Port of Abbot Point Ambient Marine Water Quality Monitoring Program: Annual report 2019-2020

Nathan Waltham, Jordan Iles, James Whinney, Blake Ramsby, and Rachael Macdonald

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A Report for North Queensland Bulk Ports Corporation

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EXECUTIVE SUMMARY

Background

1. In November 2017, North Queensland Bulk Ports implemented an ambient marine water quality monitoring program surrounding the Port of Abbot Point. The objective of the program is to collect a long term water quality dataset to characterise marine water quality conditions within the Abbot Point region, and to support future planned Port activities. This document reports on data collected from July 2019 to July 2020
2. This program has incorporated a combination approaches to collect ambient water quality data from the coastal ocean. The approaches adopted include spot field measurements and water sample collection, acquisition of data via deployment of high frequency continuous loggers, and laboratory analysis of samples for a range of nutrients, herbicides and heavy metals.
3. The Port of Abbot Point has five established sites for ambient water quality monitoring whose locations align with key sensitive receptor habitats (e.g. corals or seagrass), along with key features in the study region (e.g. river flow points).

Climatic conditions

1. The total wet season rainfall of Bowen region during 2019-2020 was average compared to wet season totals since 1961.
2. Inter-annual variability of wet season rainfall and catchment discharge to the coastal ocean highlights the necessity for a long-term commitment to ambient marine monitoring programs, as continued monitoring will allow changes in ambient environmental conditions due to differences in annual rainfall to be better understood.

Water chemistry

1. Water quality conditions were measured at all sites on a ~6 weekly basis. Parameters collected were water temperature, electrical conductivity, pH, dissolved oxygen and photosynthetically active radiation at three depths (surface, mid-water and bottom), along with Secchi disk depth.
2. Seasonal differences in water quality were minor, except for temperature which was highest during the summer months.
3. There was little difference in water temperature between the three depths examined, indicating that the water column was well mixed during each survey.
4. Particulate nitrogen concentrations exceeded the guidelines throughout most of the 2019-2020 monitoring period.
5. Chlorophyll-*a* concentrations exceeded the GBRMPA guideline trigger value in November 2019 and May 2020
6. Lead, Nickel, and Arsenic were detected in water samples, although the concentrations were below relevant guideline values. No other metals were detected throughout the reporting period.
7. Pesticides targeted for analysis were not detected above the Great Barrier Reef Marine Park guideline trigger values for 95% protection level. Hexazinone and Atrazine were present at low concentrations for all inshore sites in May 2020.

Sediment deposition and turbidity

1. RMS water height values were mostly driven by weather events and this is clearly evident in the data as peaks in RMS water heights were 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.
2. The NTUe/SSC time series data at each site followed a typical pattern of low background values with recurring peak events. These peak events occurred at the same times at each site and

coincided with peaks in RMS water height. This is a typical pattern which is similar to data collected in coastal locations in north Queensland.

3. Time series deposition data shows 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.
4. Current meter data indicates the prominent current direction and velocity at each site and shows that coastal current, tidal current or a combination of both influence current direction and magnitude.

Light attenuation (Photosynthetically active radiation; PAR)

1. 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 experienced in the region. The data series here continues to increase, which is slowly providing a greater insight into trends, and whether these be tidally influenced or dependent on seasonality and cloud cover. Benthic PAR is also important to assess and validate NTUe sensor data.

Recommendations

1. This monitoring program has been underway for three years, and should remain in place to continue to characterise and build a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities, but will also assist with future strategic planning and management.

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1 INTRODUCTION

1.1 Port operations

The Port of Abbot Point is situated in naturally deep waters off the central Queensland Coast (Figure 1.1). The Port of Abbot Point is located approximately 25 kilometers north of Bowen, and North Queensland Bulk Ports Corporation (NQBP) is the Port Authority. The Port has one operating terminal and provides important services for the surrounding region.

1.2 Program outline

NQBP committed to an ambient marine water quality monitoring program in and around the coastal waters of the Port of Abbot Point. The program aims to characterise the natural variability in water quality by monitoring key parameters. The monitoring program is designed to better define the potential impacts associated with port operations within port areas and adjacent sensitive habitats (Figure 1.1; Table 1.1). Routine maintenance dredging is periodically required at the Port of Abbot Point to maintain vessel navigational depths. As part of this program, water quality parameters are being investigated at a range of sites. This monitoring program contains a range of ambient water quality components that collectively continue to characterise the natural variability in key water quality parameters.

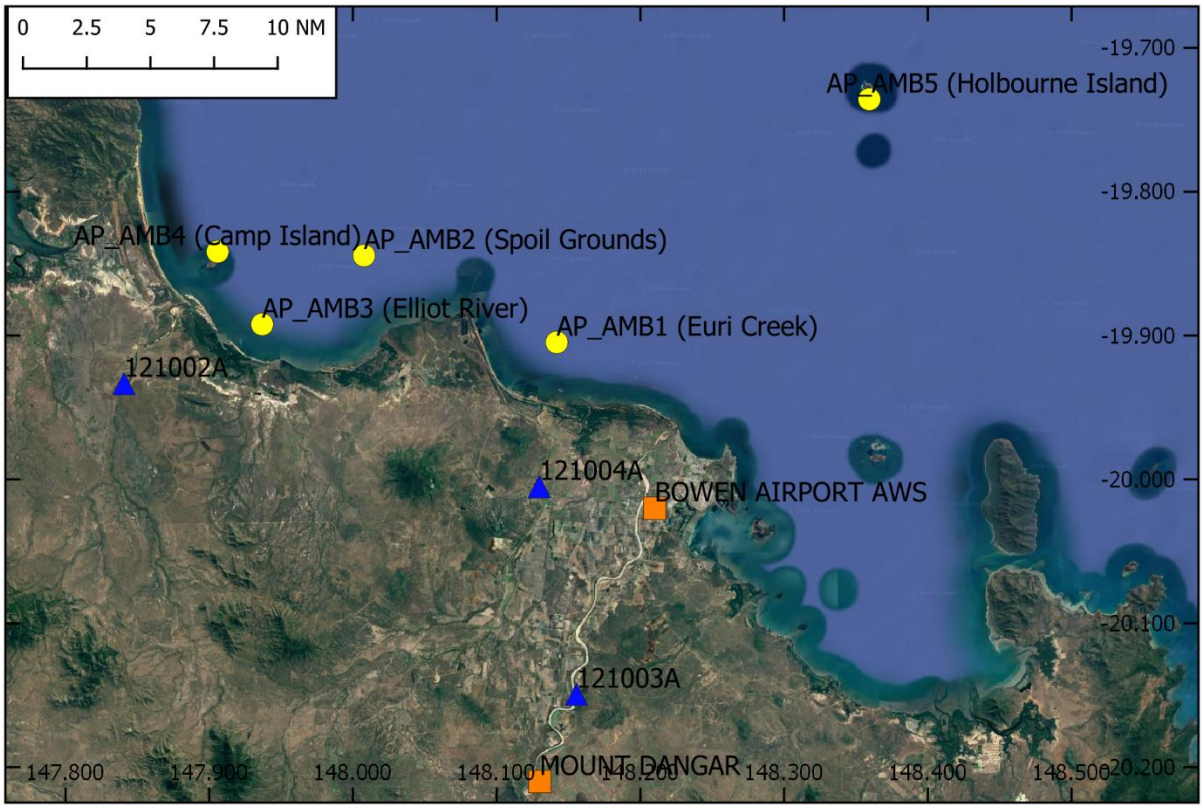

Figure 1.1 Location of water quality monitoring sites (yellow circle) utilised in the 2019-2020 reporting period. Also shown are meteorological stations (orange square), and stream gauging stations (blue triangle) referred to in this report.

Table 1.1 Descriptions for the locations of the ambient marine water quality monitoring program sites

Site name	Site code	Latitude	Longitude	Water quality	Logger
Euri Creek	AP_AMB1	-19.9047	148.1418	Yes	Yes
Spoil Grounds	AP_AMB2	-19.8444	148.0077	Yes	Yes
Elliot River	AP_AMB3	-19.8922	147.9368	Yes	Yes
Camp Island	AP_AMB4	-19.8417	147.9058	Yes	Yes
Holbourne Island	AP_AMB5	-19.7358	148.3593	Yes	Yes

1.3 Rainfall and river flows

Daily rainfall for the Bowen region is shown on

Figure **1.2**. The first rainfall greater than 5 mm for the year occurred on 30/12/2019, with the rainfall onset occurring on 16/01/2020. The rainfall onset is calculated as the date when the rainfall total reaches 50mm since 1st September. The majority of rainfall occurred from 16/01/2020 though to 12/03/2020, although there was an unseasonal rainfall event from 18/05/2020 to 24/05/2020. The 2019-2020 wet season rainfall total was 587.4 mm, which was comparable to the median wet season rainfall total calculated for wet seasons since 1961-1962 (Figure 1.3).

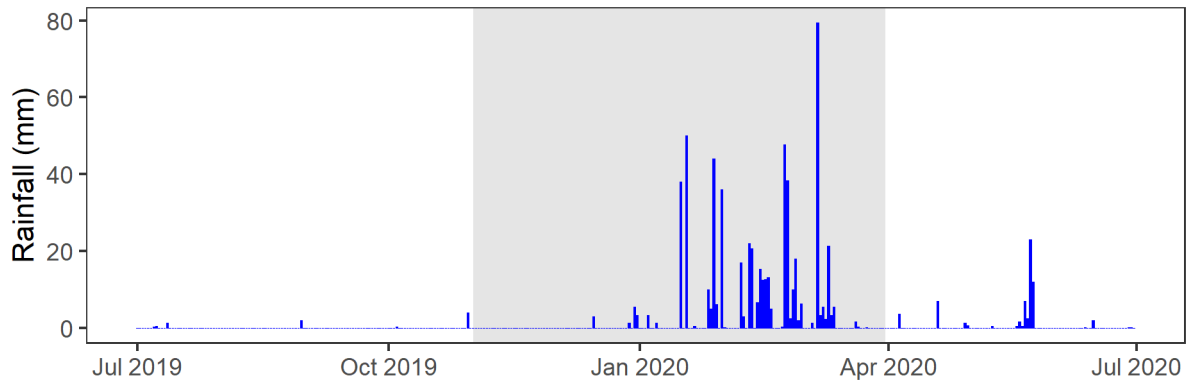

Figure 1.2 Rainfall recorded at Mount Danger (station 033096) for the 2019-2020 reporting period. The nominal wet season period is shaded grey. Data source: http://www.bom.gov.au/climate/data/

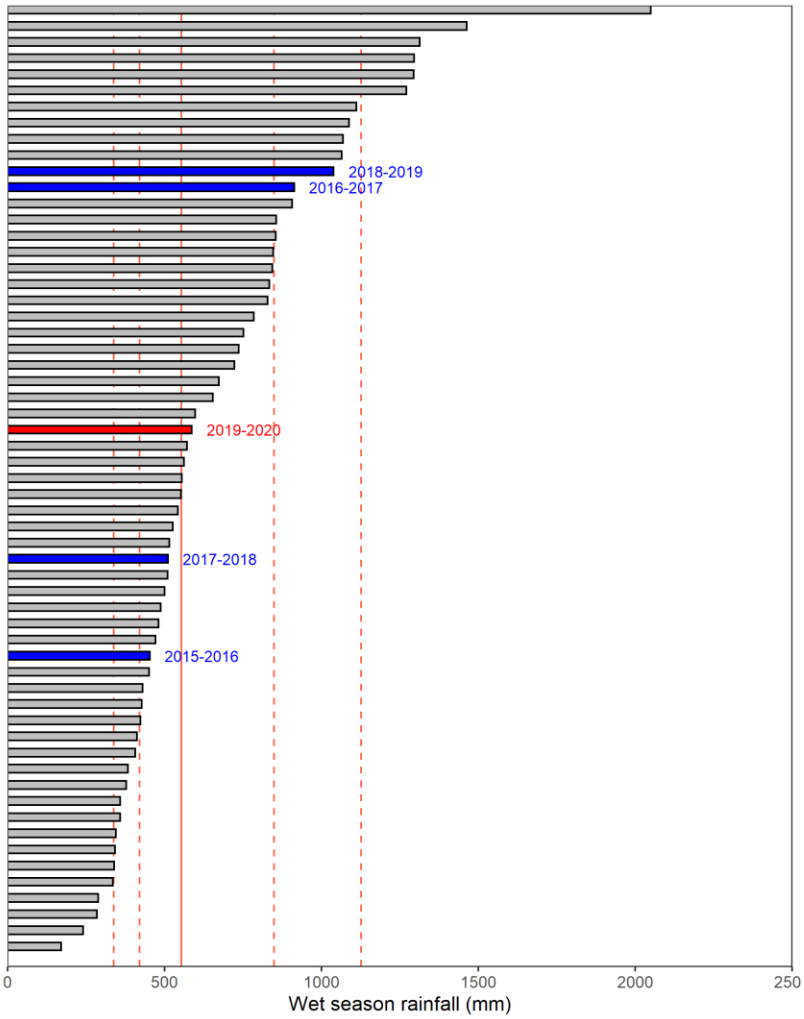

Figure 1.3 Wet season rainfall for the Bowen region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Mount Danger weather station (station 033096). Totals were calculated for the wet season period 1st November to 31st March for each reporting year. Red bar represents the 2019-2020 reporting period, blue bars show total rainfall over the previous four years. Solid red line represents median wet season rainfall 1961-1962 to 2019-2020, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Data source: http://www.bom.gov.au/climate/data/

Hydrographs for streams from the Don River catchment show onset of stream discharge on 26/01/2020 with a series of pulses through to 10/03/2020 (

Figure **1.4**). Total discharge for the 2019-2020 reporting period was 61.1 GL (Don River), 43.8 GL (Elliot River), and 88.2 GL (Euri Creek).

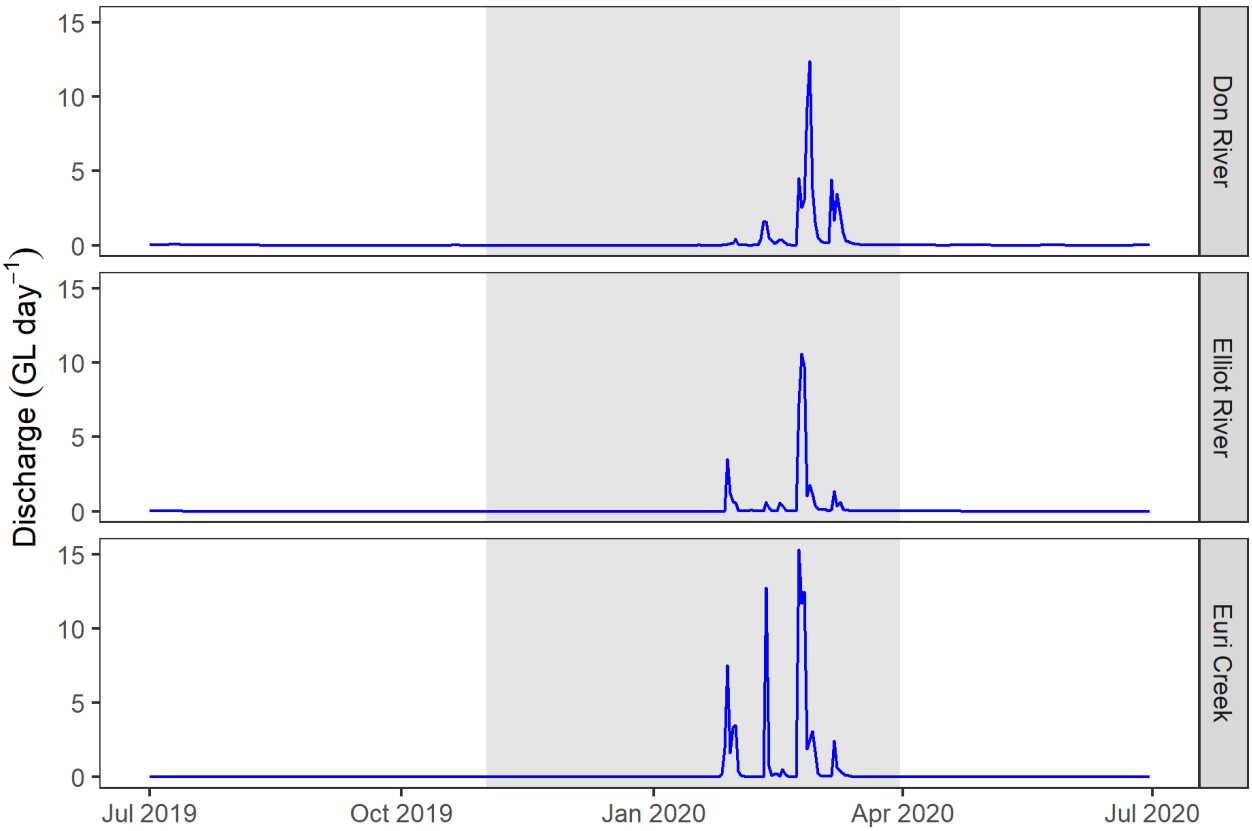

Figure 1.4 Stream discharge (GL d^{-1}) from the Don River (station 121003A), Elliot River (station 121002A), and Euri Creek (station 121004A) during the 2019-2020 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/.

1.4 Project objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region and adjacent to the Port of Abbot Point. This report provides a review and analysis of data collected between 01/07/2019 and 30/06/2020. 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 6 week basis (Table 1.1) from a research vessel. At each site, a calibrated multiprobe is used to measure water temperature, salinity, dissolved oxygen (%sat), 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.

In considering key priority outcomes outlined in recently published Coastal Strategic Assessment and Marine Strategic Assessments for the Great Barrier Reef World Heritage area (GBRMPA, 2013), the water quality program design below was completed. The list of parameters examined consisted of:

- 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

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods. 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 2.1. 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).

Table 2.1 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 (Figure 2.2). The nets were towed at a speed of approximately 6 kts, with the position recorded by GPS at the start and end of each plankton tow. At the end of each plankton tow, the nets were retrieved, and the contents retained in the plastic jar attached to the net was immediately transferred to preservation containers. Samples were identified to the lowest possible taxon.

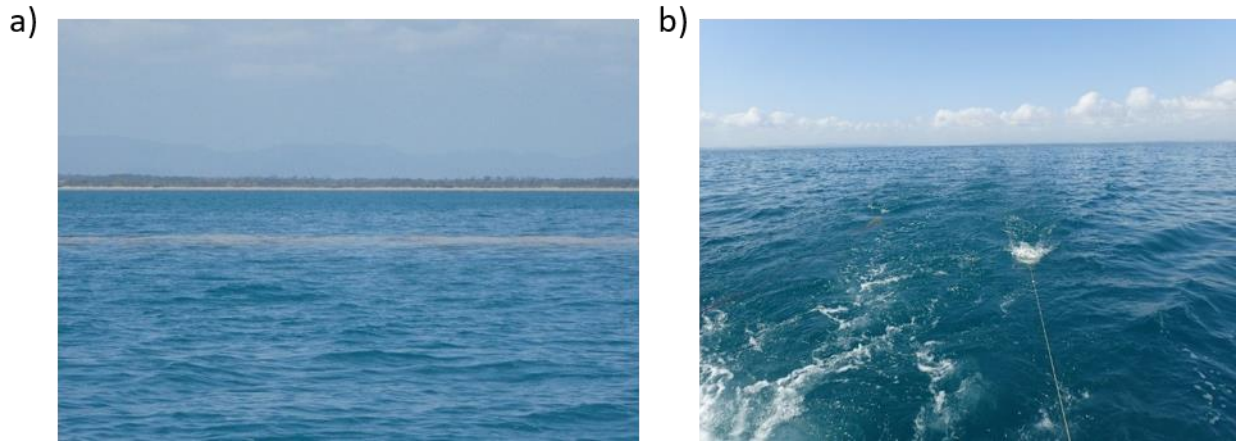

Figure 2.2 Example plankton sample. a) Trichodesmium bloom on sea surface; b) phytoplankton (60µm) tow behind the survey vessel

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

2.3.3 Pressure

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

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

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

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

2.3.4 Water temperature

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

a) b)

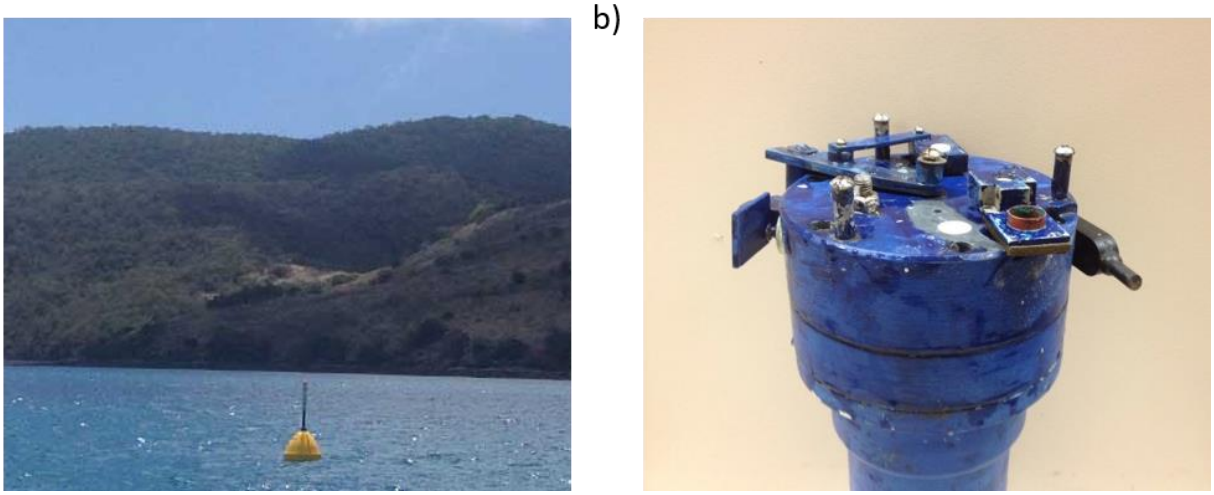

Figure 2.3 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

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 m^{-2} d^{-1}) the values recorded are multiplied by 600 to provide an estimate 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 add value to the project outcomes and deliverables.

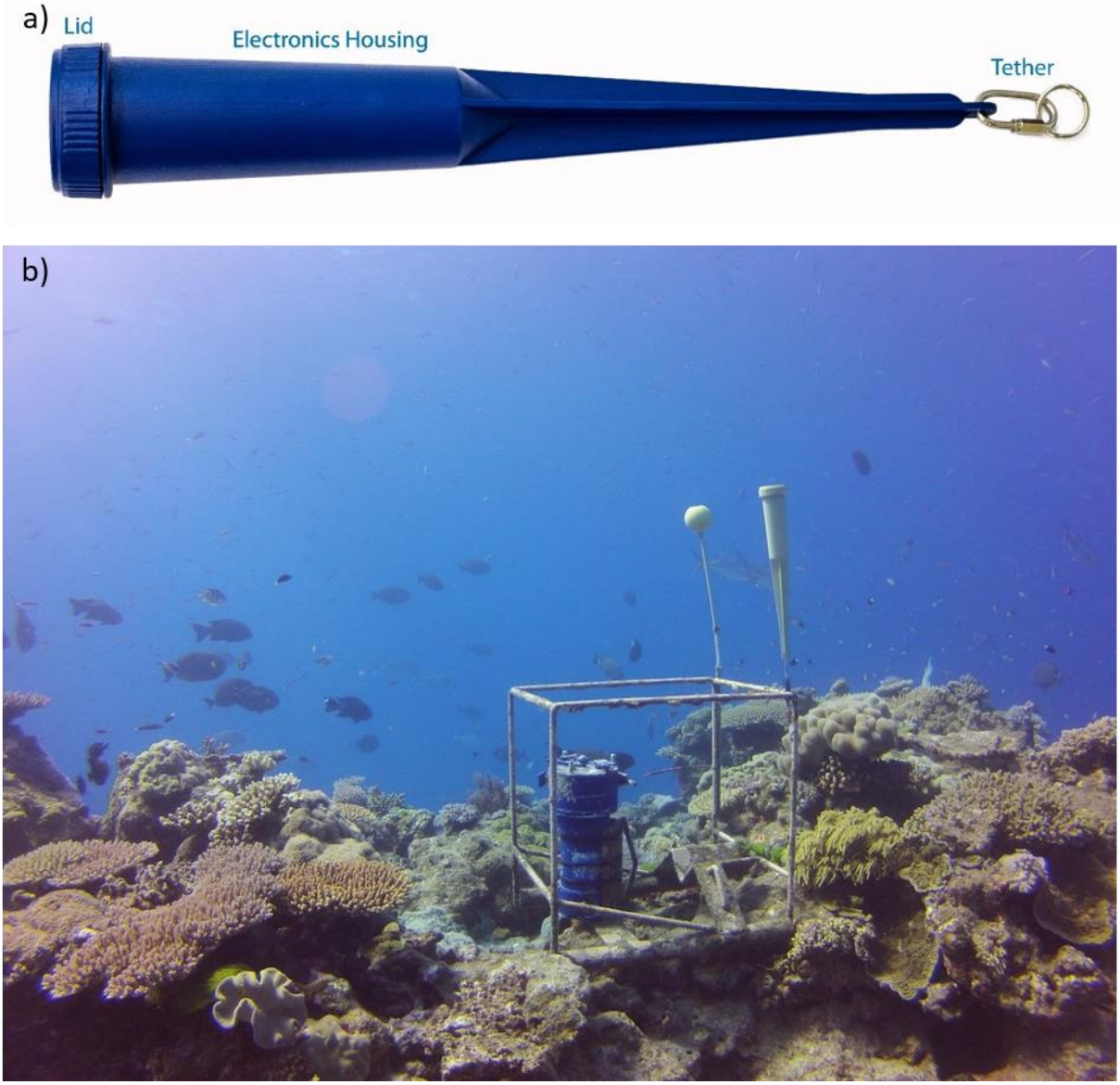

Figure 2.4 a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte at Moore Reef. Image courtesy of Eric Fisher

3 RESULTS AND DISCUSSION

There were eight sampling and maintenance trips in the 2019-2020 reporting period (Table 3.1). Loggers were removed from sites during April-May 2020 due to COVID-19 response.

Table 3.1 Summary of instrument maintenance and water quality surveys completed during the 2018/19 reporting period

Date	Nutrients, TSS, pH, EC, Chl-a	Metals, herbicides	Plankton	Logger maintenance
17/07/2019	Yes	-	-	Yes
22/08/2019	Yes	Yes	-	Yes
14/10/2019	Yes	-	Yes	Yes
12/11/2019	Yes	-	-	Yes
08/01/2020	Yes*	-	-	Yes*
02/02/2020	Yes#	-	-	Yes#
04/04/2020	Yes	-	Yes	Loggers removed
29/05/2020	Yes	Yes	-	Loggers reinstalled

* AP_AMB4 only, # All sites except AP_AMB4

3.1 Ambient water quality

3.1.1 Physio-chemical measurements

Water temperature ranged between 20.7 and 30.2 °C (Figure 3.1). There is 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 (Figure 3.1). The annual temperature range at the offshore site AP_AMB5 (Holbourne Island) was less than inshore sites. Water temperature was generally similar through the water column for all sites, indicating that the water column profile is vertically well mixed throughout the region. Electrical conductivity (EC) ranged 48.0 and 55.3 mS cm^{-1} and was in the range typical of seawater (Figure 3.2). Conductivity values followed seasonality with higher values occurring during summer months and lower values during winter months. Dissolved oxygen ranged between 87 to 112 %sat (Figure 3.3). The water column was well mixed, with dissolved oxygen saturation not significantly changing through the vertical profile. pH ranged between 7.4 and 9.2 (Figure 3.4).

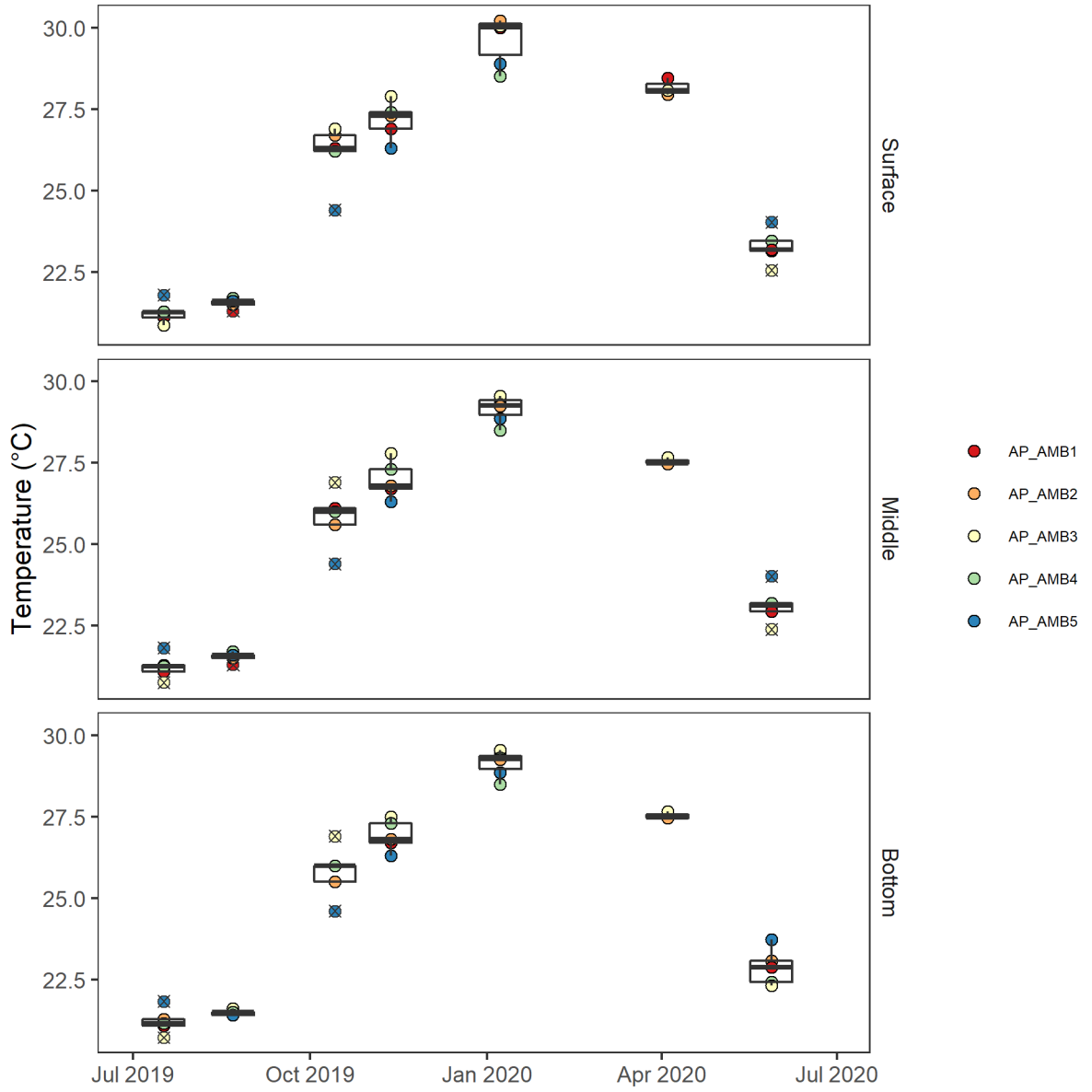

Figure 3.1 Water temperature recorded at three depths at the five water quality sites throughout the reporting period. Outlier values are marked with an '×'.

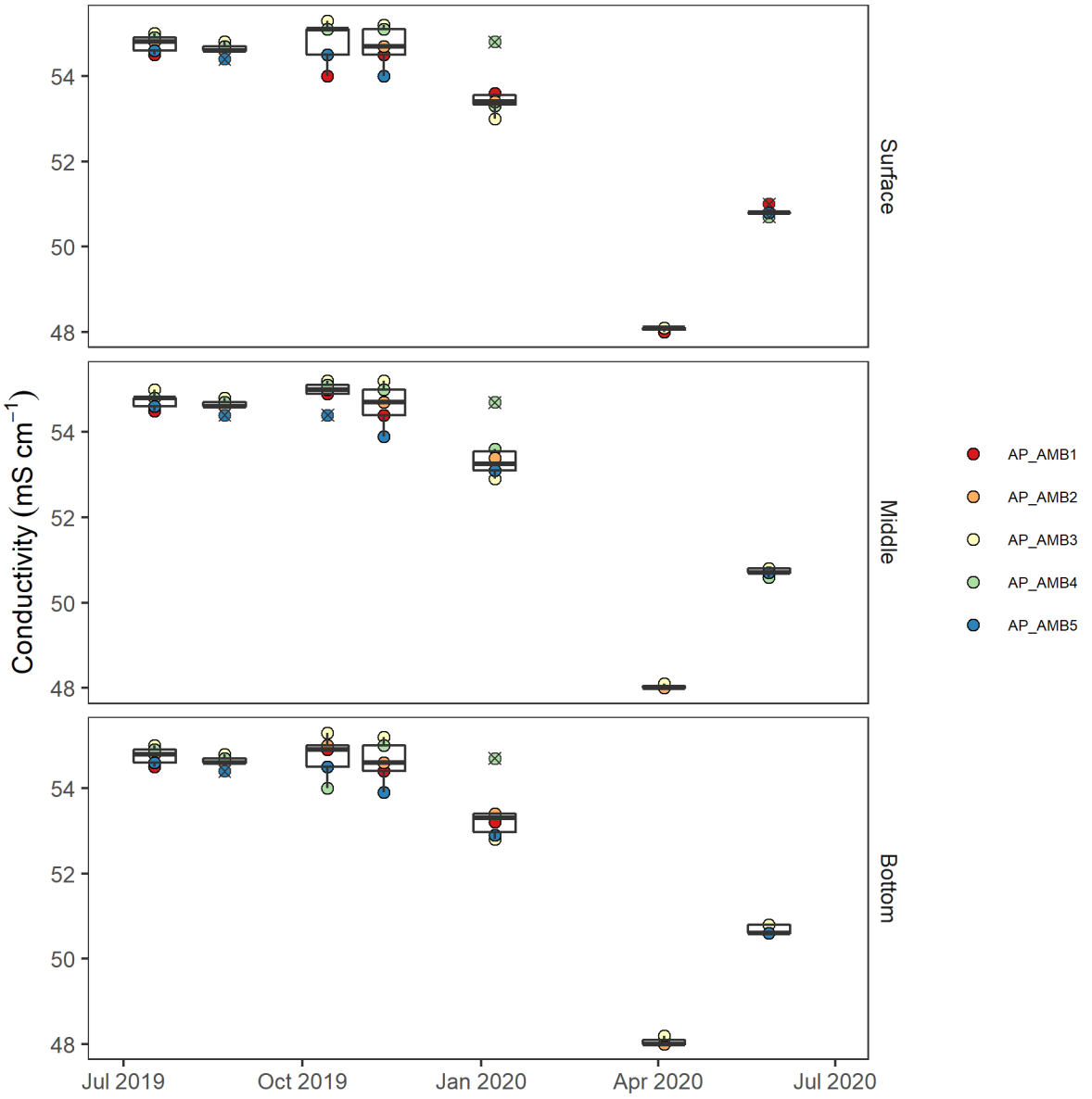

Figure 3.2 Electrical conductivity recorded at three depths at the five water quality sites throughout the reporting period. Outlier values are marked with an '×'.

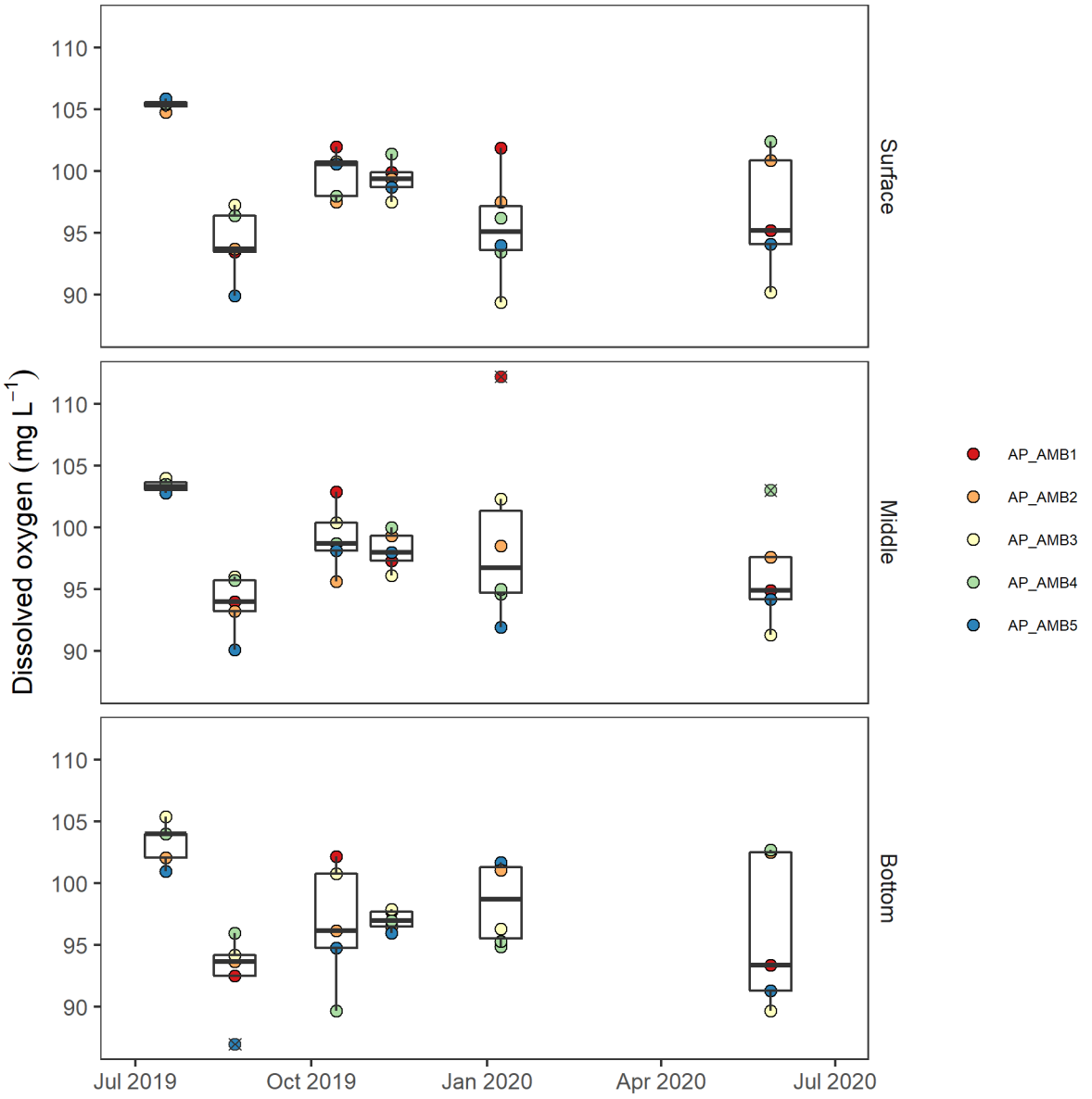

Figure 3.3 Dissolved oxygen (%sat) recorded at three depths at the five water quality sites throughout the reporting period. Outlier values are marked with an '×'.

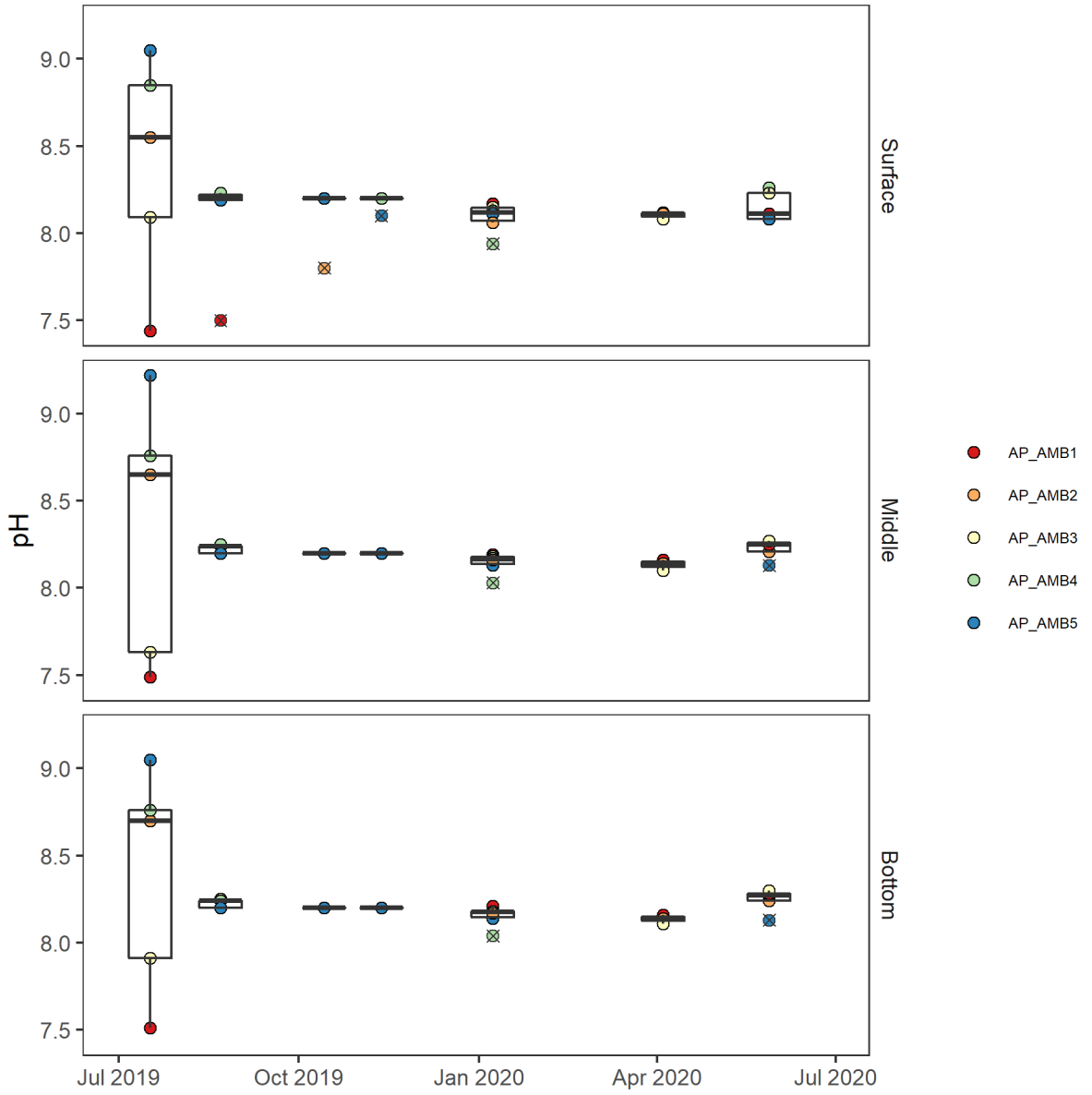

Figure 3.4 pH recorded at three depths at the five water quality sites throughout the reporting period. Outlier values are marked with an 'x'.

3.1.2 Nutrients, water clarity and chlorophyll-*a*

Particulate nitrogen (PN) concentrations ranged from 1 to 412 µg L^{-1} (Figure 3.5). Mean PN across the five sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} for all sampling events with the exception of April 2020. Statistical outliers were present in August 2019 (AP_AMB5 Holbourne Island) and May 2020 (AP_AMB3 Elliot River). Outliers have been retained in the dataset as no reason to exclude them was identified during quality control.

Particulate phosphorus (PP) concentrations ranged from <1 to 32 µg L^{-1} (Figure 3.6). Mean PP was generally below the GBRMPA guideline trigger value of 2.8 µg L^{-1} for all sampling events with the exception of August 2019.

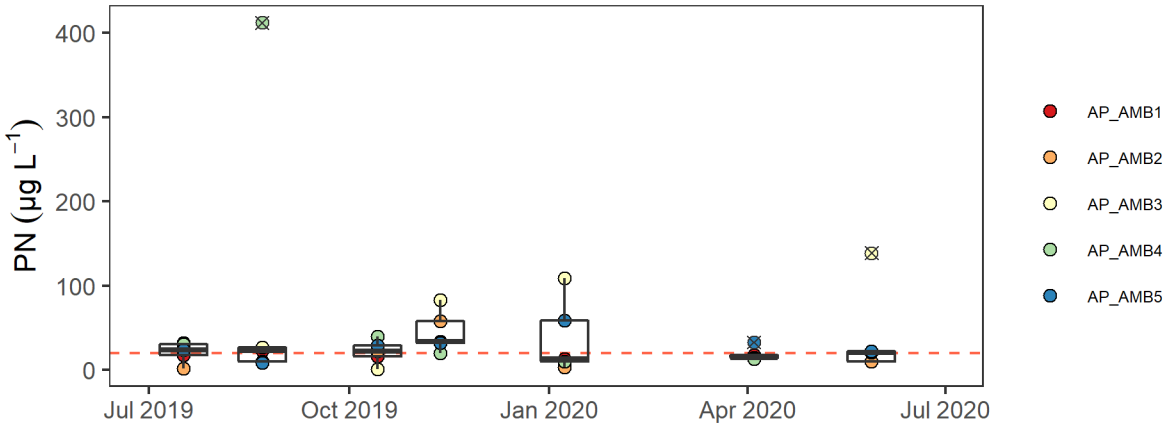

Figure 3.5 Particulate nitrogen (PN) concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Outlier values are marked with an '×'. Horizontal dashed line indicates the GBRMPA open coastal guideline trigger value.

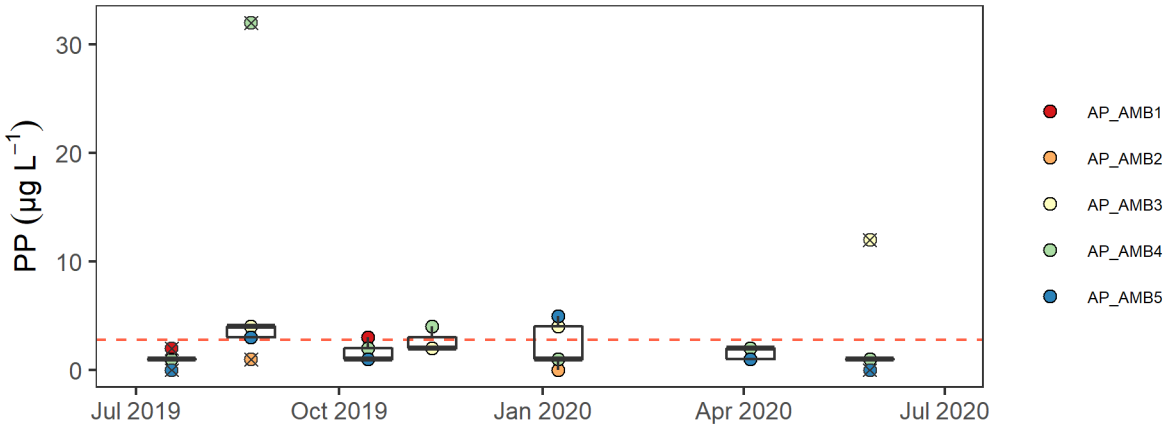

Figure 3.6 Particulate phosphorus (PP) concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Outlier values are marked with an '×'. Horizontal dashed line indicates the GBRMPA open coastal guideline trigger value.

Total suspended solids ranged from 1.0 to 7.6 mg L^{-1} (Figure 3.7). Mean TSS across the five sites exceeded the GBRMPA guideline trigger value of 2.0 mg L^{-1} for all sampling events with the exception of July 2019 and May 2020. Secchi depth ranged from 2.5 to 10.0 m (Figure 3.8). Chlorophyll-*a* concentrations ranged from 0.20 to 1.27 µg L^{-1} (Figure 3.9). Chlorophyll-*a* concentrations exceeded the GBRMPA guideline trigger value in November 2019 (mean = 0.73 µg L^{-1}) and May 2020 (mean = 0.67 µg L^{-1}).

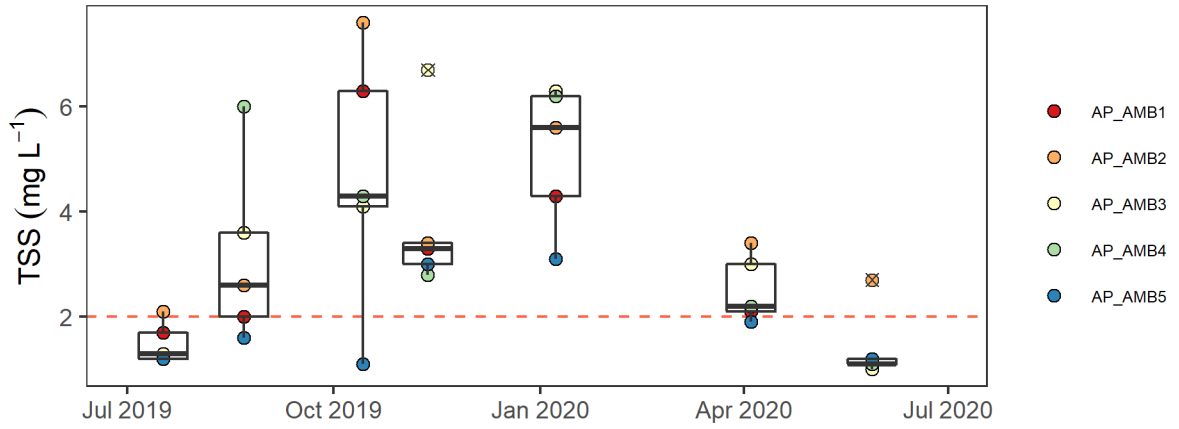

Figure 3.7 Total suspended solids (TSS) measured in water samples at the five water quality sites throughout the reporting period. Outlier values are marked with an '×'. Horizontal dashed line indicates the GBRMPA open coastal guideline trigger value.

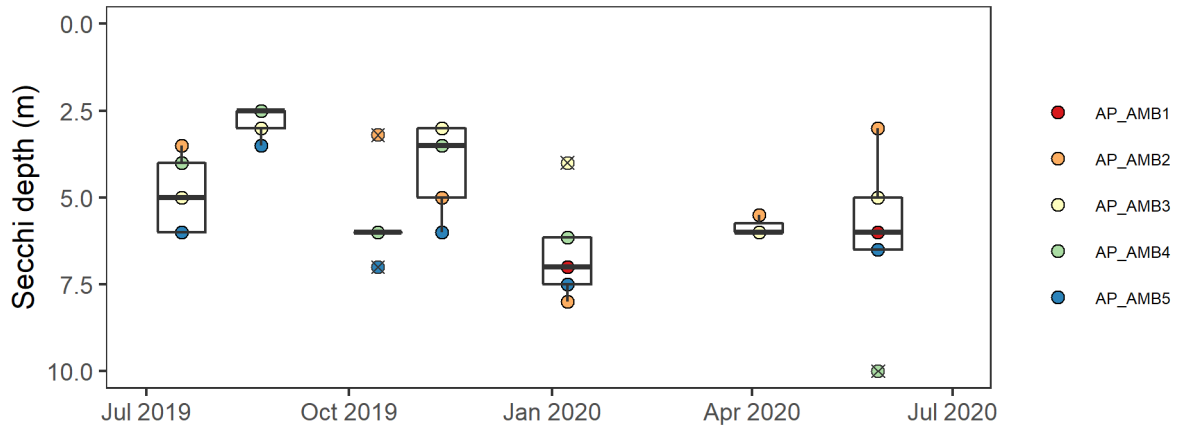

Figure 3.8 Secchi disk depth recorded at the five water quality sites throughout the reporting period.

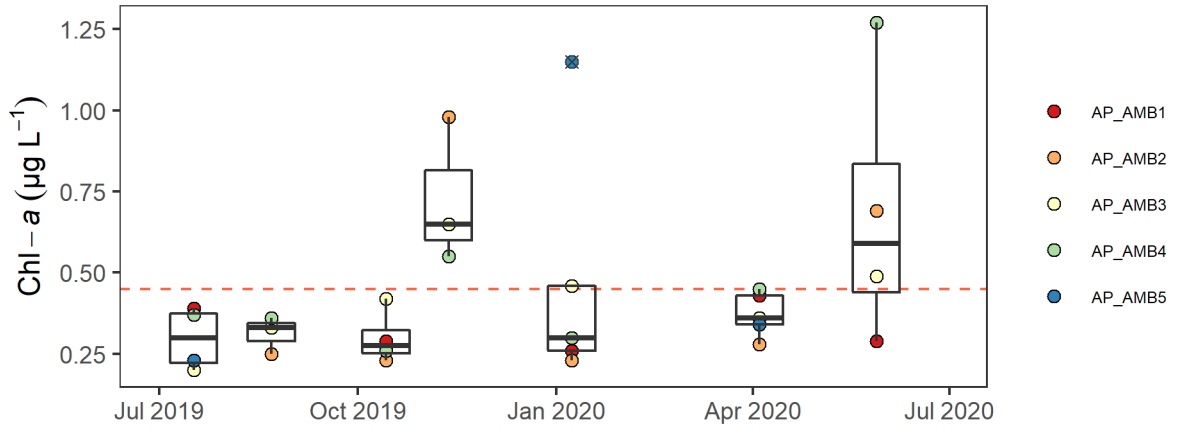

Figure 3.9 Chlorophyll-*a* concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Outlier values are marked with an '×'. Horizontal dashed line indicates the GBRMPA open coastal guideline trigger value.

3.1.3 Heavy metals

Heavy metal concentrations are presented in Table 3.2. Concentrations were compared to the ANZECC and ARMCANZ 2000 water quality guidelines (ANZECC, 2000). Metals targeted for analysis were not detected above the 95% level of protection trigger values for marine waters. Silver, Cadmium, Copper, Zinc, and Mercury were not detected (< LOD). Lead, Nickel, and Arsenic were detected at low concentrations. Lead and Nickel were only detected in August 2019, and < LOD in May 2020. Arsenic was detected at low concentrations. Note that ANZECC guidelines do not have a trigger value for arsenic. 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. Arsenic measured concentrations were below these low reliability trigger values, and similar concentrations have been recorded consistently at these sites since mid-2016.

Table 3.2 Heavy metal concentrations measured in water samples collected from the five water quality sites throughout the reporting period. ANZECC and ARMCANZ 2000 water quality guideline 95% level of protection trigger values for marine waters are shown for comparison (ANZECC, 2000).

Month	Sample_date	Site_code	Site_name	Silver	Cadmium	Copper	Lead	Nickel	Arsenic	Zinc	Mercury
			Units	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	mg L^{-1}
			Limit of reporting (LOR)	0.1	0.2	1	0.2	0.5	-	5	0.001
			ANZECC 95% level	1.4	5.5	1.3	4.4	70	-	15	0.4
Aug-19	22/08/2019	AP_AMB1	Euri Creek	< 0.1	< 0.2	< 1.0	< 0.2	3.0	1.6	< 5.0	< 0.001
	22/08/2019	AP_AMB2	Spoil Grounds	< 0.1	< 0.2	< 1.0	0.5	1.2	1.6	< 5.0	< 0.001
	22/08/2019	AP_AMB3	Elliot River	< 0.1	< 0.2	< 1.0	0.4	0.8	1.5	< 5.0	< 0.001
	22/08/2019	AP_AMB4	Camp Island	< 0.1	< 0.2	< 1.0	0.9	0.8	1.7	< 5.0	< 0.001
	23/08/2019	AP_AMB5	Holbourne Island	< 0.1	< 0.2	< 1.0	0.6	0.6	1.6	< 5.0	< 0.001
May-20	29/05/2020	AP_AMB1	Euri Creek	< 0.1	< 0.2	< 1.0	< 0.2	< 0.5	1.9	< 5.0	< 0.001
	28/05/2020	AP_AMB2	Spoil Grounds	< 0.1	< 0.2	< 1.0	< 0.2	< 0.5	2.0	< 5.0	< 0.001
	29/05/2020	AP_AMB3	Elliot River	< 0.1	< 0.2	< 1.0	< 0.2	< 0.5	1.8	< 5.0	< 0.001
	28/05/2020	AP_AMB4	Camp Island	< 0.1	< 0.2	< 1.0	< 0.2	< 0.5	1.9	< 5.0	< 0.001
	29/05/2020	AP_AMB5	Holbourne Island	< 0.1	< 0.2	< 1.0	< 0.2	< 0.5	2.0	< 5.0	< 0.001

3.1.4 Pesticides

Pesticide concentrations are presented in Table 3.3. Concentrations were compared to the Great Barrier Reef Marine Park guideline trigger values for 95% protection level (GBRMPA, 2010). Pesticides targeted for analysis were not detected above the trigger values for the GBR. The herbicides Chlorpyrifos, Diazinon, and Ametryn were not detected (< LOD). Hexazinone was < LOD in August 2019 but present at low concentrations for all inshore sites in May 2020. The insecticide Simazine was not detected (< LOD). Atrazine was < LOD in August 2019 but present at low concentrations for all inshore sites in May 2020.

Table 3.3 Pesticide concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Great Barrier Reef Marine Park guideline trigger values for 95% protection level are shown for comparison (GBRMPA, 2010).

Month	Sample_date	Site_code	Site_name	Chlorpyrifos	Diazinon	Hexazinone	Diuron	Ametryn	Atrazine	Simazine
			Units	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
			Limit of reporting (LOR)	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
			GBRMPA 95% level	0.009	0.01	1.2	1.6	1	1.4	3.2
Aug-19	22/08/2019	AP_AMB1	Euri Creek	< 0.001	< 0.0002	< 0.0002	0.0014	< 0.0002	< 0.0002	< 0.0002
	22/08/2019	AP_AMB2	Spoil Grounds	< 0.001	< 0.0002	< 0.0002	0.0006	< 0.0002	< 0.0002	< 0.0002
	22/08/2019	AP_AMB3	Elliot River	< 0.001	< 0.0002	< 0.0002	0.0003	< 0.0002	< 0.0002	< 0.0002
	22/08/2019	AP_AMB4	Camp Island	< 0.001	< 0.0002	< 0.0002	0.0070	< 0.0002	< 0.0002	< 0.0002
	23/08/2019	AP_AMB5	Holbourne Island	< 0.001	< 0.0002	< 0.0002	0.0009	< 0.0002	< 0.0002	< 0.0002
May-20	29/05/2020	AP_AMB1	Euri Creek	< 0.001	< 0.0002	0.0008	0.0035	< 0.0002	0.0007	< 0.0002
	28/05/2020	AP_AMB2	Spoil Grounds	< 0.001	< 0.0002	0.0003	0.0005	< 0.0002	0.0004	< 0.0002
	29/05/2020	AP_AMB3	Elliot River	< 0.001	< 0.0002	0.0005	0.0070	< 0.0002	0.0005	< 0.0002
	28/05/2020	AP_AMB4	Camp Island	< 0.001	< 0.0002	0.0006	0.0008	< 0.0002	0.0006	< 0.0002
	29/05/2020	AP_AMB5	Holbourne Island	< 0.001	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002	< 0.0002

3.2 Plankton communities

3.2.1 Abundance and diversity

A total of 29 phytoplankton taxa were identified from phytoplankton net tow samples. Phytoplankton abundance ranged from 1360 to 86710 individuals (Figure 3.10). Cyanobacteria was proportionally most common group in October 2019 (Figure 3.11). *Trichodesmium sp*. was the dominant taxa present. Species richness ranged from 6 to 19 taxa for any one sampling event. Species richness was generally higher in April 2020 compared to October 2019, with the exception of AP_AMB5 (Holbourne Island). Shannon diversity (H') ranged from 0.11 to 1.87. Simpson diversity (D) ranged from 0.03 to 0.80 and was higher in April 2020 than October 2019 for all sites.

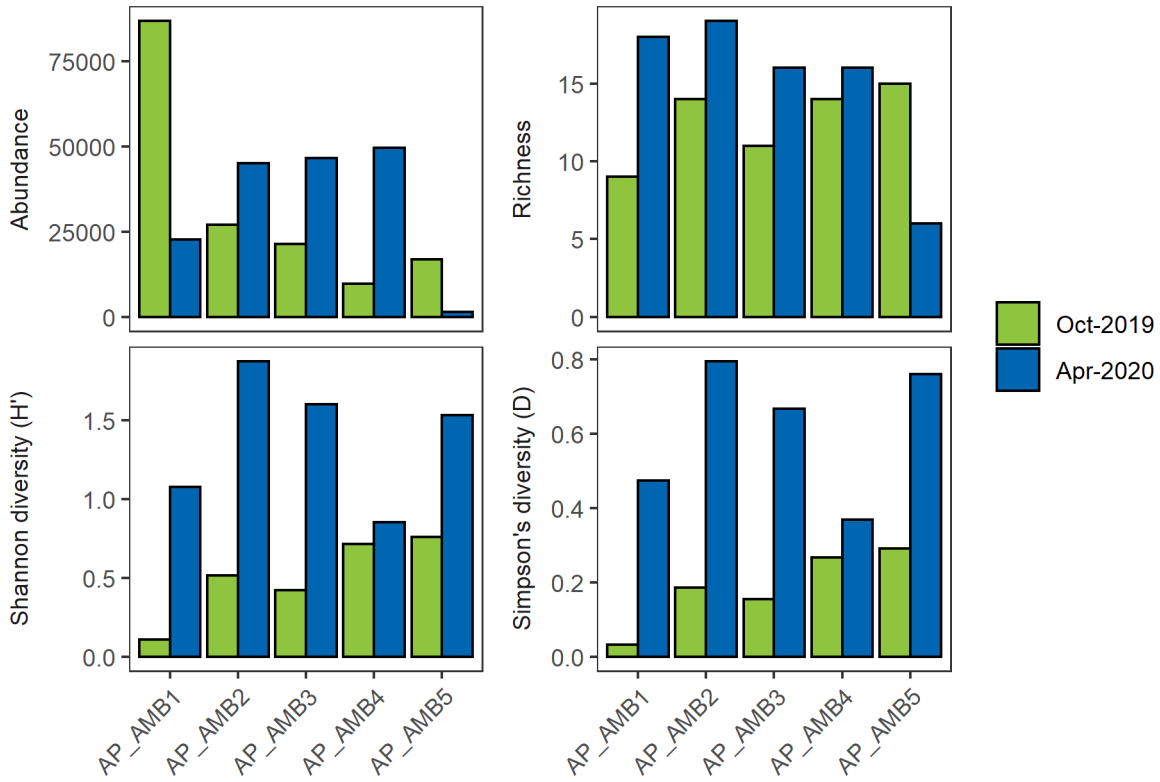

Figure 3.10 Phytoplankton abundance, richness, and diversity indices calculated at each site during the October 2019 and April 2020 survey events.

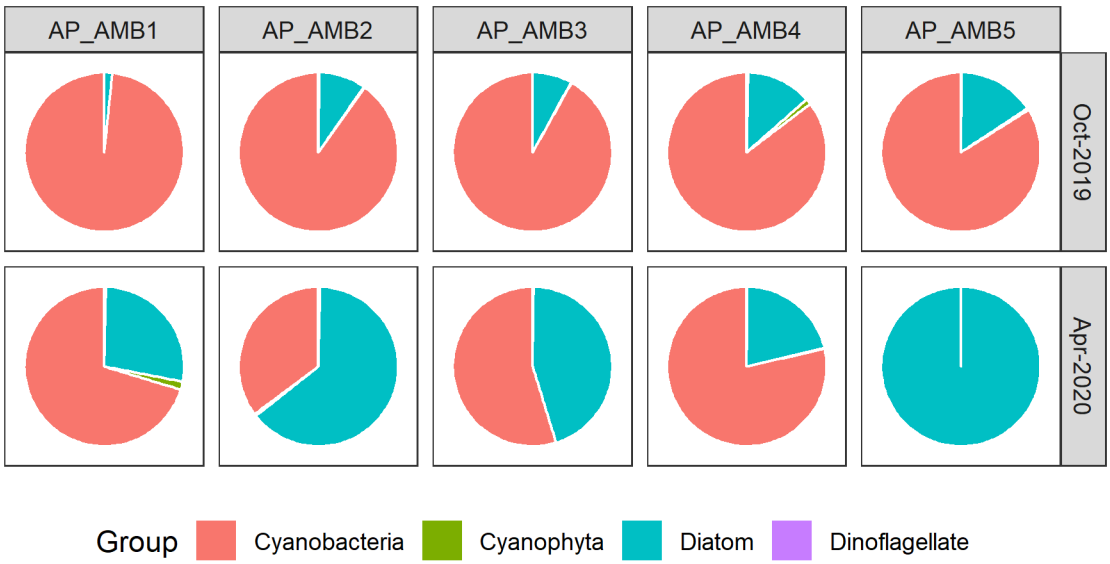

Figure 3.11 Proportion of individuals present from each phytoplankton group in tow net samples.

A total of 23 zooplankton taxa were identified from zooplankton net tow samples. Zooplankton abundance ranged from 14 to 92 individuals (Figure 3.12). Species richness ranged from 5 to 12 taxa for any one sampling event. Shannon diversity (H') ranged from 1.37 to 1.92. Simpson diversity (D) ranged from 0.61 to 0.84. The proportion of zooplankton individuals present in tow net samples is shown in Figure 3.13.

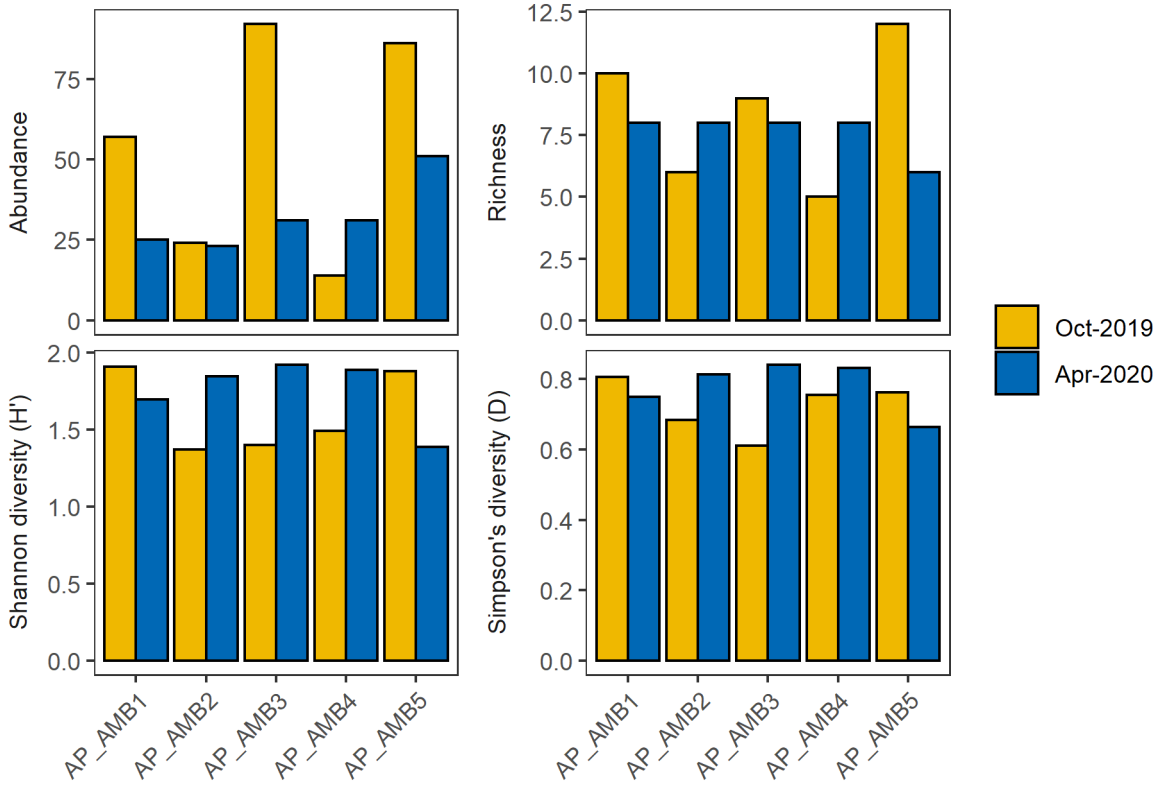

Figure 3.12 Zooplankton abundance, richness, and diversity indices calculated at each site during the October 2019 and April 2020 survey events.

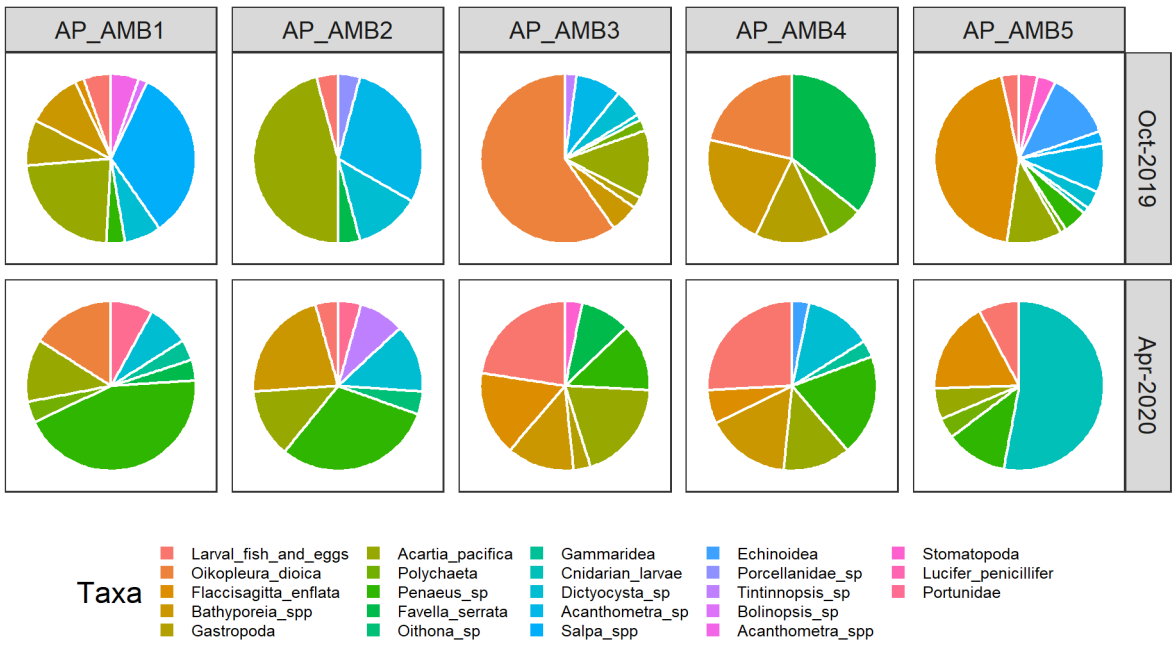

Figure 3.13 Proportion of zooplankton individuals present in tow net samples.

3.2.2 Community structure

The plankton community was visualised via non-metric multidimensional scaling with comparison made between October 2019 and April 2020 sampling events. The phytoplankton community showed dissimilarity between events (Figure 3.14, ANOSIM: R = 0.56, *P* = 0.007). Dissimilarity was mostly driven by the Trichodesmium bloom which was present during the October 2019 sampling event. The zooplankton community was similar between sampling events (Figure 3.15, ANOSIM: R = 0.256, *P* = 0.053).

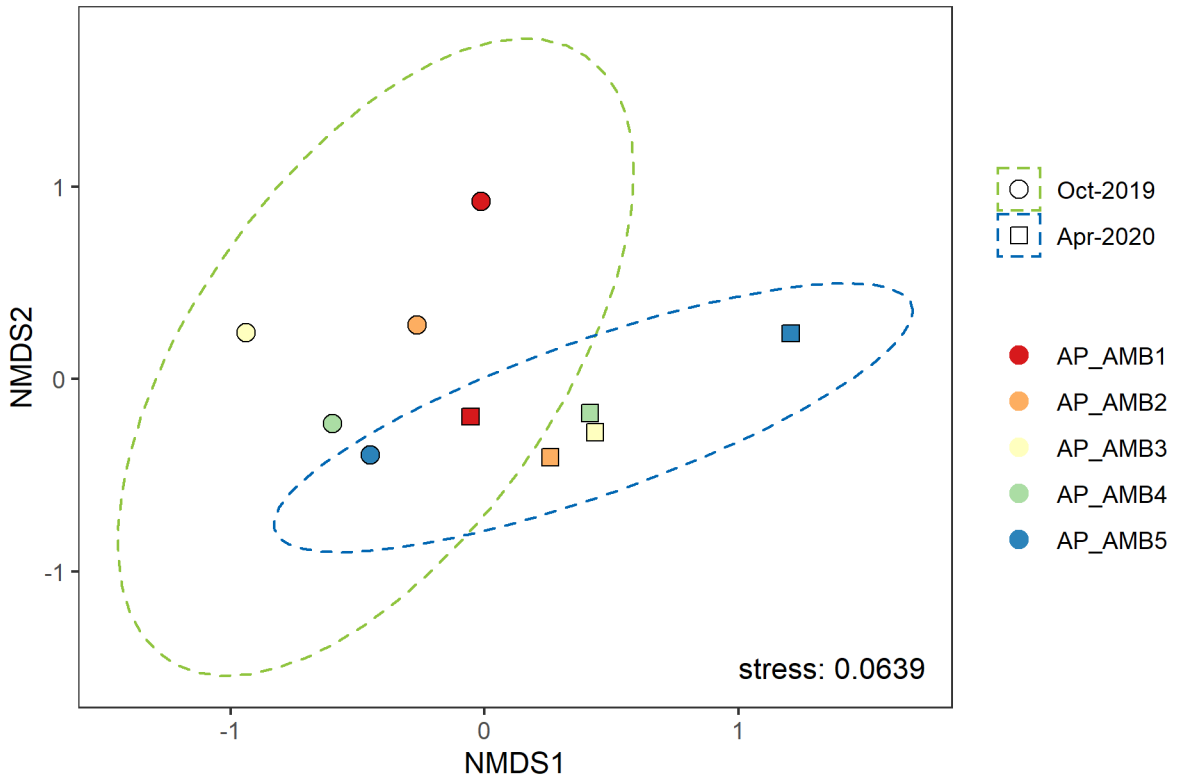

Figure 3.14 Non-metric multidimensional scaling (nMDS) plot of phytoplankton abundance data from samples collected during the 2019-2020 period. Ellipses represent 95 % confidence interval for each survey period. Data has been squared root transformed on the Bray Curtis distance matrix.

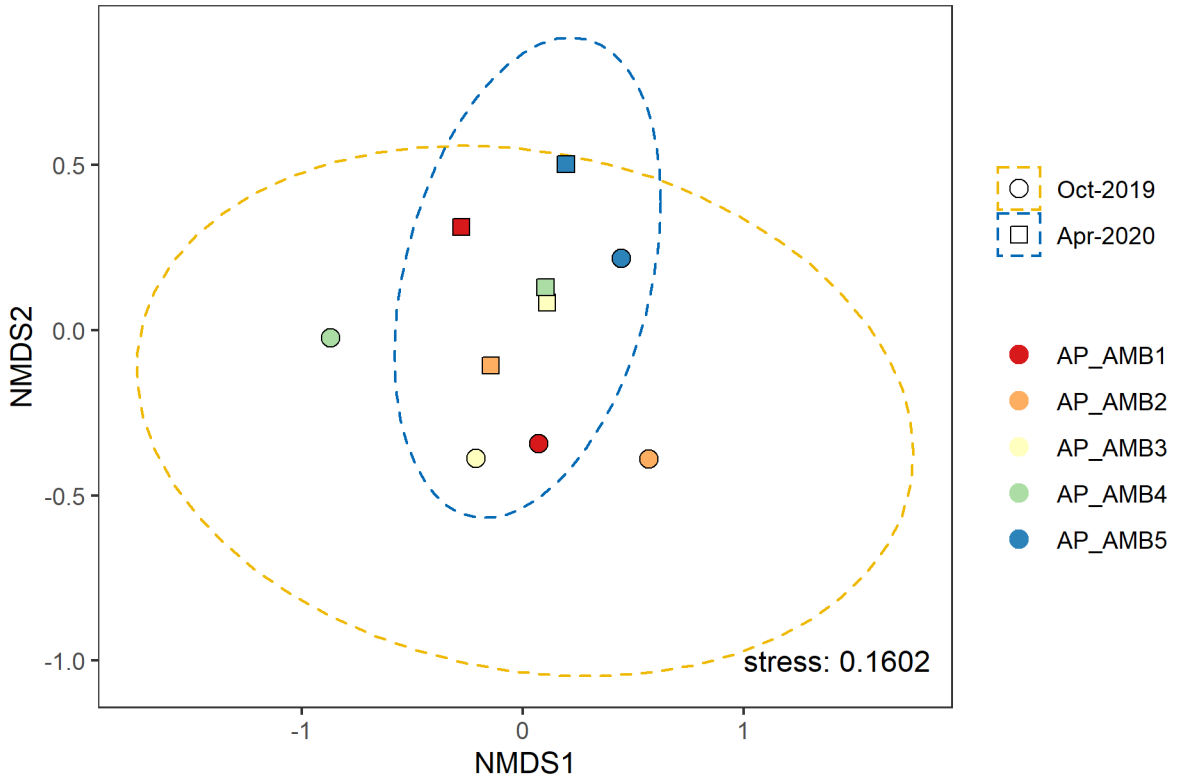

Figure 3.15 Non-metric multidimensional scaling (nMDS) plot of zooplankton communities based on abundance data from samples collected during the 2019-2020 period. Ellipses represent 95 % confidence interval for each survey period. Data has been squared root transformed on the Bray Curtis dissimilarity matrix.

3.3 Multiparameter water quality logger

Instruments were deployed at five sites, AMB 1 to 5, from July 2019 to July 2020 (see Table 1.1). Using standard statistics, we describe observed trends and differences between sites and discuss the driving forces in these environments. For each site, an annual statistical summary of root mean square water height (RMS; m), suspended sediment concentration (SSC; mg l^{-1}), sediment deposition rate (mg cm^{-2} day^{-1}), water temperature (°C), and photosynthetically available radiation (PAR; mol m^{-2} d^{-1}) is presented. The summary is depicted using box plots, whereby the central diamonds represent the mean value, the central line represents the median value, and the central box represents the range of the 25 and 75% quartiles. The vertical bars represent the range of the 90th and 10th percentiles. Time series and monthly summaries are included in the appendices.

Table 3.4 Data recovery (%) at each Abbot Point site between July 2019 and July 2020. Data recovery is reported as a percentage of 10 minute intervals for suspended sediment concentration (SSC), root mean square water depth (RMS), temperature, and depth. Recovery is reported as a proportion of days with data for deposition rate and photosynthetically available radiation (PAR).

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
SSC	0.63	0.61	0.61	0.61	0.40
Deposition rate	0.67	0.78	0.71	0.79	0.52
PAR	0.76	0.88	0.87	0.72	0.90
RMS	0.93	0.99	0.95	0.99	0.85
Temperature	0.95	0.99	0.95	0.99	0.85
Depth	0.95	0.99	0.95	0.99	0.85
Mean recovery	0.81	0.87	0.84	0.85	0.73

3.3.1 RMS water height

Root mean square water height (RMS) is mostly driven by weather events that increase RMS simultaneously at all sites. Variation in RMS during and in-between peak events differs among sites due to differences in water depth and exposure to wave energy. All sites had similar RMS values, with median values ranging from 0.013 m to 0.021 m (Figure 3.16, Table 3.5). AMB2 and AMB5 had the lowest median RMS (0.013) while AMB3 had the highest median RMS (0.021). Peaks in RMS occurred throughout the deployment period at all sites (Appendix A1.2, Appendix A1.3).

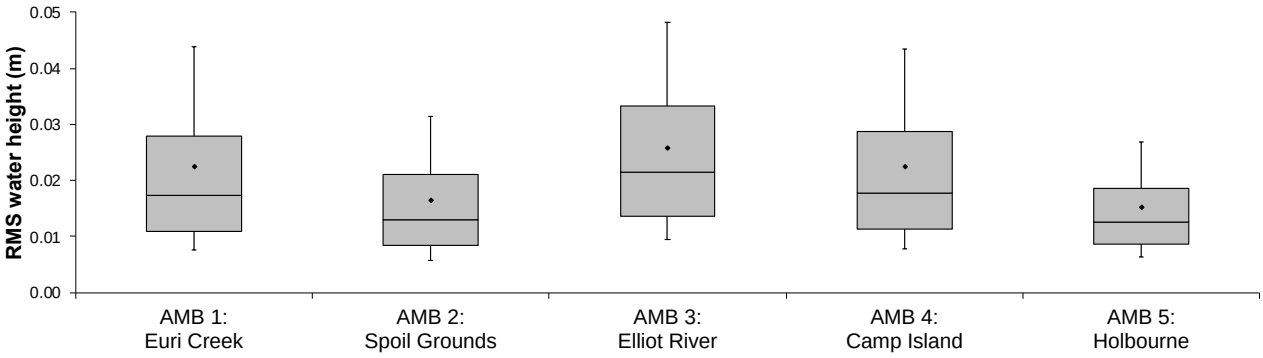

Figure 3.16 Box plot of RMS water height (m) at the five sites for the monitoring period from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamonds represent the mean values.

Table 3.5 Summary of RMS water height (m) statistics at the five sites from July 2019 to July 2020.

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
Mean	0.022	0.016	0.026	0.023	0.015
Median	0.017	0.013	0.021	0.018	0.013
Minimum	0.000	0.000	0.001	0.000	0.000
Lower quartile	0.011	0.008	0.014	0.011	0.009
Upper quartile	0.028	0.021	0.033	0.029	0.019
Maximum	0.205	0.201	0.163	0.183	0.149
90th percentile	0.044	0.031	0.048	0.043	0.027
10th percentile	0.008	0.006	0.009	0.008	0.006
n	45564	48481	46352	48472	48747
St. Dev	0.017	0.012	0.017	0.016	0.010
St. Error	0.000	0.000	0.000	0.000	0.000

3.3.2 NTUe/SSC

Median suspended sediment concentrations (SSC) were ≤2.4 mg L^{-1} at all sites (Figure 3.17, Table 3.6). Higher mean SSC at AMB2 suggests that this site experienced more extreme turbidity events during the monitoring period. AMB2 also had the highest variance in SSC (5.5 SD). AMB5 had the lowest SSC compared to the other sites.

The NTUe/SSC time series data follows a typical pattern of low background values with recurring peak events (Appendix A1.2). Most sites exhibited SSC extremes in October-December (Appendix A1.2). These events typically occurred simultaneously at all sites and coincided with increases in RMS. This is a typical pattern which is similar to data collected in coastal locations in north Queensland by the James Cook University Marine Geophysics group (Ridd et al., 2001). Differences in NTUe/SSC among sites result from differences in RMS water height, water depth, benthic geology, hydrodynamics, and proximity to river mouths.

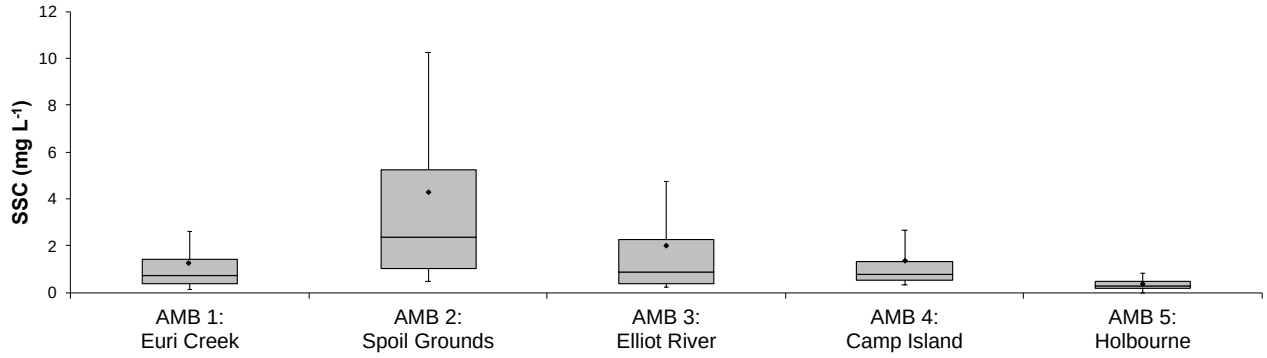

Figure 3.17 Box plot of SSC (mg L^{-1}) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.6 Summary of SSC (mg L^{-1}) statistics at the five sites from July 2019 to July 2020.

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
Mean	1.26	4.30	2.03	1.38	0.39
Median	0.75	2.38	0.88	0.78	0.29
Minimum	0.02	0.00	0.00	0.00	0.00
Lower quartile	0.37	1.03	0.39	0.53	0.17
Upper quartile	1.42	5.24	2.25	1.32	0.48
Maximum	18.67	40.72	66.85	51.07	8.73
90th percentile	2.64	10.26	4.73	2.64	0.82
10th percentile	0.16	0.50	0.22	0.33	0.00
n	30997	30021	29740	30066	22808
St. Dev	1.77	5.46	3.65	2.43	0.43
St. Error	0.01	0.03	0.02	0.01	0.00

3.3.3 Deposition

Deposition of sediment is a natural process in all coastal marine waters. Suspended sediment is transported by currents and deposited in environments where wave energy is not sufficient to keep sediment suspended in the water column. The time series of deposition rates indicate that deposition peaks following RMS events but with a lag so that peak deposition occurs when RMS has decreased to near background levels (Appendix A1.2). An explanation for this lag is that, as waves resuspend sediment, little deposition occurs because the energy in the system keeps sediment in suspension. However, when waves decrease and there is no longer enough energy in the system to keep sediment in suspension and deposition occurs.

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

All coastal sites (AMB1-4), as well as AMB5, exceeded the mean sediment deposition trigger value (Figure 3.18, Table 3.7). However, as these deposition rates are not normally distributed, we focus our interpretation on median values, which ranged from 0.6 (AMB5) - 9.1 (AMB2) mg cm^{-2} day^{-1}. The variability in deposition rates among the coastal sites mirrors the relative differences in turbidity (Figure 3.18).

Differences in deposition rates may be more easily visualised by estimating the thickness of the sediment deposited. For example, using the relationship between density, mass and volume: median deposition value of 5 mg cm^{-2} day^{-1} (e.g, AMB1) is equivalent to a layer of sediment of thickness less than 35 µm, assuming a sediment density of 1.5 g cm^{-3}.

At most sites, the highest deposition rates were observed between November and February (Appendix A1.3).

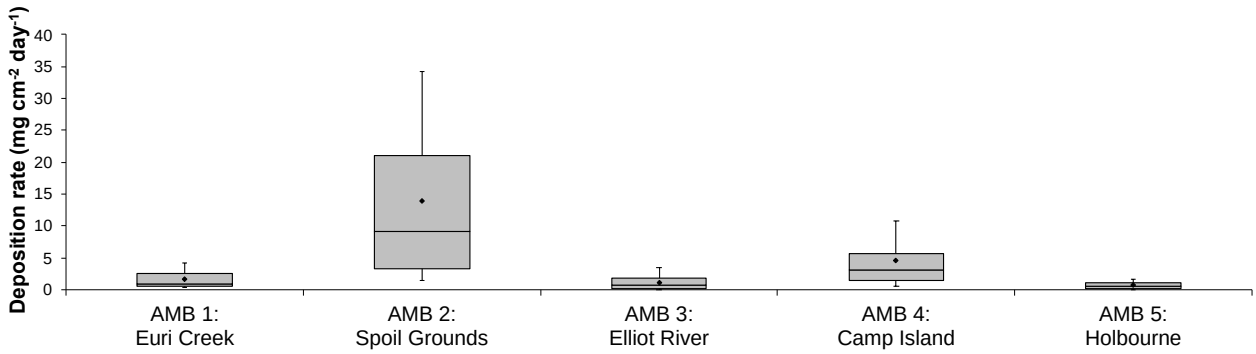

Figure 3.18 Box plot of deposition rates (mg cm^{-2} day^{-1}) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.7 Summary of the mean daily deposition rate (mg cm^{-2} day^{-1}) statistics from July 2019 to July 2020.

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
Mean	1.70	13.90	1.16	4.47	0.77
Median	0.92	9.12	0.66	3.06	0.55
Minimum	0.02	0.15	0.01	0.03	0.01
Lower quartile	0.47	3.29	0.12	1.43	0.18
Upper quartile	2.59	20.95	1.71	5.69	1.03
Maximum	8.98	64.91	5.58	24.56	4.81
90th percentile	4.09	34.20	3.38	10.78	1.68
10th percentile	0.25	1.48	0.05	0.47	0.07
n	228	265	240	270	177
St. Dev	1.79	13.12	1.30	4.42	0.81
St. Error	0.12	0.81	0.08	0.27	0.06

3.3.4 Water temperature

Water temperatures were similar among all sites with medians of 24-26 °C and similar ranges of temperatures (Figure 3.19, Table 3.8). Water temperature at all sites approached 30 °C from December until

March (Appendix A.2). Water temperature is 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).

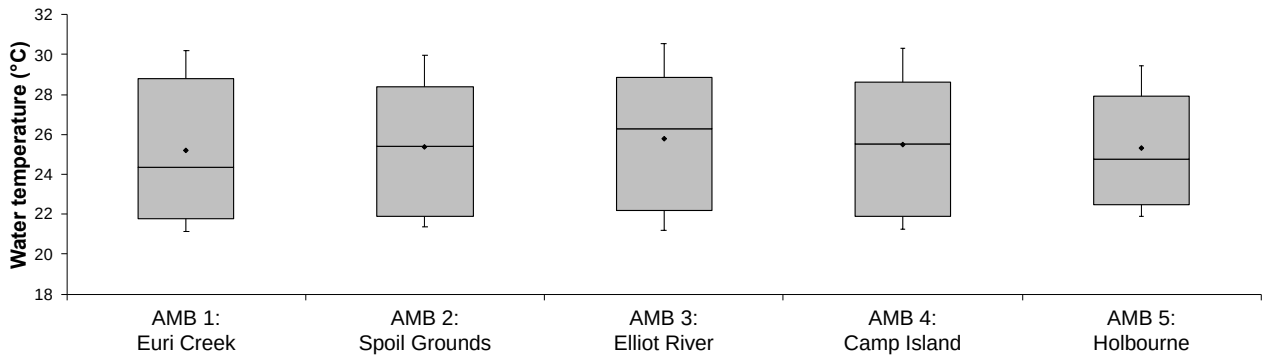

Figure 3.19 Box plot of the water temperature (°C) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.8 Summary of water temperature (°C) from July 2019 to July 2020.

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
Mean	25.19	25.34	25.73	25.46	25.30
Median	24.34	25.38	26.28	25.52	24.74
Minimum	20.05	20.77	19.90	20.32	20.22
Lower quartile	21.79	21.92	22.20	21.91	22.49
Upper quartile	28.82	28.41	28.86	28.65	27.94
Maximum	31.66	31.30	32.59	32.31	31.21
90th percentile	30.18	29.97	30.56	30.34	29.44
10th percentile	21.11	21.35	21.18	21.23	21.92
n	46506	48445	46313	48436	48731
St. Dev	3.51	3.29	3.58	3.48	2.88
St. Error	0.02	0.01	0.02	0.02	0.01

3.3.5 PAR

Mean levels of benthic photosynthetically available radiation (PAR) ranged from 0.7 to 10.5 mol m^{-2} day^{-1} (Figure 3.20, Table 3.9). AMB3 and AMB5 had the highest mean and variance in PAR and are in coral habitat. AMB2 had the lowest mean and lowest variance in PAR, likely due to its deeper location.

Benthic PAR was highly variable within sites throughout the year, but PAR was generally highest in July-August and lowest in December-January (Figure 3.21, Figure 3.22). Semi-regular oscillations between low and high PAR were overridden by larger episodic events caused by storm or rainfall.

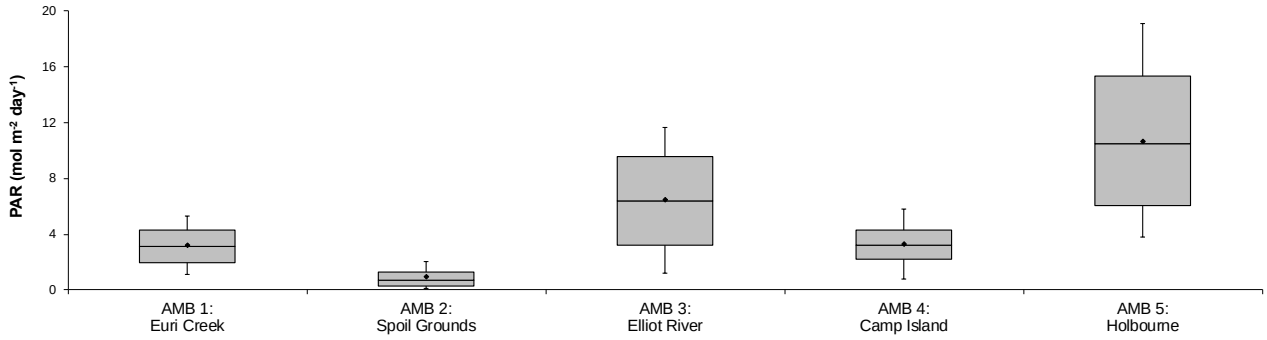

Figure 3.20 Box plot of daily PAR (mol m^{-2} day^{-1}) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.9 Summary of daily PAR (mol m^{-2} day^{-1}) from July 2019 to July 2020.

Site	AMB 1: Euri Creek	AMB 2: Spoil Grounds	AMB 3: Elliot River	AMB 4: Camp Island	AMB 5: Holbourne
Mean	3.21	0.93	6.47	3.26	10.69
Median	3.14	0.68	6.41	3.18	10.47
Minimum	0.25	0.00	0.02	0.03	1.23
Lower quartile	1.99	0.30	3.23	2.19	6.08
Upper quartile	4.29	1.27	9.57	4.32	15.33
Maximum	6.89	5.03	16.19	7.99	21.55
90^{th} percentile	5.30	2.07	11.66	5.77	19.09
10^{th} percentile	1.08	0.13	1.21	0.81	3.79
n	258	299	296	243	305
St. Dev	1.55	0.86	3.88	1.76	5.41
St. Error	0.10	0.05	0.23	0.11	0.31

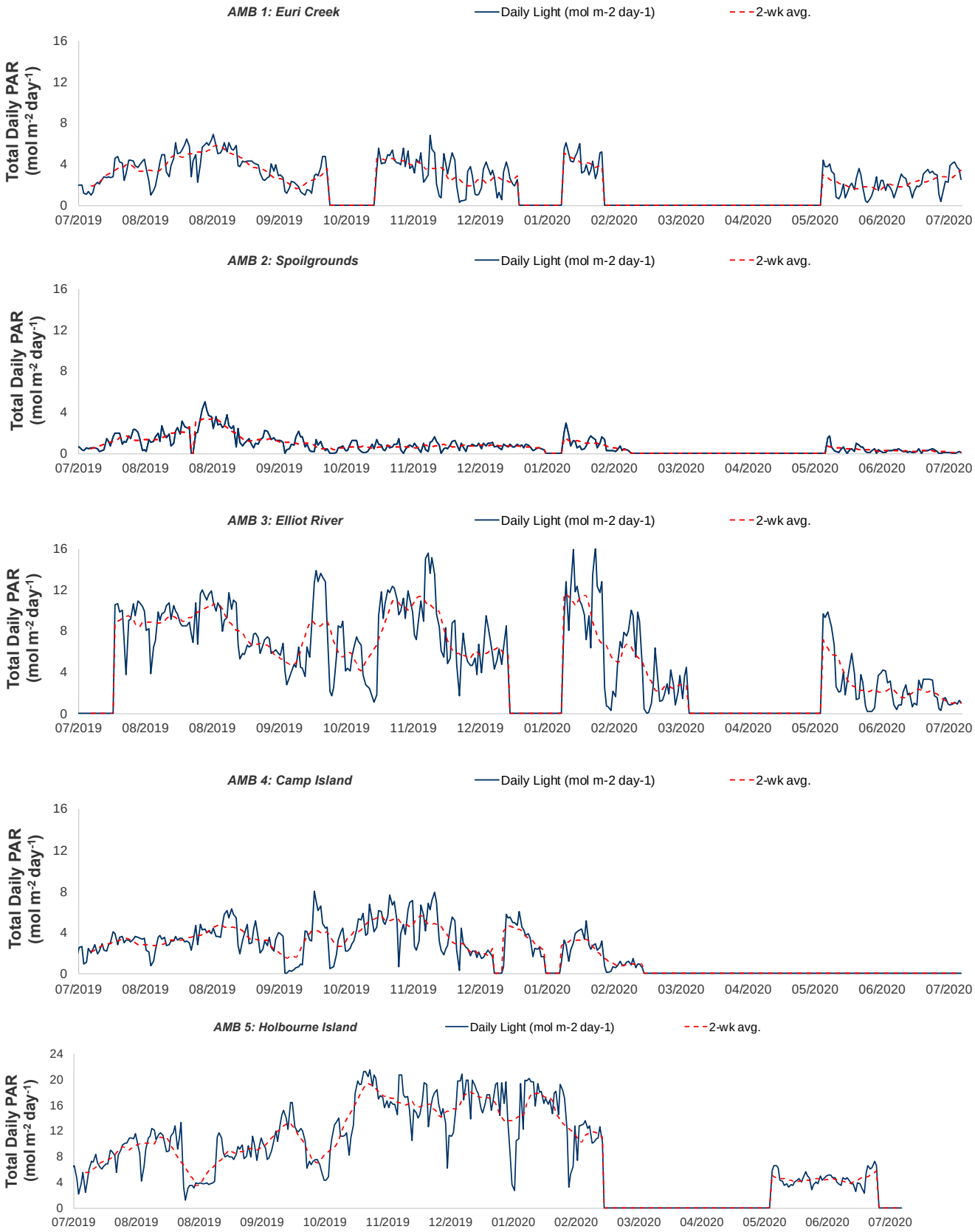

Figure 3.21 Time series of total daily PAR (mol m^{-2} day^{-1}) from July 2019 to July 2020. Daily mean PAR is plotted in blue and a 2-week moving average of daily mean PAR is plotted in red. Note that AMB5: Holbourne Island is shown on a different y-axis scale relative to the other sites.

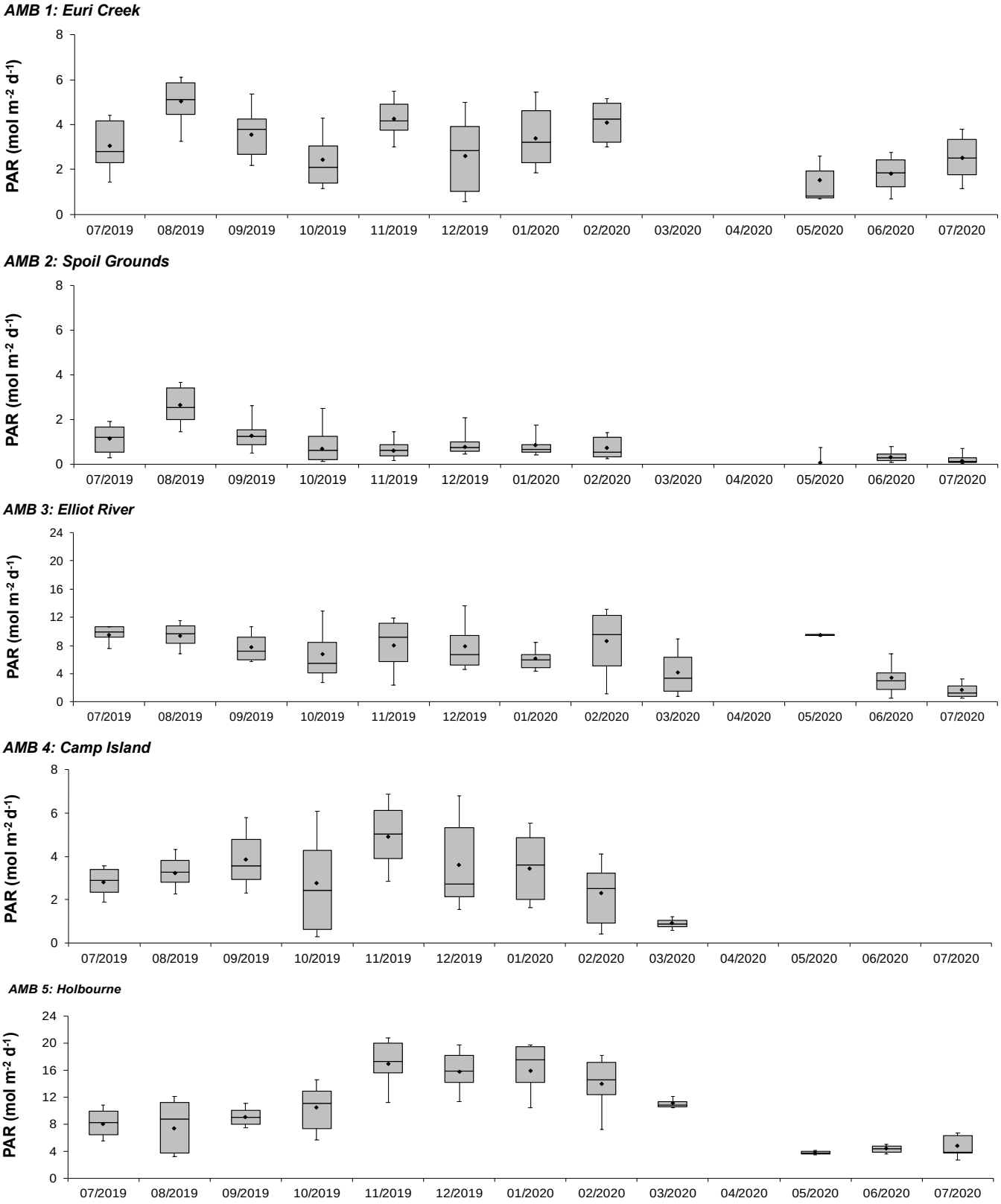

Figure 3.22 Monthly boxplots illustrating the variation in total daily PAR (mol m^{-2} day^{-1}) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value. Note AMB3 and AMB5 are on y-axis scales up to 24 while AMB1, 2, and 4 are on scales up to 8.

Similarities in patterns of PAR among sites

Direct comparisons of PAR among sites are confounded by the different water depths at each location. However, there are some weak relationships between the benthic PAR at different locations (Figure 3.23). Less than 42% of the variation in PAR at a given site could be explained by the PAR at any other site, highlighting the influence of location conditions (depth, turbidity, etc.) on benthic irradiance. AMB4 and AMB5 have the strongest association (R^2 = 0.42) while AMB3 and AMB4 have the second strongest association (R^2 = 0.40). These three coastal sites are relatively close together, supporting the strong association between their respective PAR. This analysis assists in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region.

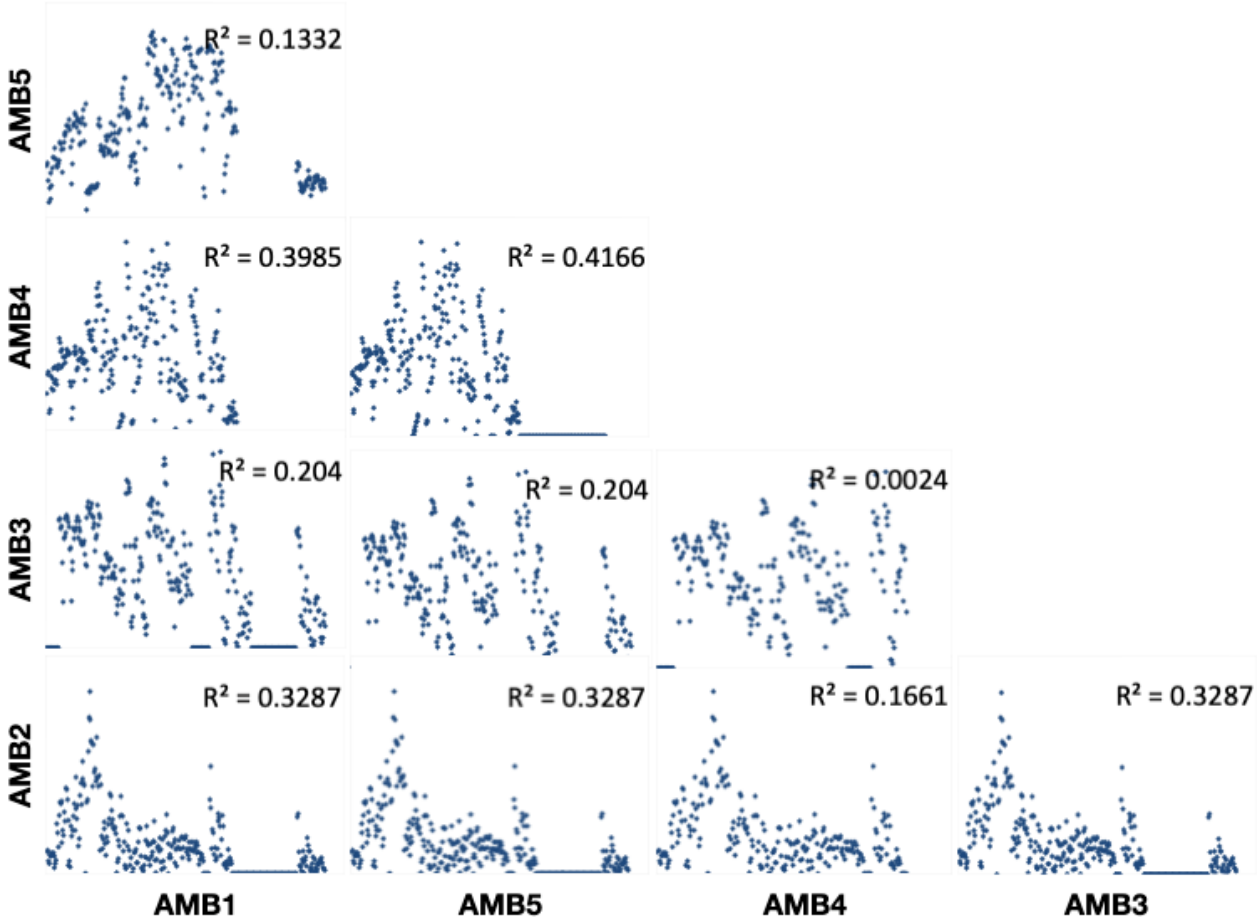

Figure 3.23 Scatterplots of PAR between sites indicating the strength of the relationships between patterns of daily PAR. R^2 values are presented for each comparison.

3.3.6 Comparison between wet and dry seasons

A comparison of wet (1/11/2019-31/3/2020) and dry season (15/7/2019-31/10/2019 & 1/4/2020-31/7/2020) water quality suggests that there are only slight differences in RMS, SSC, sediment deposition rates, and PAR between seasons.

RMS water height

Overall, RMS was similar between seasons (

Figure **3.24**). However, several sites exhibit marginally higher RMS in the dry season, including AMB 1, AMB2, and AMB 4.

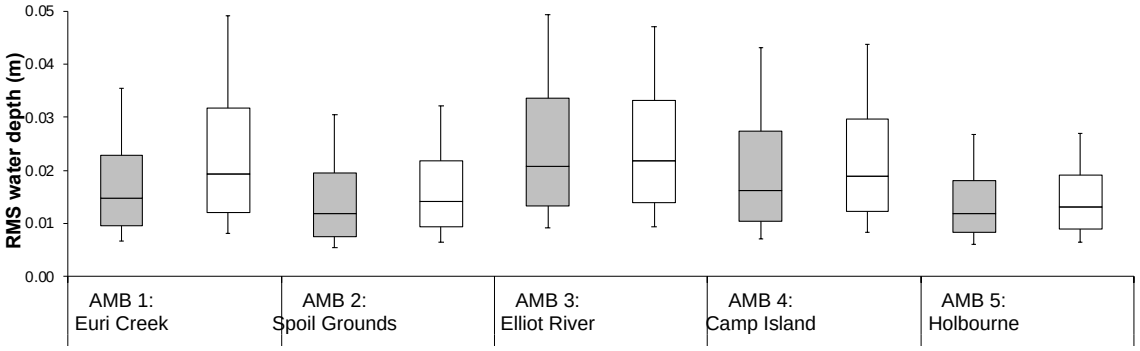

Figure 3.24 RMS box plots for AMB1-AMB5. Grey boxes represent the wet season (1 November-31 March) while white boxes represent the dry season (15 July-31 Oct and 1 April-31 July).

SSC

Turbidity was largely similar between seasons (Figure 3.25). Several sites had marginally higher turbidity in the wet season (AMB1, AMB2, AMB3), but there was considerable overlap with the dry season data. AMB4 and AMB5 may exhibit the opposite trend, with slightly higher turbidity in the dry season.

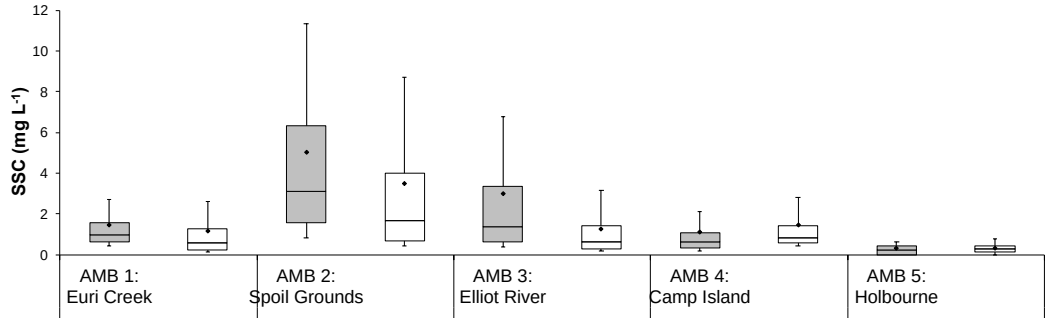

Figure 3.25 SSC box plots for AMB1-AMB5. Grey boxes represent the wet season (1 November-31 March) while white boxes represent the dry season (15 July-31 Oct and 1 April-31 July).

Deposition rate

Only AMB3 showed evidence of increased deposition during the wet season (Figure 3.26). AMB2 had higher deposition rates in the dry season compared to the wet season.

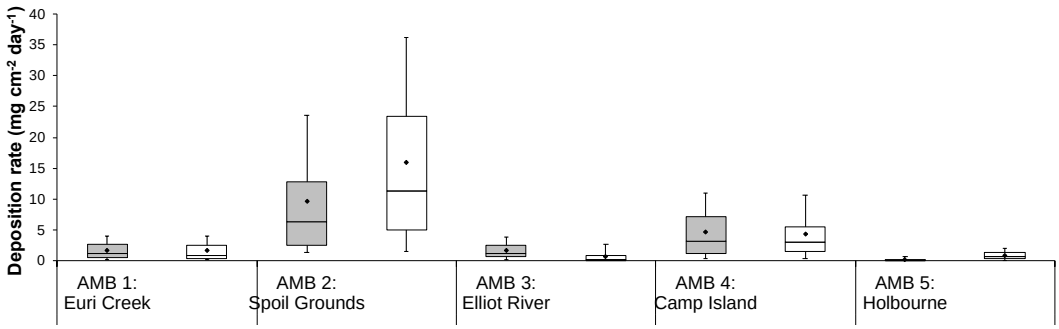

Figure 3.26 Deposition box plots for AMB1-AMB5. Grey boxes represent the wet season (1 November-31 March) while white boxes represent the dry season (15 July-31 Oct and 1 April-31 July).

Total daily PAR

Photosynthetically available radiation (PAR) could differ between seasons due to longer daylength or increased cloud cover during the wet season. Daily PAR did not exhibit a consistent difference between seasons (Figure 3.27). Daily PAR totals for AMB1 and AMB2 were generally similar between wet and dry seasons, except for AMB5 where PAR was higher in the wet season, which was also observed in 2019. These sites suggest that there isn't a general pattern in PAR between seasons. Differences in depth, distance from the coast, and distance from river mouths may influence how PAR differs between seasons at a given location.

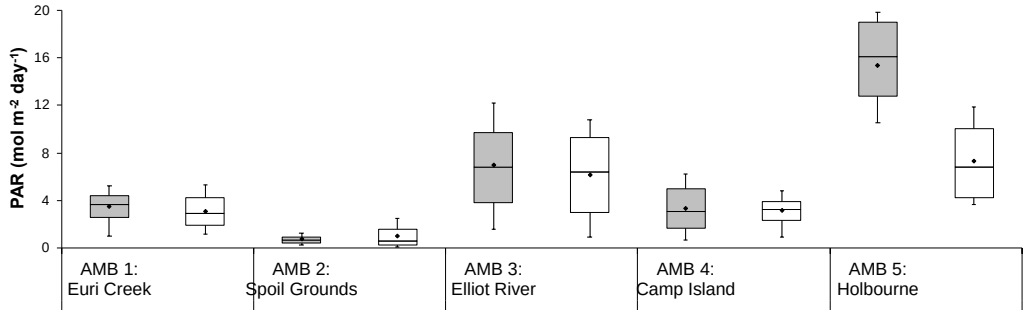

Figure 3.27 PAR box plots for AMB1-AMB5. Gray boxes represent the wet season (1 November-31 March) while white boxes represent the dry season (15 July-31 Oct and 1 April-31 July).

Water temperature

There is a clear difference in water temperature between the wet and dry seasons (Figure 3.28). Temperatures are higher during the wet season, with median temperatures between 28 and 29 °C at all sites. Median dry season temperatures ranged from 22 to 23 °C.

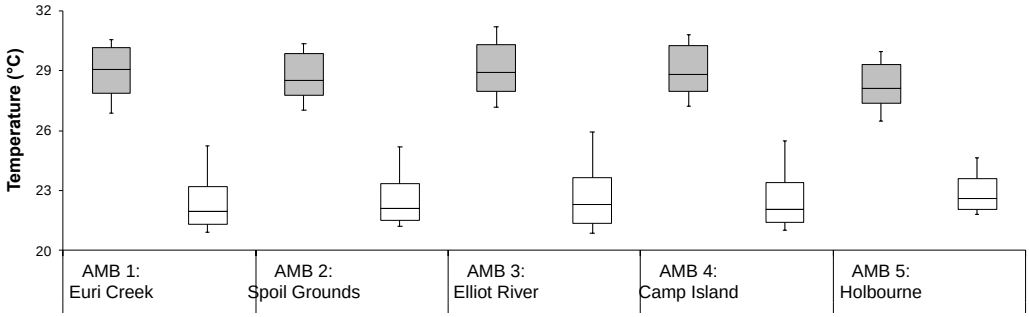

Figure 3.28 Temperature boxplots for AMB1-AMB5. Gray boxes represent the wet season (1 November-31 March) while white boxes represent the dry season (15 July-31 Oct and 1 April-31 July).

3.4 Current meter

Current meter data was collected at all five sites. Marotte HS current meter instruments were deployed for the full monitoring period from July 2019 to July 2020 for AMB 1-5. Data is available for the entire period for AMB 1, 3, and 5. For AMB2, data is available for July through April; for AMB5, data is available from July through February.

The current meter data indicates the prominent current direction, current velocity, and temperature 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 which provide a visual representation of the frequency of current velocity, direction, and temperature.

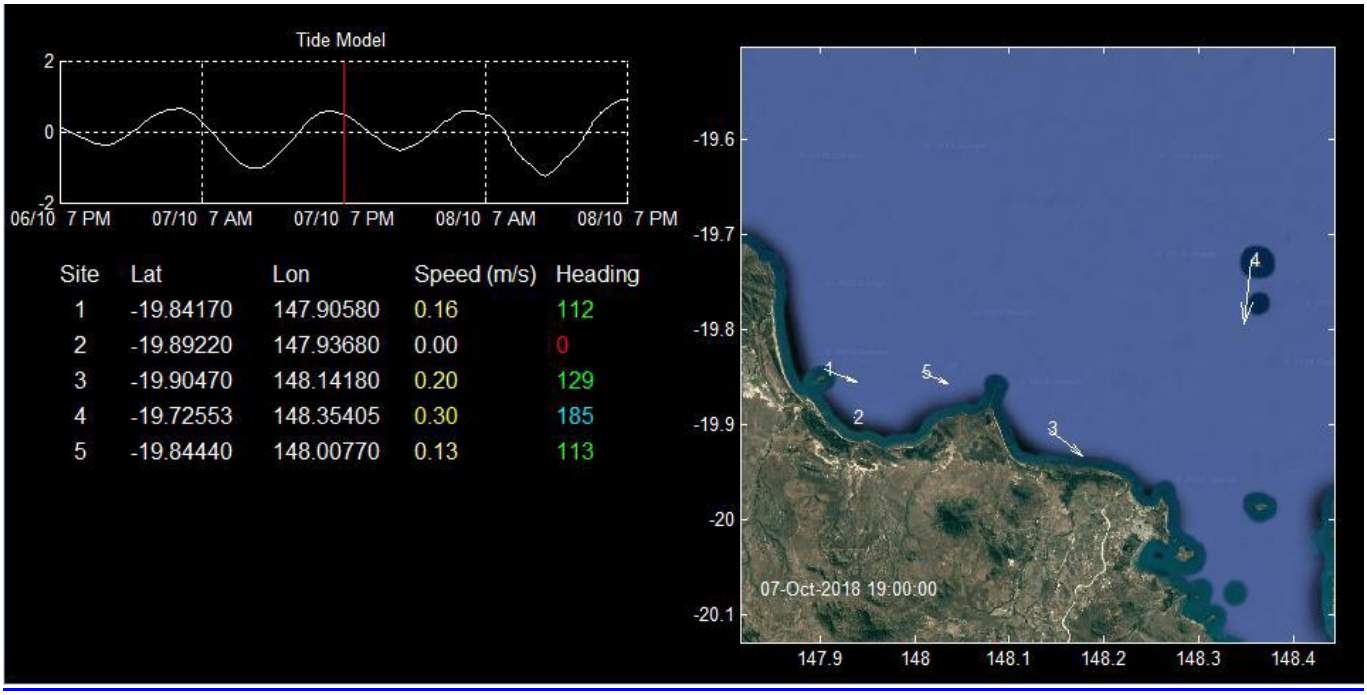

Figure 3.29 Example screengrab from current speed and direction animations.

The predominant currents were from the northwest and southeast for the sites closest to the coast (AMB 1, 3, and 4), indicating flow along the coast (Figure 3.30). AMB2 is deeper and experienced currents equally from all directions, likely due to tidal influence. AMB5 is farthest from shore and experienced predominantly currents from the south. In general, faster current speeds were more frequently observed in the prevailing current direction (Figure 3.31). The warmest temperatures were recorded at AMB1 but did not show a directional pattern. Warm currents originated from the south at AMB4 but from the northeast at AMB2.

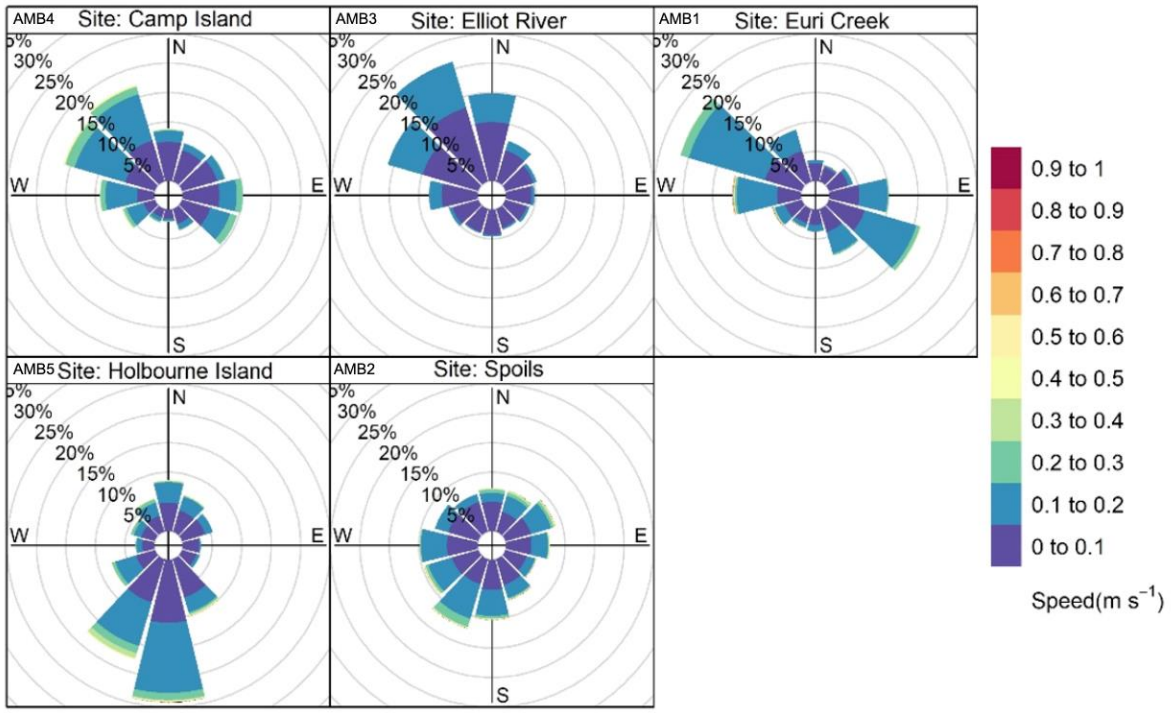

Figure 3.30 Rose plot of the distribution of current direction for the monitoring period from July 2019 to July 2020. The length of each bar indicates the proportion of measurement in each direction. Within each bar, colours indicate the proportion of measurement in each current speed category.

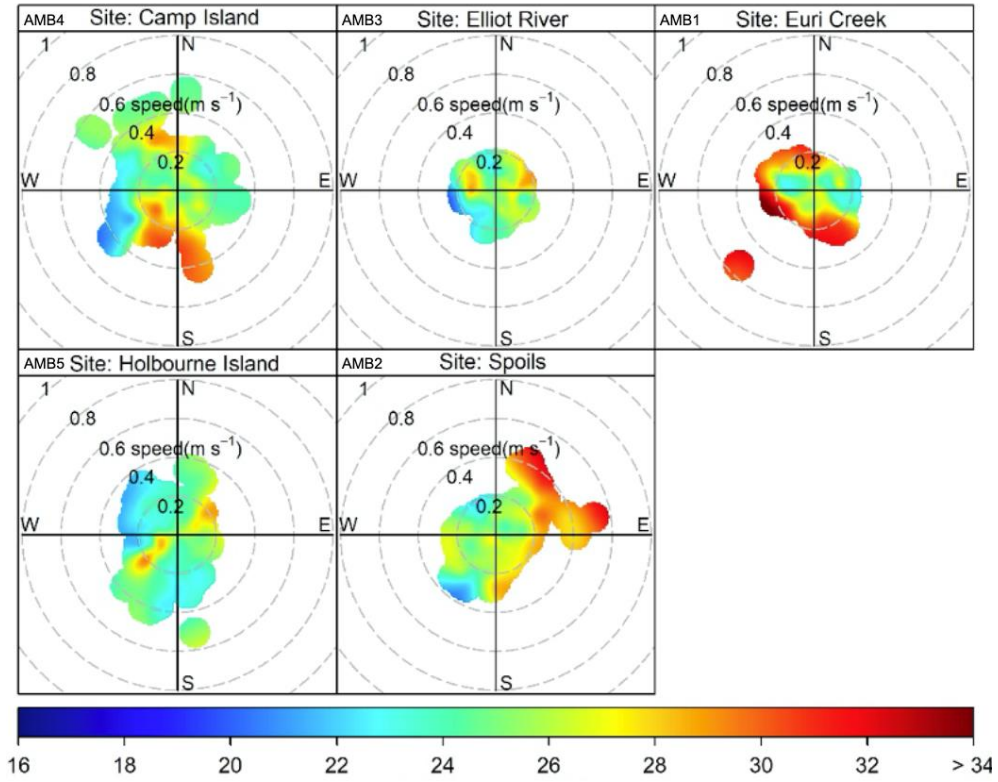

Figure 3.31 Current speed and temperature for the monitoring period from July 2019 to July 2020. The position of the data indicates current direction and the distance from the origin indicates current speed (m s^{-1}). Data points are coloured according to water temperature (°C).

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

4.1.1 Climatic conditions

- The total wet season rainfall of Bowen region during 2019-2020 was average compared to wet season totals since 1961.
- Inter-annual variability of wet season rainfall and catchment discharge to the coastal ocean highlights the necessity for a long-term commitment to ambient marine monitoring programs, as continued monitoring will allow changes in ambient environmental conditions due to differences in annual rainfall to be better understood.

4.1.2 Ambient water quality

- Water quality conditions were measured at all sites on a ~6 weekly basis. Parameters collected were water temperature, electrical conductivity, pH, dissolved oxygen and photosynthetically active radiation at three depths (surface, mid-water and bottom), along with Secchi disk depth.
- Seasonal differences in water quality were minor, except for temperature which was highest during the summer months.
- There was little difference in water temperature between the three depths examined, indicating that the water column was well mixed during each survey.
- Particulate nitrogen concentrations exceeded the guidelines throughout most of the 2019-2020 monitoring period.
- Chlorophyll-*a* concentrations exceeded the GBRMPA guideline trigger value in November 2019 and May 2020
- Lead, Nickel, and Arsenic were detected in water samples, although the concentrations were below relevant guideline values. No other metals were detected throughout the reporting period.
- Pesticides targeted for analysis were not detected above the Great Barrier Reef Marine Park guideline trigger values for 95% protection level. Hexazinone and Atrazine were present at low concentrations for all inshore sites in May 2020.

4.1.3 Sediment deposition and turbidity

- RMS water height values were mostly driven by weather events and this is clearly evident in the data as peaks in RMS water heights were 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 NTUe/SSC time series data at each site followed a typical pattern of low background values with recurring peak events. These peak events occurred at the same times at each site and coincided with peaks in RMS water height. This is a typical pattern which is similar to data collected in coastal locations in north Queensland.
- Time series deposition data shows 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.
- Current meter data indicates the prominent current direction and velocity at each site and shows that coastal current, tidal current or a combination of both influence current direction and magnitude.

4.1.4 Photosynthetically active radiation (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 experienced in the region. The data series here continues to increase, which is slowly providing a greater insight into trends, and whether these be tidally influenced or dependent on seasonality and cloud cover. Benthic PAR is also important to assess and validate NTUe sensor data.

4.2 Recommendations

4.2.1 Consolidation of the water quality loggers

- This monitoring program has been underway for three years, and should remain in place to continue to characterise and build a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities, but will also assist with future strategic planning and management.

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A1 APPENDIX

A1.1 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/cm2 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 r2 value equal to or greater than 0.9.

Light Calibration

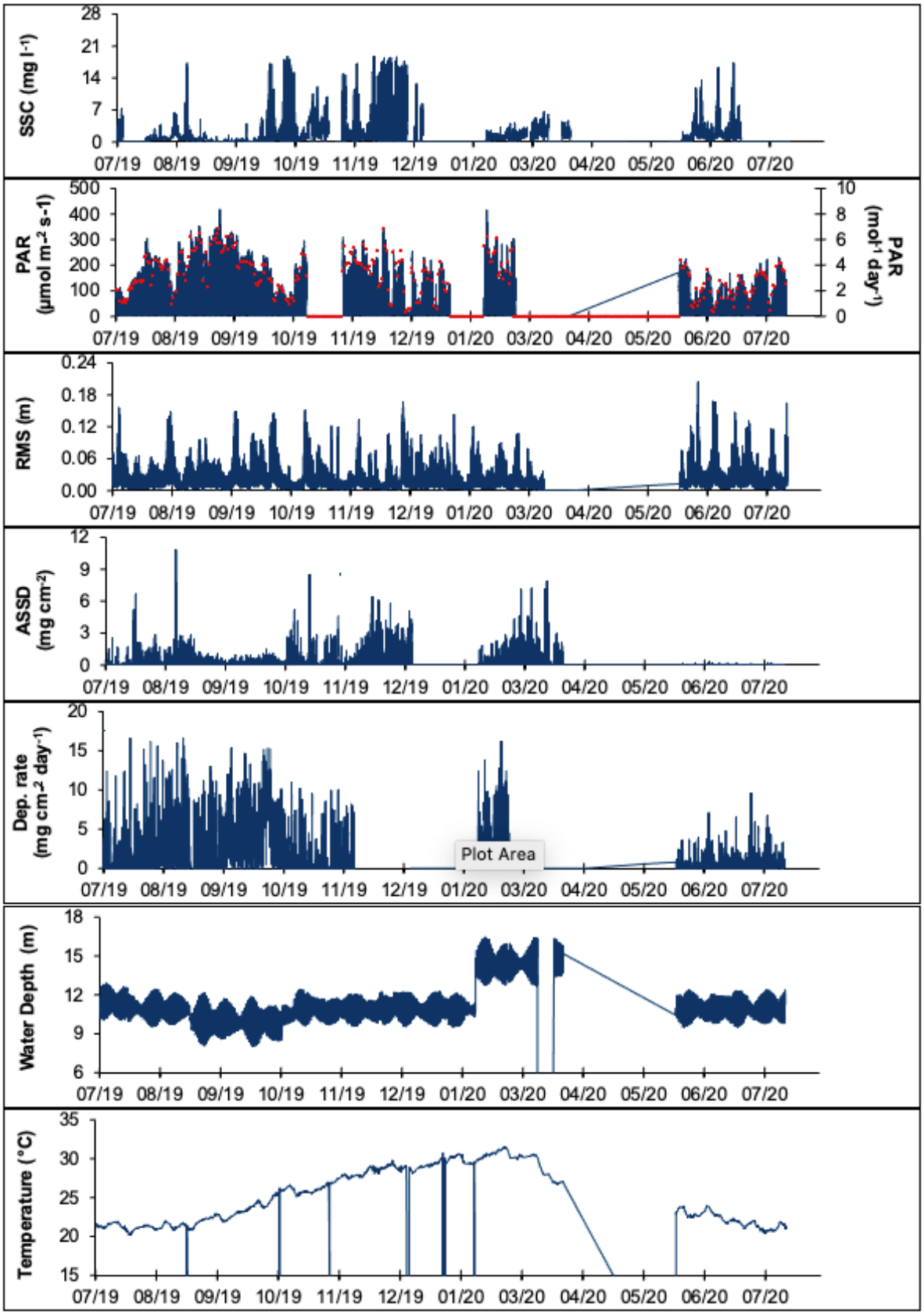
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration coefficient is used to ensure accurate reporting of PAR data. An infield 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

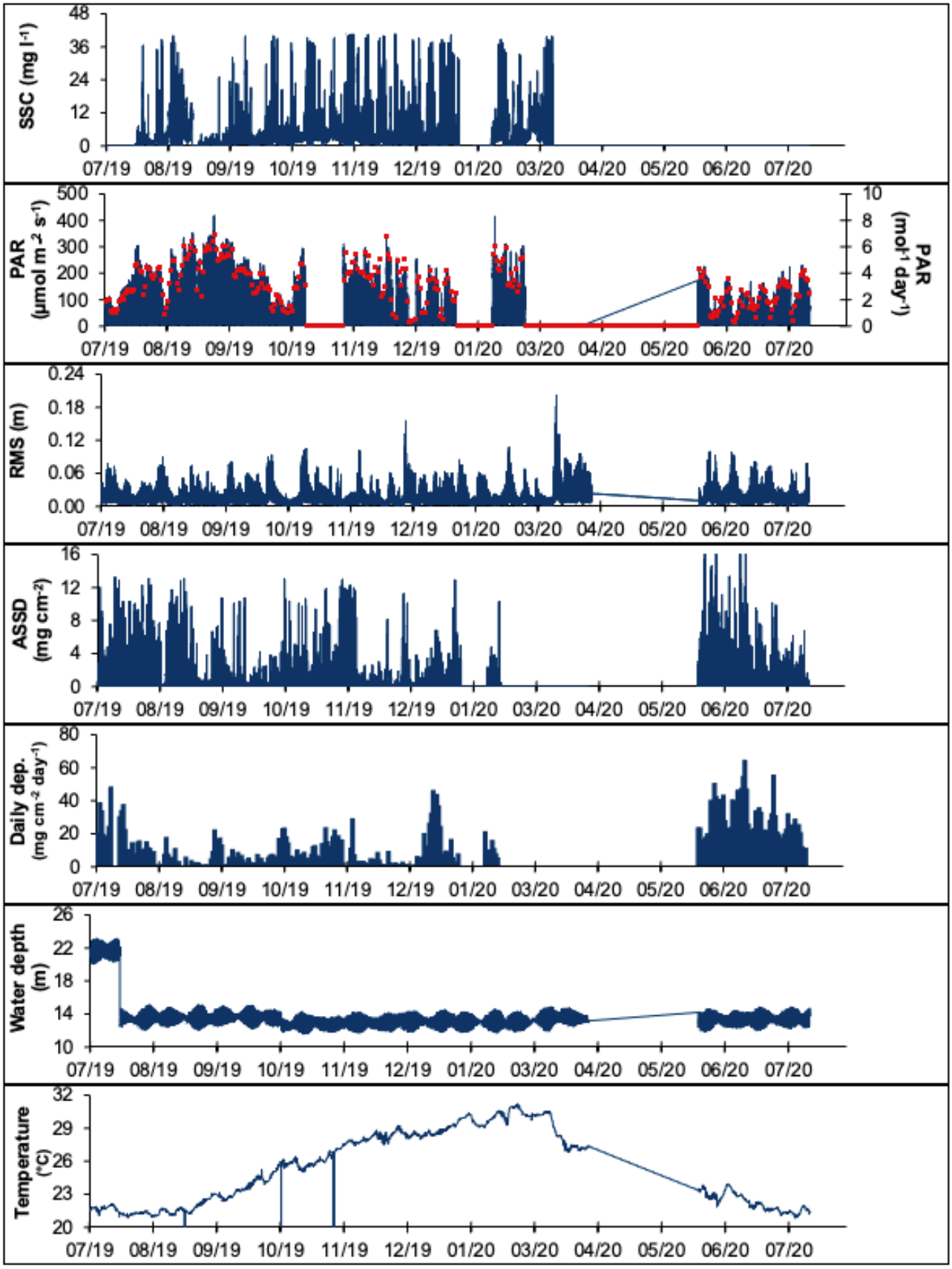
All pressure sensors are calibrated against a pressure gauge and the pressure is converted into depth in metres.

A1.2 Time series data

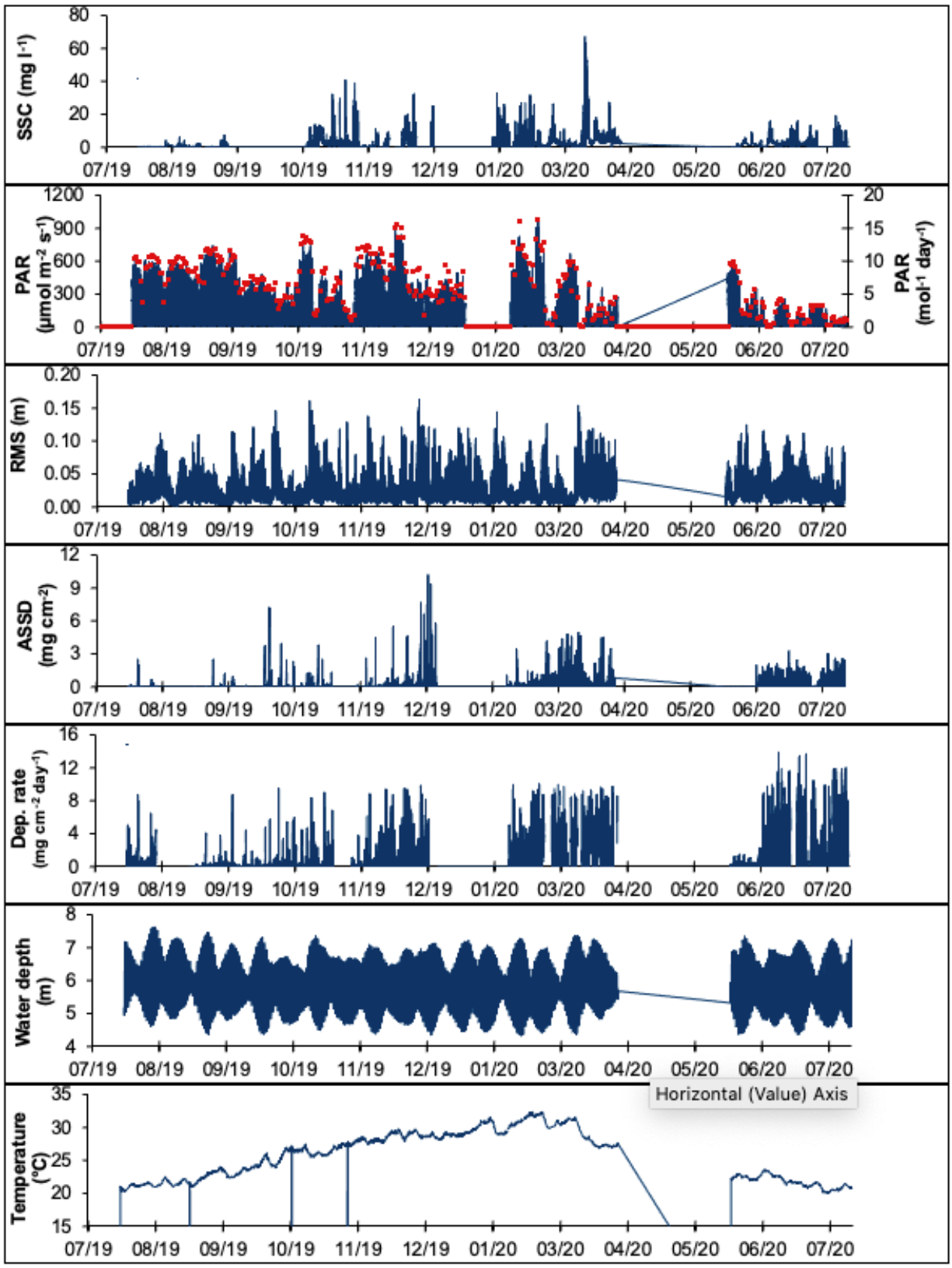
A1.2.1 AMB 1: Euri Creek



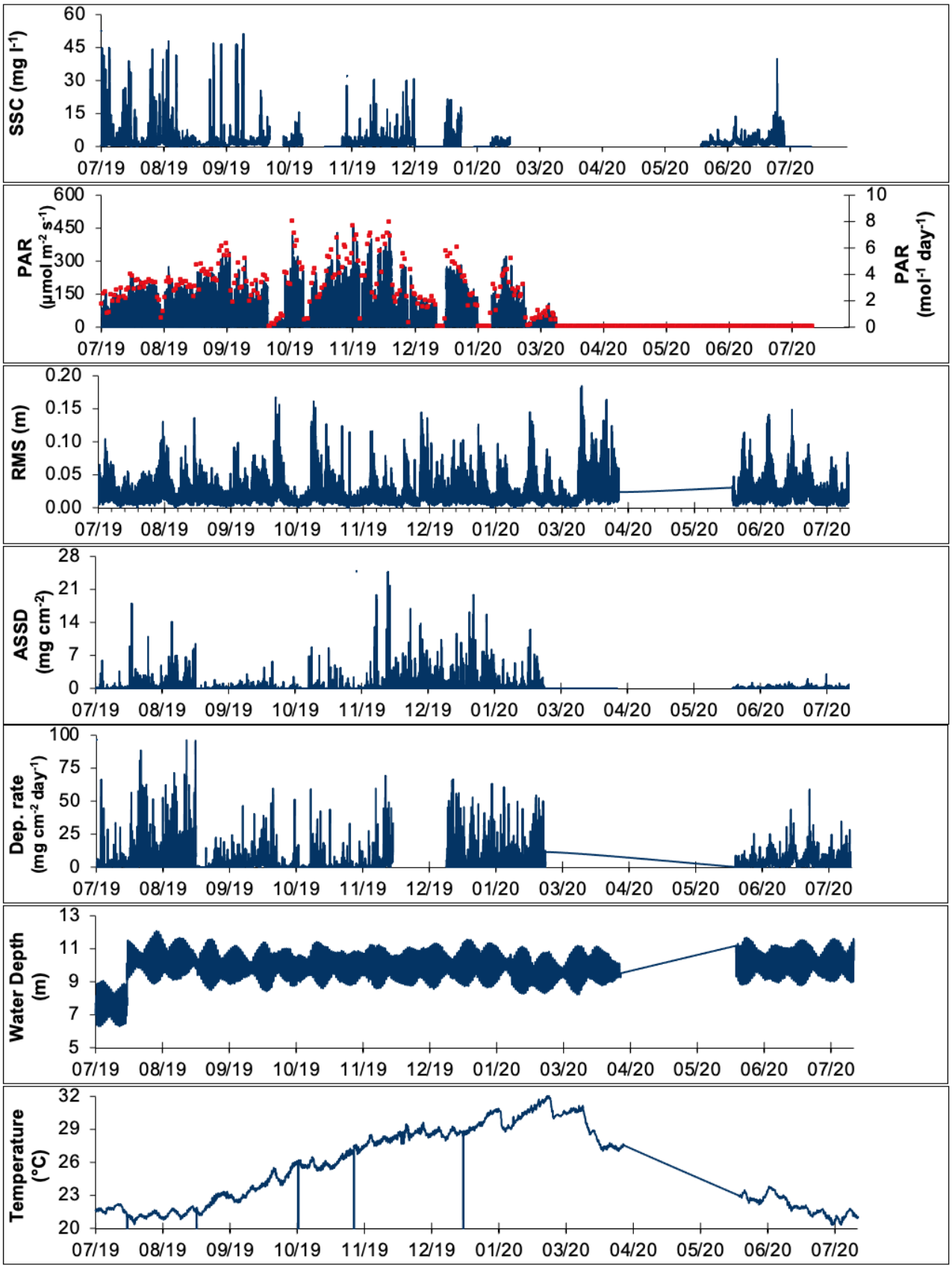
A1.2.2 AMB 2: Spoil Grounds



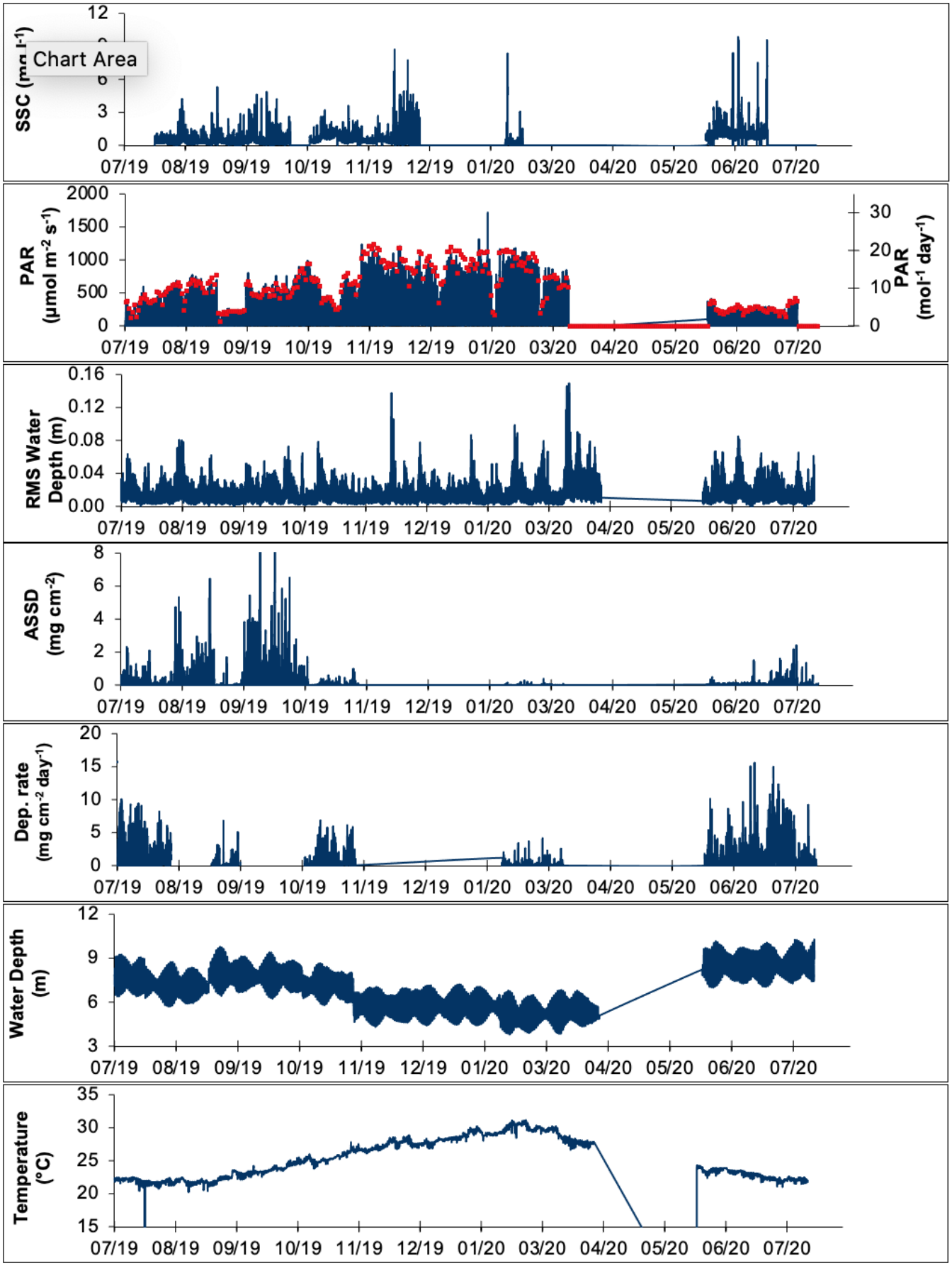
A1.2.3 AMB 3: Elliot River



A1.2.4 AMB 4: Camp Island



A1.2.5 AMB 5: Holbourne



A1.3 Summary of monthly statistics

A1.3.1 AMB 1: Euri Creek

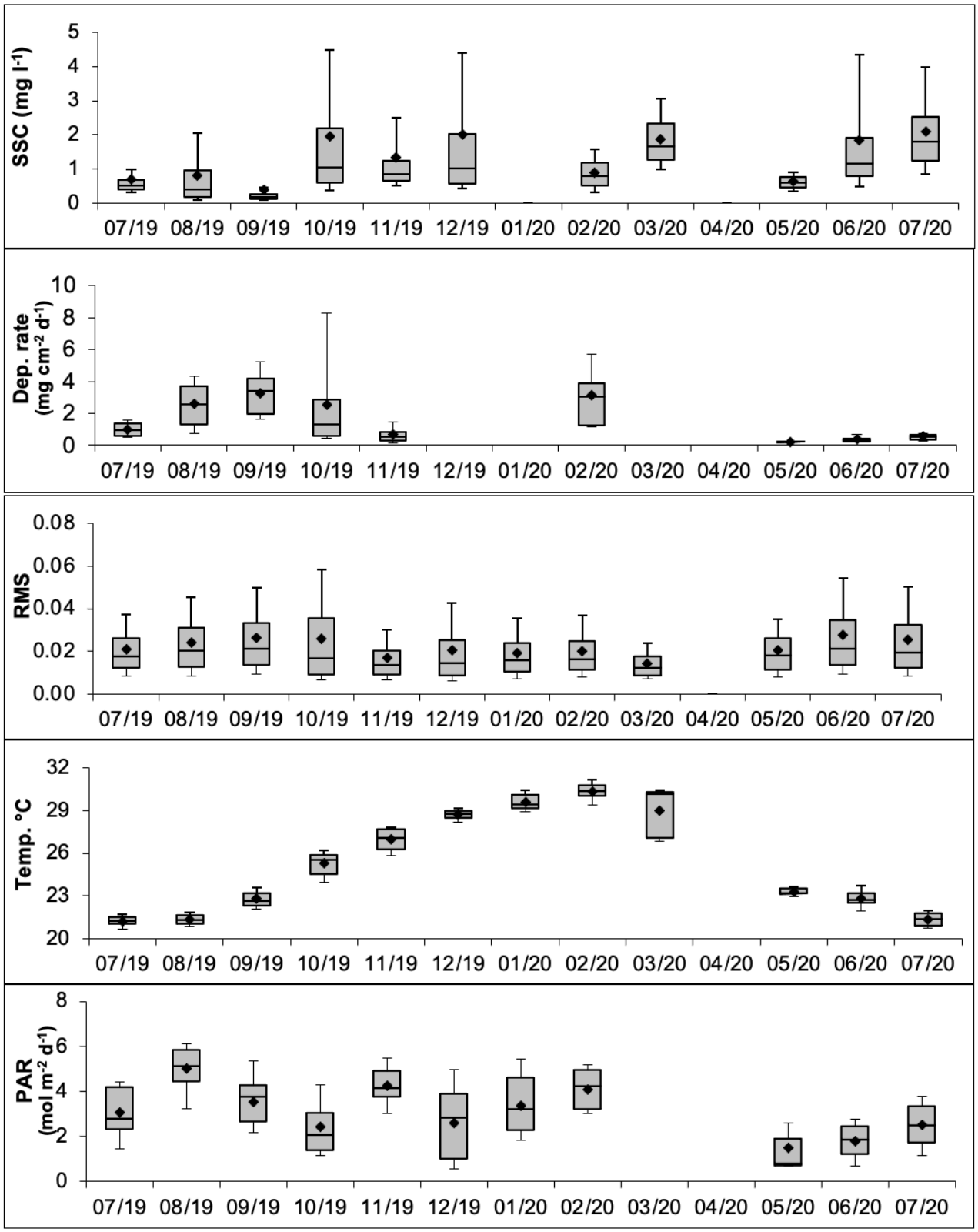
SCC (mg L^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.68	0.82	0.38	1.95	1.35	2.02		0.90	1.88		0.63	1.85	2.09
median	0.52	0.41	0.17	1.05	0.84	1.02		0.80	1.67		0.60	1.16	1.81
min	0.16	0.03	0.03	0.15	0.15	0.05		0.05	0.29		0.16	0.02	0.43
lower	0.41	0.17	0.11	0.59	0.64	0.58		0.52	1.27		0.46	0.79	1.23
upper	0.69	0.95	0.25	2.18	1.25	2.04		1.19	2.33		0.77	1.91	2.53
max	7.40	16.98	17.22	18.67	18.44	18.55		4.15	6.61		2.34	17.32	7.84
90^{th} %	1.00	2.04	0.46	4.50	2.49	4.40		1.57	3.05		0.90	4.34	3.99
10^{th} %	0.32	0.10	0.09	0.36	0.50	0.42		0.30	0.99		0.35	0.48	0.85
n	2491	4450	4309	3710	3009	2627	0	3396	1964	0	215	4313	294
St. Dev	0.65	1.20	1.01	2.51	1.67	2.85		0.52	0.84		0.25	2.02	1.32
St. Error	0.01	0.02	0.02	0.04	0.03	0.06		0.01	0.02		0.02	0.03	0.08

Daily dep. (mg cm^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	1.00	2.59	3.24	2.51	0.70			3.11			0.18	0.38	0.54
median	0.94	2.57	3.40	1.33	0.54			3.03			0.20	0.37	0.51
min	0.13	0.42	0.41	0.05	0.02			0.83			0.11	0.04	0.17
lower	0.60	1.32	2.00	0.61	0.29			1.28			0.15	0.25	0.35
upper	1.37	3.72	4.18	2.87	0.85			3.89			0.21	0.43	0.64
max	2.07	5.53	5.85	8.98	2.32			8.47			0.23	1.35	1.59
90^{th} %	1.58	4.32	5.24	8.26	1.43			5.73			0.22	0.66	0.73
10^{th} %	0.49	0.72	1.67	0.46	0.15			1.17			0.13	0.11	0.28
n	31	30	30	31	23	0	0	19	0	0	3	30	31
St. Dev	0.47	1.43	1.40	2.75	0.59			2.07			0.06	0.27	0.30
St. Error	0.08	0.26	0.25	0.49	0.12			0.47			0.04	0.05	0.05

RMS depth	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.021	0.024	0.026	0.026	0.017	0.020	0.019	0.020	0.014		0.021	0.028	0.025
median	0.018	0.020	0.021	0.017	0.014	0.014	0.016	0.016	0.012		0.018	0.021	0.020
min	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.005	0.000	0.000
lower	0.012	0.013	0.014	0.009	0.009	0.009	0.010	0.011	0.009		0.012	0.014	0.012
upper	0.026	0.031	0.033	0.036	0.021	0.025	0.024	0.025	0.017		0.026	0.035	0.032
max	0.156	0.146	0.149	0.151	0.134	0.167	0.143	0.108	0.079		0.076	0.205	0.165
90^{th} %	0.037	0.045	0.050	0.058	0.030	0.043	0.035	0.037	0.024		0.035	0.054	0.050
10^{th} %	0.008	0.008	0.009	0.007	0.006	0.006	0.007	0.008	0.007		0.008	0.009	0.009
n	4463	4461	4320	4459	4242	4464	4462	4112	1360	0	216	4320	4464
St. Dev	0.014	0.017	0.018	0.023	0.012	0.018	0.013	0.013	0.008		0.012	0.022	0.019
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.001	0.000	0.000

Temp. (°C)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	21.2	21.3	22.8	25.3	27.0	28.7	29.6	30.4	29.0		23.3	22.8	21.3
median	21.3	21.3	22.7	25.5	27.1	28.8	29.5	30.4	30.2		23.2	22.7	21.4
min	20.1	20.7	21.8	23.7	25.4	27.6	28.5	29.1	26.6		22.9	21.6	20.3
lower	21.0	21.0	22.3	24.5	26.3	28.5	29.1	30.0	27.1		23.1	22.5	20.9
upper	21.5	21.6	23.2	25.9	27.7	29.0	30.1	30.8	30.3		23.5	23.2	21.7
max	22.0	22.3	24.3	26.6	28.1	29.8	30.8	31.7	30.7		23.7	24.0	22.3
90^{th} %	21.7	21.9	23.6	26.2	27.8	29.1	30.4	31.2	30.5		23.7	23.7	22.0
10^{th} %	20.6	20.9	22.1	24.0	25.8	28.2	28.9	29.4	26.9		23.0	21.9	20.7
n	4463	4455	4320	4451	4234	4282	4443	4107	2537	0	209	4320	4464
St. Dev	0.4	0.4	0.6	0.8	0.8	0.4	0.6	0.6	1.6		0.2	0.6	0.5
St. Error	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0

Light (mol m^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	3.05	5.03	3.53	2.43	4.25	2.61	3.38	4.10			1.50	1.80	2.52
median	2.80	5.14	3.78	2.08	4.15	2.84	3.23	4.24			0.80	1.85	2.49
min	0.95	2.25	1.15	0.98	2.20	0.25	0.52	2.59			0.66	0.25	0.38
lower	2.32	4.47	2.66	1.40	3.77	1.01	2.30	3.21			0.73	1.23	1.76
upper	4.18	5.86	4.26	3.04	4.90	3.92	4.60	4.95			1.92	2.45	3.34
max	4.74	6.89	6.11	4.76	6.82	5.48	6.13	5.99			3.05	3.56	4.17
90^{th} %	4.42	6.12	5.36	4.31	5.47	4.99	5.46	5.18			2.60	2.78	3.79
10^{th} %	1.44	3.26	2.20	1.17	3.03	0.56	1.84	3.01			0.69	0.70	1.15
n	31	31	30	15	25	31	11	15	0	0	3	30	25
St. Dev	1.14	1.15	1.25	1.26	1.03	1.65	1.70	1.00			1.34	0.84	1.07
St. Error	0.20	0.21	0.23	0.32	0.21	0.30	0.51	0.26			0.77	0.15	0.21


SSC (mg l-1)
0
1
2
3
4
5
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Dep. rate (mg cm-2 d-1)
0
2
4
6
8
10
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
RMS
0.00
0.02
0.04
0.06
0.08
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Temp. °C
20
23
26
29
32
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
PAR (mol m-2 d-1)
0
2
4
6
8
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20

A1.3.2 AMB 2: Spoil Grounds

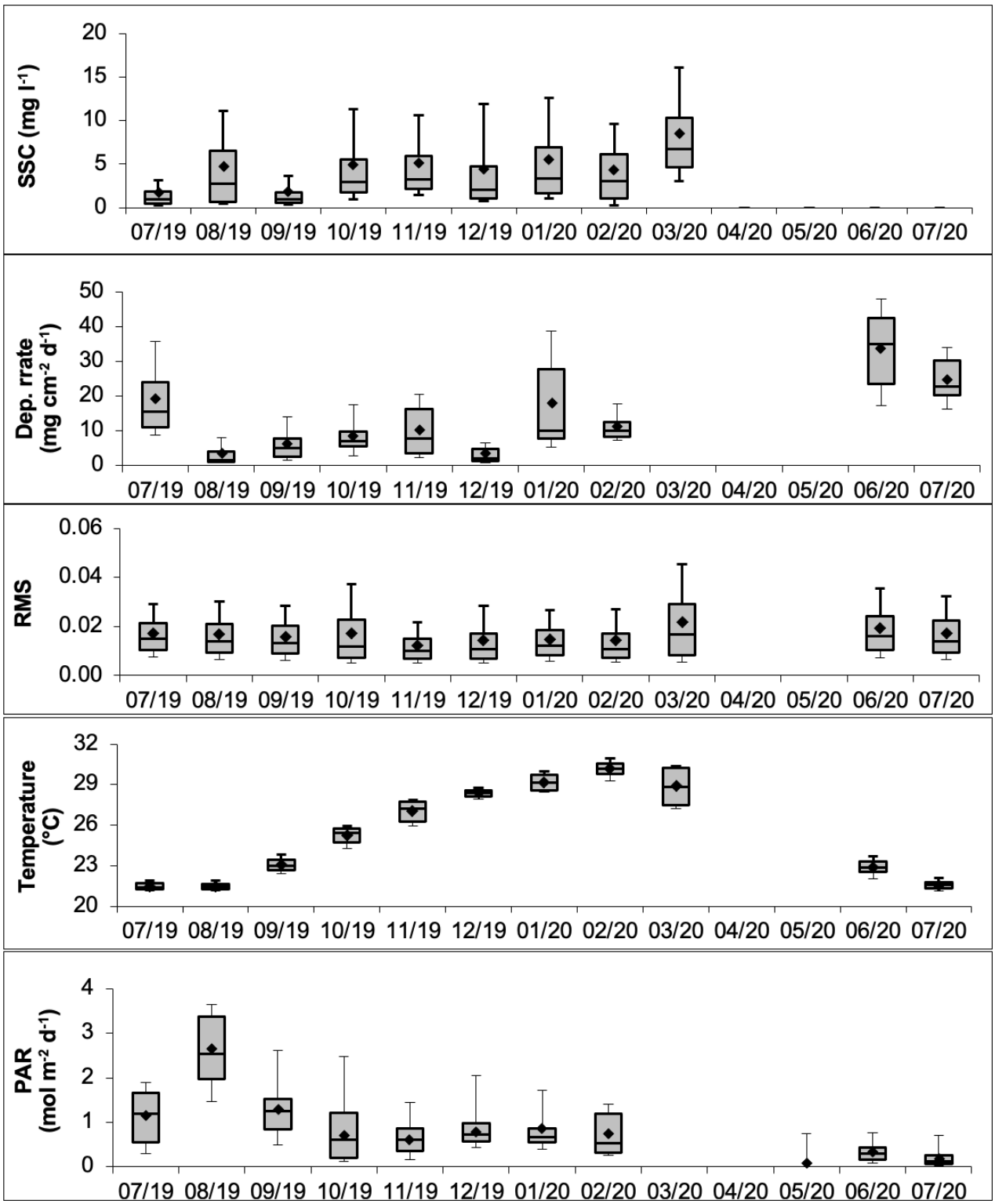
SCC (mg L^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	1.78	4.66	1.83	4.92	5.12	4.46	5.53	4.34	8.44				
median	0.95	2.73	0.94	2.91	3.24	2.00	3.31	3.09	6.75				
min	0.01	0.01	0.00	0.01	0.43	0.07	0.17	0.07	0.93				
lower	0.49	0.66	0.57	1.70	2.10	1.09	1.64	1.06	4.64				
upper	1.85	6.53	1.77	5.54	5.89	4.69	6.89	6.17	10.35				
max	36.59	40.06	39.95	39.99	40.63	40.72	40.41	38.73	39.91				
90^{th} percentile	3.13	11.06	3.61	11.30	10.58	11.94	12.57	9.66	16.10				
10^{th} percentile	0.30	0.40	0.34	0.90	1.46	0.72	1.03	0.20	3.02				
n	2000	3736	4271	4350	4165	4318	2148	3794	1163	0	0	0	0
St. Dev	3.15	5.72	3.17	5.75	5.49	6.15	6.30	4.57	6.16				
St. Error	0.07	0.09	0.05	0.09	0.08	0.09	0.14	0.07	0.18				

Dep. rate (mg cm^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	19.20	3.49	6.36	8.66	10.32	3.58	17.99	11.43				33.65	24.69
median	15.43	1.61	5.04	7.08	7.73	2.03	9.93	10.07				34.90	22.72
min	2.39	0.15	0.32	1.15	1.27	0.47	2.61	5.63				7.20	7.59
lower	10.99	1.03	2.57	5.52	3.47	1.32	7.84	8.23				23.58	20.15
upper	23.90	3.97	7.89	9.85	16.20	4.72	27.77	12.60				42.60	30.27
max	48.66	18.22	22.70	23.86	29.49	20.53	46.54	21.64				64.91	55.85
90^{th} percentile	35.85	8.15	13.93	17.59	20.57	6.63	38.77	17.89				48.09	34.11
10^{th} percentile	8.90	0.88	1.46	2.86	2.31	0.81	5.38	7.36				17.15	16.34
n	27	31	30	31	27	31	19	8	0	0	0	30	31
St. Dev	11.40	3.99	5.40	5.76	7.93	3.98	14.18	5.16				13.58	9.12
St. Error	2.19	0.72	0.99	1.03	1.53	0.71	3.25	1.82				2.48	1.64

RMS depth	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.017	0.017	0.016	0.017	0.012	0.014	0.015	0.014	0.022			0.019	0.017
median	0.015	0.014	0.013	0.012	0.010	0.011	0.012	0.011	0.017			0.016	0.014
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000
lower	0.011	0.009	0.009	0.007	0.007	0.007	0.008	0.007	0.008			0.011	0.009
upper	0.021	0.021	0.020	0.023	0.015	0.017	0.019	0.017	0.029			0.024	0.022
max	0.076	0.090	0.081	0.105	0.102	0.155	0.084	0.107	0.201			0.099	0.081
90th percentile	0.029	0.030	0.029	0.037	0.022	0.028	0.027	0.027	0.045			0.036	0.032
10th percentile	0.008	0.007	0.006	0.005	0.005	0.005	0.006	0.005	0.006			0.007	0.007
n	4462	4462	4320	4463	4242	4464	4462	4174	3530	0	106	4320	4464
St. Dev	0.009	0.010	0.010	0.014	0.008	0.011	0.009	0.011	0.018			0.013	0.011
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000

Temp. (°C)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	21.48	21.47	23.07	25.25	27.02	28.36	29.16	30.16	28.91			22.88	21.57
median	21.41	21.45	22.98	25.44	27.22	28.37	29.17	30.16	28.82			22.85	21.58
min	20.77	20.85	22.09	23.91	25.46	27.42	28.23	29.03	26.82			21.63	20.79
lower	21.24	21.24	22.64	24.74	26.29	28.14	28.58	29.78	27.45			22.54	21.34
upper	21.70	21.64	23.42	25.73	27.71	28.55	29.72	30.57	30.21			23.29	21.77
max	22.23	22.43	24.69	26.43	28.24	29.30	30.39	31.30	30.60			24.03	22.38
90th percentile	21.93	21.87	23.81	25.93	27.89	28.77	30.01	30.94	30.34			23.68	22.07
10th percentile	21.12	21.12	22.44	24.25	25.96	27.95	28.43	29.27	27.22			22.04	21.14
n	4458	4448	4320	4453	4234	4464	4462	4174	3530	0	106	4320	4464
St. Dev	0.30	0.30	0.53	0.62	0.76	0.33	0.61	0.57	1.30			0.56	0.33
St. Error	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.02			0.01	0.00

Light (mol quanta m^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	1.17	2.66	1.29	0.70	0.61	0.78	0.84	0.73			0.08	0.33	0.17
median	1.20	2.55	1.24	0.61	0.61	0.72	0.66	0.54			0.08	0.29	0.12
min	0.16	0.76	0.03	0.00	0.02	0.01	0.27	0.15			0.08	0.03	0.01
lower	0.54	1.98	0.85	0.20	0.36	0.57	0.55	0.32			0.08	0.17	0.07
upper	1.65	3.38	1.52	1.22	0.87	0.99	0.87	1.19			0.08	0.44	0.26
max	2.36	5.03	2.71	2.14	1.45	1.64	2.96	1.67			0.08	0.99	0.46
90^{th} percentile	2.01	3.87	2.42	1.59	1.00	1.18	1.63	1.50			0.08	0.62	0.40
10^{th} percentile	0.29	1.46	0.49	0.11	0.16	0.44	0.39	0.25			0.08	0.08	0.03
n	31	29	30	31	30	31	23	27	0	0	1	30	25
St. Dev	0.68	1.01	0.70	0.58	0.36	0.34	0.62	0.49				0.23	0.14
St. Error	0.12	0.19	0.13	0.10	0.07	0.06	0.13	0.09				0.04	0.03


SSC (mg l-1)
20
15
10
5
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Dep. rrate (mg cm-2 d-1)
50
40
30
20
10
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
RMS
0.06
0.04
0.02
0.00
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Temperature (°C)
32
29
26
23
20
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
PAR (mol m-2 d-1)
4
3
2
1
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20

A1.3.3 AMB 3: Elliot River

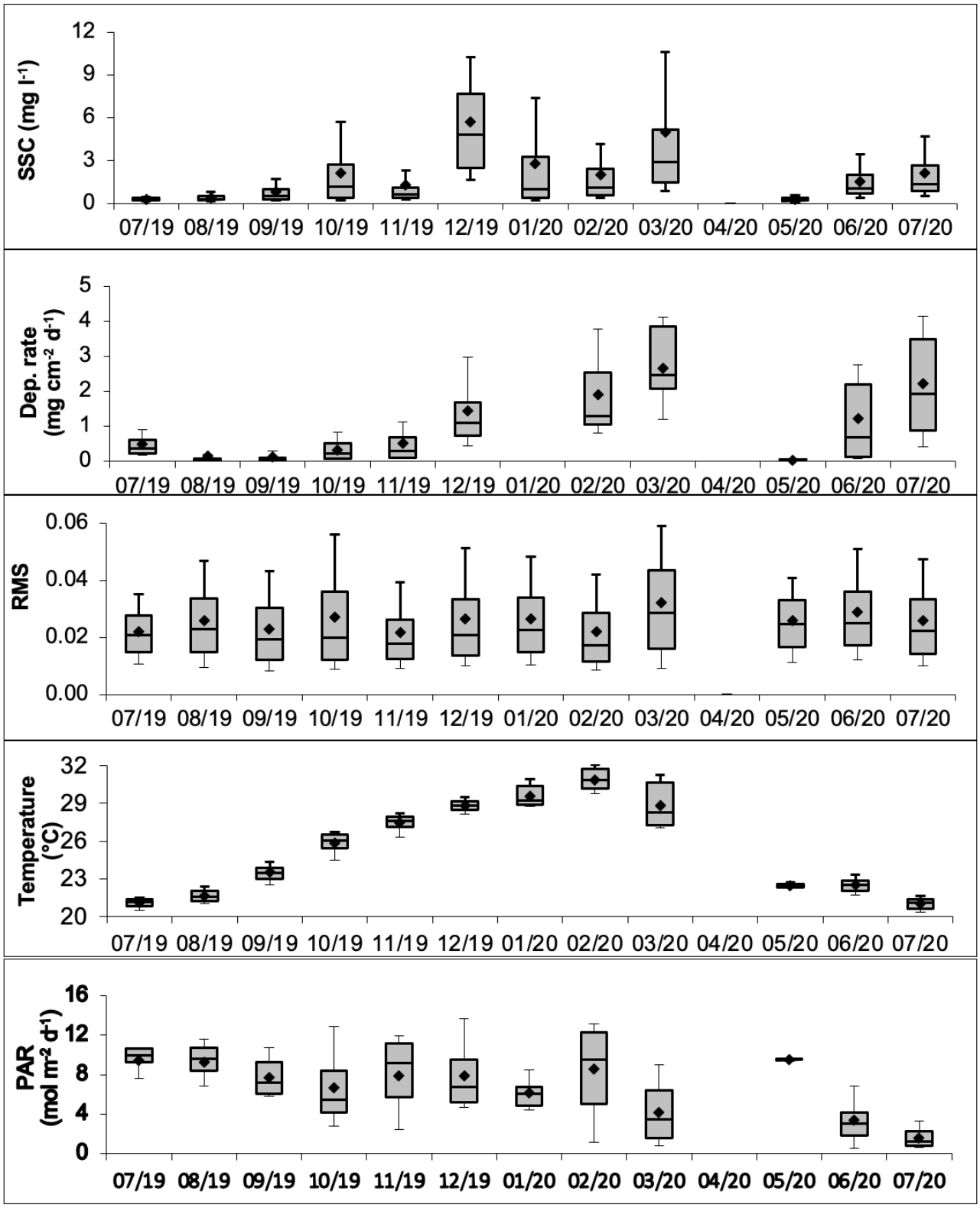
SCC (mg L^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.30	0.41	0.79	2.12	1.26	5.73	2.75	1.99	4.98		0.30	1.55	2.13
median	0.30	0.30	0.50	1.15	0.65	4.79	0.96	1.14	2.90		0.24	1.04	1.37
min	0.07	0.04	0.05	0.07	0.00	0.01	0.00	0.06	0.00		0.06	0.02	0.19
lower	0.22	0.21	0.27	0.37	0.41	2.47	0.39	0.60	1.47		0.16	0.71	0.85
upper	0.38	0.49	0.97	2.70	1.10	7.66	3.24	2.42	5.20		0.41	1.99	2.64
max	1.25	6.20	7.75	32.12	40.76	32.40	32.85	31.39	66.85		0.83	15.75	18.98
90^{th} percentile	0.44	0.83	1.71	5.69	2.32	10.28	7.40	4.13	10.63		0.56	3.42	4.71
10^{th} percentile	0.13	0.16	0.18	0.24	0.25	1.66	0.19	0.40	0.88		0.12	0.39	0.53
n	2073	4179	358	2478	3311	506	1119	3711	4450	0	364	4317	2872
St. Dev	0.12	0.39	0.91	2.74	2.58	4.42	4.21	2.62	6.88		0.17	1.42	2.05
St. Error	0.00	0.01	0.05	0.06	0.04	0.20	0.13	0.04	0.10		0.01	0.02	0.04

Daily dep. rate (mg cm^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.48	0.16	0.14	0.33	0.52	1.45		1.89	2.66		0.04	1.23	2.21
median	0.37	0.04	0.07	0.23	0.29	1.10		1.31	2.46		0.04	0.69	1.94
min	0.13	0.01	0.01	0.02	0.03	0.38		0.62	0.09		0.02	0.04	0.24
lower	0.23	0.03	0.04	0.08	0.10	0.74		1.06	2.08		0.03	0.12	0.88
upper	0.61	0.07	0.11	0.51	0.69	1.69		2.54	3.87		0.05	2.19	3.50
max	1.54	1.15	0.90	1.07	1.57	3.94		4.92	4.81		0.05	5.58	4.69
90^{th} percentile	0.90	0.20	0.29	0.84	1.14	2.99		3.78	4.12		0.05	2.76	4.15
10^{th} percentile	0.19	0.02	0.02	0.06	0.07	0.45		0.82	1.20		0.02	0.08	0.42
n	15	11	30	31	21	23	0	23	26	0	3	30	27
St. Dev	0.38	0.33	0.21	0.30	0.48	1.02		1.21	1.25		0.02	1.39	1.45
St. Error	0.10	0.10	0.04	0.05	0.10	0.21		0.25	0.25		0.01	0.25	0.28

RMS depth	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.022	0.026	0.023	0.027	0.022	0.027	0.026	0.022	0.032		0.026	0.029	0.026
median	0.021	0.023	0.019	0.020	0.018	0.021	0.022	0.017	0.029		0.025	0.025	0.022
min	0.002	0.001	0.003	0.002	0.003	0.002	0.003	0.002	0.002		0.003	0.003	0.002
lower	0.015	0.015	0.012	0.012	0.012	0.014	0.015	0.012	0.016		0.017	0.017	0.014
upper	0.028	0.034	0.030	0.036	0.026	0.033	0.034	0.028	0.044		0.033	0.036	0.033
max	0.076	0.111	0.121	0.161	0.138	0.163	0.145	0.126	0.154		0.070	0.125	0.112
90th percentile	0.035	0.047	0.043	0.056	0.039	0.051	0.048	0.042	0.059		0.041	0.051	0.047
10th percentile	0.011	0.009	0.008	0.009	0.009	0.010	0.010	0.008	0.009		0.011	0.012	0.010
n	2074	4462	4320	4462	4318	4464	4462	4175	4464	0	365	4320	4464
St. Dev	0.010	0.015	0.015	0.020	0.015	0.019	0.016	0.015	0.020		0.012	0.016	0.016
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.001	0.000	0.000

Temp. (°C)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	21.08	21.65	23.50	25.85	27.44	28.80	29.56	30.87	28.80		22.44	22.50	21.01
median	21.17	21.55	23.47	26.02	27.61	28.81	29.21	30.83	28.25		22.43	22.52	21.08
min	20.11	20.74	22.15	23.86	25.52	27.52	28.31	28.86	26.78		22.04	21.12	19.90
lower	20.85	21.24	23.02	25.42	27.11	28.46	28.91	30.17	27.25		22.31	22.05	20.62
upper	21.37	22.05	23.90	26.48	27.95	29.13	30.38	31.73	30.62		22.60	22.84	21.40
max	21.90	23.24	25.88	27.49	28.68	29.91	31.63	32.59	31.66		22.77	23.81	21.89
90^{th} percentile	21.53	22.36	24.37	26.73	28.22	29.48	30.94	32.07	31.22		22.69	23.33	21.64
10^{th} percentile	20.48	21.03	22.51	24.46	26.32	28.15	28.71	29.77	27.05		22.25	21.69	20.33
n	2064	4454	4320	4455	4313	4464	4462	4170	4464	0	361	4320	4464
St. Dev	0.40	0.51	0.73	0.82	0.70	0.49	0.85	0.92	1.67		0.17	0.57	0.49
St. Error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02		0.01	0.01	0.01

Light (mol m^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	9.45	9.29	7.68	6.68	7.90	7.85	6.10	8.55	4.13		9.48	3.39	1.60
median	9.98	9.63	7.21	5.48	9.21	6.71	6.03	9.53	3.43		9.48	3.06	1.25
min	3.79	3.87	5.30	1.72	1.11	1.71	4.34	0.31	0.02		9.33	0.18	0.25
lower	9.24	8.38	6.02	4.13	5.74	5.19	4.84	5.06	1.52		9.40	1.80	0.82
upper	10.61	10.76	9.23	8.43	11.12	9.50	6.75	12.26	6.37		9.55	4.12	2.27
max	10.95	12.01	11.75	13.86	12.32	15.60	8.54	16.19	10.01		9.63	9.80	3.30
90^{th} percentile	10.71	11.56	10.72	12.84	11.91	13.62	8.47	13.14	8.97		9.60	6.82	3.27
10^{th} percentile	7.63	6.85	5.77	2.79	2.38	4.67	4.41	1.15	0.80		9.36	0.51	0.59
n	14	31	30	31	30	31	10	26	30	0	2	30	31
St. Dev	1.92	1.87	1.93	3.75	3.68	3.68	1.53	4.87	3.14		0.21	2.52	1.01
St. Error	0.51	0.34	0.35	0.67	0.67	0.66	0.48	0.95	0.57		0.15	0.46	0.18


SSC (mg l-1)
12
9
6
3
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Dep. rate (mg cm-2 d-1)
5
4
3
2
1
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
RMS
0.06
0.04
0.02
0.00
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
Temperature (°C)
32
29
26
23
20
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20
PAR (mol m-2 d-1)
16
12
8
4
0
07/19 08/19 09/19 10/19 11/19 12/19 01/20 02/20 03/20 04/20 05/20 06/20 07/20

A1.3.4 AMB 4: Camp Island

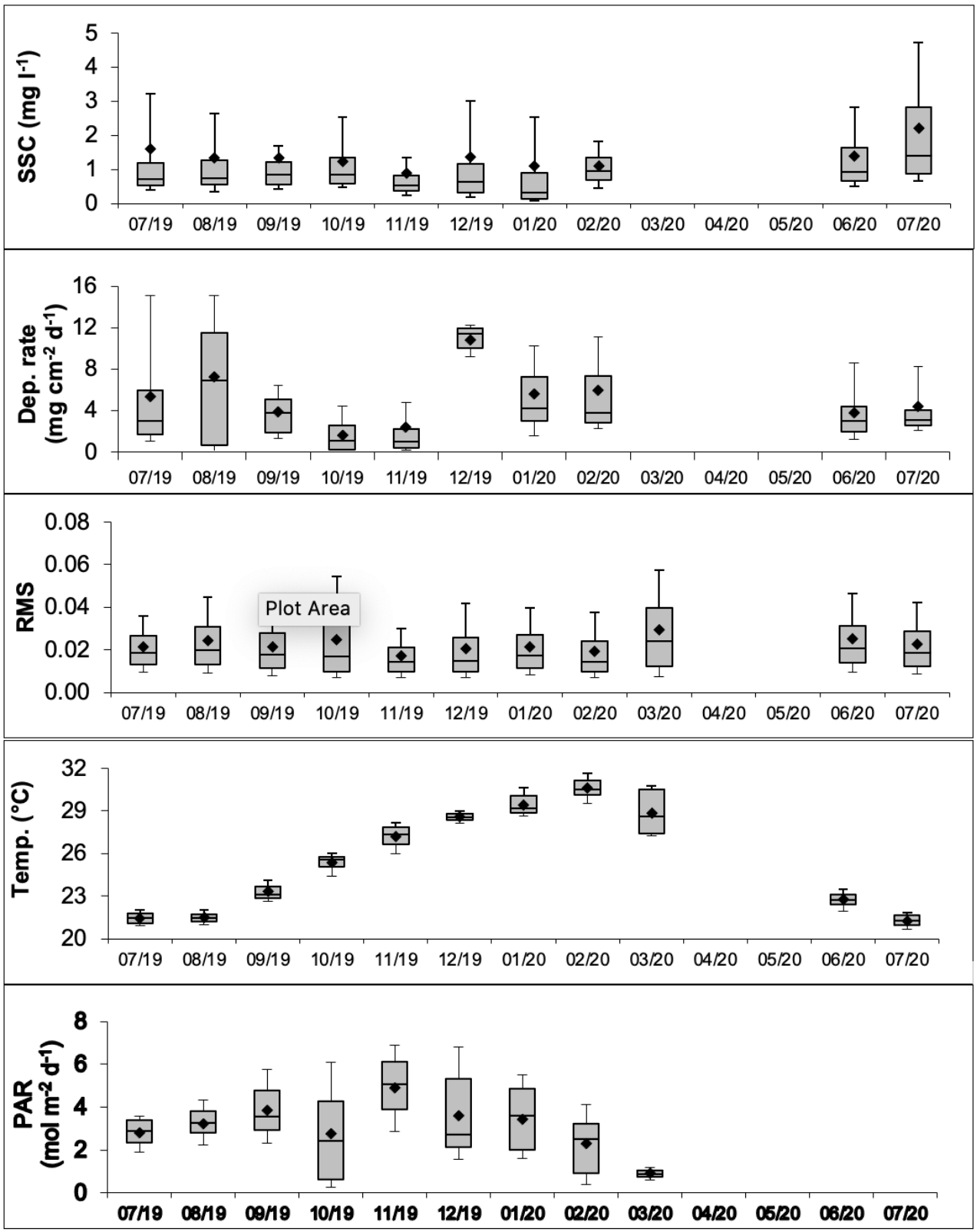
SCC (mg/L)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	1.60	1.35	1.35	1.25	0.88	1.36	1.12	1.10				1.38	2.22
median	0.71	0.74	0.85	0.84	0.53	0.63	0.33	0.96				0.92	1.40
min	0.13	0.00	0.23	0.14	0.00	0.00	0.00	0.06				0.03	0.30
lower	0.52	0.56	0.57	0.60	0.36	0.33	0.15	0.69				0.66	0.87
upper	1.20	1.27	1.22	1.36	0.82	1.17	0.89	1.36				1.65	2.82
max	44.85	47.47	51.07	15.42	30.41	30.57	21.51	4.62				13.68	39.09
90th percentile	3.22	2.63	1.68	2.53	1.35	3.00	2.54	1.83				2.83	4.71
10th percentile	0.40	0.35	0.43	0.49	0.25	0.19	0.07	0.45				0.50	0.65
n	4376	4444	4292	1818	2644	3150	1270	1558	0	0	105	4320	2089
St. Dev	3.24	2.51	3.21	1.22	1.82	2.48	2.43	0.64				1.25	2.33
St. Error	0.05	0.04	0.05	0.03	0.04	0.04	0.07	0.02				0.02	0.05

Daily dep. rate (mg cm^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	5.29	7.20	3.85	1.62	2.40	10.86	5.58	5.98				3.75	4.42
median	3.01	6.91	3.75	1.05	0.98	11.44	4.22	3.78				2.96	3.05
min	0.45	0.04	0.63	0.08	0.03	8.67	0.59	1.17				0.91	1.38
lower	1.73	0.66	1.90	0.25	0.39	10.06	2.98	2.80				1.99	2.54
upper	5.98	11.50	5.04	2.52	2.26	11.95	7.22	7.33				4.42	4.05
max	21.69	18.17	9.20	5.63	19.97	12.46	24.56	19.24				10.89	17.96
90^{th} percentile	15.06	15.10	6.43	4.44	4.79	12.25	10.25	11.07				8.56	8.21
10^{th} percentile	1.00	0.09	1.30	0.23	0.21	9.23	1.53	2.23				1.26	2.08
n	31	31	30	31	30	3	31	21	0	0	1	30	31
St. Dev	5.37	5.80	2.16	1.64	4.18	1.96	4.71	4.71				2.75	3.86
St. Error	0.96	1.04	0.40	0.29	0.76	1.13	0.85	1.03				0.50	0.69

RMS depth	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.021	0.024	0.021	0.025	0.017	0.021	0.021	0.019	0.030			0.025	0.023
median	0.019	0.020	0.018	0.017	0.014	0.015	0.017	0.014	0.024			0.021	0.019
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.002	0.002
lower	0.013	0.013	0.011	0.010	0.010	0.010	0.012	0.010	0.012			0.014	0.012
upper	0.027	0.031	0.028	0.034	0.021	0.026	0.027	0.024	0.040			0.031	0.029
max	0.104	0.136	0.098	0.167	0.124	0.144	0.126	0.145	0.183			0.141	0.145
90^{th} percentile	0.036	0.045	0.040	0.055	0.030	0.042	0.040	0.038	0.058			0.046	0.042
10^{th} percentile	0.010	0.009	0.008	0.007	0.007	0.007	0.008	0.007	0.007			0.010	0.009
n	4462	4462	4320	4462	4314	4464	4458	4175	4464	0	105	4320	4464
St. Dev	0.011	0.016	0.014	0.021	0.012	0.017	0.014	0.015	0.023			0.017	0.015
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			0.000	0.000

Temp. (°C)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	21.44	21.51	23.30	25.40	27.22	28.58	29.44	30.58	28.86			22.74	21.28
median	21.44	21.48	23.12	25.57	27.35	28.57	29.19	30.49	28.64			22.74	21.31
min	20.37	20.77	22.28	23.88	25.36	27.67	28.36	28.97	27.02			21.57	20.32
lower	21.12	21.19	22.84	25.07	26.63	28.34	28.86	30.14	27.42			22.44	20.97
upper	21.76	21.74	23.70	25.79	27.88	28.82	30.09	31.14	30.52			23.11	21.63
max	22.27	23.02	25.26	26.53	28.51	29.63	30.93	32.31	31.19			23.84	22.11
90^{th} percentile	22.06	22.03	24.12	26.03	28.17	29.02	30.64	31.68	30.77			23.50	21.84
10^{th} percentile	20.94	21.00	22.61	24.38	25.99	28.13	28.65	29.54	27.24			21.96	20.66
n	4451	4456	4320	4454	4310	4464	4451	4175	4464	0	105	4320	4464
St. Dev	0.41	0.42	0.61	0.59	0.79	0.36	0.74	0.77	1.45			0.52	0.43
St. Error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02			0.01	0.01

Light (mol m^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	2.80	3.22	3.85	2.77	4.90	3.61	3.44	2.29	0.91				
median	2.87	3.26	3.54	2.42	5.05	2.72	3.60	2.50	0.87				
min	0.97	0.71	1.88	0.03	0.65	0.31	0.61	0.14	0.58				
lower	2.34	2.81	2.95	0.62	3.89	2.12	2.00	0.90	0.74				
upper	3.39	3.80	4.79	4.27	6.11	5.33	4.87	3.21	1.04				
max	4.03	4.74	6.32	7.99	7.67	7.91	6.05	5.17	1.43				
90^{th} percentile	3.57	4.34	5.78	6.10	6.90	6.82	5.52	4.11	1.19				
10^{th} percentile	1.89	2.25	2.30	0.27	2.87	1.56	1.61	0.41	0.59				
n	31	31	30	31	30	31	22	27	10	0	0	0	0
St. Dev	0.75	0.93	1.27	2.28	1.63	2.07	1.64	1.44	0.26				
St. Error	0.13	0.17	0.23	0.41	0.30	0.37	0.35	0.28	0.08				


SSC (mg l-1)
0
1
2
3
4
5
07/19
08/19
09/19
10/19
11/19
12/19
01/20
02/20
03/20
04/20
05/20
06/20
07/20
Dep. rate (mg cm-2 d-1)
0
4
8
12
16
RMS
0.00
0.02
0.04
0.06
0.08
Plot Area
Temp. (°C)
20
23
26
29
32
PAR (mol m-2 d-1)
0
2
4
6
8

A1.3.5 AMB 5: Holbourne

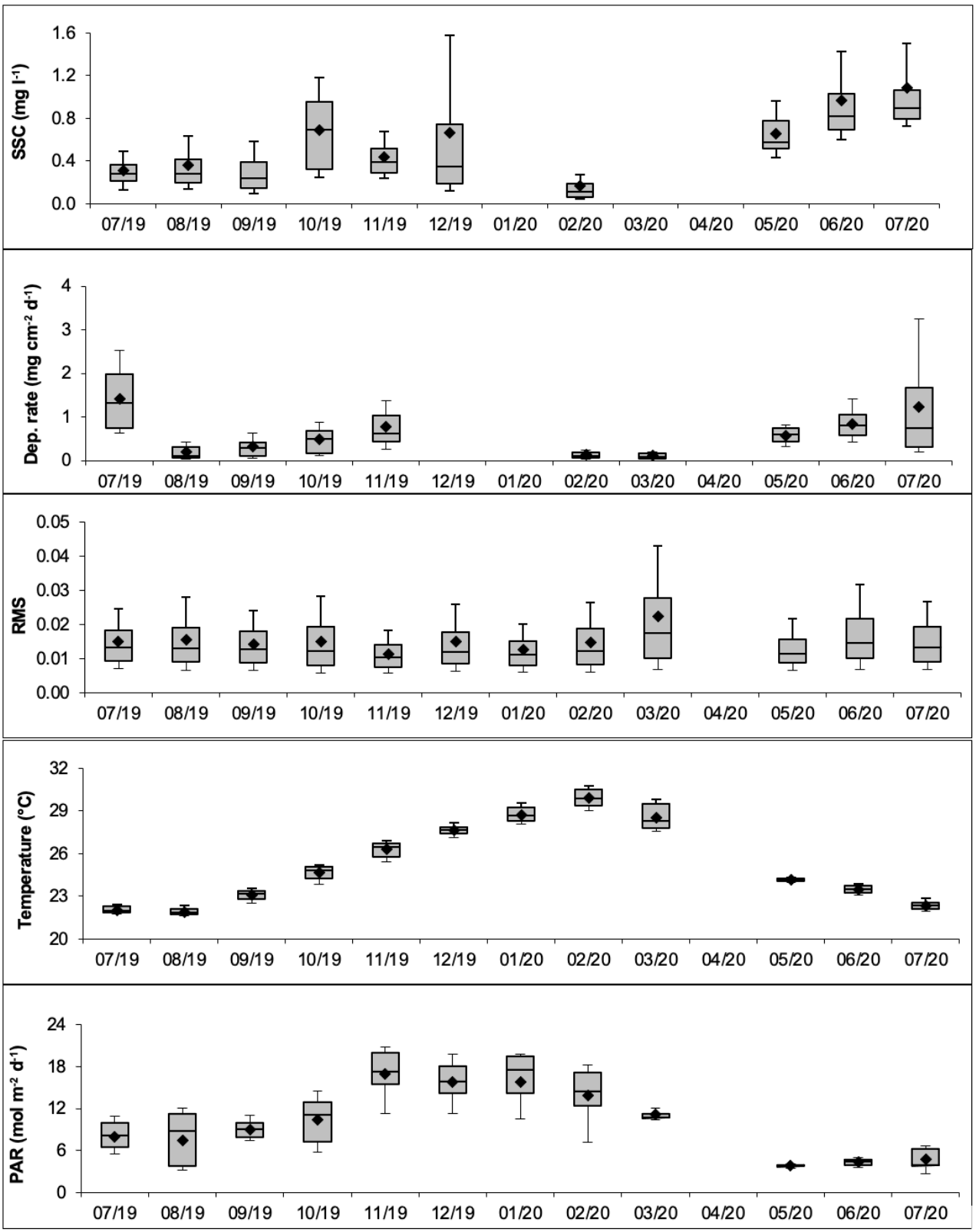
SCC (mg/L)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.31	0.36	0.32	0.69	0.44	0.66		0.17			0.66	0.97	1.08
median	0.28	0.28	0.24	0.69	0.39	0.35		0.11			0.58	0.82	0.89
min	0.02	0.02	0.00	0.01	0.13	0.01		0.00			0.37	0.32	0.61
lower	0.21	0.20	0.15	0.32	0.29	0.19		0.06			0.51	0.69	0.79
upper	0.37	0.41	0.39	0.95	0.52	0.74		0.19			0.77	1.03	1.07
max	1.49	5.31	4.87	3.18	3.61	8.73		8.31			1.36	9.86	9.34
90th percentile	0.49	0.63	0.58	1.18	0.67	1.58		0.27			0.96	1.43	1.50
10th percentile	0.13	0.13	0.09	0.25	0.24	0.12		0.04			0.43	0.60	0.73
n	1963	4458	4320	2827	4224	2291	0	1436	0	0	238	4269	395
St. Dev	0.17	0.33	0.34	0.39	0.23	0.87		0.38			0.22	0.63	0.81
St. Error	0.00	0.00	0.01	0.01	0.00	0.02		0.01			0.01	0.01	0.04

Daily dep. rate (mg cm^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	1.42	0.19	0.31	0.49	0.78			0.13	0.11		0.58	0.84	1.24
median	1.31	0.11	0.29	0.49	0.61			0.11	0.08		0.61	0.80	0.73
min	0.34	0.02	0.05	0.04	0.18			0.01	0.03		0.25	0.14	0.07
lower	0.75	0.06	0.11	0.16	0.44			0.07	0.04		0.43	0.57	0.32
upper	1.98	0.31	0.41	0.69	1.03			0.19	0.16		0.74	1.05	1.68
max	2.98	0.61	0.80	1.36	1.96			0.31	0.30		0.87	1.48	4.81
90^{th} percentile	2.53	0.42	0.62	0.87	1.37			0.24	0.20		0.82	1.41	3.24
10^{th} percentile	0.62	0.03	0.05	0.12	0.26			0.04	0.03		0.32	0.42	0.19
n	31	9	7	17	13	0	0	26	10	0	3	30	31
St. Dev	0.75	0.20	0.27	0.36	0.51			0.08	0.09		0.31	0.37	1.27
St. Error	0.13	0.07	0.10	0.09	0.14			0.02	0.03		0.18	0.07	0.23

RMS depth	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	0.015	0.016	0.014	0.015	0.011	0.015	0.013	0.015	0.022		0.013	0.017	0.015
median	0.013	0.013	0.013	0.012	0.010	0.012	0.011	0.012	0.017		0.011	0.015	0.013
min	0.000	0.001	0.000	0.002	0.002	0.002	0.002	0.002	0.002		0.003	0.000	0.000
lower	0.009	0.009	0.009	0.008	0.007	0.009	0.008	0.008	0.010		0.009	0.010	0.009
upper	0.018	0.019	0.018	0.019	0.014	0.018	0.015	0.019	0.028		0.016	0.022	0.019
max	0.063	0.081	0.055	0.077	0.040	0.137	0.086	0.097	0.149		0.035	0.085	0.065
90^{th} percentile	0.025	0.028	0.024	0.028	0.018	0.026	0.020	0.026	0.043		0.022	0.032	0.027
10^{th} percentile	0.007	0.007	0.006	0.006	0.006	0.006	0.006	0.006	0.007		0.006	0.007	0.007
n	4462	4460	4320	4462	4235	4464	4462	4174	4464	0	239	4320	4464
St. Dev	0.008	0.010	0.007	0.010	0.005	0.010	0.007	0.009	0.018		0.006	0.011	0.008
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000

Temp. (°C)	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	22.02	21.90	23.10	24.65	26.29	27.66	28.74	29.90	28.52		24.16	23.47	22.34
median	21.99	21.86	23.20	24.80	26.46	27.66	28.66	29.85	28.29		24.16	23.47	22.33
min	20.38	20.22	22.03	23.42	25.05	26.72	27.70	28.42	26.65		23.82	22.14	20.95
lower	21.82	21.73	22.81	24.25	25.74	27.41	28.27	29.39	27.79		24.09	23.23	22.11
upper	22.27	22.08	23.37	25.05	26.71	27.86	29.22	30.50	29.52		24.26	23.77	22.55
max	22.58	22.73	24.35	26.02	27.79	28.94	30.30	31.21	30.28		24.36	24.11	23.16
90th percentile	22.40	22.34	23.54	25.22	26.88	28.17	29.54	30.76	29.83		24.33	23.87	22.87
10th percentile	21.72	21.61	22.49	23.81	25.44	27.13	28.08	29.05	27.54		23.99	23.09	21.94
n	4454	4460	4320	4462	4235	4464	4462	4174	4464	0	231	4320	4464
St. Dev	0.31	0.30	0.41	0.53	0.57	0.38	0.56	0.64	0.90		0.12	0.32	0.36
St. Error	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01		0.01	0.00	0.01

Light (mol m^{-2} day^{-1})	07/2019	08/2019	09/2019	10/2019	11/2019	12/2019	01/2020	02/2020	03/2020	04/2020	05/2020	06/2020	07/2020
Mean	7.96	7.39	8.99	10.40	16.91	15.73	15.82	13.86	11.11		3.78	4.31	4.72
median	8.18	8.72	9.02	11.10	17.29	15.80	17.54	14.51	10.76		3.76	4.40	3.91
min	2.44	1.23	4.18	4.25	8.24	6.16	2.74	3.29	10.25		3.45	2.81	2.30
lower	6.49	3.74	7.93	7.27	15.53	14.19	14.21	12.39	10.59		3.61	3.87	3.70
upper	9.88	11.20	9.99	12.93	19.99	18.11	19.51	17.10	11.28		3.94	4.69	6.25
max	11.54	13.35	12.00	16.35	21.55	20.86	20.09	19.35	12.68		4.12	5.68	7.28
90^{th} percentile	10.86	12.07	11.03	14.56	20.76	19.75	19.73	18.18	12.12		4.05	5.04	6.63
10^{th} percentile	5.49	3.23	7.48	5.69	11.26	11.30	10.47	7.14	10.38		3.51	3.55	2.71
n	31	31	30	31	30	31	31	29	4	0	3	30	13
St. Dev	2.27	4.00	1.62	3.61	3.62	3.36	4.63	4.29	1.07		0.34	0.64	1.70
St. Error	0.41	0.72	0.30	0.65	0.66	0.60	0.83	0.80	0.54		0.19	0.12	0.47


SSC (mg l-1)
1.6
1.2
0.8
0.4
0.0
Dep. rate (mg cm-2 d-1)
4
3
2
1
0
RMS
0.05
0.04
0.03
0.02
0.01
0.00
Temperature (°C)
32
29
26
23
20
PAR (mol m-2 d-1)
24
18
12
6
0
07/19
08/19
09/19
10/19
11/19
12/19
01/20
02/20
03/20
04/20
05/20
06/20
07/20

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