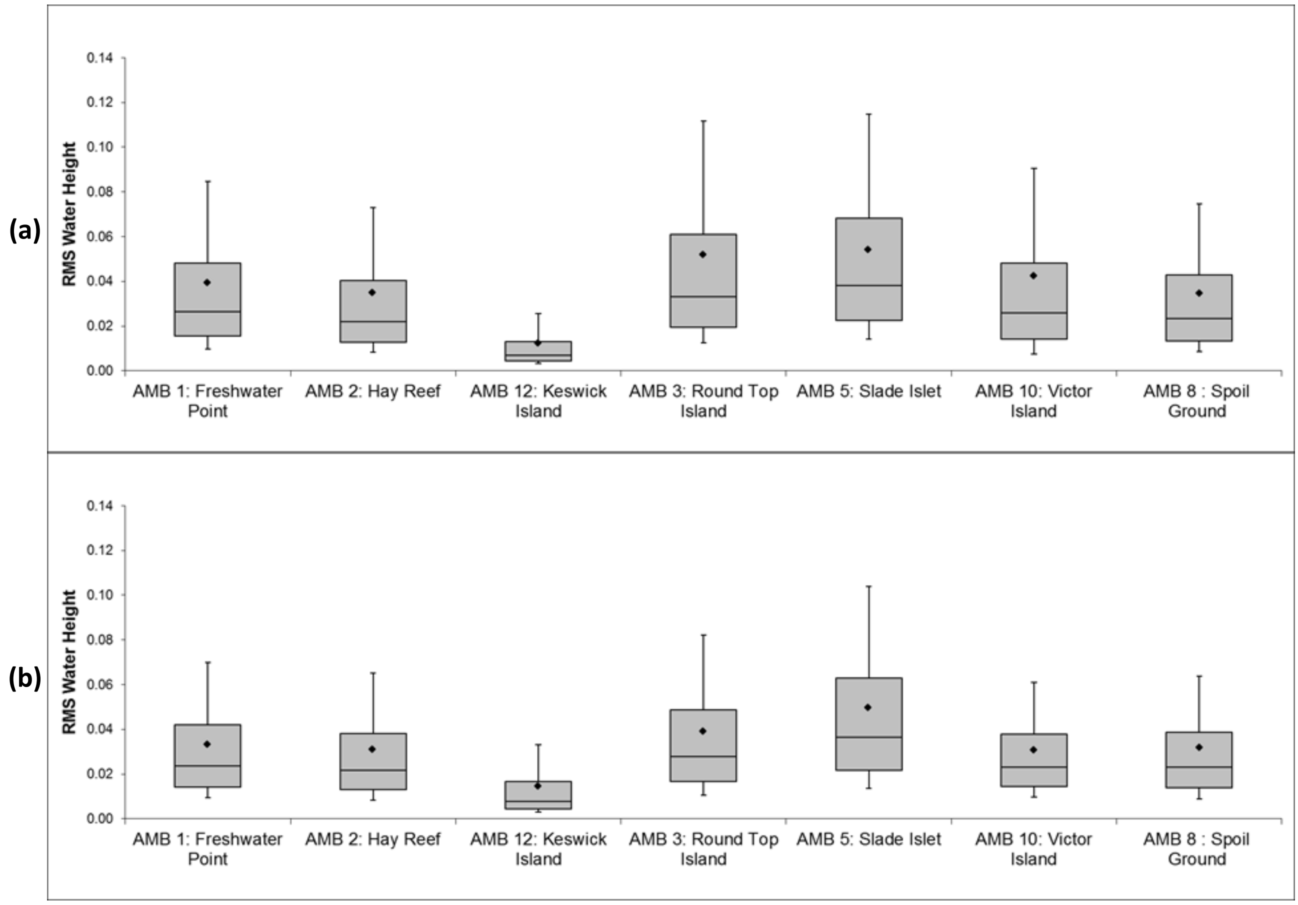


Figure 3.28 2014-2018 RMS water height box plots for: a) wet seasons (1 November-31 March); and b) dry seasons (1 April-31 October)

SSC

For some sites small differences in the statistical SSC results, between the wet and dry seasons, have been found (Figure 3.29). Median values were larger during the wet season for Freshwater Point, Hay Reef and Slade by approximately 2 mg/l. This may be due to the location of these sites being comparatively shallow and therefore more subject to resuspension effects. For the other four sites; Keswick Island, Round Top Island, Victor Island and the Relocation grounds, median values varied approximately 1 mg/l between the dry and wet season. Wet season was calculated same as the previous years (1/11/2016-31/3/2017). Overall the SSC values do not change considerably between the wet and dry season statistics.

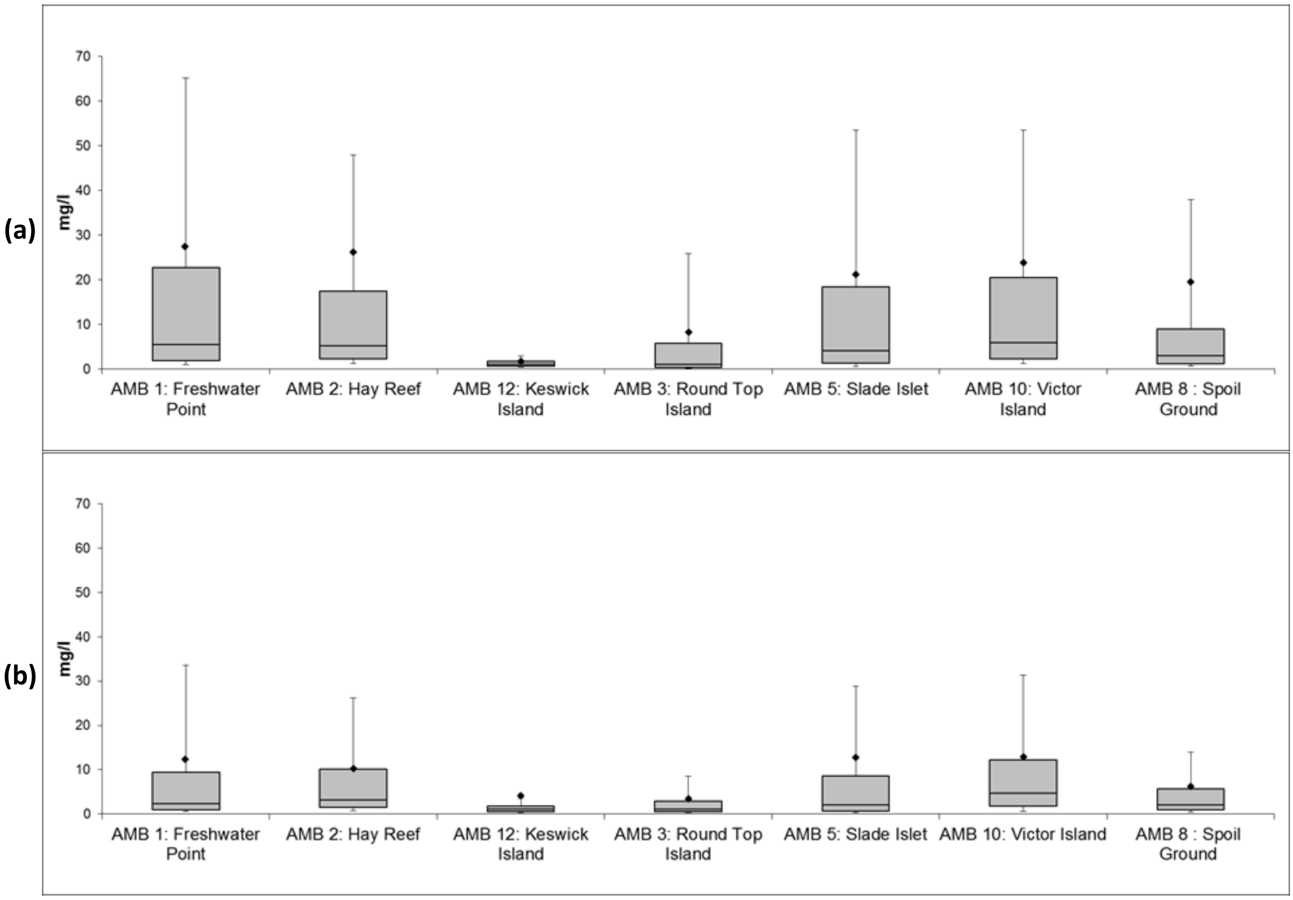
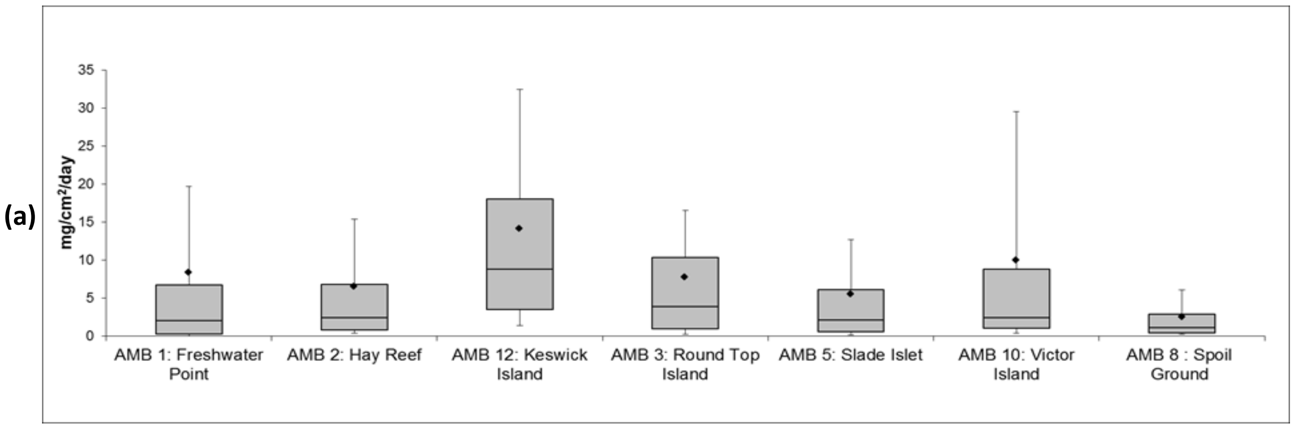


Figure 3.29 2014-2018 SSC box plots for: a) wet seasons (1 November-31 March); and b) dry seasons (1 April-31 October)

2hr deposition rate

The deposition rate statistics observed during the wet and dry seasons are notably different at Hay Reef (AMB 2), Keswick Island (AMB 12), Round Top Island (AMB 3) and Victor Island (AMB 10) (Figure 3.30). These sites show increases in the median and variance values during the wet season period. Investigating the season to season variance in deposition rate values in future studies will allow for these results to be either verified to be seasonal trends or to show they are non-seasonal events that drove the statistical values observed in the 2014-2018 results.



(b)

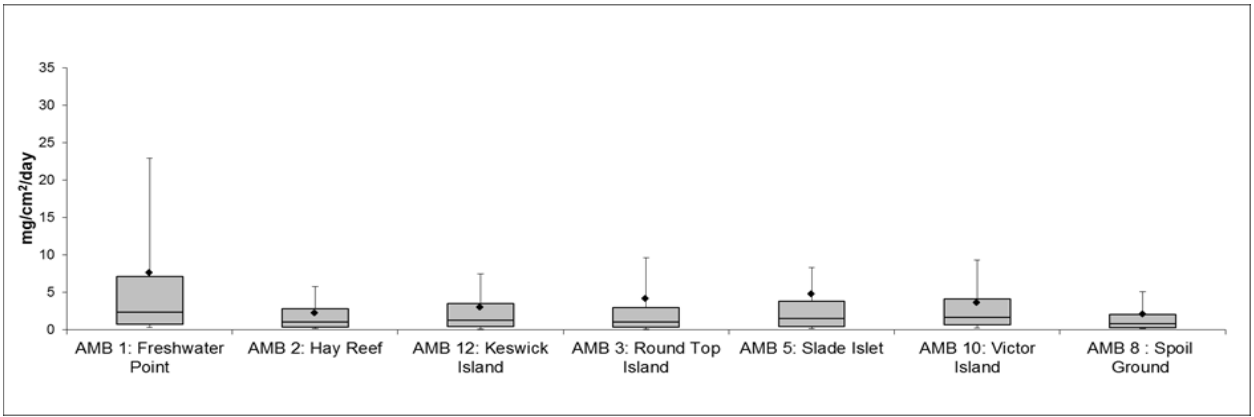
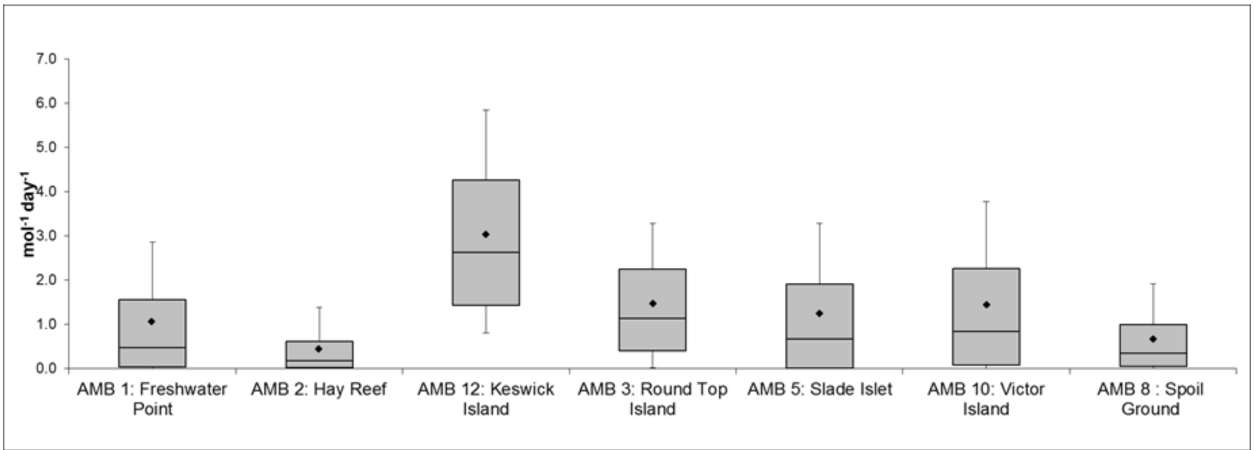


Figure 3.30 2014-2018 2hr deposition rate box plots for: a) wet seasons (1 November-31 March); and b) dry seasons (1 April-31 October)

Total daily PAR

Daily total PAR values appear very similar between the wet and dry season statistics (Figure 3.31). Some sites show increased total daily PAR during the wet season while others have increased total daily PAR during the dry season. Keswick Island showed the greatest variance in PAR over the wet seasons across 2014-2018. It may have been expected that the wet season data would show increased total daily PAR due to the longer daylight hours, although the data shows that there is no indication of this being an influential factor in the statistical results. This could be due to more cloud cover or oceanic drivers, such as high SSC.

(a)



(b)

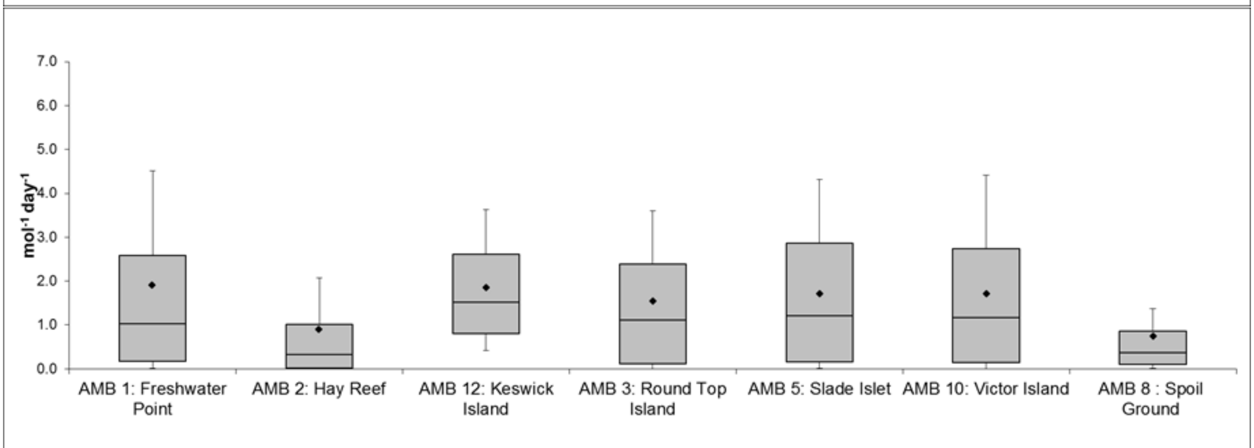


Figure 3.31 2014-2018 PAR box plots for: a) wet seasons (1 November-31 March); and b) dry seasons (1 April-31 October)

Water temperature

There is a clear pattern of differences in water temperature between the wet and dry season (Figure 3.32). Temperatures during the wet season are notably higher, median temperatures between 28 and 29^{o}C at all sites, and have much less variation. Dry season temperature statistics show all sites to have median temperature values between 22 and 24^{o}C and variation to be larger than during the wet season.

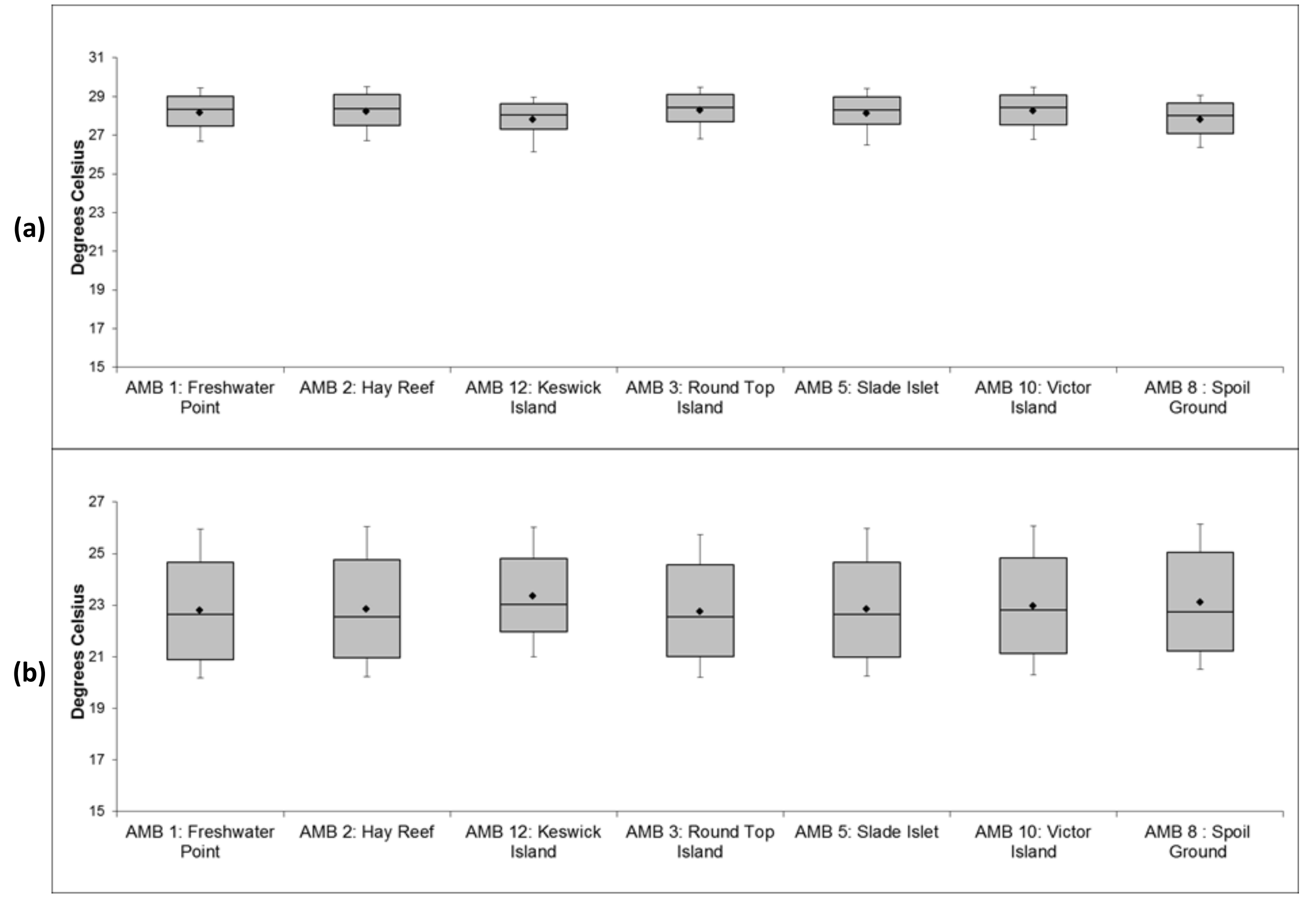


Figure 3.32 2014-2018 water temperature box plots for: a) wet seasons (1 November-31 March); and b) dry seasons (1 April-31 October)

3.4.5 Current meter

Current meter data was collected at all seven sites. Marotte HS current meter instruments were deployed for the full monitoring period from July 2017 to July 2018 for sites AMB 1, 2, 3, 4 and 5. However, as a result of data loss; the current meter data for the Spoil Grounds (AMB 8) only extends from July 2017 to February 2018.

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 video illustrating how the current speed and direction changes over time at each site is shared privately on YouTube: https://youtu.be/OI_N3N60bhM and is made available with this report.

AMB 1: Freshwater Point

The current at Freshwater Point ranges from NW to SE with NW peak and low average velocities ranging from 0.04 m/s to 0.1 m/s (as shown in Figures 3.33 and 3.34). The predominant flow of current is along the coast in both directions at this site as expected from the dominant tidal currents.

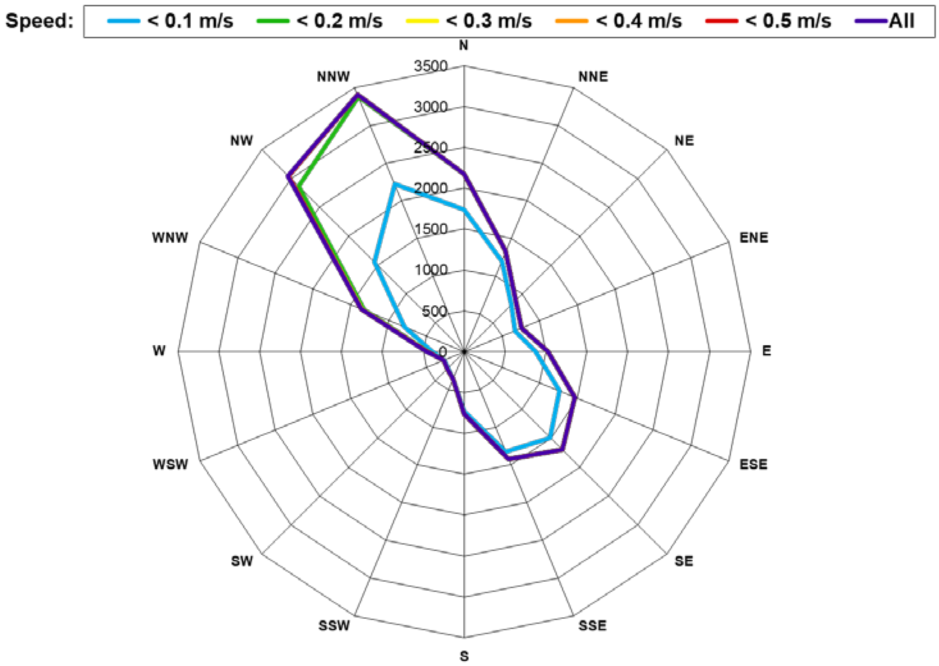


Figure 3.33 Current rose at Freshwater Point (AMB 1) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

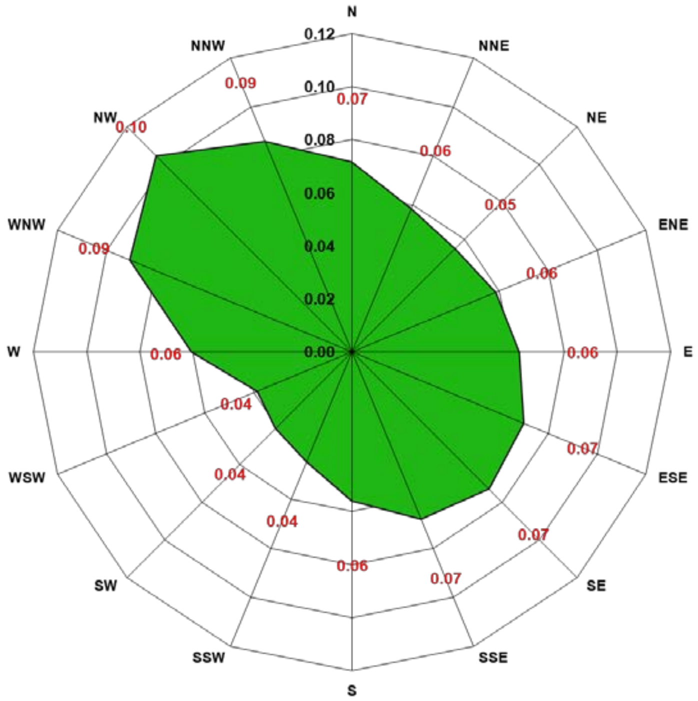


Figure 3.34 Average current speed rose at Freshwater Point (AMB 1) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 2: Hay Reef

The current at Hay Reef flows between NW and SE with very strong current peaks of 0.34 m/s and 0.32 m/s average velocity in the ESE and NW directions, respectively (as shown in Figures 3.35 and 3.36). Like site AMB 1, the predominant flow of current is along the coast in both directions at this site as expected from the dominant tidal currents.

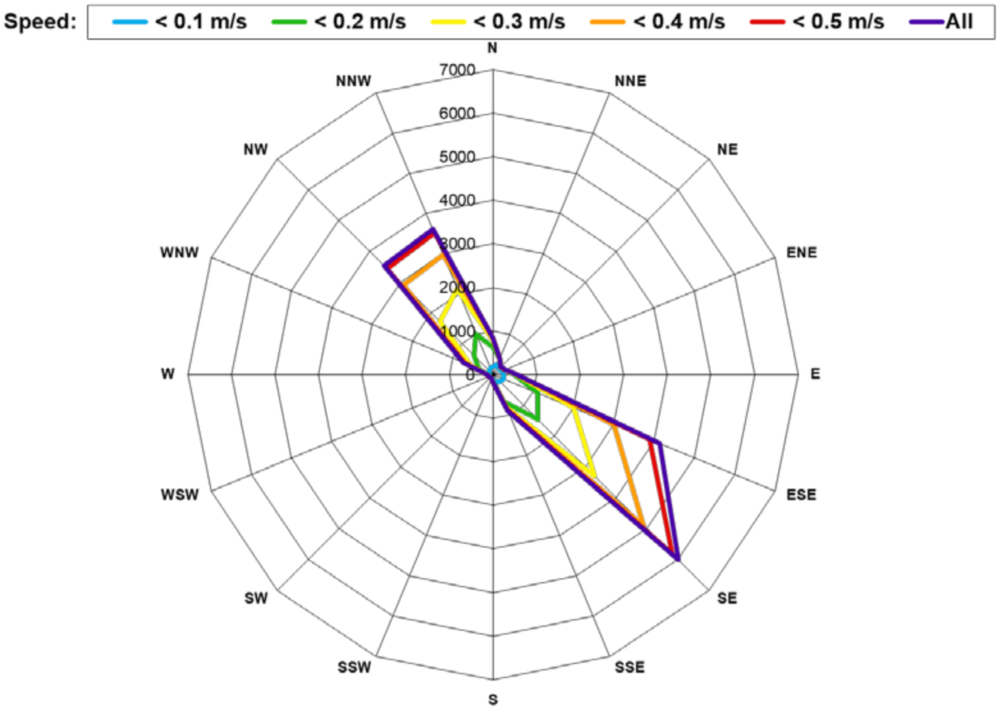


Figure 3.35 Current rose at Hay Reef (AMB 2) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

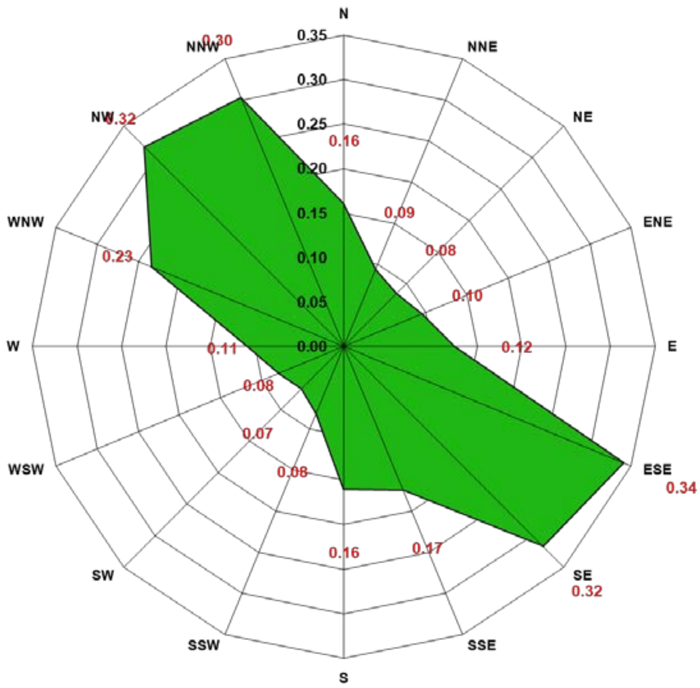


Figure 3.36 Average current speed rose at Hay Reef (AMB 2) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 12: Keswick Island

The current at Keswick Island flows predominantly in the NE direction with average velocities between 0.06 and 0.25 m/s (as shown in Figures 3.37 and 3.38). This has shown that the NE current is due to the current flow between the islands of Keswick and St. Bees.

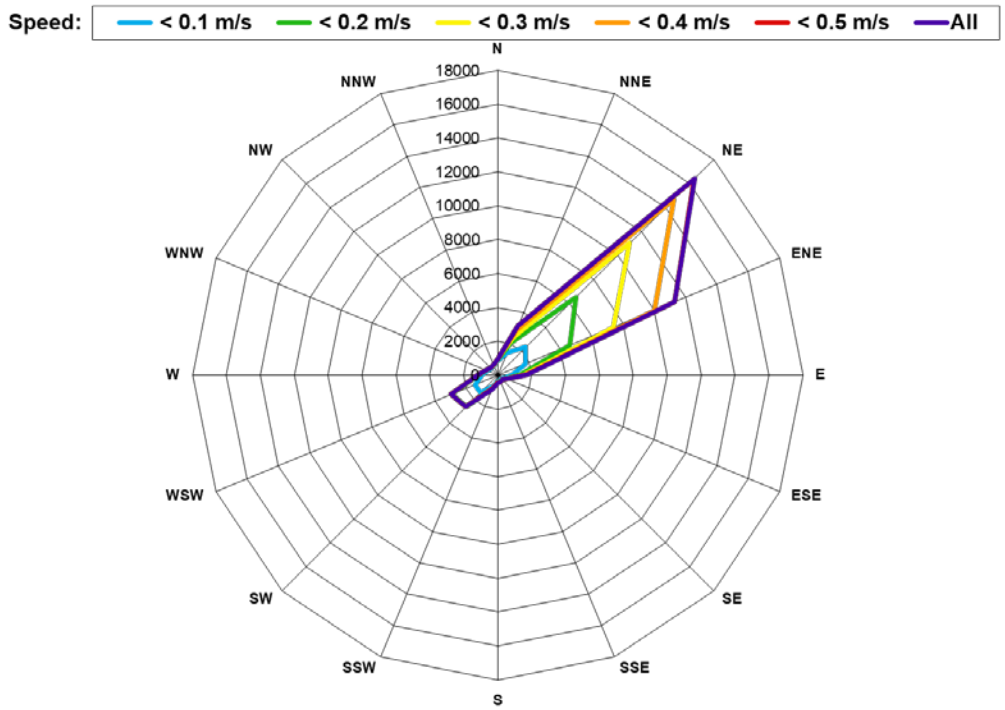


Figure 3.37 Current rose at Keswick Island (AMB 12) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

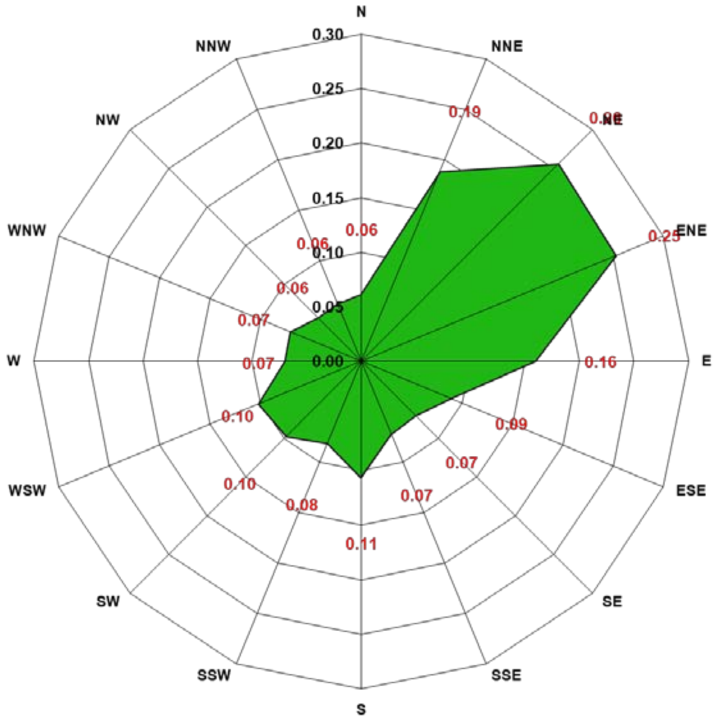


Figure 3.38 Average current speed rose at Keswick Island (AMB 12) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 3: Round Top Island

The two current directions that dominate at Round Top Island are in the NNW and S directions (Figure 3.39). An average current velocity of 0.33 m/s and 0.20 m/s were recorded in the NNW and S directions, respectively (Figure 3.40). Again, the change in direction is likely explained by changes in tidal current direction.

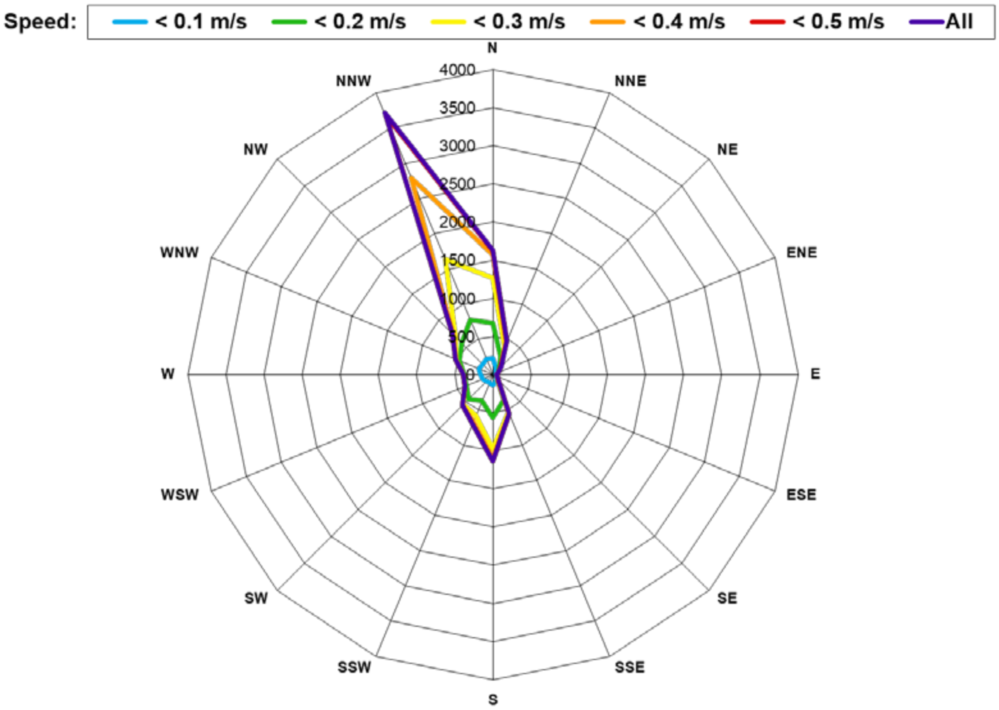


Figure 3.39 Current rose at Round Top Island (AMB 3) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

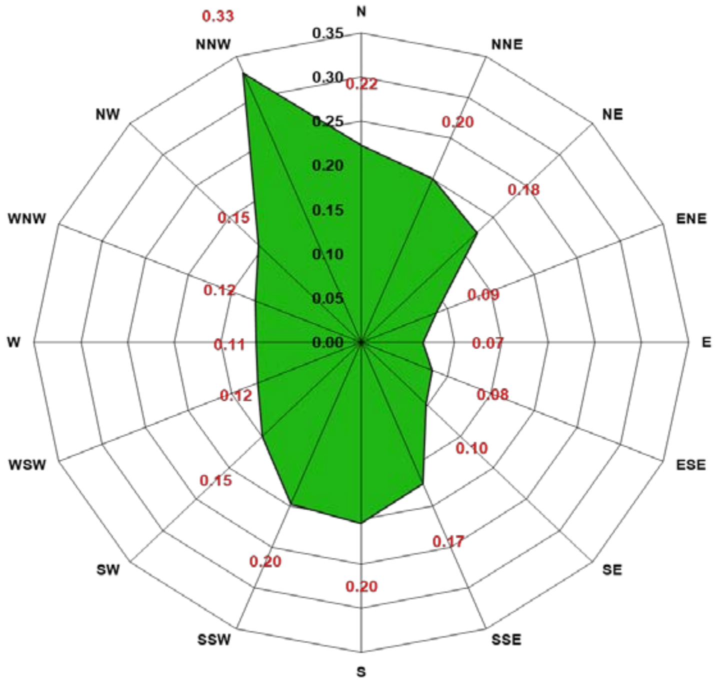


Figure 3.40 Average current speed rose at Round Top Island (AMB 3) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 5: Slade Island

The current at Slade Island ranges from WSW to SSW with a strong peak at SSW (Figure 3.41). The average recorded current velocities range from 0.11 to 0.19 m/s across all directions (Figure 3.42). Though little data exists for north eastern currents. This strong SW current flow is due to the monitoring site location being strongly protected on the NE side by Slade Island.

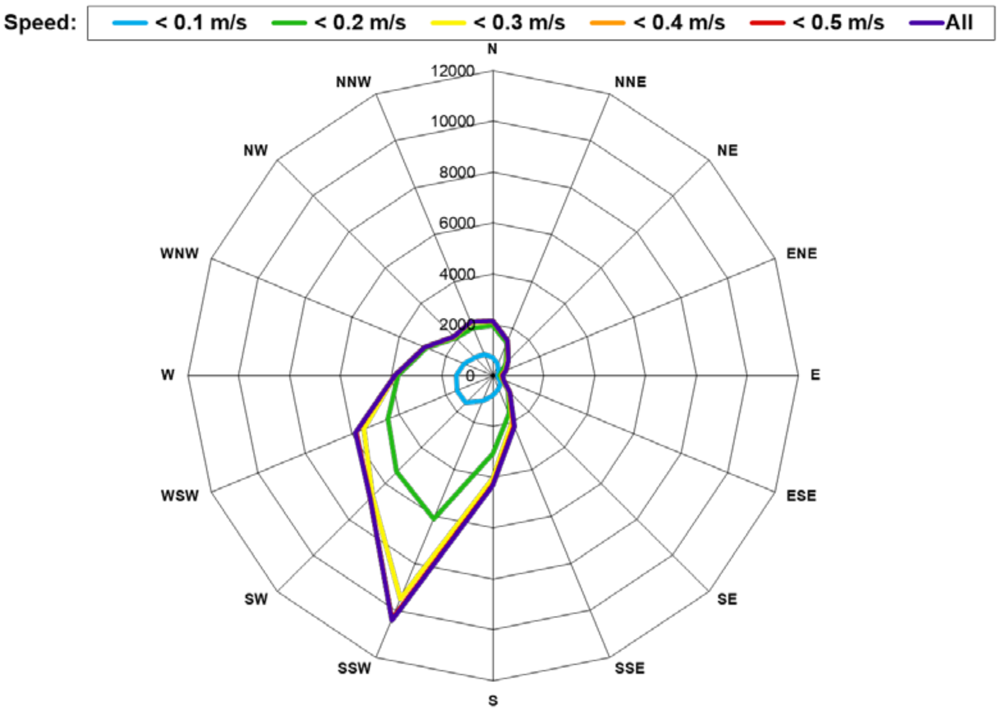


Figure 3.41 Current rose at Slade Island (AMB 5) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

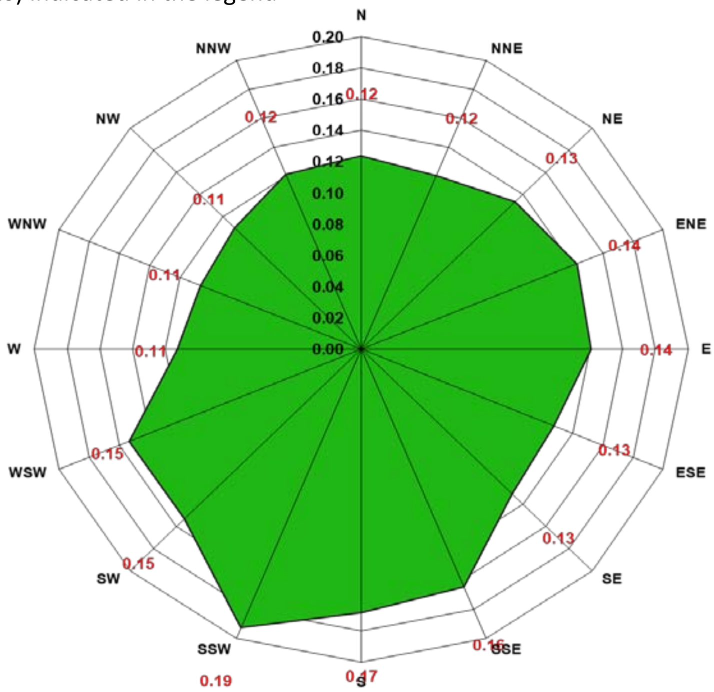


Figure 3.42 Average current speed rose at Slade Island (AMB 5) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 10: Victor Island

The current at Victor Island predominantly flows in the N and NE directions with average current velocity peaks of 0.21 and 0.23 m/s, respectively (as shown in Figures 3.43 and 3.44). The currents at this site run parallel with the coast indicating strong tidal influence on the recorded current data.

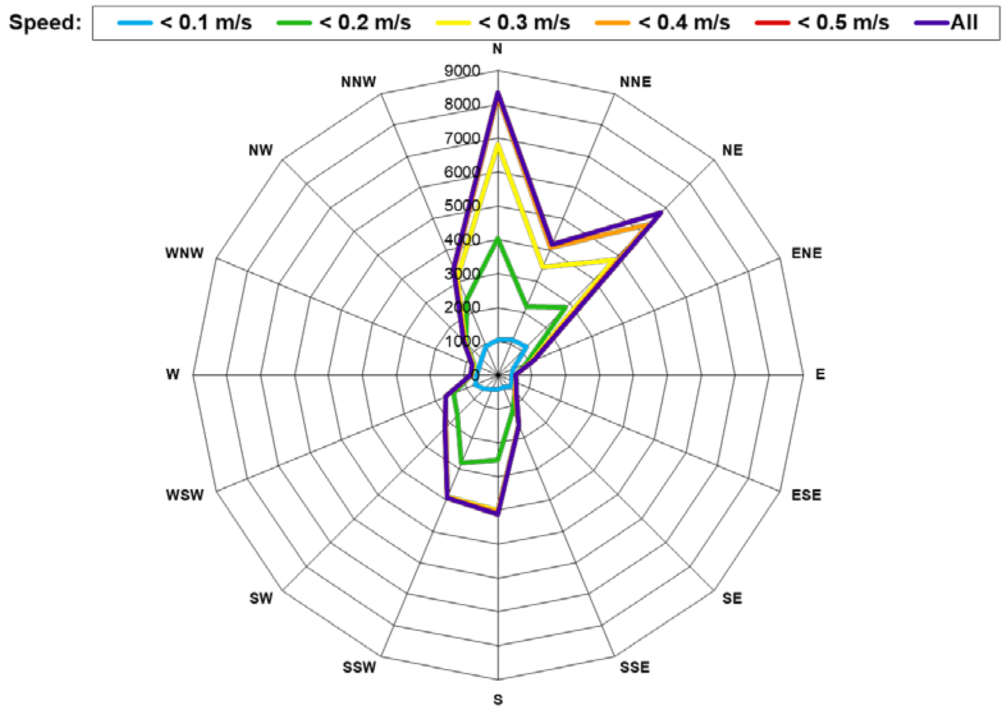


Figure 3.43 Current rose at Victor Island (AMB 10) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

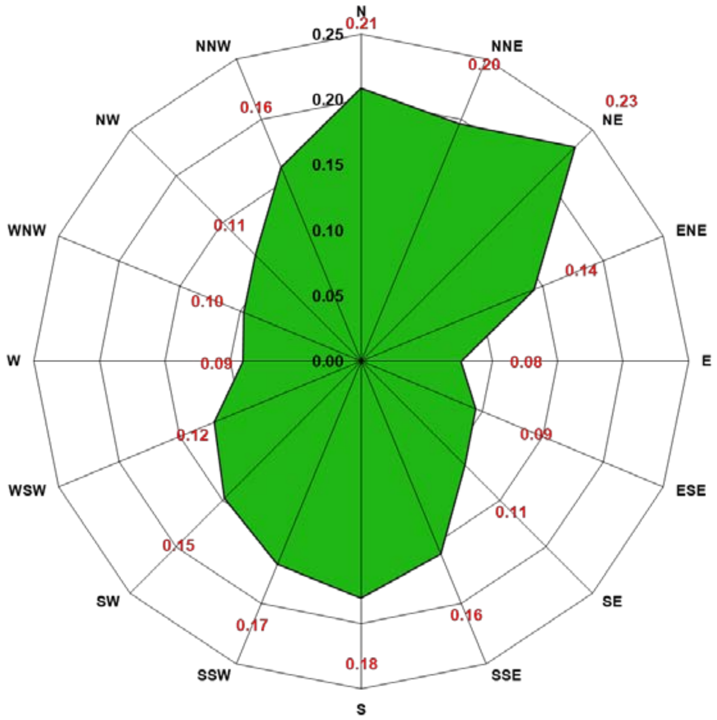


Figure 3.44 Average current speed rose at Victor Island (AMB 10) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

AMB 8: Spoil Grounds

The current at the Spoil Grounds flowed predominantly to the North and South indicating tidal currents with a change of direction between the ebb flood tides (Figure 3.45). Average current speeds ranged between 0.10 to 0.27 m/s (Figure 3.46). Like site AMB 10, the currents at this site run parallel with the coast indicating strong tidal influence on the recorded current data.

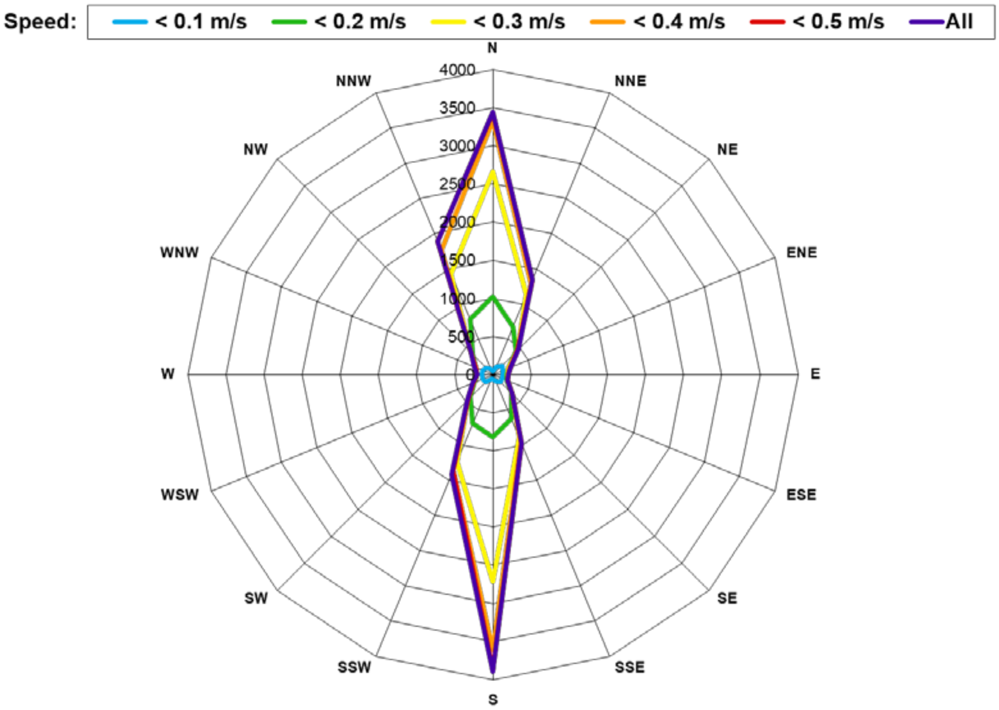


Figure 3.45 Current rose at the Spoil Grounds (AMB 8) for the monitoring period from July 2017 to July 2018. The current rose plots the number of currents recorded in each direction within the ranges of different current speeds (*cs*) indicated in the legend

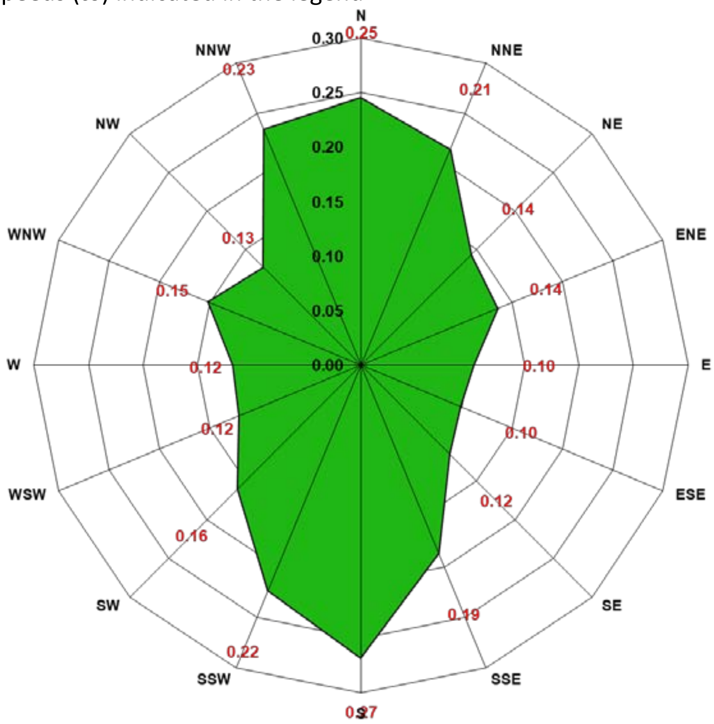


Figure 3.46 Average current speed rose at the Spoil Grounds (AMB 8) for the monitoring period from July 2017 to July 2018. The average current speed is rose is coloured in green, while the red values indicate the average current value at each specific direction

3.5 River Plumes

3.5.1 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, both wind components, tide amplitude and the Pioneer River discharge explained 51% of the SSC variability (Table 3.8). The relative importance analysis suggested that RMS of water depth is the most influential parameter on SSC (44% of overall R^2), followed by the two wind components (NWSE = 29% of overall R^2, and NESW = 25% of overall R^2; Figure 3.47). Tidal amplitude was the least influential variable (only 1% of overall R^2). Results of the partial effects plots (Figure 3.48) followed expected trends for SSC in relation to each environmental parameter selected in the model. Clear patterns in SSC were observed against all the environmental parameters, with the wind_NESW component exhibiting the widest confidence intervals. 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 and negative values for wind_NWSE) the higher the SSC readings were. These results are extremely similar to previous years, with the exception of Pioneer River discharge was an important parameter in the 2016/17 period.

Table 3.8 Statistical summary of the stepwise regression analysis to Freshwater Point in 2017/18

	Freshwater Point		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.61	3.18 – 6.05	**<0.001**
log(RMS)	1.16	0.83 – 1.49	**<0.001**
wind NESW	0.10	0.08 – 0.12	**<0.001**
wind NWSE	-0.05	-0.08 – -0.02	**<0.001**
Amplitude	0.18	0.05 – 0.30	**0.006**
Observations	304		
R^2 / adjusted R^2	0.509 / 0.502		

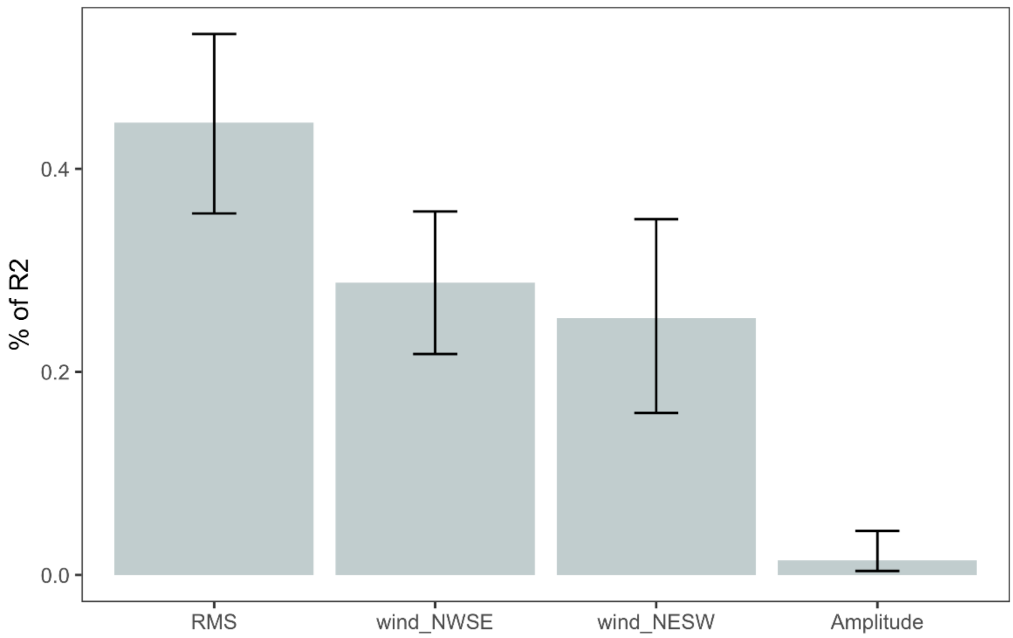


Figure 3.47 Freshwater Point bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

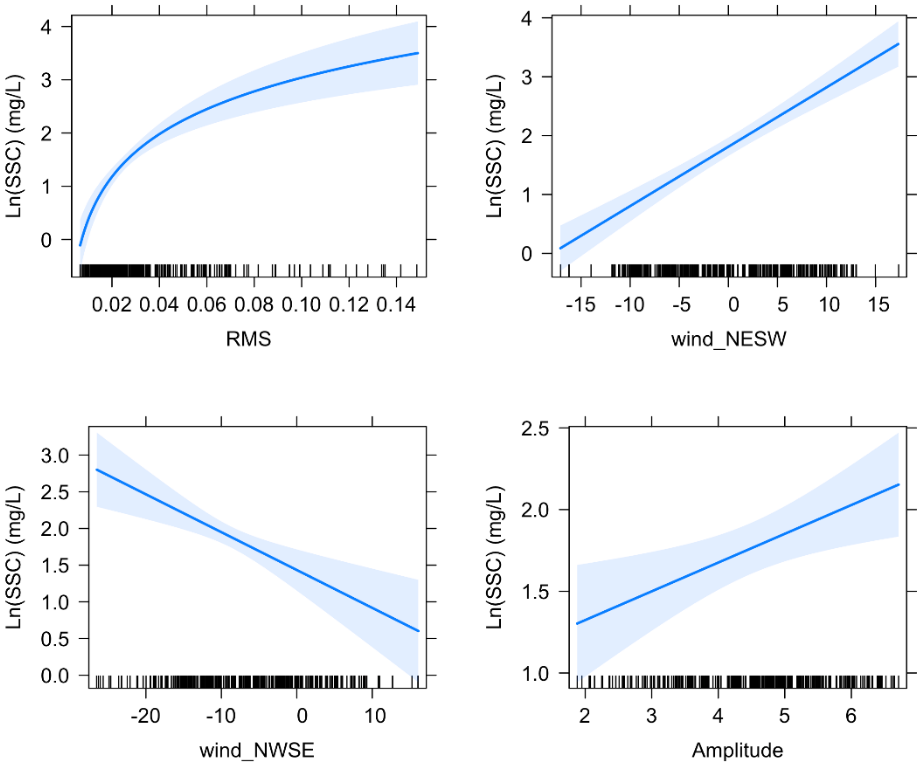


Figure 3.48 Partial effect plots for Freshwater Point parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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 58% of the SSC variability (Table 3.9). The relative importance analysis suggested that RMS of water depth is by far the most influential parameter on SSC (46% of overall R^2), and both wind components (NESW and NWSE) and tide amplitude each contributed similarly to SSC variability (17-19% of overall R^2) (Figure 3.49). Results of the partial effects plots (Figure 3.50) followed expected trends for SSC in relation to each environmental parameter selected in the model. Clear patterns in SSC were observed against all the environmental parameters. Overall, an increase in SSC was observed with increases in the environmental predictors. These results are similar to the Hay Point Reef site specific outputs in previous year's, although the Pioneer River discharge was no longer found to be an influential variable in this years' model compared to 2016/17 period (Waltham et al., 2017).

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

	Hay Reef		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	3.59	2.11 – 5.06	**<0.001**
log(RMS)	1.24	0.92 – 1.55	**<0.001**
wind NESW	0.08	0.06 – 0.10	**<0.001**
wind NWSE	-0.04	-0.06 – -0.01	**0.002**
Amplitude	0.43	0.30 – 0.56	**<0.001**
Observations	182		
R^2 / adjusted R^2	0.580 / 0.571		

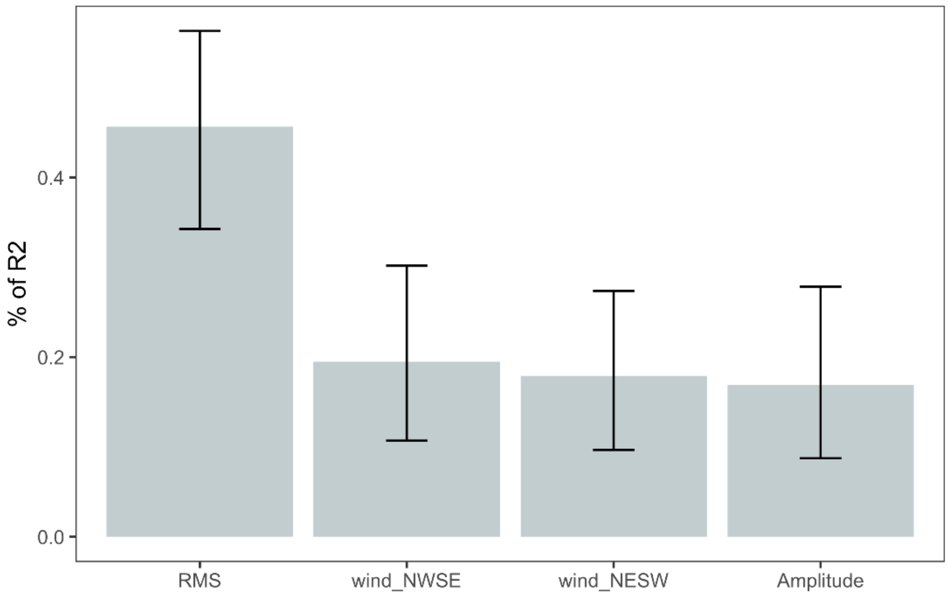


Figure 3.49 Hay Reef bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

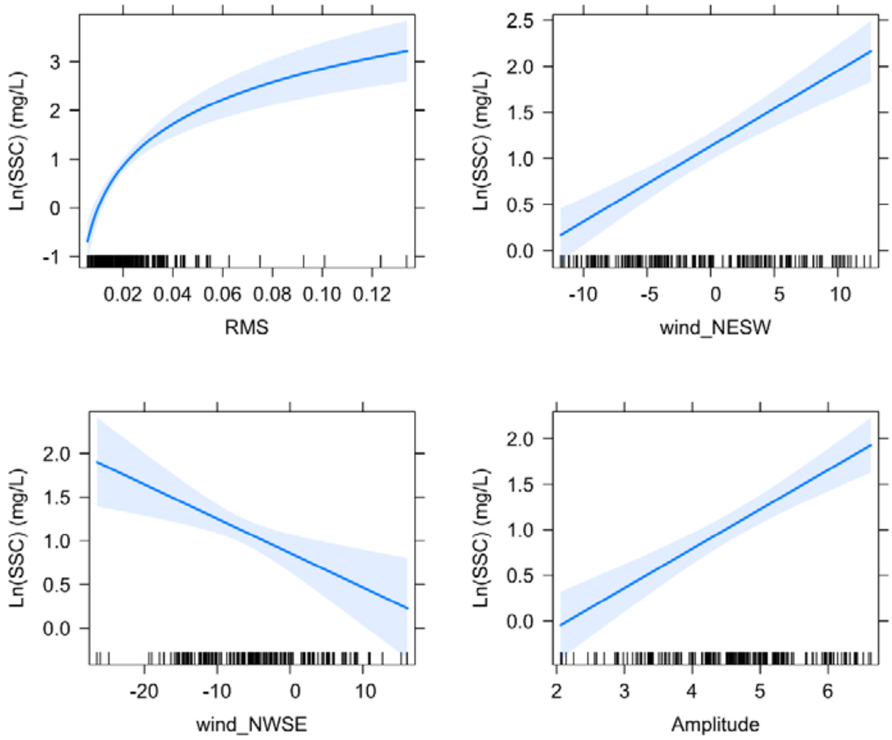


Figure 3.50 Partial effect plots for Hay Reef parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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, the wind component NWSE, tide amplitude and the Pioneer River discharges explained about 39% of the SSC variability (Table 3.10). The relative importance analysis suggested that the NESW wind component was the most influential parameter on SSC (36% of overall R^2), while tidal amplitude, water depth, and discharge from Pioneer River were less important (26%, 22%, and 15% of overall R^2, respectively) (Figure 3.51). Results of the partial effects plots (Figure 3.52) generally followed expected trends for SSC in relation to each environmental parameter selected in the model, a positive relationship with increasing flow from Pioneer River and tidal amplitude, while a negative relationship with increasing wind_NWSE. The results this year differ from 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)	-1.23	-2.00 – -0.47	**0.002**
log(RMS)	0.24	0.13 – 0.36	**<0.001**
log(Pioneer+1)	0.26	0.14 – 0.38	**<0.001**
wind NWSE	-0.04	-0.05 – -0.03	**<0.001**
Amplitude	0.32	0.23 – 0.40	**<0.001**
Observations	318		
R^2 / adjusted R^2	0.392 / 0.384		

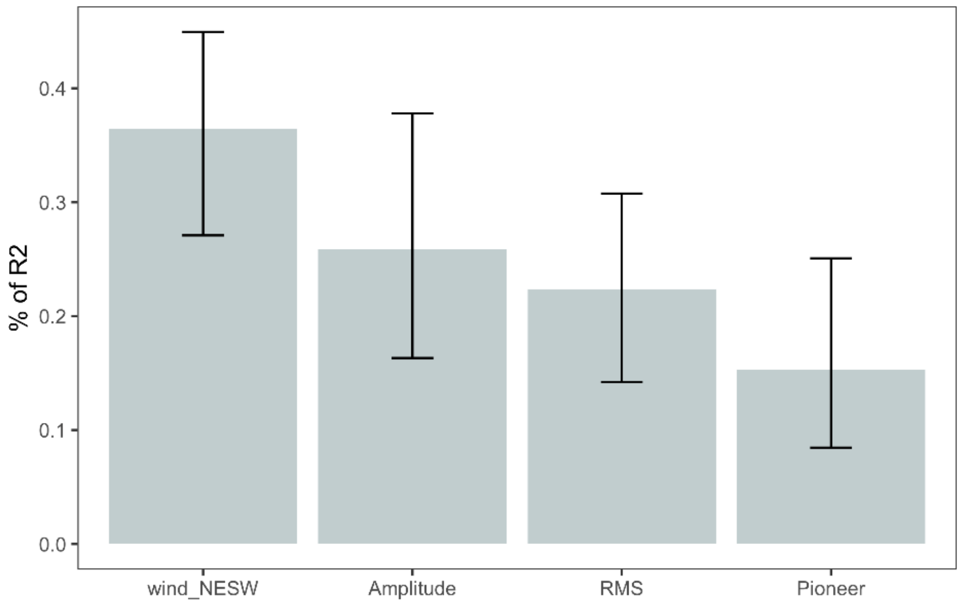


Figure 3.51 Keswick Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

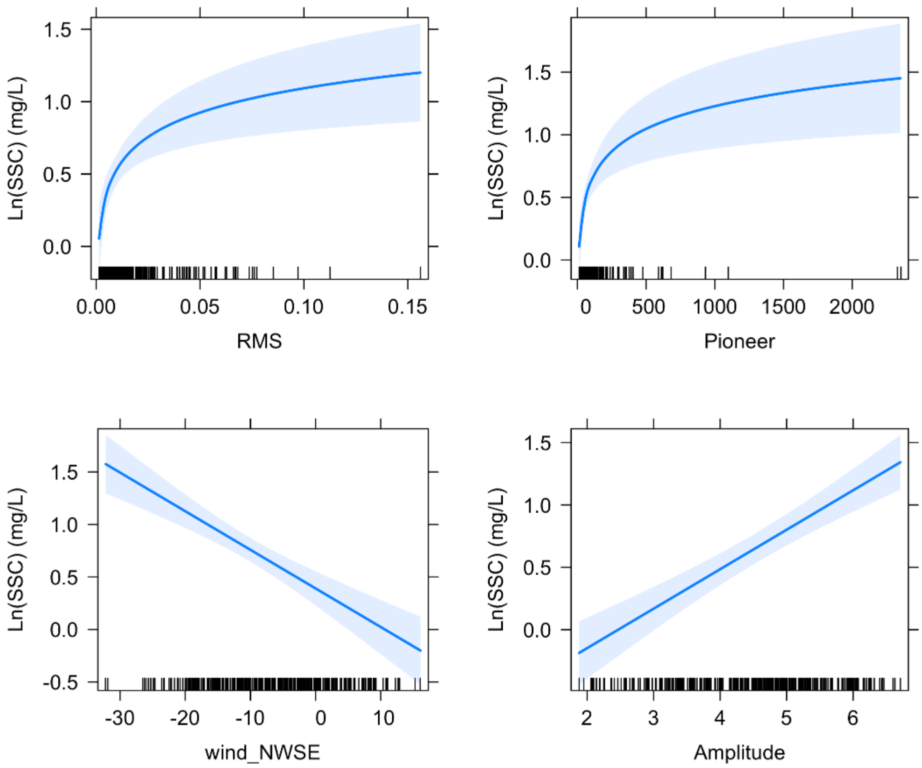


Figure 3.51 Partial effect plots for Keswick Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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, discharge from Pioneer River, and tide amplitude were the most influential factors of SSC variability, together explaining 26% of SSC variability (Table 3.11). The relative importance analysis suggested that the RMS of water depth component was the most influential parameter on SSC (74% of overall R^2), while Pioneer river discharge and tidal amplitude were less important (19% and 17% of overall R^2) (Figure 3.52). Overall, an increase in SSC was observed with increases in the environmental predictors. Results of the partial effects plots (Figure 3.53). These results differ with the models for Round Top Island reported for the 2016/17 monitoring where RMS of water depth, wind_NESW and tidal amplitude were important. Notably, RMS was again the most influential parameter on SSC at this site (same as 2016/17 report), though this year, additionally, discharge from the Pioneer River is again an important determinant 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)	1.01	-0.14 – 2.17	0.087
log(RMS)	0.81	0.61 – 1.02	**<0.001**
log(Pioneer+1)	0.39	0.19 – 0.60	**<0.001**
Amplitude	0.15	0.03 – 0.27	**0.017**
Observations	223		
R^2 / adjusted R^2	0.263 / 0.253		

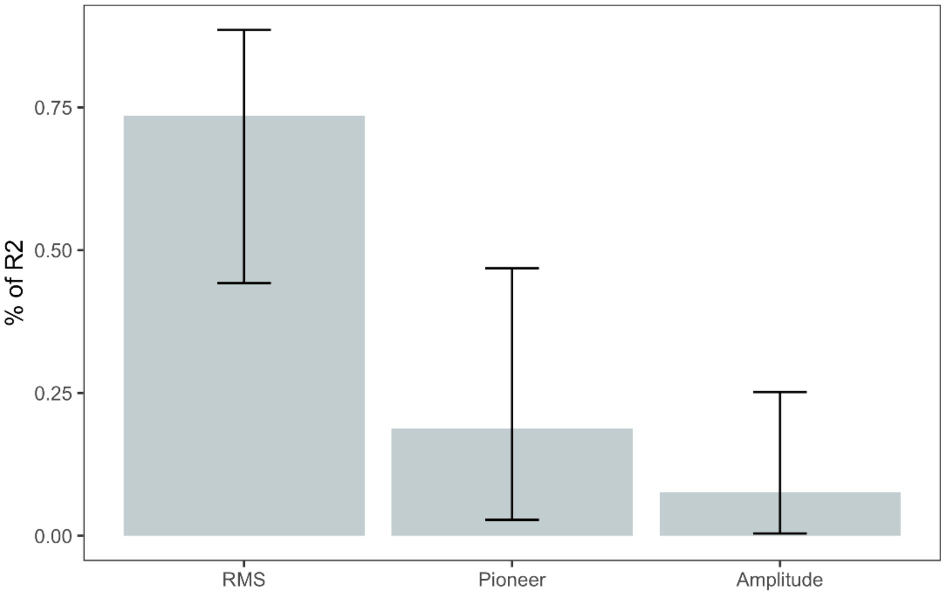


Figure 3.52 Round Top Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

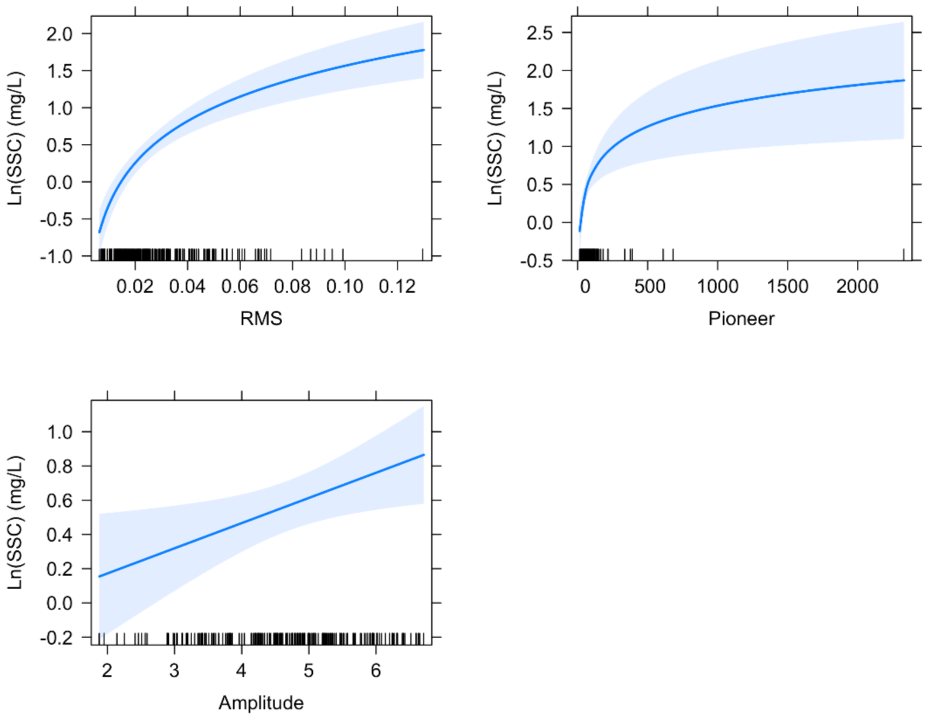


Figure 3.53 Partial effect plots for Round Top Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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, Sandy River discharge, the NESW wind component, and tide amplitude together explained about 37% of the SSC variability (Table 3.12). The relative importance analysis suggested that RMS of water depth was the single most influential parameter on SSC (55% of overall R^2) (Figure 3.54). The NESW wind component also contributed to explaining SSC variability (32% of overall R^2), and Sandy river discharge and the NESW wind component were less important (each contributing 6% to the overall R^2). Overall, an increase in SSC was observed with increases in the environmental predictors (Figure 3.55). The results differ from the 2016/17 slightly where Pioneer River flow is related with Sandy Creek flow this year.

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

	Slade		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	4.03	2.66 – 5.39	**<0.001**
log(RMS)	1.39	1.10 – 1.68	**<0.001**
log(Sandy+1)	0.19	0.03 – 0.36	**0.018**
wind NESW	0.10	0.08 – 0.13	**<0.001**
Amplitude	0.20	0.05 – 0.35	**0.010**
Observations	249		
R^2 / adjusted R^2	0.372 / 0.362		

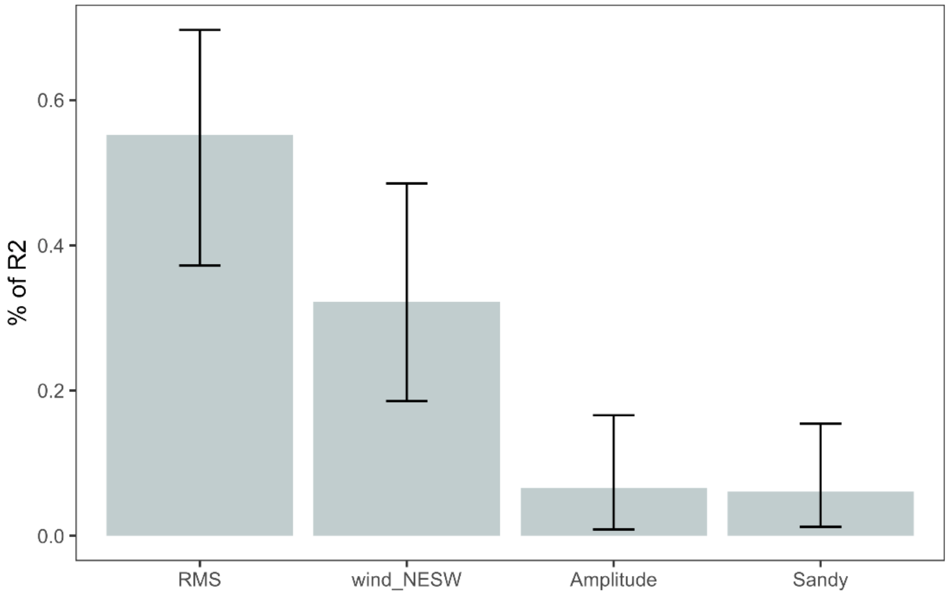


Figure 3.54 Slade Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

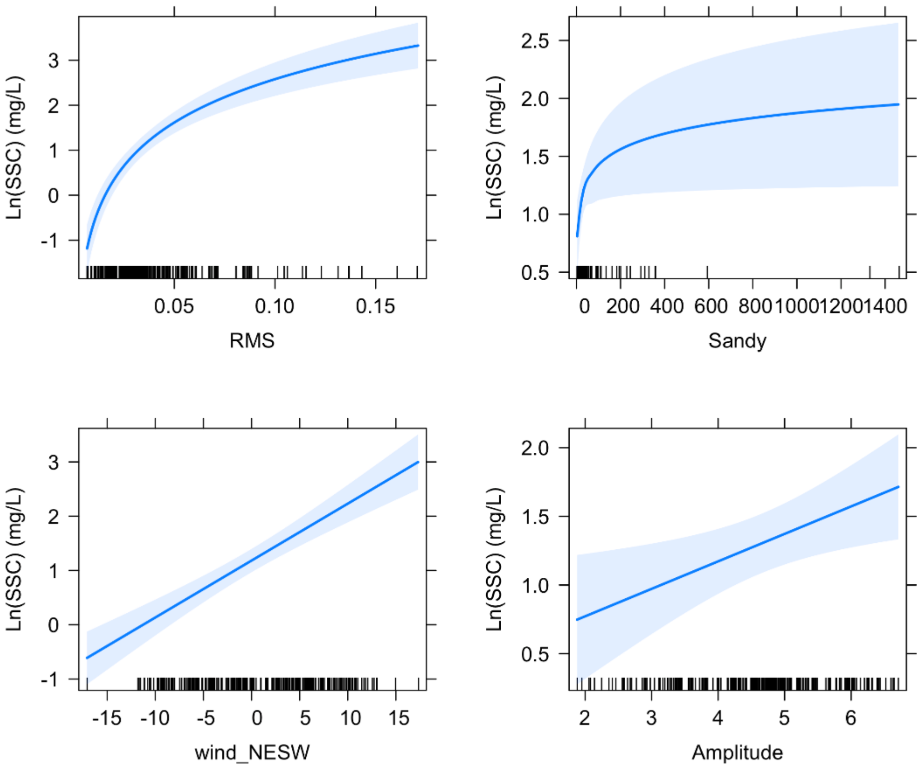


Figure 3.55 Partial effect plots for Slade Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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, Sandy River discharge, the NESW wind component, and tide amplitude together explained about 32% of the SSC variability (Table 3.13). The relative importance analysis suggested that the NWSE wind component was the most influential parameter on SSC (59% of the overall R^2), while water depth, the NESW wind component, and tidal amplitude (19%, 13%, and 9% of the overall R^2, respectively) (Figure 3.56). Results of the partial effects plots (Figure 3.57) followed expected trends for SSC in relation to each environmental parameter selected in the model. Clear patterns in SSC were observed against all the environmental parameters. Overall, an increase in SSC was observed with increases in the environmental predictors, except for the NESW wind component. Strong winds from the west (i.e. negative values for wind_NWSE) were associated with high SSC. This contrasts results from previous monitoring periods, where stronger the winds coming from the east were related to higher SSC readings. In addition, in the 2016/17 period flow from the Sandy River was important, but is not the case during this reporting period.

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

	Victor		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.14	0.34 – 1.93	**0.006**
log(RMS)	0.21	0.08 – 0.34	**0.002**
wind NESW	0.06	0.04 – 0.08	**<0.001**
wind NWSE	-0.08	-0.10 – -0.06	**<0.001**
Amplitude	0.26	0.13 – 0.39	**<0.001**
Observations	272		
R^2 / adjusted R^2	0.324 / 0.314		

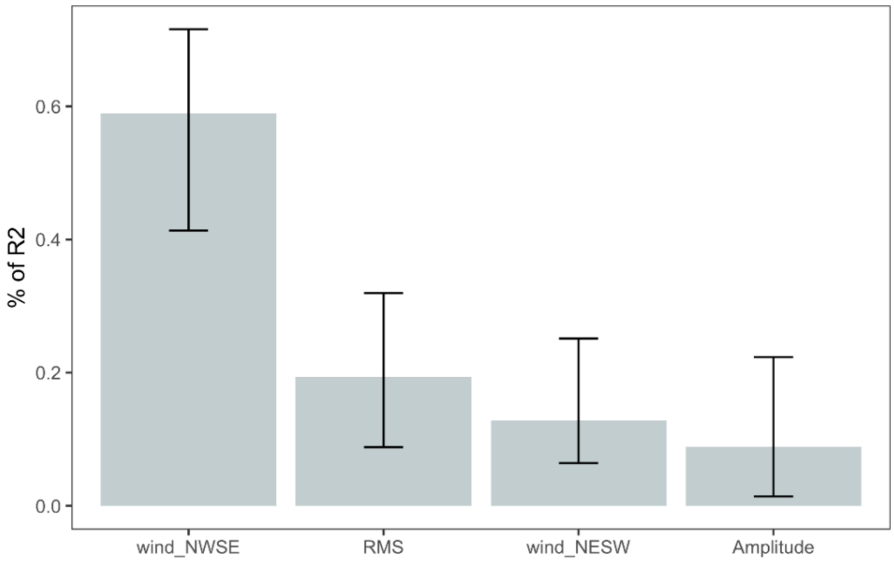


Figure 3.56 Victor Island bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

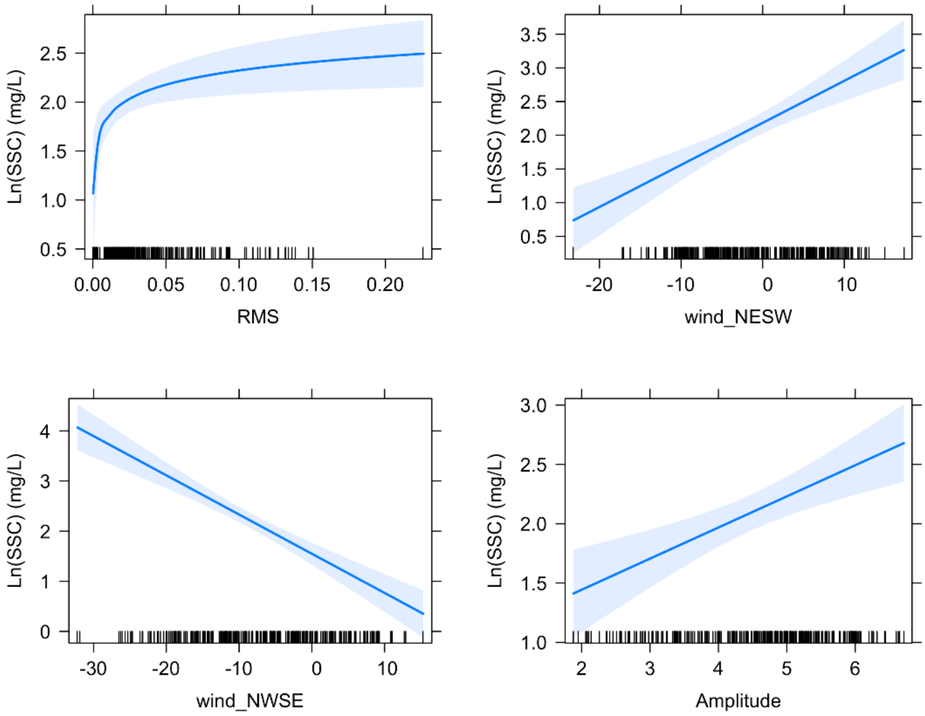


Figure 3.57 Partial effect plots for Victor Island parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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. RMS of water depth, wind_NESW and wind_NWSE together explained about 53% of the SSC variability (Table 3.14). The relative importance analysis suggested that RMS of water depth was the most influential parameter on SSC (54% of overall R^2), while the NESW and NWSE wind components were less important (26% and 20% of overall R^2, respectively) (Figure 3.58). Results of the partial effects plots (Figure 3.59) followed expected trends for SSC in relation to each environmental parameter selected in the model. Clear patterns in SSC were observed against all the environmental parameters, with an overall increase in SSC with increases in the environmental predictors, the exception was wind_NWSE which had a negative relationship. In the 2016/17 period Sandy River flow and tidal amplitude contributed to the SSC variability, but not during the present reporting period.

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

	Relocation Grounds		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.97	4.92 – 7.02	**<0.001**
log(RMS)	1.30	1.05 – 1.56	**<0.001**
wind NESW	0.08	0.07 – 0.10	**<0.001**
wind NWSE	-0.02	-0.04 – -0.00	**0.027**
Observations	247		
R^2 / adjusted R^2	0.533 / 0.527		

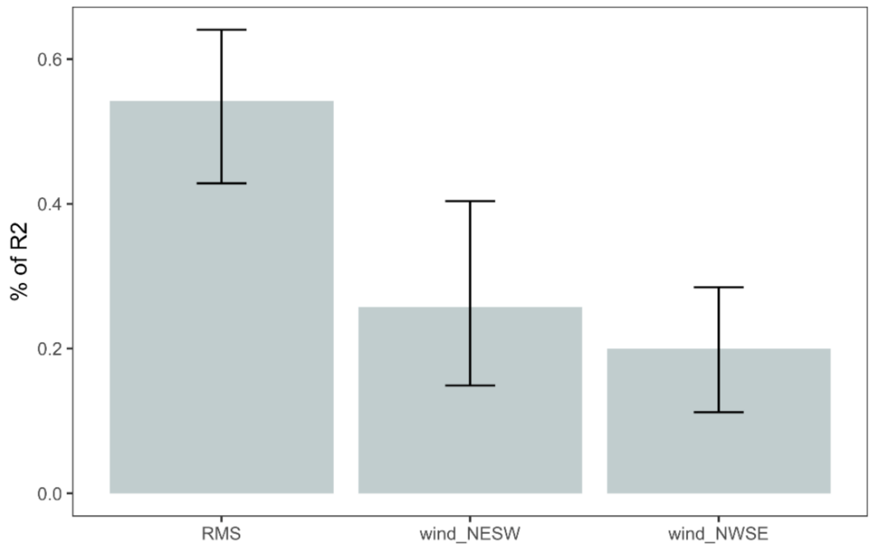


Figure 3.58 Spoil Grounds bootstrapping relative importance analysis following a stepwise multiple regression analysis. Bars represent 95% bootstrap confidence intervals, and % of r squared values are normalized to sum 100%

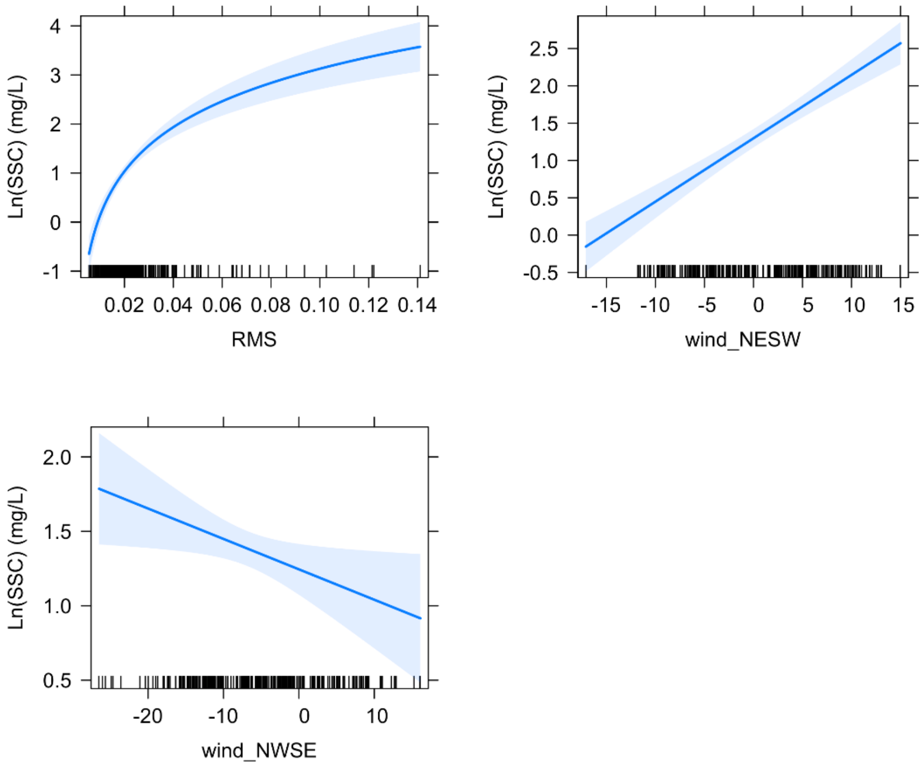


Figure 3.59 Partial effect plots for Relocation Ground parameters affecting the concentration of suspended solids in the water column. Grey area indicates 95% CI and rug on x-axis stand for data density

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 2017/18 wet season was in the order of the 10 %ile for the Mackay and Hay Point region.
- In the years' prior to commencement of the ambient marine monitoring program, rainfall in the Mackay region was lower. In fact, the 2014/15 wet season was in the lower 5 %ile, as with 2015/16, but 2016/17 was within the 90 %ile of the distribution of rainfall over the past 115 years because of a cyclone cross through this region. This year rainfall was, again, below the long term average. 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, particularly should the program experience above average rainfall in the future. Care is needed with the analysis of long term data series, to ensure that underlying conditions are taken into consideration. Here only one wet season was well above average, one year is around the long term average, while two years are well below long term 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 (2017/18) was, again, predominantly from the south east and south west. The strongest winds (>24km/hr) were predominantly from the south east (more than 45% 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^{o}C, with typically less than 2^{o}C difference through the water column. This patter is consistent from year to year over the four years of this program.
- The water column profile for dissolved oxygen, temperature, electrical conductivity and pH continue to be well mixed. The exception is turbidity which is 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 benthic habitats.
- Particulate nitrogen and phosphorus are elevated again this reporting period, above local relevant guidelines. The contributing factors to these data results might include some localised signal associated with runoff from land use activities such as farming and urban runoff from centres along the Mackay coastline region. The elevation is a concern for the region and requires ongoing investigation and management in order to identify broader catchment landscape processes. The Mackay/Whitsunday region has been previously

identified as a high risk area for nutrient, sediment and herbicides, in light of extensive agricultural activity (Waterhouse et al., 2012). Based on these data, and in previous years, a revision of the local guidelines is necessary to correctly align with local conditions.

- Chlorophyll-*a* concentrations continue to exceed local relevant guidelines, particularly when associated with high nutrient concentrations. In fact concentrations where highest in coastal sites, including Dudgeon Reef (AMB 6B), and in the Mackay Marina (AMB 11), presumably influenced by local land uses.
- Phytoplankton and zooplankton communities were most similar in their species composition during the dry season (May, July, and September 2017), and there is a weak, but significant, relationship with plankton communities and available nutrients.
- Trace heavy metals continue to be non-detectable across the monitoring period this year. Atrazine, Diuron, and Hexaninone were detected at several coastal sites.
- Diuron, atrazine and hexazinone were the only herbicides detected across the site network this year. These herbicides are used in agricultural cultivation activities (Lewis et al., 2009). However, the input and influence of wet season flow has been limited, and thus would be reflected in the low to no detection of PS II herbicides in the marine environment. In a higher rainfall year it might be expected to detect herbicides at coastal marine monitoring sites, given the extensive agricultural activities that occur in the region. PSII herbicides have been a continuing concern in the Mackay region (Mitchell et al., 2005), and have been previously linked to the dieback of mangroves in the region in the 1990's (see Bell and Duke 2005), though there is no evidence of more recent events of this nature in the region.
- 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, there is a possibility to begin to investigate the implications of the measured water quality conditions as part of this program on sensitive receptor habitats and species, such as coral reefs (De'ath and Fabricius, 2010), marine plants (see Coles et al., 2015; McKenna et al., 2015), and also economically important marine fauna (Jones et al., 2000).
- 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 four year-long data set comparing wet and dry seasons shows little difference in SSC for the sites AMB 3, 8 10 and 12, however there were differences for sites AMB1, 2 and 5. At AMB 1, 2 and 5 wet season means and medians were approximately twice that of dry season values, however there was no discernible difference between wet and dry RMS wave height

values. This indicates that the increase in turbidity at these inshore sites is not likely to be due to an increase in wave activity.

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). 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 (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, suggesting that the increase in available light during the wet season is offset by the increased cloud cover. Most sites showed no difference between wet and dry, while AMB 1 and 2, showed increases of mean and median values of more than 40% during the dry season and AMB 12 showed a decrease in mean and median values of more than 60%.

4.2 Recommendations

4.2.1 Consolidation of the water quality loggers

As part of a review of the data during the March 2017 progress report, it was recommended that the ambient monitoring program remain into the 2018/19 period. This recommendation was put forward as the region continues to experience below average rainfall conditions. It will be important to ensure that the site network is ready to capture a full wet season, in order to characterise the upper water quality conditions for the region.

4.2.2 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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6 APPENDIX

A.1 Calibration Procedures

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* (2000) 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.

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.

Light Calibration

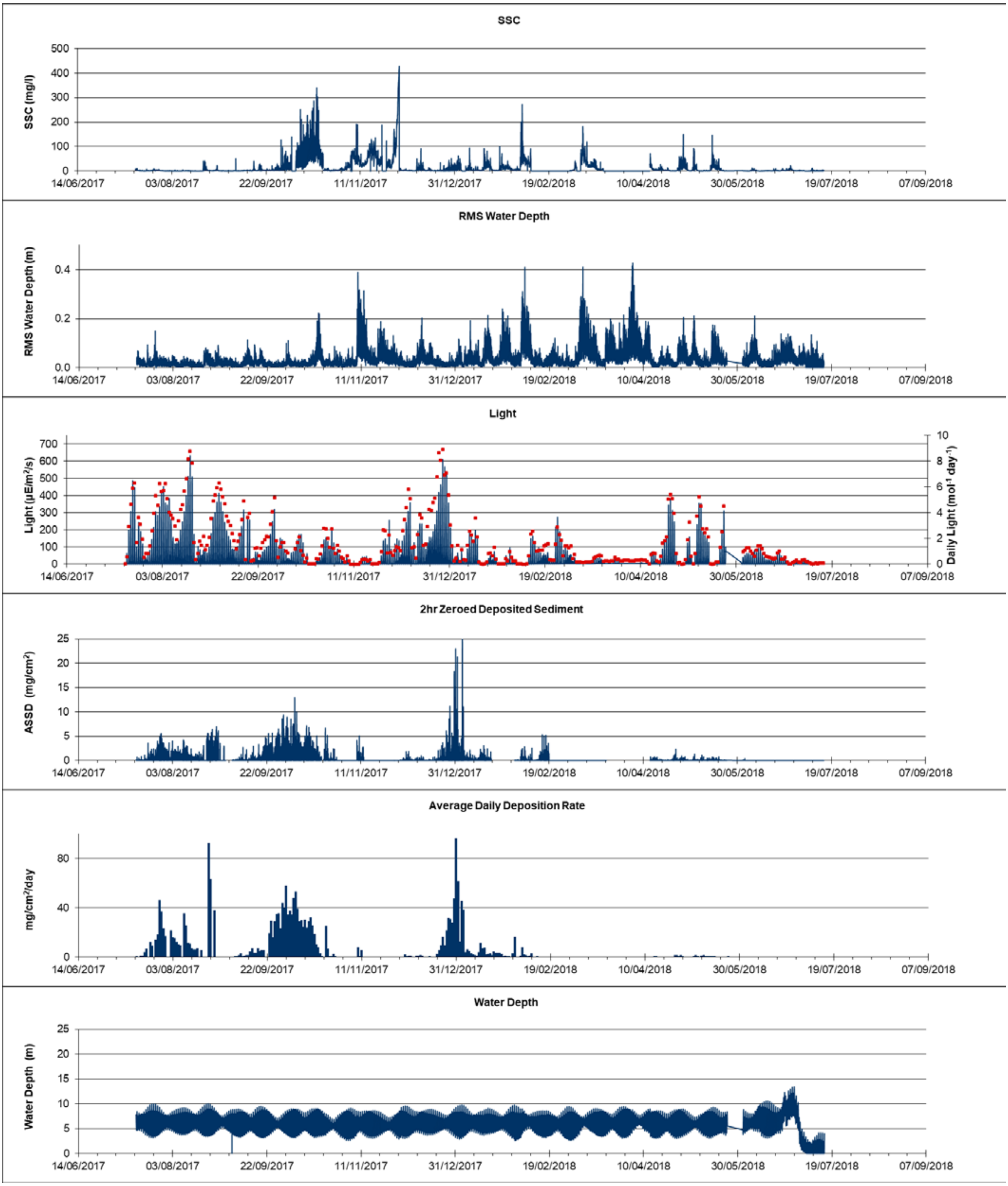
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration 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.

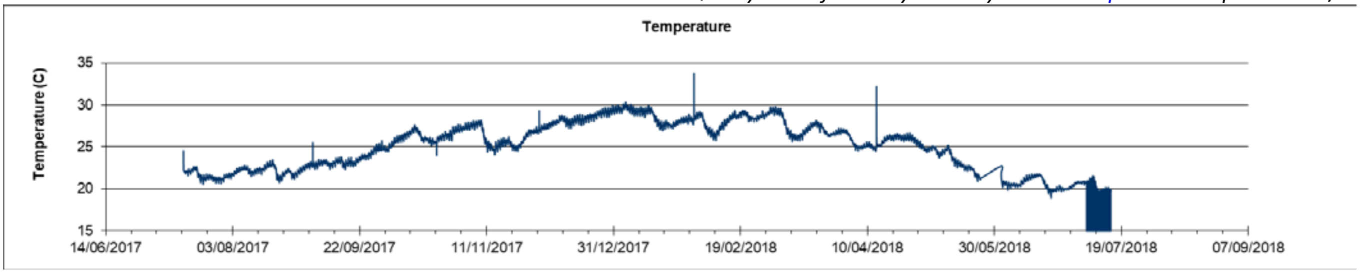
Pressure Sensor Calibration

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

A.2 Time series data

AMB 1: Freshwater Point





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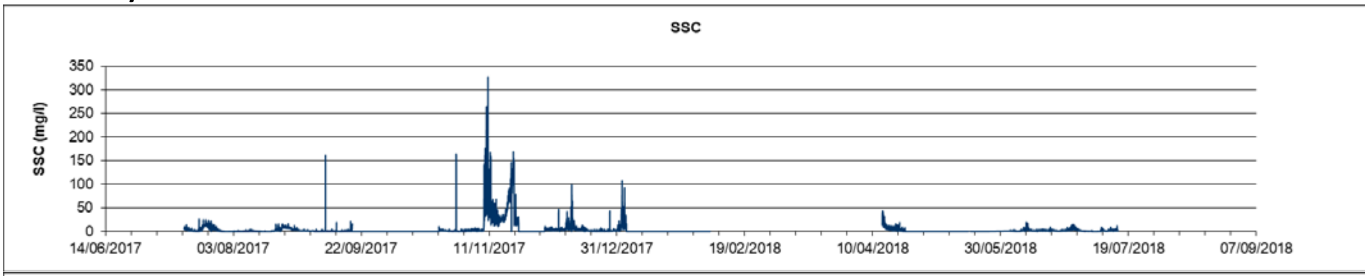

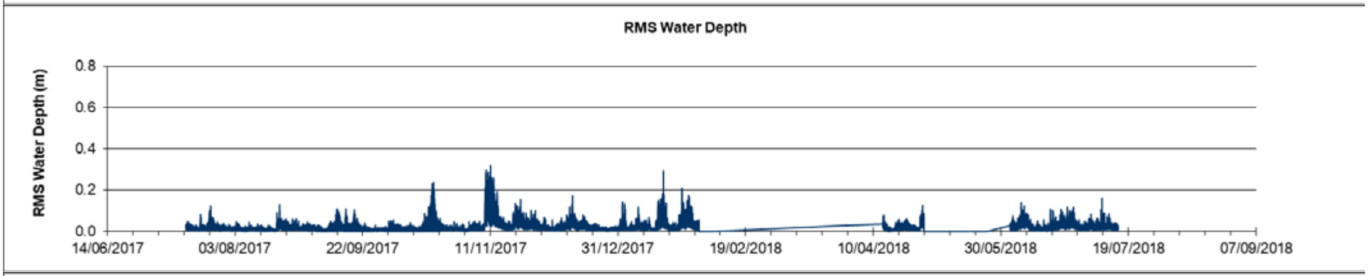

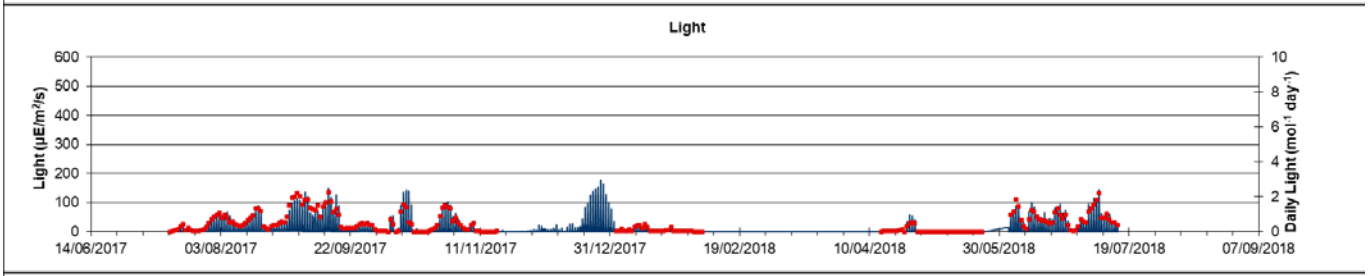

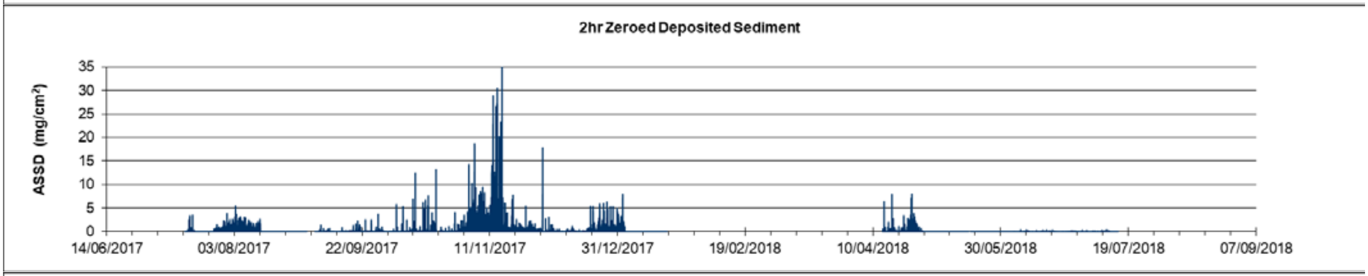

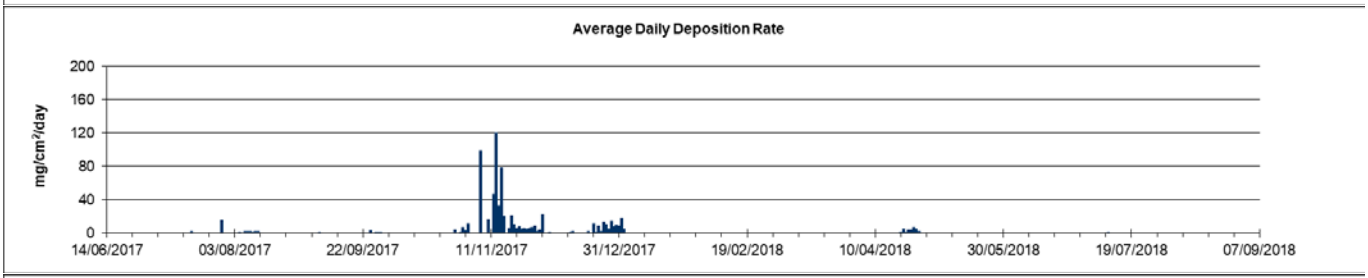

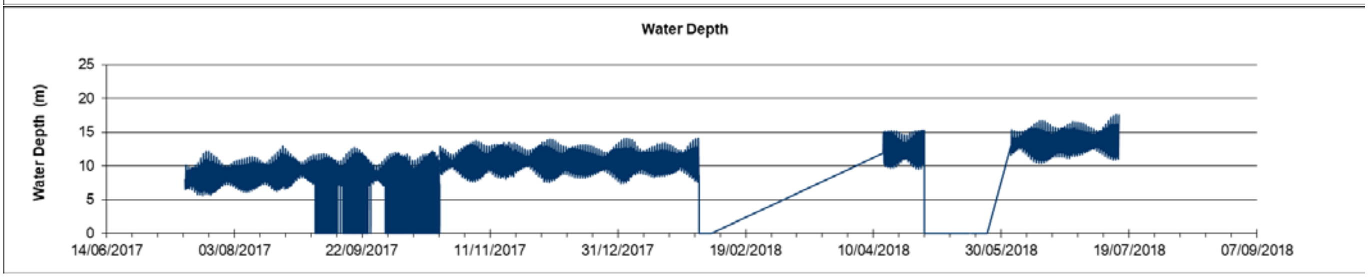

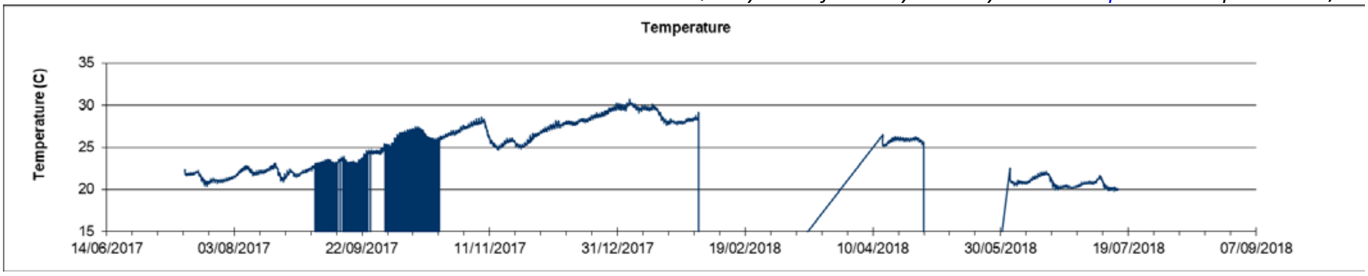
Temperature
Temperature (C)
35
30
25
20
15
14/06/2017
03/08/2017
22/09/2017
11/11/2017
31/12/2017
19/02/2018
10/04/2018
30/05/2018
19/07/2018
07/09/2018

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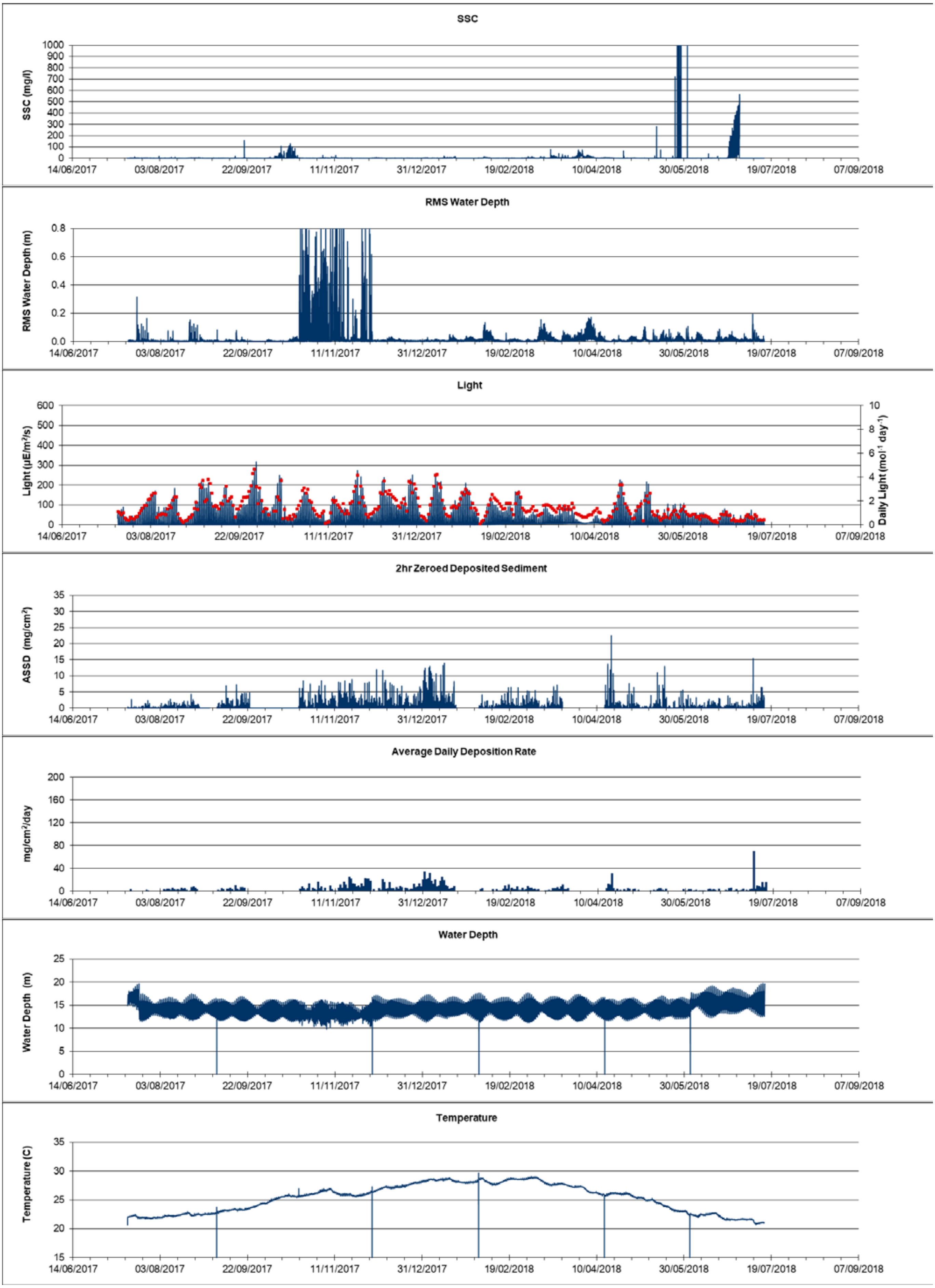

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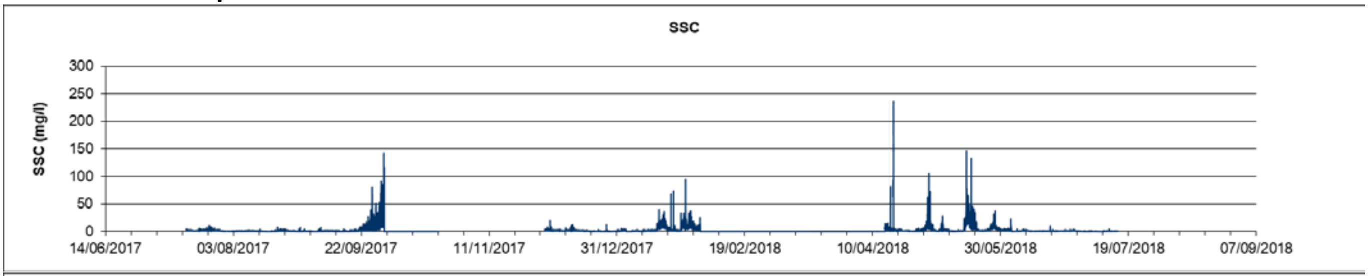

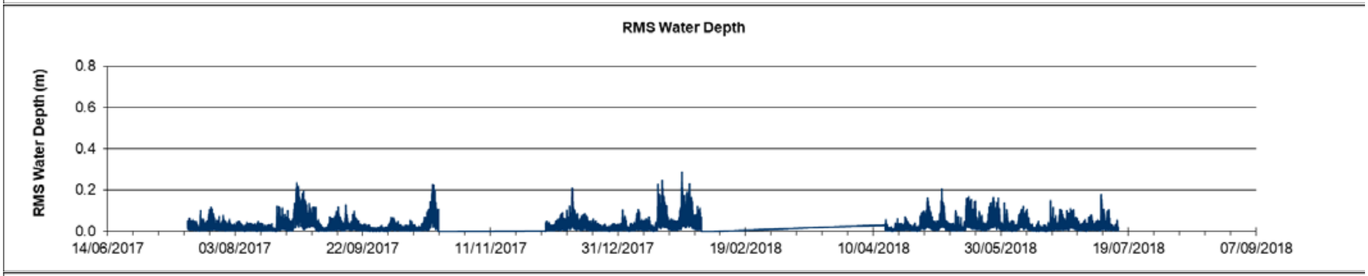

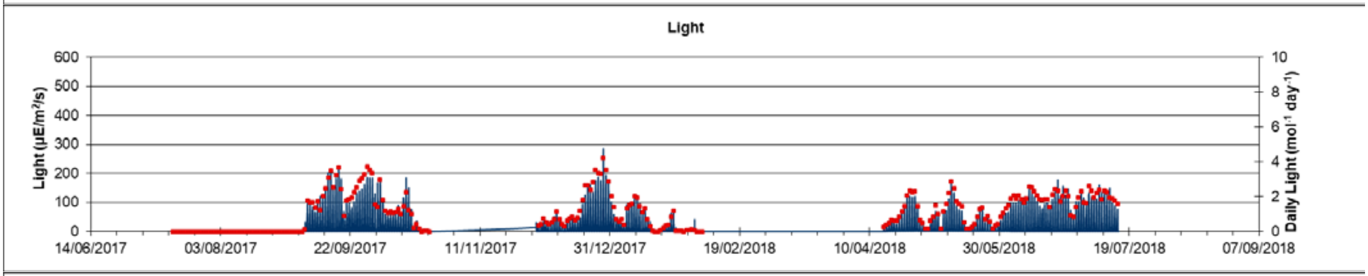

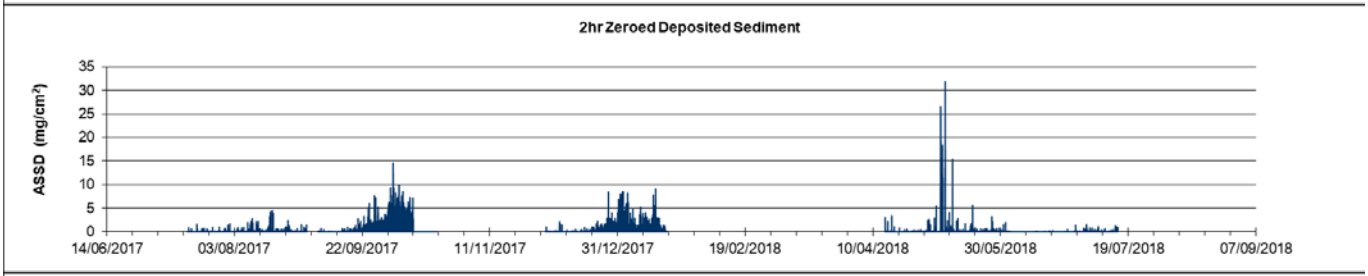

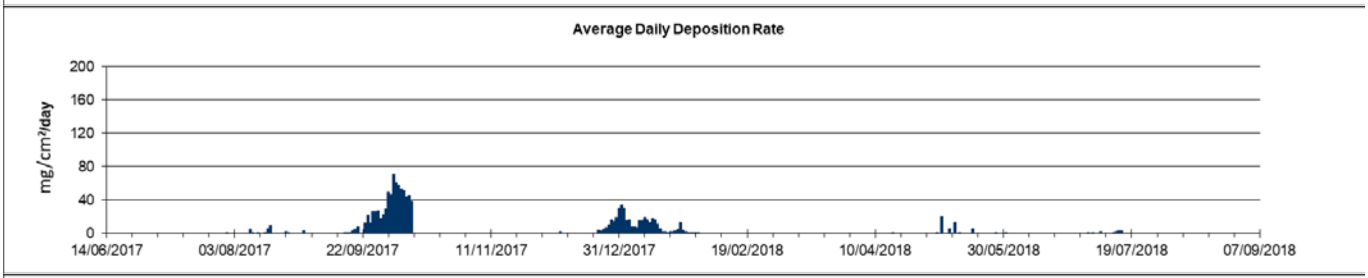

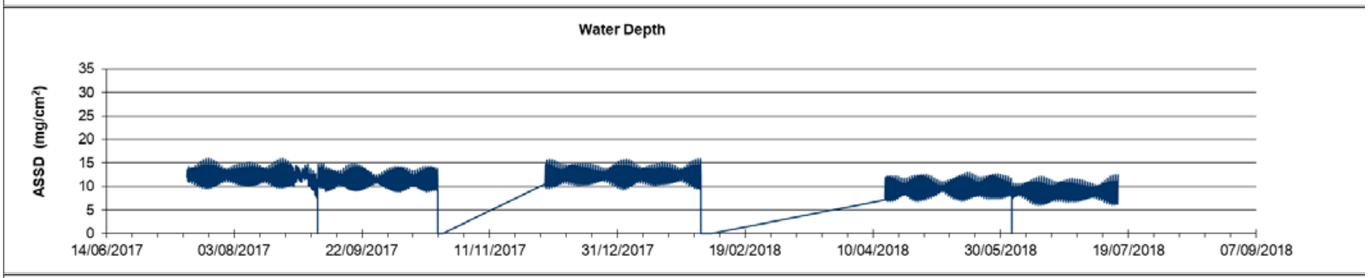

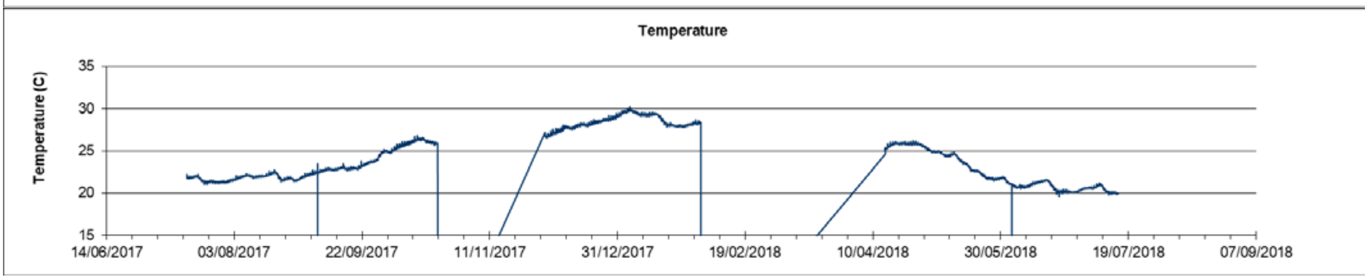

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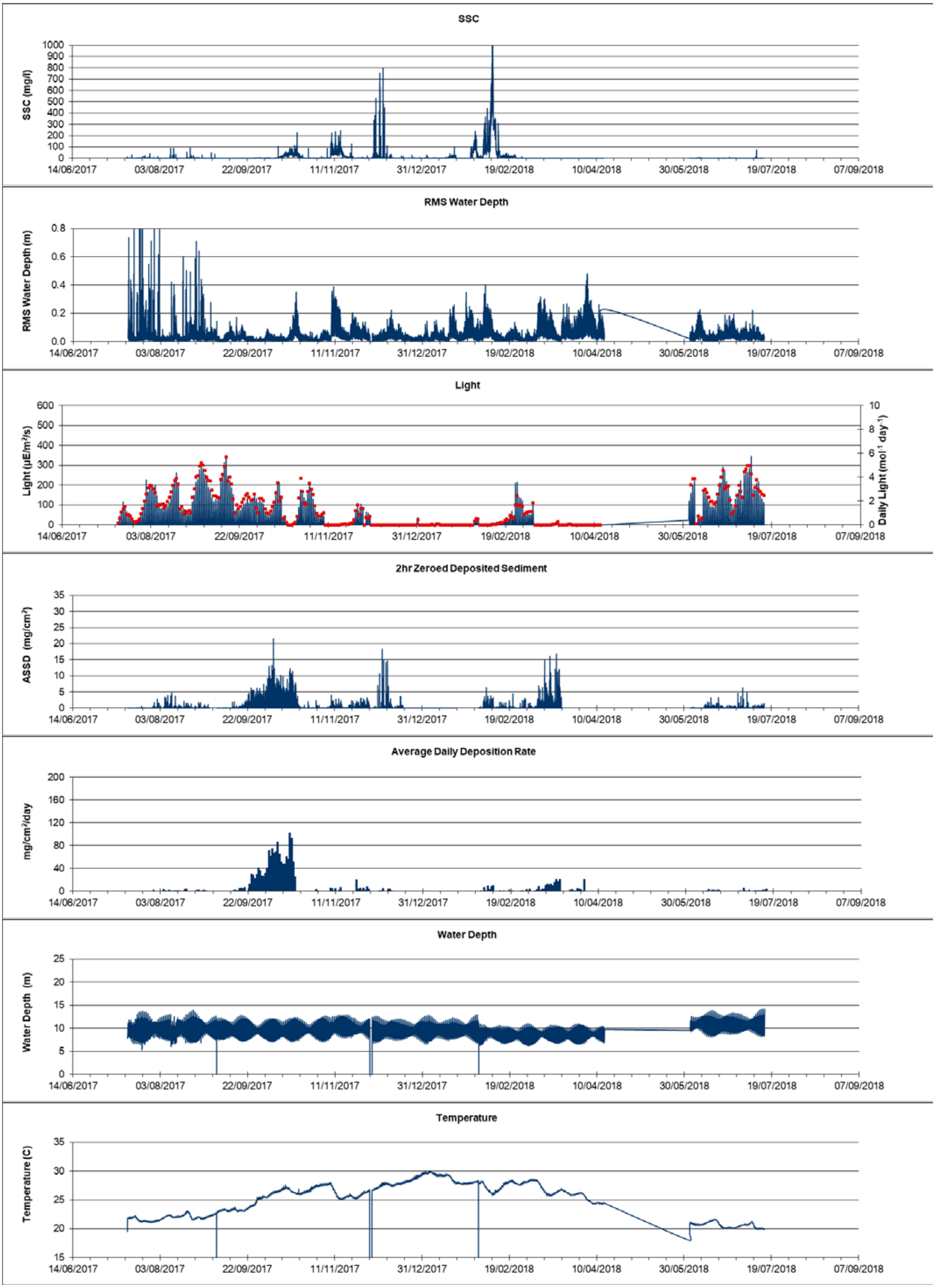

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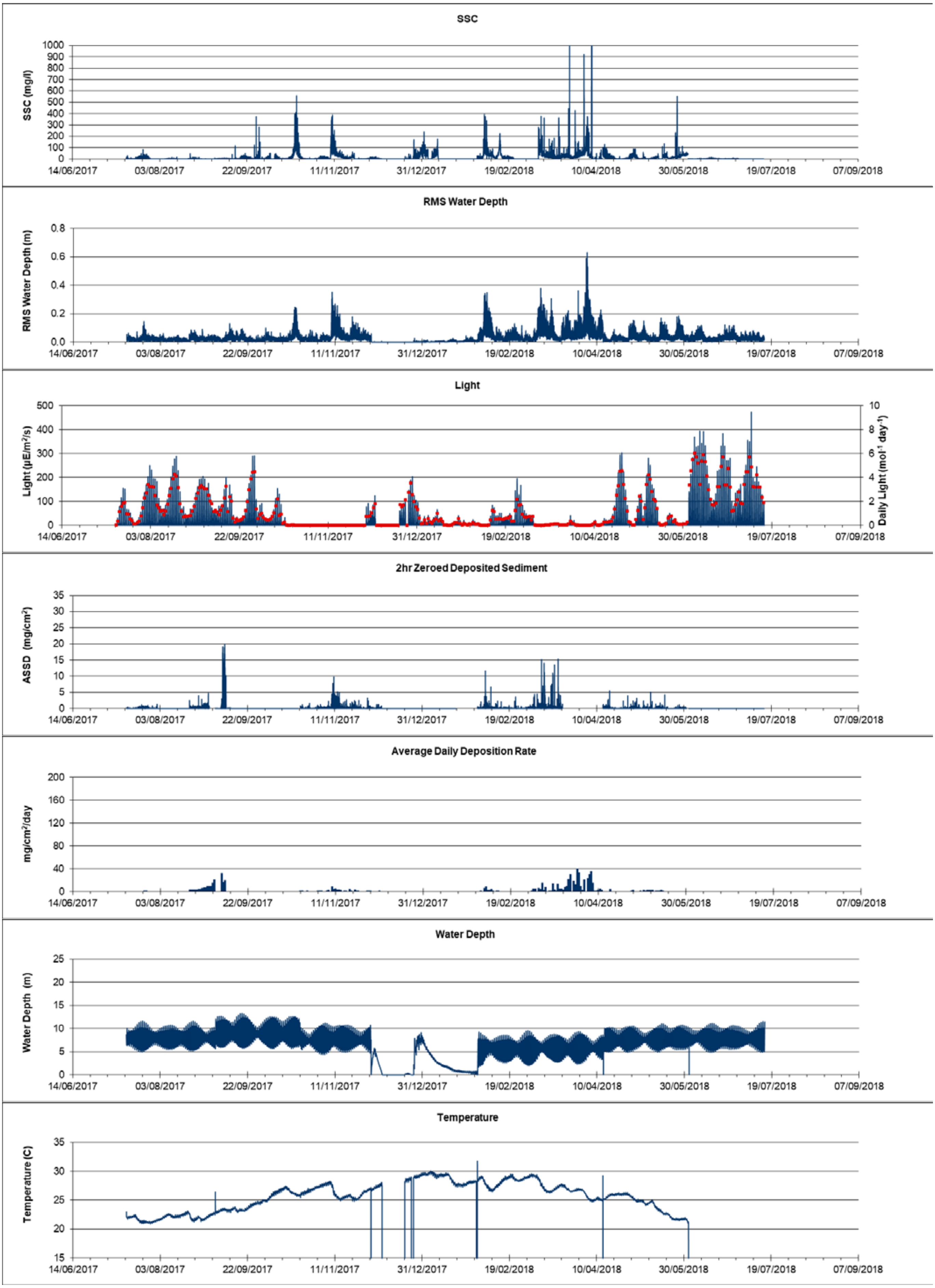
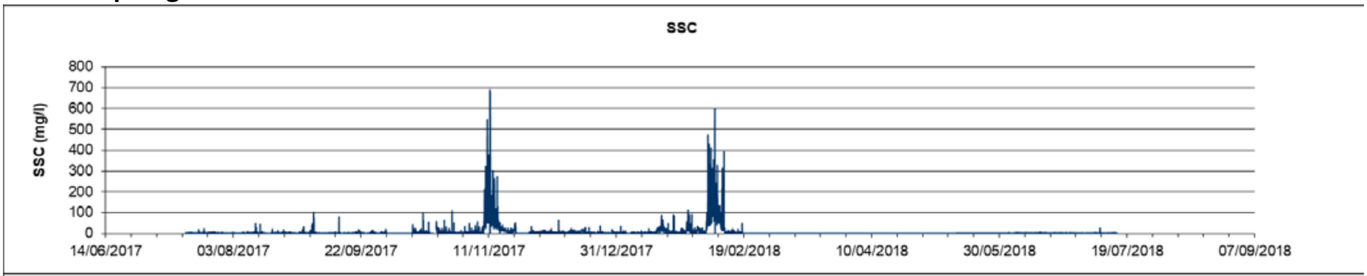
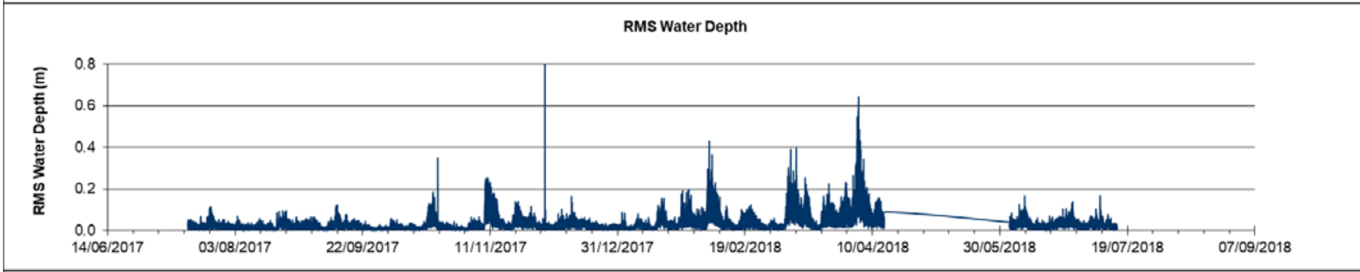
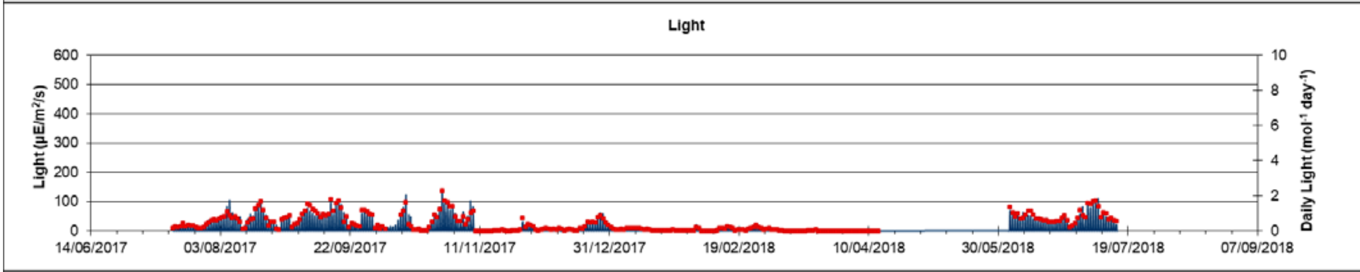
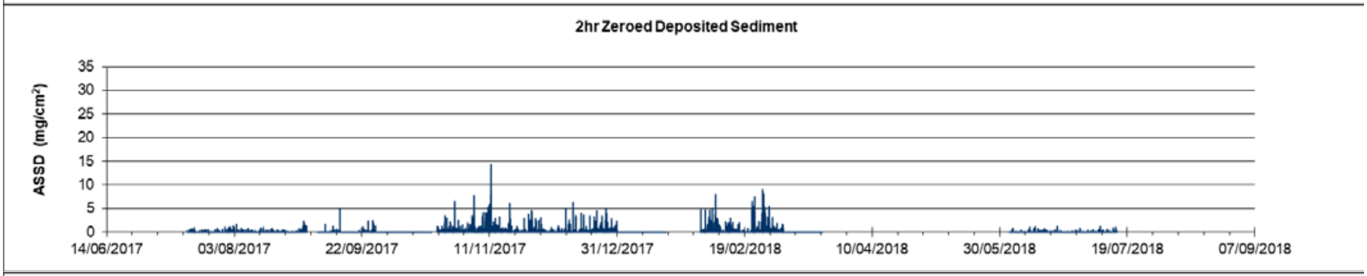


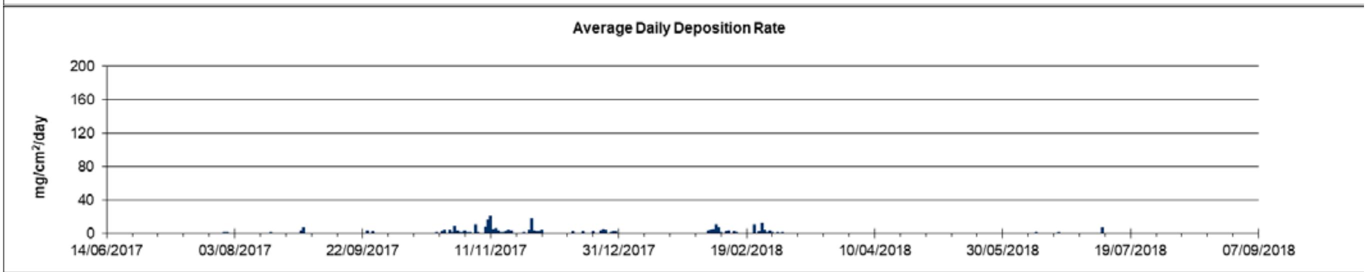
AMB 8: Spoil ground

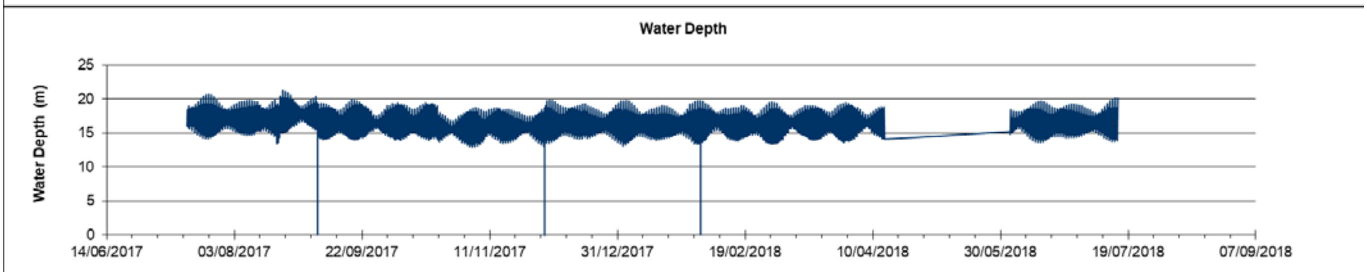


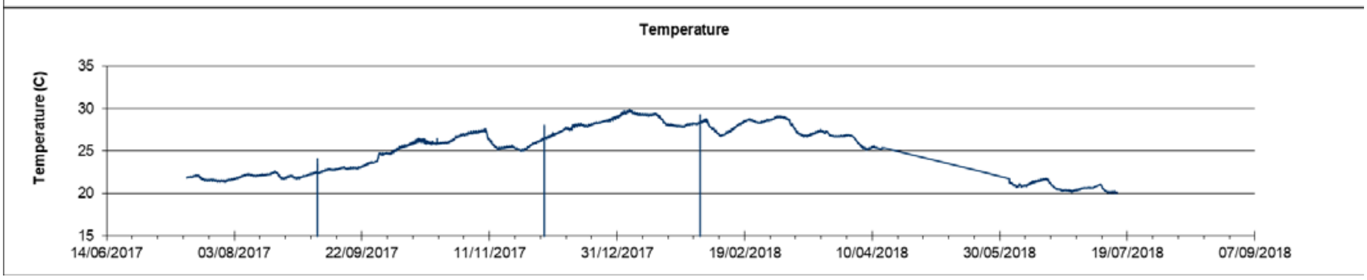












A.3 Summary of monthly statistics

AMB 1: Freshwater Point

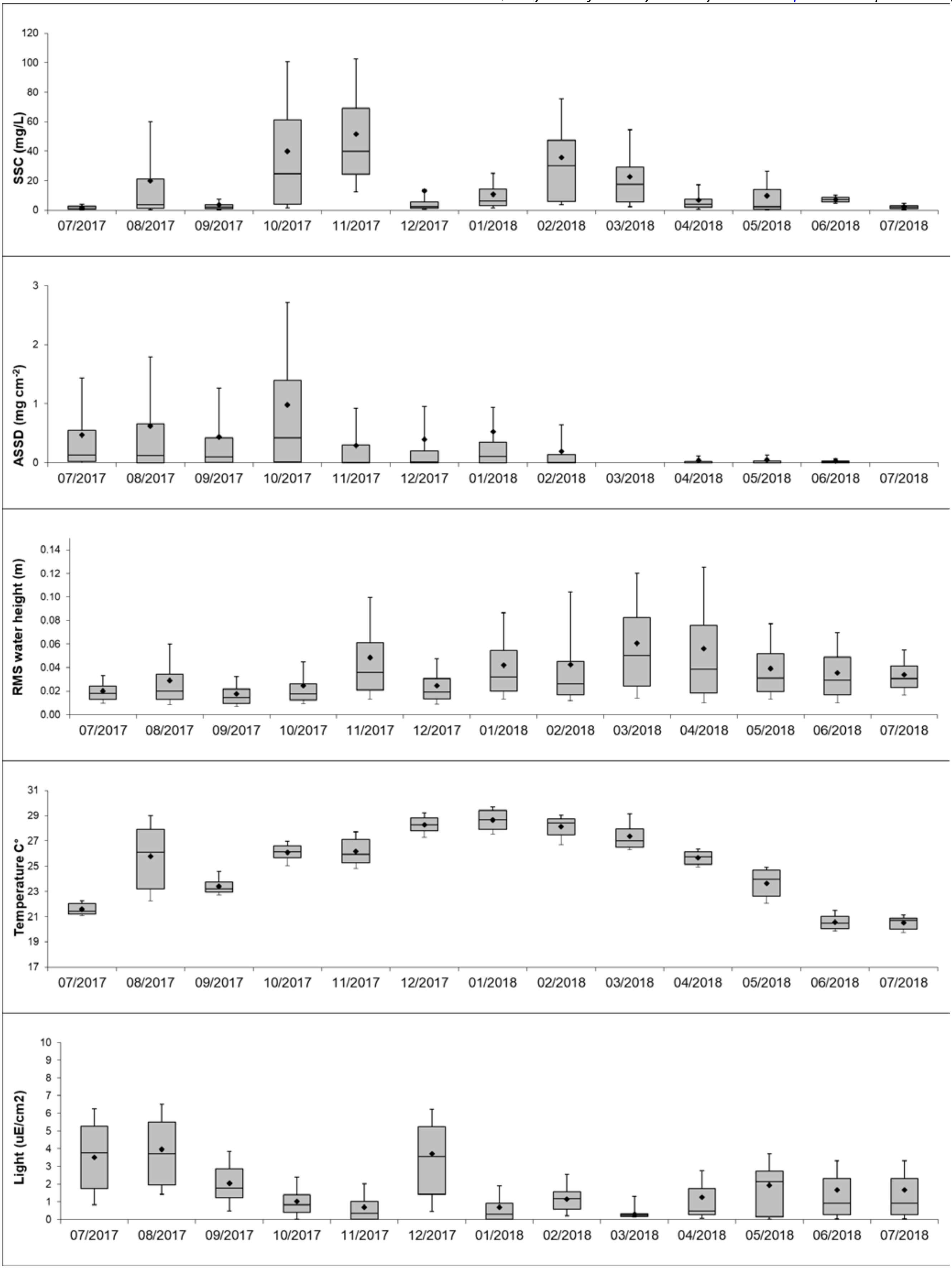
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	1.79	19.69	3.48	40.08	51.68	12.95	10.91	35.85	22.91	6.84	9.72	7.31	2.36
median	1.14	3.75	2.09	24.71	40.09	2.37	6.35	30.21	17.43	3.96	2.45	7.19	2.07
min	0.08	0.00	0.00	0.00	0.42	0.00	0.88	0.88	0.00	0.07	0.00	3.13	0.01
lower	0.63	1.30	0.87	3.80	24.37	1.24	2.87	5.91	5.71	1.89	0.78	5.58	1.11
upper	2.60	21.16	3.75	61.27	68.99	5.41	14.42	47.28	29.39	7.56	13.84	8.72	3.08
max	9.86	428.99	127.69	340.80	291.47	428.99	99.85	272.63	182.68	70.80	149.69	13.45	10.24
90th percentile	4.04	59.99	7.40	100.65	102.63	13.96	25.00	75.73	54.38	17.14	26.26	10.22	4.47
10th percentile	0.37	0.44	0.39	1.69	12.41	0.81	1.80	3.74	2.39	0.68	0.44	4.59	0.48
n	2494	25176	4308	4142	3996	4439	4145	1232	2265	2496	3355	4222	1430
St. Dev	1.65	39.17	5.77	45.75	42.37	54.45	11.85	37.14	24.65	8.50	14.90	2.15	1.74
St. Error	0.03	0.25	0.09	0.71	0.67	0.82	0.18	1.06	0.52	0.17	0.26	0.03	0.05

	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.47	0.62	0.44	0.98	0.29	0.40	0.53	0.19		0.04	0.04	0.03	
median	0.13	0.12	0.10	0.42	0.00	0.02	0.10	0.01		0.00	0.00	0.01	
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	
lower	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00		0.00	0.00	0.00	
upper	0.55	0.65	0.42	1.40	0.30	0.20	0.35	0.14		0.02	0.03	0.03	
max	5.50	32.81	9.15	12.62	5.06	22.85	32.81	5.32	0.00	2.33	1.32	0.37	
90th percentile	1.43	1.79	1.26	2.71	0.92	0.96	0.94	0.64		0.11	0.13	0.07	
10th percentile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	
n	2431	17900	3833	3738	465	4249	2690	2520	0	2415	3280	216	
St. Dev	0.79	1.37	0.88	1.42	0.59	1.33	1.99	0.47		0.13	0.11	0.06	
St. Error	0.02	0.01	0.01	0.02	0.03	0.02	0.04	0.01		0.00	0.00	0.00	

	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.02	0.03	0.02	0.02	0.05	0.02	0.04	0.04	0.06	0.06	0.04	0.04	0.03
median	0.02	0.02	0.01	0.02	0.04	0.02	0.03	0.03	0.05	0.04	0.03	0.03	0.03
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	0.01
lower	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02
upper	0.02	0.03	0.02	0.03	0.06	0.03	0.05	0.05	0.08	0.08	0.05	0.05	0.04
max	0.15	0.39	0.11	0.22	0.39	0.20	0.24	0.41	0.41	0.43	0.21	0.21	0.13
90th percentile	0.03	0.06	0.03	0.04	0.10	0.05	0.09	0.10	0.12	0.12	0.08	0.07	0.05
10th percentile	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02
n	2505	26492	4319	4463	4320	4462	4464	4032	4464	4320	3373	4222	1430
St. Dev	0.01	0.03	0.01	0.02	0.04	0.02	0.03	0.04	0.05	0.05	0.03	0.02	0.02
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 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.59	25.80	23.41	26.10	26.17	28.29	28.65	28.12	27.37	25.68	23.62	20.57	20.53
median	21.44	26.09	23.21	26.11	25.93	28.28	28.65	28.43	27.00	25.74	23.96	20.48	20.71
min	20.53	20.73	22.29	24.02	24.06	26.54	26.91	25.75	25.64	24.48	20.89	18.91	19.22
lower	21.22	23.22	22.94	25.68	25.25	27.80	27.90	27.48	26.51	25.14	22.61	20.04	19.99
upper	22.04	27.92	23.76	26.60	27.09	28.81	29.42	28.74	27.95	26.14	24.68	21.02	20.85
max	24.54	33.74	25.73	27.67	28.17	29.96	33.74	29.36	29.81	32.02	25.34	22.70	21.54
90th percentile	22.28	29.01	24.59	26.96	27.70	29.21	29.70	29.02	29.15	26.37	24.92	21.52	21.14
10th percentile	21.06	22.23	22.71	25.03	24.83	27.29	27.55	26.71	26.28	24.92	22.05	19.87	19.75
n	2505	26494	4320	4464	4320	4462	4464	4032	4464	4320	3373	4222	1430
St. Dev	0.49	2.50	0.69	0.71	1.07	0.71	0.84	0.85	1.09	0.59	1.16	0.61	0.53
St. Error	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01

	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	3.52	3.97	2.06	1.01	0.71	3.73	0.70	1.17	0.30	1.26	1.94	1.67	1.67
median	3.78	3.73	1.78	0.84	0.35	3.58	0.29	1.19	0.27	0.48	2.14	0.93	0.93
min	0.52	0.34	0.26	0.01	0.00	0.22	0.00	0.00	0.14	0.00	0.00	0.00	0.00
lower	1.74	1.97	1.24	0.40	0.02	1.42	0.03	0.58	0.19	0.27	0.15	0.27	0.27
upper	5.28	5.50	2.85	1.41	1.03	5.25	0.93	1.56	0.31	1.75	2.74	2.32	2.32
max	6.27	8.77	5.16	2.79	2.63	8.93	3.57	2.88	0.69	5.40	5.22	8.93	8.93
90^{th} percentile	5.89	6.66	3.94	2.30	2.30	7.09	2.11	2.31	0.58	4.07	4.52	4.74	4.74
10^{th} percentile	0.83	1.44	0.49	0.02	0.00	0.47	0.01	0.22	0.15	0.08	0.02	0.05	0.05
n	18	31	30	28	30	31	31	28	31	30	17	354	354
St. Dev	1.98	2.24	1.32	0.85	0.84	2.59	0.91	0.78	0.16	1.64	1.80	1.92	1.92
St. Error	0.47	0.40	0.24	0.16	0.15	0.47	0.16	0.15	0.03	0.30	0.44	0.10	0.10


SSC (mg/L)
ASSD (mg cm-2)
RMS water height (m)
Temperature C°
Light (uE/cm2)
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

AMB 2: Hay Reef

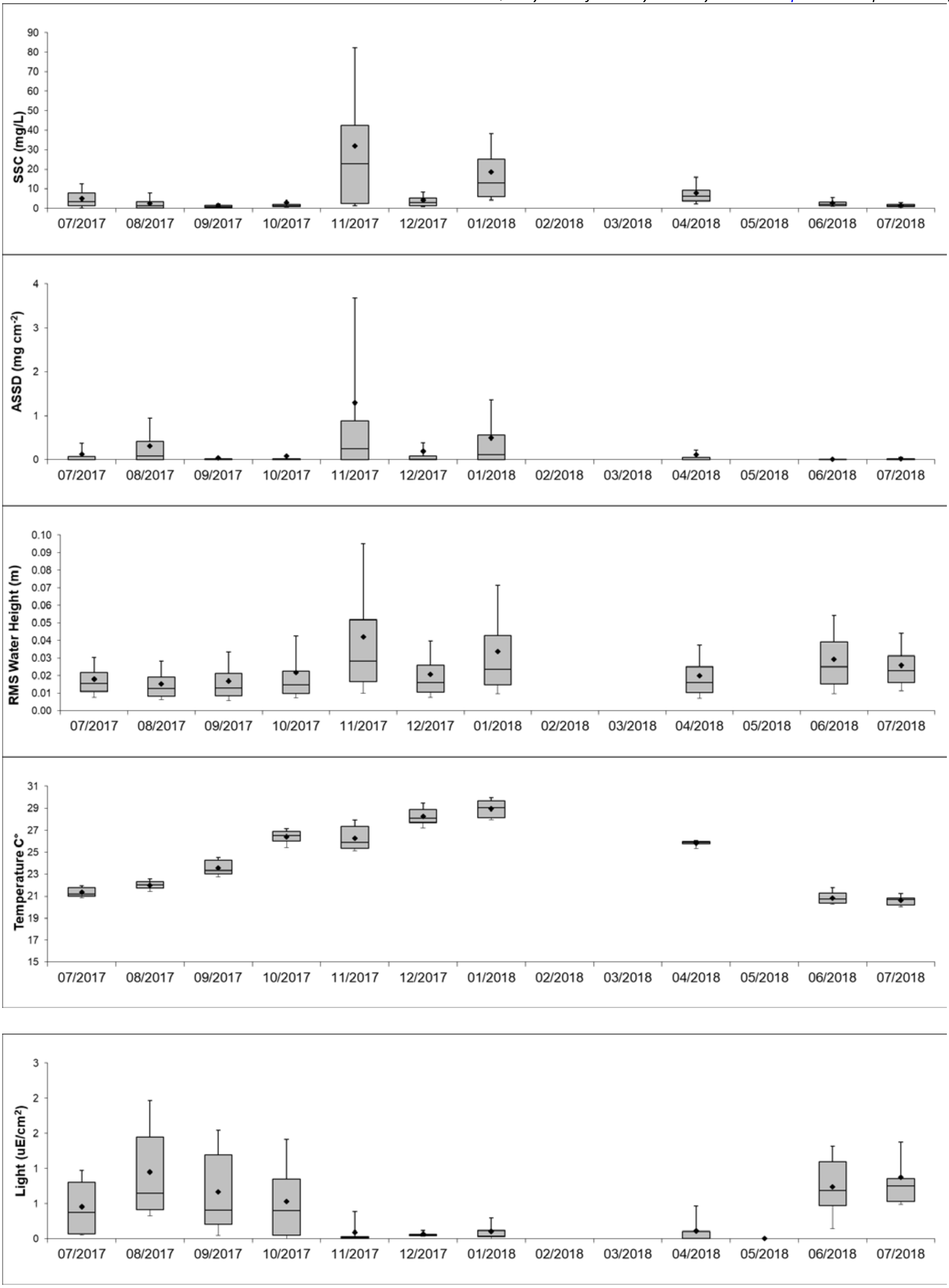
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	5.01	2.52	1.45	3.02	31.96	4.35	18.50			7.93		2.72	1.68
median	3.39	1.34	0.89	1.43	22.67	3.03	13.03			6.09		2.06	1.37
min	0.00	0.00	0.00	0.00	0.02	0.00	2.91			0.00		0.27	0.10
lower	1.28	0.15	0.47	0.91	2.62	1.34	5.91			3.83		1.41	0.89
upper	7.86	3.55	1.45	2.13	42.37	5.18	25.28			9.37		3.15	2.14
max	25.78	16.92	160.08	164.24	326.65	98.74	107.10			43.60		19.80	12.02
90th percentile	12.57	7.82	2.18	3.14	82.30	8.36	38.28			16.02		5.41	3.02
10th percentile	0.19	0.00	0.25	0.56	1.38	0.75	4.23			2.38		1.03	0.57
n	2479	4145	2039	1236	3033	4204	393			1291		4070	1701
St. Dev	4.81	3.16	5.17	14.57	38.10	5.72	16.74			6.67		2.18	1.23
St. Error	0.10	0.05	0.11	0.41	0.69	0.09	0.84			0.19		0.03	0.03

	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.13	0.32	0.04	0.09	1.30	0.19	0.49			0.11		0.01	0.02
median	0.00	0.08	0.01	0.00	0.25	0.01	0.12			0.00		0.00	0.00
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00		0.00	0.00
lower	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00		0.00	0.00
upper	0.07	0.42	0.02	0.03	0.89	0.09	0.56			0.05		0.01	0.02
max	3.84	5.44	3.68	13.18	36.83	17.50	7.75			7.94		0.36	0.34
90th percentile	0.37	0.96	0.06	0.08	3.68	0.39	1.36			0.22		0.02	0.05
10th percentile	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00		0.00	0.00
n	1367	1620	3178	3516	3727	4205	269			2235		3981	1503
St. Dev	0.37	0.52	0.17	0.54	3.14	0.73	1.03			0.44		0.02	0.04
St. Error	0.01	0.01	0.00	0.01	0.05	0.01	0.06			0.01		0.00	0.00

	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.02	0.02	0.02	0.02	0.04	0.02	0.03			0.02		0.03	0.03
median	0.02	0.01	0.01	0.01	0.03	0.02	0.02			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
lower	0.01	0.01	0.01	0.01	0.02	0.01	0.01			0.01		0.02	0.02
upper	0.02	0.02	0.02	0.02	0.05	0.03	0.04			0.03		0.04	0.03
max	0.12	0.13	0.11	0.24	0.32	0.17	0.29			0.13		0.14	0.16
90th percentile	0.03	0.03	0.03	0.04	0.10	0.04	0.07			0.04		0.05	0.04
10th percentile	0.01	0.01	0.01	0.01	0.01	0.01	0.01			0.01		0.01	0.01
n	2491	4464	3632	3717	4320	4463	4433			2328		4081	2016
St. Dev	0.01	0.01	0.01	0.02	0.04	0.01	0.03			0.01		0.02	0.01
St. Error	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00		0.00	0.00

	Temp 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.33	22.02	23.54	26.42	26.28	28.26	28.96			25.83		20.86	20.61
median	21.16	22.03	23.33	26.53	25.88	28.11	29.05			25.90		20.77	20.71
min	20.40	20.92	22.23	24.98	24.71	26.67	27.62			25.16		19.98	19.81
lower	21.00	21.74	23.05	26.01	25.39	27.71	28.13			25.76		20.34	20.18
upper	21.78	22.31	24.28	26.89	27.38	28.87	29.69			25.98		21.26	20.85
max	22.38	23.10	25.44	27.65	28.64	30.29	30.76			26.45		22.52	21.68
90th percentile	21.95	22.56	24.51	27.13	27.93	29.50	29.97			26.07		21.77	21.22
10th percentile	20.84	21.44	22.75	25.44	25.12	27.23	27.97			25.36		20.24	20.04
n	2491	4464	3632	3717	4320	4463	4433			2328		4081	2016
St. Dev	0.44	0.42	0.69	0.60	1.06	0.80	0.82			0.24		0.55	0.43
St. Error	0.01	0.01	0.01	0.01	0.02	0.01	0.01			0.01		0.01	0.01

	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	0.45	0.95	0.66	0.53	0.09	0.07	0.10			0.11	0.00	0.74	0.87
median	0.37	0.65	0.41	0.40	0.01	0.06	0.03			0.00	0.00	0.69	0.75
min	0.04	0.12	0.01	0.00	0.01	0.03	0.00			0.00	0.00	0.05	0.40
lower	0.07	0.41	0.21	0.05	0.01	0.04	0.03			0.00	0.00	0.47	0.53
upper	0.80	1.45	1.19	0.85	0.03	0.06	0.12			0.11	0.00	1.10	0.85
max	1.08	2.20	2.25	1.55	0.47	0.15	0.43			0.54	0.00	1.80	2.20
90^{th} percentile	0.97	1.97	1.54	1.42	0.39	0.12	0.29			0.46	0.00	1.31	1.38
10^{th} percentile	0.06	0.32	0.04	0.00	0.01	0.03	0.00			0.00	0.00	0.14	0.49
n	18	31	30	31	11	5	29			18	17	29	8
St. Dev	0.38	0.65	0.63	0.54	0.17	0.05	0.13			0.19	0.00	0.45	0.57
St. Error	0.09	0.12	0.11	0.10	0.05	0.02	0.02			0.04	0.00	0.08	0.20


SSC (mg/L)
ASSD (mg cm⁻²)
RMS Water Height (m)
Temperature C°
Light (uE/cm²)
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018

AMB 12: Keswick Island

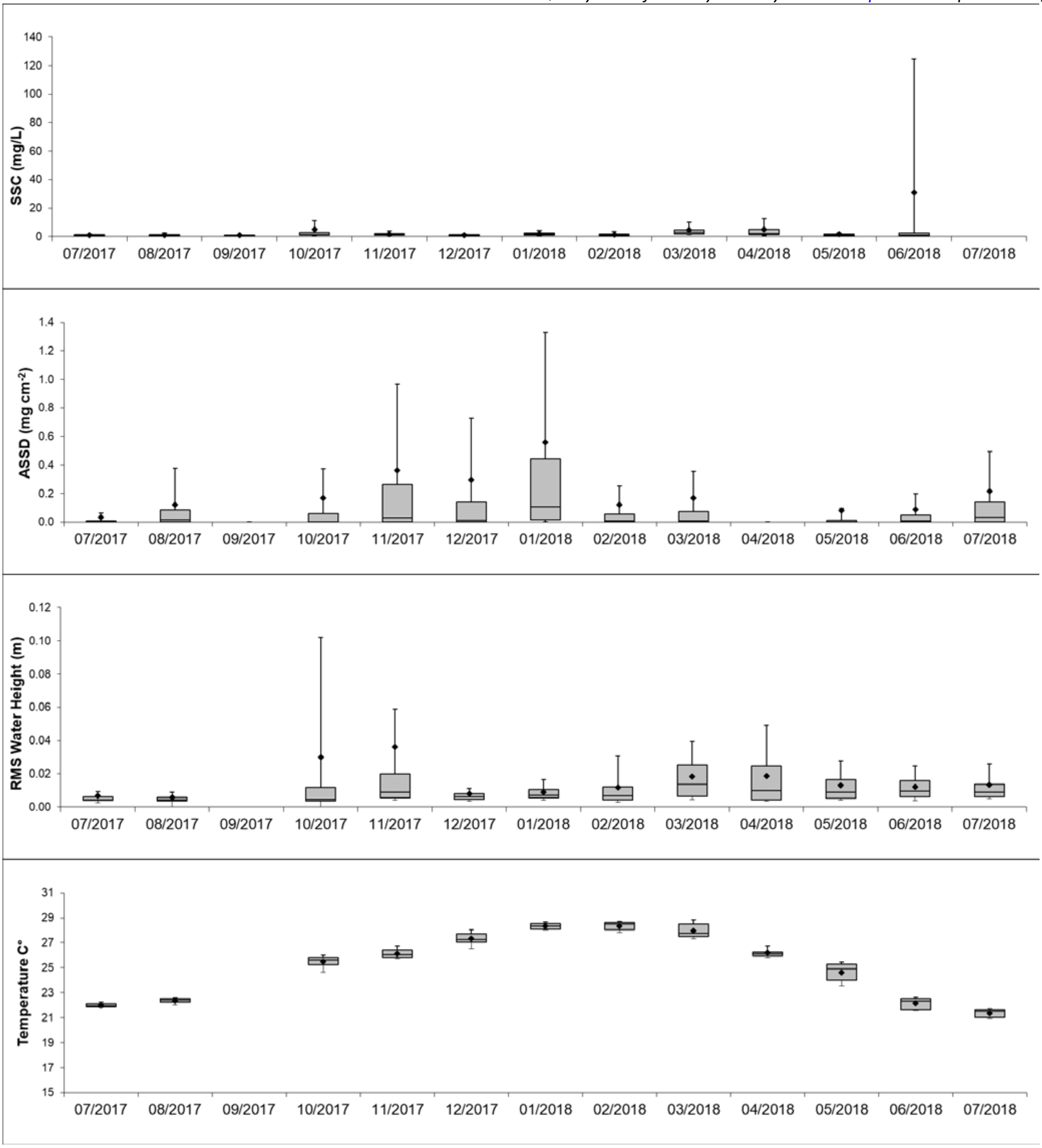
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	1.00	1.04	1.04	4.88	1.86	1.08	2.15	1.49	4.79	4.90	1.72	30.83	
median	0.79	0.67	0.71	1.37	1.43	0.91	1.65	0.94	2.65	2.10	0.98	0.90	
min	0.09	0.00		0.00	0.01	0.00	0.05	0.00	0.57	0.00	0.00	0.00	
lower	0.50	0.38	0.45	0.82	0.90	0.59	0.98	0.61	1.68	1.22	0.64	0.51	
upper	1.23	1.38	1.04	2.97	2.22	1.36	2.59	1.64	4.77	4.98	1.58	2.61	
max	12.11	18.12		128.66	27.62	8.91	19.76	12.09	76.24	72.99	279.84	563.32	
90th percentile	1.85	2.30	1.50	11.22	4.08	1.90	4.47	3.43	10.08	12.84	2.34	124.41	
10th percentile	0.37	0.20	0.28	0.55	0.36	0.40	0.55	0.38	1.23	0.63	0.38	0.34	
n	2377	4144	4319	4137	4000	4448	2340	3960	4149	4309	3360	4209	
St. Dev	0.83	1.17	4.39	11.74	1.67	0.76	1.87	1.54	6.46	7.26	9.74	80.52	
St. Error	0.02	0.02	0.07	0.18	0.03	0.01	0.04	0.02	0.10	0.11	0.17	1.24	

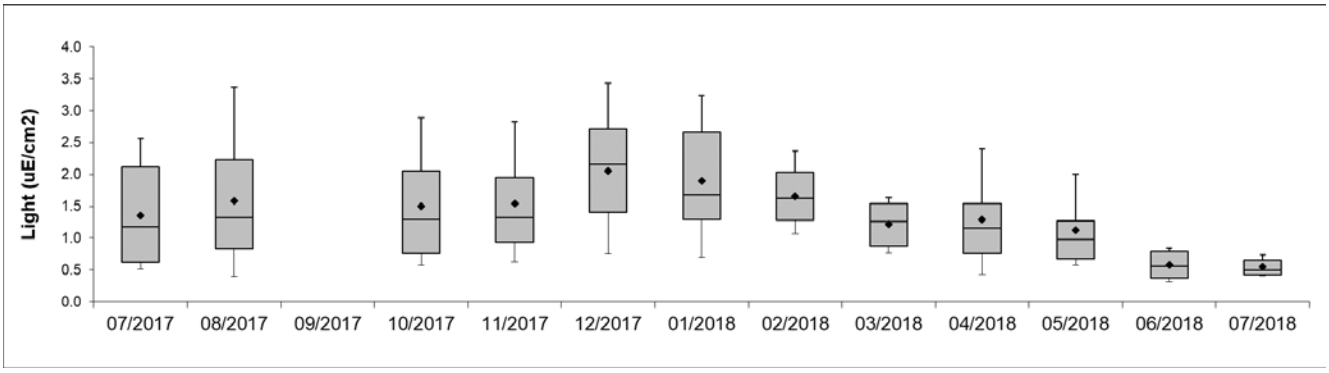
	ASSD 07/2015	ASSD 08/2015	ASSD 09/2015	ASSD 10/2015	ASSD 11/2015	ASSD 12/2015	ASSD 01/2016	ASSD 02/2016	ASSD 03/2016	ASSD 04/2016	ASSD 05/2016	ASSD 06/2016	ASSD 07/2016
Mean	0.03	0.12		0.17	0.36	0.30	0.56	0.12	0.17		0.08	0.09	0.22
median	0.00	0.01		0.00	0.03	0.01	0.11	0.01	0.01		0.00	0.01	0.03
min	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
lower	0.00	0.00		0.00	0.00	0.00	0.02	0.00	0.00		0.00	0.00	0.00
upper	0.01	0.09		0.06	0.26	0.14	0.44	0.05	0.08		0.01	0.05	0.14
max	2.63	4.25		8.41	8.84	12.00	14.00	6.53	7.18		12.94	3.71	15.31
90th percentile	0.06	0.38		0.37	0.97	0.73	1.33	0.25	0.35		0.10	0.20	0.50
10th percentile	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00
n	2345	3367		1511	4135	4335	2624	3866	2893		3373	4132	1981
St. Dev	0.17	0.29		0.61	0.94	0.91	1.38	0.44	0.57		0.49	0.28	0.68
St. Error	0.00	0.00		0.02	0.01	0.01	0.03	0.01	0.01		0.01	0.00	0.02

	RMS 07/2015	RMS 08/2015	RMS 09/2015	RMS 10/2015	RMS 11/2015	RMS 12/2015	RMS 01/2016	RMS 02/2016	RMS 03/2016	RMS 04/2016	RMS 05/2016	RMS 06/2016	RMS 07/2016
Mean	0.01	0.01		0.03	0.04	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01
median	0.00	0.00		0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
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
lower	0.00	0.00		0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.01
upper	0.01	0.01		0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.02	0.02	0.01
max	0.31	0.15		0.95	2.68	0.61	0.05	0.14	0.16	0.17	0.11	0.09	0.19
90th percentile	0.01	0.01		0.10	0.06	0.01	0.02	0.03	0.04	0.05	0.03	0.02	0.03
10th percentile	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
n	2395	4464		4464	4320	4462	4464	4030	4464	4319	3373	4220	2016
St. Dev	0.01	0.01		0.07	0.11	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.01
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

	Temp 07/2015	Temp 08/2015	Temp 09/2015	Temp 10/2015	Temp 11/2015	Temp 12/2015	Temp 01/2016	Temp 02/2016	Temp 03/2016	Temp 04/2016	Temp 05/2016	Temp 06/2016	Temp 07/2016
Mean	22.00	22.37		25.49	26.14	27.31	28.32	28.34	27.94	26.19	24.63	22.15	21.36
median	21.95	22.39		25.62	26.03	27.26	28.33	28.52	27.76	26.12	24.89	22.30	21.54
min	20.62	21.81		24.30	25.53	26.11	27.86	27.51	27.13	25.16	23.05	19.89	20.69
lower	21.88	22.22		25.24	25.84	27.02	28.10	28.06	27.51	25.97	23.99	21.65	21.04
upper	22.12	22.53		25.81	26.42	27.72	28.53	28.63	28.52	26.26	25.28	22.51	21.63
max	22.51	22.94		26.94	26.99	28.44	28.88	29.62	29.04	27.35	25.68	22.79	21.76
90th percentile	22.24	22.63		26.00	26.75	28.03	28.65	28.71	28.85	26.75	25.43	22.65	21.68
10th percentile	21.81	22.02		24.62	25.72	26.50	28.01	27.79	27.30	25.82	23.54	21.57	20.94
n	2395	4464		4464	4320	4462	4464	4030	4464	4319	3373	4220	2016
St. Dev	0.17	0.23		0.49	0.38	0.52	0.24	0.36	0.56	0.38	0.70	0.43	0.31
St. Error	0.00	0.00		0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01

	Light 07/2015	Light 08/2015	Light 09/2015	Light 10/2015	Light 11/2015	Light 12/2015	Light 01/2016	Light 02/2016	Light 03/2016	Light 04/2016	Light 05/2016	Light 06/2016	Light 07/2016
Mean	1.35	1.58		1.50	1.55	2.06	1.90	1.65	1.22	1.29	1.12	0.58	0.55
median	1.18	1.32		1.29	1.32	2.15	1.68	1.63	1.26	1.16	0.98	0.56	0.50
min	0.41	0.19		0.47	0.14	0.37	0.10	0.74	0.65	0.26	0.33	0.22	0.40
lower	0.63	0.83		0.76	0.94	1.40	1.29	1.28	0.88	0.76	0.67	0.38	0.43
upper	2.11	2.23		2.06	1.95	2.71	2.66	2.03	1.54	1.54	1.27	0.79	0.65
max	2.68	3.83		3.71	4.18	3.68	4.22	2.69	1.84	3.38	2.68	1.07	0.85
90th percentile	2.57	3.37		2.89	2.83	3.43	3.24	2.37	1.64	2.40	2.00	0.84	0.74
10th percentile	0.52	0.40		0.58	0.62	0.75	0.70	1.06	0.77	0.44	0.58	0.32	0.41
n	17	31		29	30	31	31	28	31	30	24	30	8
St. Dev	0.82	1.08		0.89	0.94	0.94	1.07	0.53	0.35	0.79	0.61	0.23	0.16
St. Error	0.20	0.19		0.17	0.17	0.17	0.19	0.10	0.06	0.14	0.13	0.04	0.06


SSC (mg/L)
0 20 40 60 80 100 120 140
ASSD (mg cm⁻²)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
RMS Water Height (m)
0.00 0.02 0.04 0.06 0.08 0.10 0.12
Temperature C°
15 17 19 21 23 25 27 29 31
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018


Light (uE/cm2)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018

AMB 3: Round Top Island

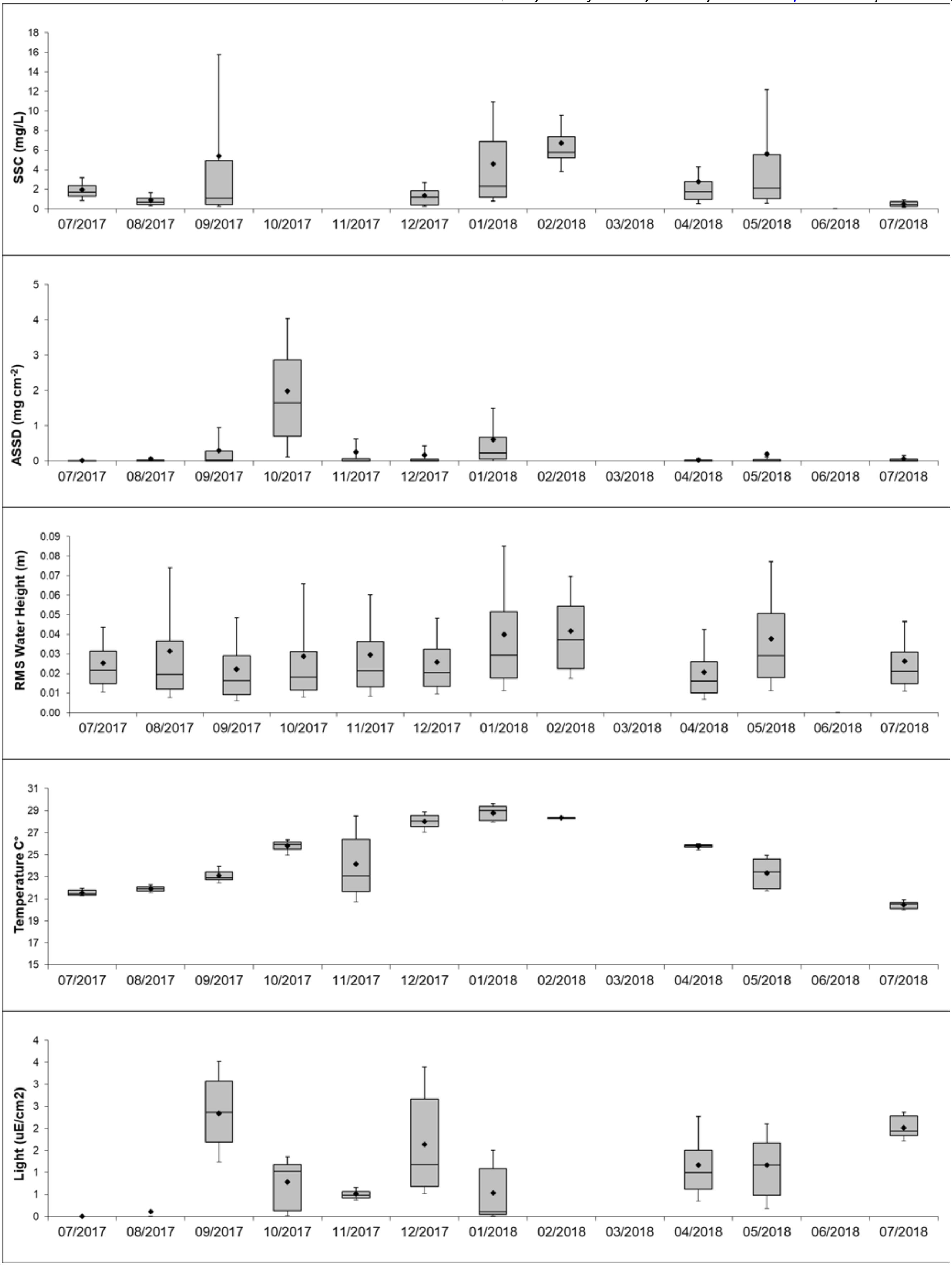
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	1.96	0.89	5.43			1.39	4.60	6.75		2.80	5.61		0.52
median	1.74	0.71	1.07			1.17	2.29	5.74		1.78	2.11		0.48
min	0.42	0.00	0.00			0.00	0.20	1.19		0.00	0.00		0.00
lower	1.30	0.48	0.48			0.42	1.18	5.21		0.96	1.05		0.25
upper	2.36	1.08	4.94			1.88	6.89	7.36		2.79	5.55		0.74
max	10.61	8.40	141.43			20.46	94.50	25.04		233.49	146.36		4.80
90th percentile	3.16	1.65	15.74			2.69	10.92	9.56		4.31	12.18		0.92
10th percentile	0.85	0.32	0.27			0.24	0.81	3.81		0.56	0.60		0.15
n	2369	4149	4073			4205	4152	94		2312	4443		1701
St. Dev	1.10	0.67	11.45			1.32	5.26	3.53		9.55	10.63		0.34
St. Error	0.02	0.01	0.18			0.02	0.08	0.36		0.20	0.16		0.01

	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.02	0.06	0.30	1.99	0.25	0.17	0.60			0.03	0.20		0.07
median	0.00	0.00	0.03	1.65	0.01	0.01	0.23			0.00	0.00		0.02
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00			0.00	0.00		0.00
lower	0.00	0.00	0.00	0.70	0.00	0.00	0.05			0.00	0.00		0.00
upper	0.01	0.02	0.29	2.88	0.07	0.05	0.68			0.02	0.04		0.05
max	1.61	4.50	7.57	14.48	31.86	8.38	9.03			3.35	31.86		1.56
90th percentile	0.03	0.09	0.95	4.04	0.62	0.43	1.50			0.07	0.12		0.17
10th percentile	0.00	0.00	0.00	0.12	0.00	0.00	0.00			0.00	0.00		0.00
n	2327	4275	3674	1541	30787	4114	2609			2252	4254		1930
St. Dev	0.09	0.31	0.63	1.73	0.92	0.53	1.04			0.12	1.53		0.16
St. Error	0.00	0.00	0.01	0.04	0.01	0.01	0.02			0.00	0.02		0.00

	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.03	0.03	0.02	0.03	0.03	0.03	0.04	0.04		0.02	0.04		0.03
median	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04		0.02	0.03		0.02
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		0.00	0.00		0.00
lower	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02		0.01	0.02		0.01
upper	0.03	0.04	0.03	0.03	0.04	0.03	0.05	0.05		0.03	0.05		0.03
max	0.11	0.23	0.13	0.23	0.29	0.21	0.29	0.11		0.10	0.21		0.18
90th percentile	0.04	0.07	0.05	0.07	0.06	0.05	0.09	0.07		0.04	0.08		0.05
10th percentile	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02		0.01	0.01		0.01
n	2379	4464	4317	2974	36061	4230	4464	94		2345	4464		2016
St. Dev	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.02		0.02	0.03		0.02
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 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.52	21.90	23.12	25.80	24.15	28.02	28.81	28.35		25.77	23.36		20.46
median	21.42	21.93	22.92	25.94	23.09	28.06	29.03	28.38		25.81	23.45		20.55
min	21.02	21.35	22.05	24.72	19.61	26.53	27.79	28.24		24.58	21.45		19.80
lower	21.31	21.68	22.74	25.50	21.65	27.60	28.08	28.29		25.68	21.93		20.12
upper	21.78	22.07	23.45	26.15	26.40	28.57	29.41	28.40		25.90	24.59		20.67
max	22.22	22.77	25.20	26.83	30.26	29.50	30.26	28.46		26.19	25.42		21.21
90th percentile	21.94	22.26	23.95	26.38	28.52	28.87	29.65	28.43		25.96	24.94		20.92
10th percentile	21.24	21.55	22.42	24.97	20.72	27.05	27.96	28.27		25.46	21.73		20.00
n	2379	4464	4317	2974	36061	4230	4464	94		2345	4464		2016
St. Dev	0.27	0.27	0.65	0.49	2.96	0.67	0.69	0.06		0.20	1.28		0.34
St. Error	0.01	0.00	0.01	0.01	0.02	0.01	0.01	0.01		0.00	0.02		0.01

	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	0.00	0.11	2.34	0.78	0.51	1.64	0.53			1.17	1.17		2.01
median	0.00	0.00	2.36	1.02	0.48	1.18	0.11			1.00	1.17		1.94
min	0.00	0.00	0.89	0.00	0.35	0.28	0.00			0.16	0.15		1.59
lower	0.00	0.00	1.70	0.14	0.43	0.69	0.05			0.62	0.48		1.84
upper	0.00	0.00	3.08	1.18	0.56	2.67	1.08			1.50	1.67		2.29
max	0.00	1.76	3.71	2.24	0.73	4.20	2.02			2.35	2.90		2.38
90th percentile	0.00	0.00	3.52	1.36	0.66	3.40	1.51			2.28	2.10		2.36
10th percentile	0.00	0.00	1.24	0.02	0.38	0.51	0.01			0.35	0.19		1.72
n	17	31	30	16	4	30	29			17	31		8
St. Dev	0.00	0.43	0.87	0.67	0.16	1.19	0.66			0.74	0.76		0.29
St. Error	0.00	0.08	0.16	0.17	0.08	0.22	0.12			0.18	0.14		0.10


SSC (mg/L)
ASSD (mg cm-2)
RMS Water Height (m)
Temperature C°
Light (uE/cm2)
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018

AMB 5: Slade Island

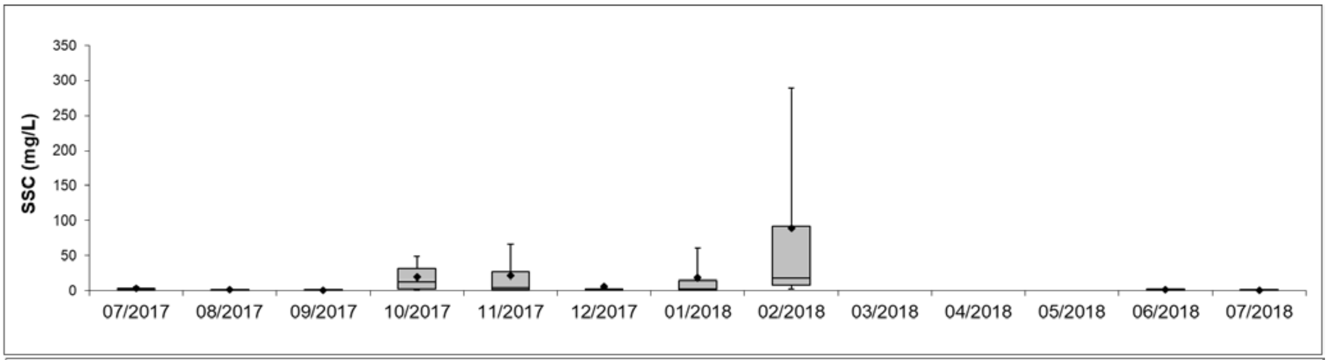
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	2.78	1.23	0.81	19.72	20.89	6.03	18.01	89.39				1.20	0.69
median	2.21	0.65	0.52	12.32	4.07	1.77	2.74	17.29				1.03	0.52
min	0.38	0.08	0.00	0.06	0.00	1.00	1.20	0.00				0.11	0.02
lower	1.42	0.43	0.30	2.38	1.54	1.17	1.71	7.50				0.68	0.19
upper	3.67	1.11	0.80	31.55	26.71	2.48	14.89	92.05				1.40	0.73
max	42.05	91.80	49.83	229.62	246.15	792.07	239.03	1163.42				9.75	73.16
90^{th} percentile	5.20	2.07	1.56	48.58	66.83	4.65	60.48	289.03				2.10	1.02
10^{th} percentile	0.92	0.32	0.19	0.79	0.74	1.10	1.49	2.05				0.46	0.13
n	2366	4099	4303	2925	3998	4216	2940	3635				4118	1696
St. Dev	2.19	3.62	1.39	21.92	33.39	35.23	32.75	161.06				0.84	2.80
St. Error	0.05	0.06	0.02	0.41	0.53	0.54	0.60	2.67				0.01	0.07

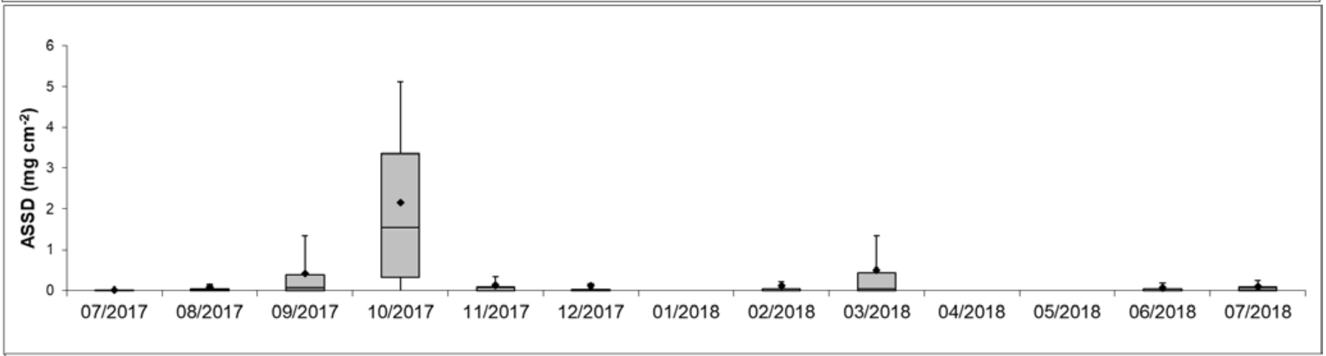
	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.02	0.08	0.43	2.15	0.13	0.12		0.12	0.51			0.07	0.09
median	0.00	0.01	0.06	1.54	0.00	0.00		0.00	0.05			0.00	0.01
min	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
lower	0.00	0.00	0.00	0.32	0.00	0.00		0.00	0.00			0.00	0.00
upper	0.01	0.05	0.39	3.35	0.08	0.03		0.04	0.43			0.05	0.09
max	1.80	4.89	6.22	21.31	4.05	18.22		6.41	16.78			4.64	6.35
90^{th} percentile	0.03	0.14	1.34	5.13	0.33	0.17		0.21	1.34			0.18	0.24
10^{th} percentile	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
n	2327	4105	3715	3061	3785	2364		3873	2797			3719	1996
St. Dev	0.08	0.27	0.87	2.23	0.35	0.87		0.40	1.30			0.20	0.28
St. Error	0.00	0.00	0.01	0.04	0.01	0.02		0.01	0.02			0.00	0.01

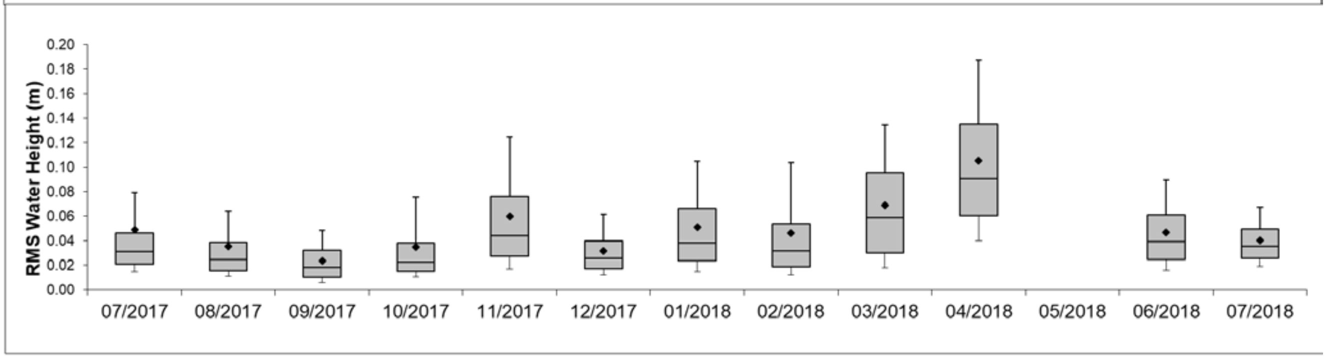
	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.05	0.04	0.02	0.03	0.06	0.03	0.05	0.05	0.07	0.11		0.05	0.04
median	0.03	0.02	0.02	0.02	0.04	0.03	0.04	0.03	0.06	0.09		0.04	0.04
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		0.00	0.01
lower	0.02	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.03	0.06		0.02	0.03
upper	0.05	0.04	0.03	0.04	0.08	0.04	0.07	0.05	0.10	0.13		0.06	0.05
max	1.30	0.93	0.17	0.35	0.39	0.22	0.35	0.40	0.32	0.48		0.23	0.22
90th percentile	0.08	0.06	0.05	0.08	0.12	0.06	0.10	0.10	0.13	0.19		0.09	0.07
10th percentile	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.04		0.02	0.02
n	2379	4464	4319	3243	4320	4230	4464	4029	4464	1922		4130	2016
St. Dev	0.08	0.05	0.02	0.04	0.05	0.02	0.04	0.04	0.05	0.06		0.03	0.02
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

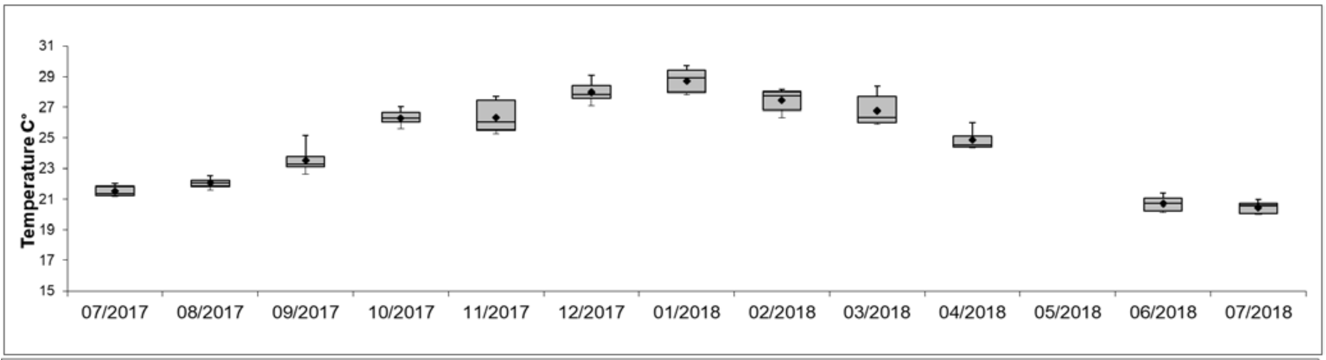
	Temp 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.51	22.05	23.52	26.31	26.31	27.99	28.72	27.45	26.77	24.86		20.71	20.47
median	21.35	22.04	23.25	26.30	26.05	27.84	28.95	27.76	26.35	24.54		20.71	20.59
min	21.03	21.27	19.61	25.38	24.99	26.62	27.64	25.80	25.68	24.22		17.96	19.87
lower	21.25	21.82	23.09	26.02	25.51	27.57	27.96	26.80	26.00	24.40		20.24	20.07
upper	21.85	22.23	23.80	26.66	27.44	28.40	29.39	28.01	27.71	25.14		21.05	20.73
max	22.31	23.07	25.72	27.60	28.05	29.83	29.99	28.48	28.65	26.20		21.71	21.28
90th percentile	22.02	22.51	25.18	27.02	27.71	29.12	29.71	28.17	28.37	26.00		21.42	20.99
10th percentile	21.17	21.61	22.62	25.58	25.28	27.10	27.81	26.30	25.88	24.32		20.15	19.98
n	2379	4464	4319	3243	4320	4230	4464	4029	4464	1922		4130	2016
St. Dev	0.33	0.35	0.81	0.49	0.94	0.71	0.75	0.72	0.94	0.62		0.46	0.39
St. Error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01

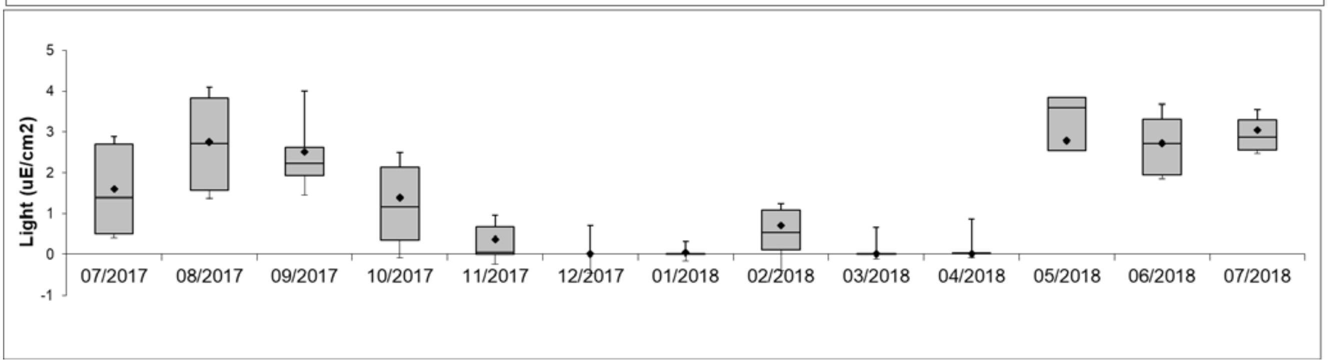
	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	1.60	2.75	2.51	1.39	0.37	0.01	0.05	0.71	0.02	0.01	2.78	2.73	3.05
median	1.39	2.73	2.23	1.17	0.05	0.00	0.00	0.53	0.01	0.01	3.60	2.73	2.87
min	0.23	0.90	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.08	0.42	2.47
lower	0.49	1.58	1.92	0.36	0.00	0.00	0.00	0.11	0.01	0.01	2.54	1.94	2.56
upper	2.71	3.83	2.62	2.13	0.69	0.00	0.00	1.09	0.01	0.01	3.84	3.31	3.29
max	3.32	5.20	5.68	3.92	1.70	0.42	0.54	2.42	0.26	0.01	3.84	4.98	4.26
90^{th} percentile	3.19	4.57	4.02	2.78	1.20	0.00	0.06	1.67	0.02	0.01	3.84	4.60	3.91
10^{th} percentile	0.28	1.15	1.38	0.03	0.00	0.00	0.00	0.01	0.00	0.01	1.07	1.06	2.47
n	17	31	30	23	30	30	31	28	31	7	4	29	8
St. Dev	1.18	1.34	1.12	1.17	0.52	0.08	0.13	0.70	0.05	0.00	1.81	1.26	0.65
St. Error	0.29	0.24	0.20	0.24	0.09	0.01	0.02	0.13	0.01	0.00	0.91	0.23	0.23


SSC (mg/L)
350
300
250
200
150
100
50
0
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018


ASSD (mg cm⁻²)
6
5
4
3
2
1
0
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018


RMS Water Height (m)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018


Temperature C°
31
29
27
25
23
21
19
17
15
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018


Light (uE/cm2)
5
4
3
2
1
0
-1
07/2017
08/2017
09/2017
10/2017
11/2017
12/2017
01/2018
02/2018
03/2018
04/2018
05/2018
06/2018
07/2018

AMB 10: Victor Is.

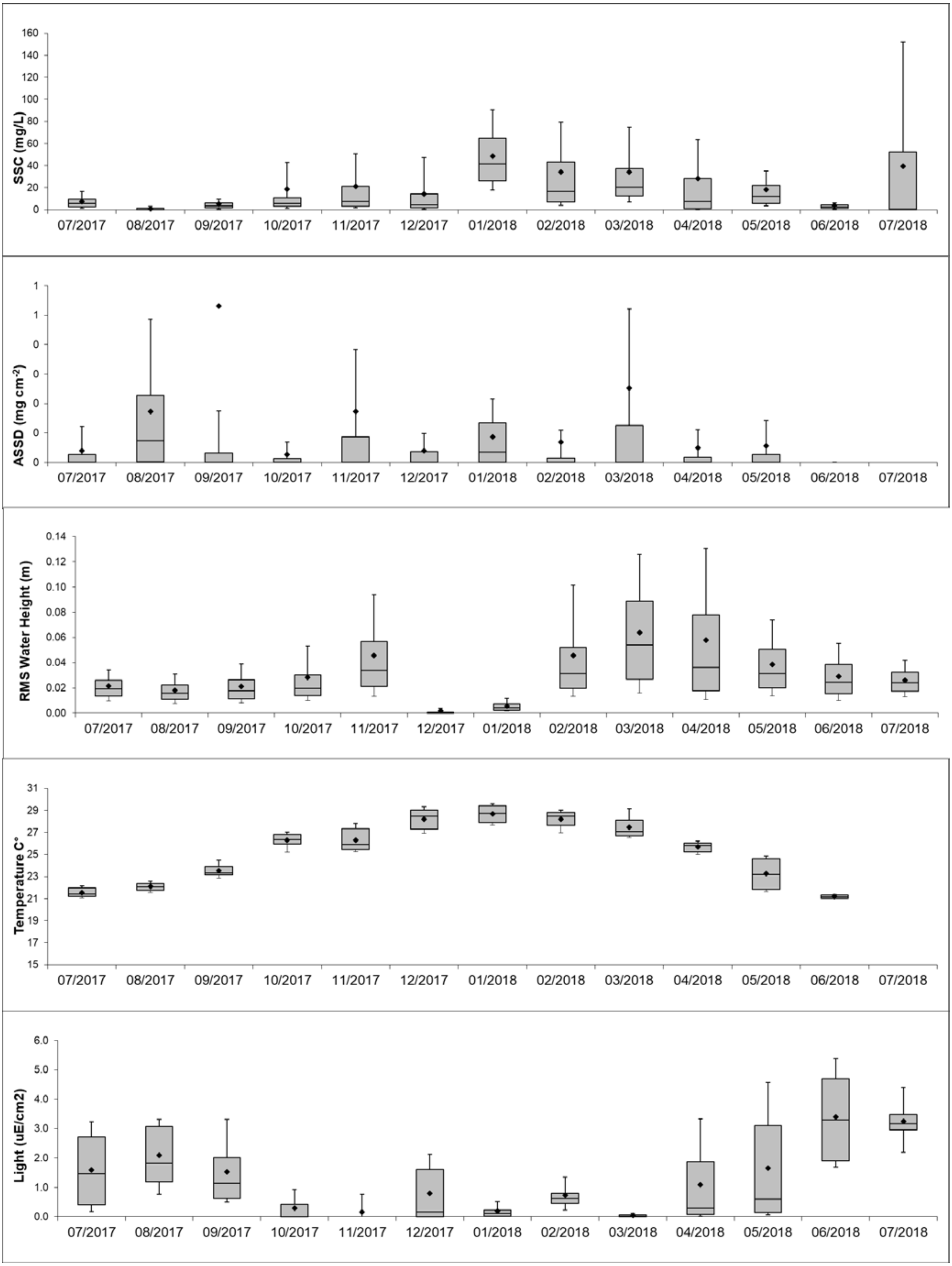
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	7.63	1.11	5.14	18.62	21.18	14.28	48.47	34.17	34.30	28.12	18.21	3.91	39.44
median	5.82	0.07	3.59	5.50	7.63	4.28	41.41	16.50	20.61	7.50	12.34	2.66	0.32
min	0.00	0.00	0.00	0.00	0.69	0.00	2.95	0.00	0.61	0.00	1.18	0.00	0.03
lower	2.72	0.00	1.86	2.97	3.04	1.67	25.86	7.13	12.49	1.05	5.92	1.43	0.06
upper	9.41	1.18	6.01	11.03	21.42	14.30	65.08	43.42	37.26	28.03	22.31	4.27	52.44
max	83.76	48.06	369.98	555.00	387.74	168.53	239.17	392.76	1128.98	1538.95	547.83	57.49	472.52
90th percentile	16.41	3.12	9.61	42.94	50.74	47.17	90.48	79.09	74.78	63.74	35.32	6.23	151.83
10th percentile	1.18	0.00	0.52	1.46	1.70	0.56	17.89	3.79	6.93	0.00	3.74	0.60	0.04
n	1917	3322	4305	4132	3996	2395	963	2970	3466	4295	4147	4241	2016
St. Dev	7.50	2.45	10.75	42.76	39.69	22.52	30.83	47.14	47.40	80.09	27.49	6.43	66.98
St. Error	0.17	0.04	0.16	0.67	0.63	0.46	0.99	0.86	0.81	1.22	0.43	0.10	1.49

	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.04	0.17	0.53	0.03	0.17	0.04	0.09	0.07	0.25	0.05	0.06		
median	0.00	0.07	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00		
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
lower	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
upper	0.03	0.23	0.03	0.01	0.09	0.04	0.13	0.01	0.13	0.02	0.03		
max	1.08	4.69	19.78	1.62	9.74	1.21	0.54	11.65	15.18	5.46	4.98		
90th percentile	0.12	0.49	0.17	0.07	0.38	0.10	0.22	0.11	0.52	0.11	0.14		
10th percentile	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
n	1929	1701	1316	1307	3840	1003	39	3942	2904	2324	4170		
St. Dev	0.10	0.29	2.36	0.09	0.59	0.11	0.13	0.39	1.00	0.22	0.21		
St. Error	0.00	0.01	0.07	0.00	0.01	0.00	0.02	0.01	0.02	0.00	0.00		

	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.02	0.02	0.02	0.03	0.05	0.00	0.01	0.05	0.06	0.06	0.04	0.03	0.03
median	0.02	0.02	0.02	0.02	0.03	0.00	0.00	0.03	0.05	0.04	0.03	0.02	0.02
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
lower	0.01	0.01	0.01	0.01	0.02	0.00	0.00	0.02	0.03	0.02	0.02	0.02	0.02
upper	0.03	0.02	0.03	0.03	0.06	0.00	0.01	0.05	0.09	0.08	0.05	0.04	0.03
max	0.14	0.09	0.13	0.25	0.35	0.06	0.06	0.34	0.38	0.63	0.18	0.12	0.08
90th percentile	0.03	0.03	0.04	0.05	0.09	0.00	0.01	0.10	0.13	0.13	0.07	0.06	0.04
10th percentile	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.01
n	2379	4464	4320	4459	4320	2407	4455	4030	4464	4310	4464	4319	2016
St. Dev	0.01	0.01	0.01	0.03	0.04	0.01	0.00	0.04	0.05	0.06	0.03	0.02	0.01
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 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.54	22.08	23.51	26.28	26.31	28.21	28.67	28.22	27.47	25.68	23.27	21.18	
median	21.40	22.08	23.33	26.34	25.92	28.45	28.72	28.44	27.09	25.80	23.17	21.17	
min	20.88	21.23	22.34	24.72	24.80	26.57	27.27	26.45	26.24	24.70	21.45	20.96	
lower	21.18	21.77	23.13	25.93	25.45	27.30	27.90	27.62	26.67	25.20	21.83	21.03	
upper	21.98	22.36	23.92	26.81	27.33	29.03	29.41	28.79	28.13	26.03	24.63	21.33	
max	22.49	23.15	26.36	27.43	28.23	29.77	31.64	29.54	29.58	29.26	25.37	21.48	
90th percentile	22.15	22.58	24.47	27.05	27.80	29.33	29.59	29.02	29.17	26.21	24.89	21.38	
10th percentile	21.06	21.57	22.85	25.18	25.22	26.91	27.64	26.97	26.52	25.01	21.65	21.00	
n	2379	4464	4320	4459	4320	2407	4455	4030	4464	4310	4464	102	
St. Dev	0.42	0.38	0.61	0.65	0.99	0.92	0.79	0.76	0.99	0.51	1.30	0.15	
St. Error	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	

	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	1.60	2.10	1.52	0.30	0.16	0.79	0.19	0.72	0.04	1.08	1.65	3.40	3.25
median	1.46	1.82	1.14	0.00	0.00	0.16	0.12	0.61	0.01	0.29	0.60	3.30	3.17
min	0.12	0.71	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.18	1.87
lower	0.40	1.18	0.62	0.00	0.00	0.00	0.02	0.45	0.00	0.07	0.15	1.90	2.96
upper	2.71	3.07	2.02	0.42	0.00	1.61	0.23	0.80	0.07	1.87	3.11	4.69	3.48
max	3.40	4.24	4.48	2.21	1.44	3.54	0.99	2.18	0.33	4.56	6.01	5.91	4.86
90th percentile	3.23	3.31	3.32	0.93	0.76	2.13	0.51	1.35	0.12	3.32	4.57	5.38	4.39
10th percentile	0.18	0.77	0.50	0.00	0.00	0.00	0.00	0.23	0.00	0.01	0.07	1.69	2.20
n	17	31	30	31	30	31	31	28	31	30	31	30	8
St. Dev	1.25	1.09	1.20	0.54	0.38	1.03	0.22	0.51	0.07	1.39	1.95	1.49	0.94
St. Error	0.30	0.20	0.22	0.10	0.07	0.19	0.04	0.10	0.01	0.25	0.35	0.27	0.33


SSC (mg/L)
0 20 40 60 80 100 120 140 160
ASSD (mg cm-2)
0 0 0 0 0 1 1
RMS Water Height (m)
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14
Temperature C°
15 17 19 21 23 25 27 29 31
Light (uE/cm2)
0.0 1.0 2.0 3.0 4.0 5.0 6.0
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018

AMB8: Spoil Ground

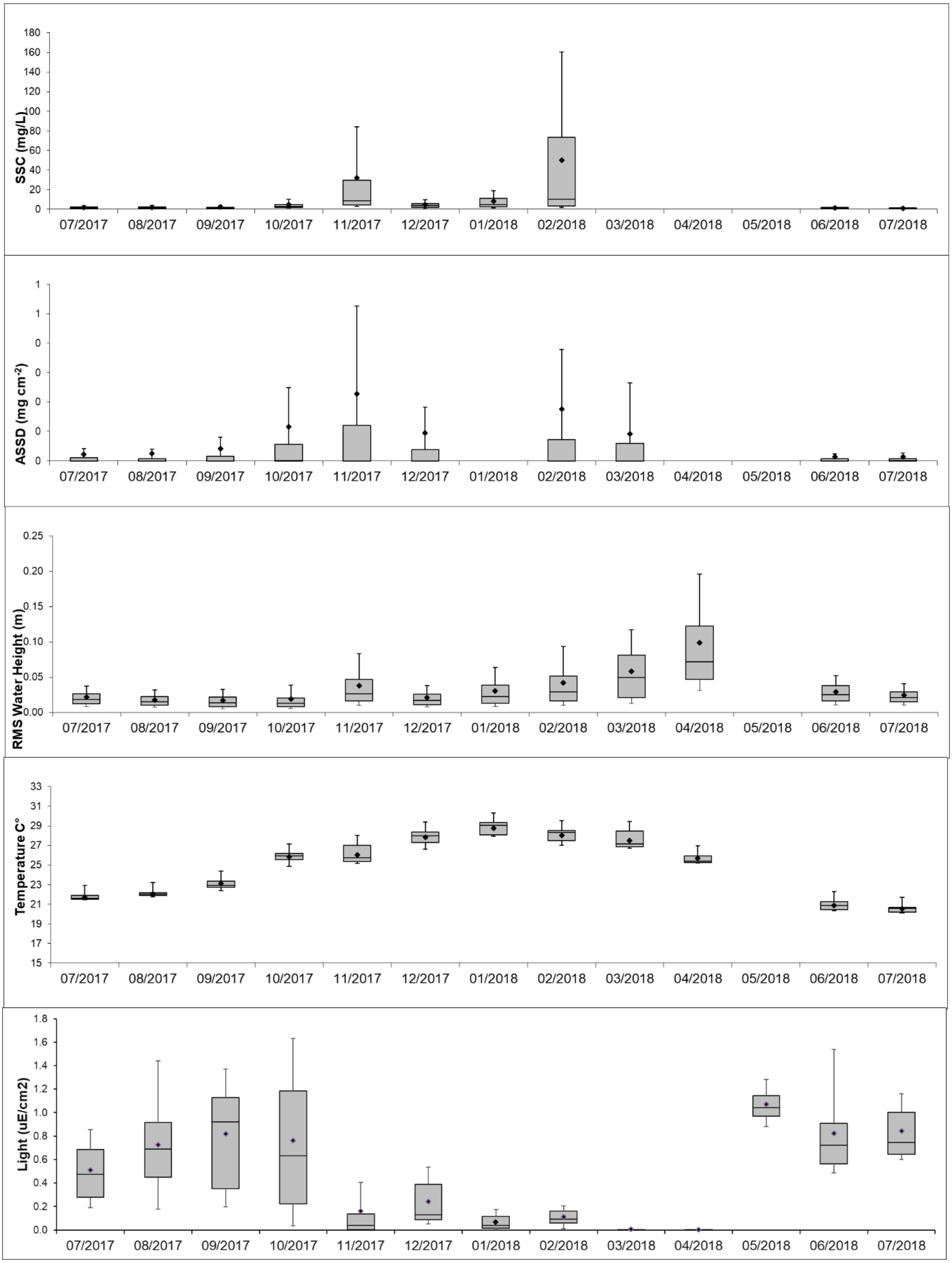
	SSC 07/2017	SSC 08/2017	SSC 09/2017	SSC 10/2017	SSC 11/2017	SSC 12/2017	SSC 01/2018	SSC 02/2018	SSC 03/2018	SSC 04/2018	SSC 05/2018	SSC 06/2018	SSC 07/2018
Mean	2.05	1.95	2.53	4.96	31.84	4.72	8.39	50.15				1.40	1.01
median	1.79	1.26	1.17	2.90	8.88	3.73	4.66	10.37				1.32	0.87
min	0.43	0.00	0.00	0.35	1.53	0.00	0.33	0.00				0.45	0.10
lower	1.17	0.67	0.76	1.85	4.20	1.68	2.45	3.34				1.05	0.49
upper	2.54	2.36	1.89	5.04	29.63	5.91	11.20	73.23				1.65	1.33
max	22.36	48.39	103.01	106.26	682.15	63.82	110.21	598.60				6.49	26.68
90th percentile	3.44	3.94	4.06	9.97	84.09	9.79	19.16	160.38				2.00	1.73
10th percentile	0.85	0.08	0.51	1.24	2.96	0.69	1.65	1.73				0.86	0.38
n	2368	4102	4123	2660	3539	4447	4150	2490				4061	2007
St. Dev	1.39	2.78	6.93	7.16	61.66	4.47	9.73	77.70				0.51	1.08
St. Error	0.03	0.04	0.11	0.14	1.04	0.07	0.15	1.56				0.01	0.02

	ASSD 07/2017	ASSD 08/2017	ASSD 09/2017	ASSD 10/2017	ASSD 11/2017	ASSD 12/2017	ASSD 01/2018	ASSD 02/2018	ASSD 03/2018	ASSD 04/2018	ASSD 05/2018	ASSD 06/2018	ASSD 07/2018
Mean	0.02	0.02	0.04	0.12	0.23	0.10		0.18	0.09			0.01	0.01
median	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
min	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
lower	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
upper	0.01	0.01	0.02	0.06	0.12	0.04		0.07	0.06			0.01	0.01
max	1.02	2.25	4.84	6.44	14.26	6.29		8.98	3.05			1.14	1.15
90th percentile	0.04	0.04	0.08	0.25	0.53	0.18		0.38	0.27			0.02	0.03
10th percentile	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00			0.00	0.00
n	2306	4268	2185	1372	3801	4120		3810	754			4014	1995
St. Dev	0.08	0.11	0.19	0.44	0.80	0.36		0.63	0.26			0.06	0.06
St. Error	0.00	0.00	0.00	0.01	0.01	0.01		0.01	0.01			0.00	0.00

	RMS 07/2017	RMS 08/2017	RMS 09/2017	RMS 10/2017	RMS 11/2017	RMS 12/2017	RMS 01/2018	RMS 02/2018	RMS 03/2018	RMS 04/2018	RMS 05/2018	RMS 06/2018	RMS 07/2018
Mean	0.02	0.02	0.02	0.02	0.04	0.02	0.03	0.04	0.06	0.10		0.03	0.02
median	0.02	0.01	0.01	0.01	0.03	0.02	0.02	0.03	0.05	0.07		0.03	0.02
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		0.00	0.00
lower	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.05		0.02	0.02
upper	0.03	0.02	0.02	0.02	0.05	0.03	0.04	0.05	0.08	0.12		0.04	0.03
max	0.11	0.10	0.12	0.35	0.25	2.33	0.20	0.43	0.39	0.64		0.17	0.17
90th percentile	0.04	0.03	0.03	0.04	0.08	0.04	0.06	0.09	0.12	0.20		0.05	0.04
10th percentile	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.03		0.01	0.01
n	2379	4464	4315	4463	4320	4462	4464	4029	4464	1965		4072	2016
St. Dev	0.01	0.01	0.01	0.02	0.04	0.04	0.03	0.04	0.05	0.08		0.02	0.01
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

	Temp 07/2017	Temp 08/2017	Temp 09/2017	Temp 10/2017	Temp 11/2017	Temp 12/2017	Temp 01/2018	Temp 02/2018	Temp 03/2018	Temp 04/2018	Temp 05/2018	Temp 06/2018	Temp 07/2018
Mean	21.70	22.04	23.09	25.85	26.06	27.82	28.76	28.01	27.51	25.68		20.90	20.52
median	21.61	22.06	22.94	25.92	25.74	27.99	29.07	28.30	27.15	25.41		20.89	20.61
min	21.33	21.52	22.17	24.62	25.00	26.14	27.78	26.74	26.67	25.09		20.14	20.02
lower	21.52	21.88	22.74	25.55	25.36	27.28	28.09	27.51	26.84	25.28		20.43	20.21
upper	21.91	22.20	23.36	26.16	27.01	28.38	29.34	28.52	28.46	25.95		21.28	20.70
max	22.20	22.61	24.79	27.06	27.61	29.23	29.86	29.25	29.16	26.91		21.79	21.09
90th percentile	22.04	22.30	23.78	26.64	27.29	28.72	29.51	28.62	28.95	26.74		21.57	20.93
10th percentile	21.46	21.74	22.40	24.86	25.18	26.64	27.94	27.03	26.74	25.20		20.32	20.12
n	2379	4464	4315	4463	4320	4462	4464	4029	4464	1965		4072	2016
St. Dev	0.23	0.22	0.62	0.57	0.83	0.75	0.65	0.60	0.85	0.55		0.46	0.29
St. Error	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.01

	Light 07/2017	Light 08/2017	Light 09/2017	Light 10/2017	Light 11/2017	Light 12/2017	Light 01/2018	Light 02/2018	Light 03/2018	Light 04/2018	Light 05/2018	Light 06/2018	Light 07/2018
Mean	0.51	0.73	0.82	0.76	0.16	0.24	0.06	0.11	0.00	0.00	1.07	0.82	0.84
median	0.47	0.69	0.92	0.63	0.04	0.13	0.04	0.09	0.00	0.00	1.04	0.72	0.75
min	0.16	0.09	0.13	0.01	0.00	0.03	0.00	0.00	0.00	0.00	0.82	0.18	0.55
lower	0.28	0.45	0.35	0.22	0.00	0.09	0.01	0.06	0.00	0.00	0.97	0.56	0.64
upper	0.68	0.92	1.13	1.18	0.14	0.39	0.12	0.16	0.00	0.00	1.14	0.91	1.00
max	1.08	1.67	1.79	2.31	1.14	0.89	0.19	0.34	0.06	0.00	1.38	1.73	1.40
90^{th} percentile	0.86	1.44	1.37	1.63	0.40	0.53	0.17	0.20	0.01	0.00	1.28	1.54	1.16
10^{th} percentile	0.19	0.18	0.20	0.04	0.00	0.05	0.01	0.01	0.00	0.00	0.88	0.49	0.60
n	17	31	29	27	30	31	31	28	31	7	4	29	8
St. Dev	0.28	0.44	0.49	0.63	0.30	0.24	0.07	0.08	0.01	0.00	0.23	0.40	0.29
St. Error	0.07	0.08	0.09	0.12	0.06	0.04	0.01	0.02	0.00	0.00	0.12	0.07	0.10


SSC (mg/L)
180
160
140
120
100
80
60
40
20
0
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018
ASSD (mg cm⁻²)
1
1
0
0
0
0
0
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018
RMS Water Height (m)
0.25
0.20
0.15
0.10
0.05
0.00
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018
Temperature C°
33
31
29
27
25
23
21
19
17
15
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018
Light (uE/cm2)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
07/2017 08/2017 09/2017 10/2017 11/2017 12/2017 01/2018 02/2018 03/2018 04/2018 05/2018 06/2018 07/2018

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