Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual report 2020-2021

Nathan Waltham, Jordan Iles, Jamie Johns

Report No. 21/74

December 2021

Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2020-2021

A Report for North Queensland Bulk Ports Corporation

Report No. 21/74

December 2021

Prepared by Nathan Waltham, Jordan Iles, Jamie Johns

Centre for Tropical Water & Aquatic Ecosystem Research
(TropWATER)
James Cook University
Townsville
Phone : (07) 4781 4262
Email: TropWATER@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

Information should be cited as:
Waltham NJ, Iles J.A., Johns, J., 2021, 'Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2020-2021', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/74, James Cook University, Townsville, 81pp.

For further information contact:
Dr Nathan Waltham
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
Nathan.waltham@jcu.edu.au

This publication has been compiled by the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University.

EXECUTIVE SUMMARY

1. North Queensland Bulk Ports commenced an ambient marine water quality monitoring program surrounding the Ports of Mackay and Hay Point in July 2014. The objective of the program is to progress a long term water quality dataset to characterise marine water quality conditions within the Mackay region that will support future planned port activities. This report presents data collected during the 2020/2021 annual monitoring period.
2. The program incorporates a field measurements and high frequency continuous data loggers, laboratory analysis for a range of nutrient, and heavy metals. In this year, pesticides were again examined, however, with the use of passive sampling technology, to provide a more time integrated measure of available pesticides.
3. Sites extend approximately 50km along the Mackay coastline, from Slade Islet to Freshwater Point. The total 2010-2021 wet season rainfall at Plane Creek Sugar Mill (17 km linear from Hay Point) is below the long-term average wet season total, proximal to the 40th percentile of long-term rainfall wet season totals. The wet season rainfall contributed to at least four flow periods, but most notably during late December 2020 and early January 2021, where rainfall and river discharge was highest.
4. Water quality samples were measured at all sites on a ~6 weekly basis using field instruments (physio-chemical) and water samples for laboratory analysis. Seasonal differences in water quality were minor, except for temperature, which continues to be highest during the summer and coolest during the winter months. Similar to previous years, dissolved oxygen levels and pH remain similar among the three depth horizons, which provides some evidence, that the water column is largely well mixed. The same was apparent for electrical conductivity.
5. Particulate nitrogen concentrations exceeded the guidelines throughout most of the period. This continues to be a regular occurrence and might require further investigation into the guidelines for the region. Chlorophyll-a concentrations exceeded the GBRMPA guideline trigger value for all sampling. This also continues to be the case each year, and suggests the need to consider the development of locally specific guidelines that reflect the natural range of conditions experience in the region.
6. Metals targeted for analysis were not detected above the 95% level of protection trigger values for marine waters. Silver, Cadmium, Nickel, Zinc, and Mercury were not detected. Copper was detected here (unlike in previous years), and we are not sure for this detection, either it could be attributed to laboratory contamination, or possible some contamination from the copper tape used on the new loggers that was transferred to our samples. We have introduced additional steps during field sampling as an extra precaution to ensure that if this is a cross contamination, it is not repeated.
7. In this reporting period we transitioned to using passive samplers (time integrated) to monitor pesticide and herbicide concentrations. Pesticides targeted for analysis using passive samplers were not detected above the trigger values for the GBR. While some pesticide/herbicides were detected, these samples were below the GBRMPA draft guidelines for 99% species protection.
8. Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment, and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week. This is similar to the pattern observed in long term annual data sets at these sites.
9. Another important finding here was that deposition data did not indicate large deposits occurring at any of the monitored sites, and this is likely attributed to re-suspension of sediment by wave energy. SSC continues to regularly exceed relevant water quality guidelines at all sites, indicating that the development of local water quality guidelines is prudent. As part of this local water quality guideline development, it is recommended that the guidelines

apply to benthic waters, adjacent to sensitive receptor habitats, rather than the current approach of surface water guidelines that can be well away from important habitats.

10. Fine-scale patterns of photosynthetically active radiation (PAR) continue to be driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids – this trend was particularly the case given the extended wet season rainfall and runoff in the region following the monsoon that covered the region in February 2019.
11. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations, the relationship between these two parameters is not always strong. At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats, such as seagrass, algae and corals, it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats. For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.
12. Overall the difference between wet and dry season PAR levels remained similar to previous years. This is probably not surprising given that the total wet season rainfall for this reporting period was within the 40th percentile of historical rainfall patterns in the region. This supports the need for on-going monitoring to further characterise water quality responses to rainfall particularly under future changing climate predictions.

TABLE OF CONTENTS

TABLE OF FIGURES

1 INTRODUCTION

1.1 Port operations

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

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

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

1.2 Program outline

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

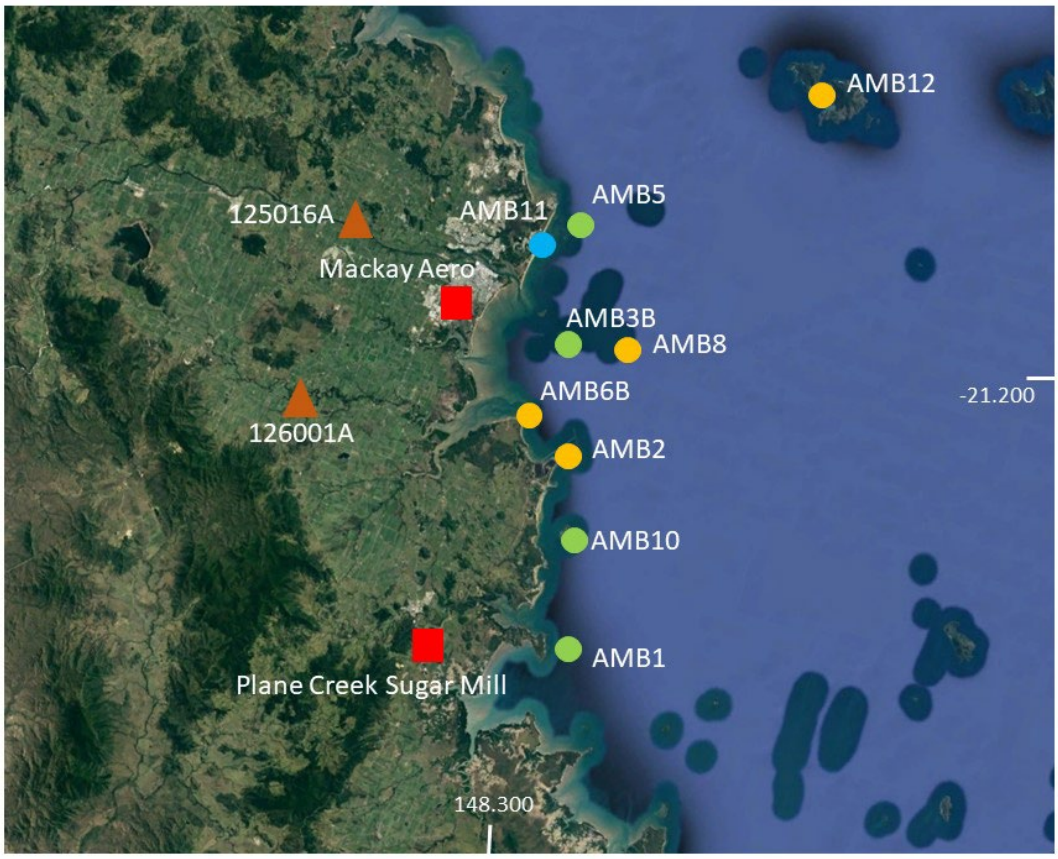


Figure 1.1 Location of water quality monitoring sites with loggers (green circle), without loggers (blue circles), and sites decommissioned (yellow circles) utilised in the 2020-2021 reporting period (exception of AMB6B which is PAR only and reported with seagrass reports). Also shown are meteorological stations (red square), and stream gauging stations (orange triangle) referred to in this report.

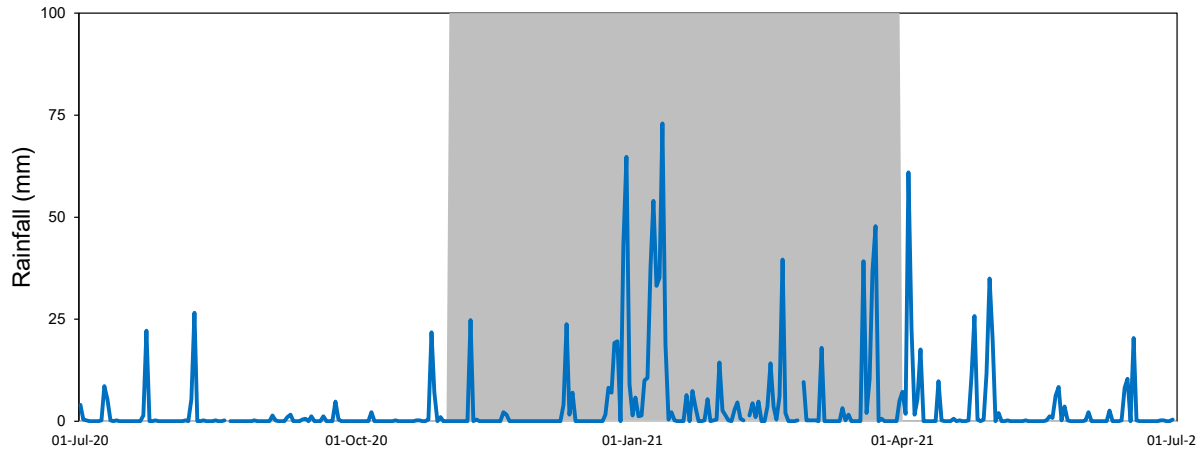
Table 1.1 Locations of the ambient marine water quality monitoring program sites

Site name	Site code	Lat.	Long.	Water quality	Logger	Decommissioned
Freshwater Point	MKY_AMB1	-21.42	149.34	Yes	Yes	
Hay Reef	MKY_AMB2	-21.26	149.30	Yes	Yes	September 2020
Round Top Island	MKY_AMB3B	-21.17	149.26	Yes	Yes	
Slade Island	MKY_AMB5	-21.09	149.24	Yes	Yes	
Dudgeon Point	MKY_AMB6B	-21.24	149.25	Yes	Yes	September 2020
Spoil Grounds	MKY_AMB8	-21.18	149.30	Yes	Yes	March 2021
Victor Island	MKY_AMB10	-21.32	149.32	Yes	Yes	
Mackay Harbour	MKY_AMB11	-21.11	149.22	Yes	No	
Keswick Island	MKY_AMB12	-20.93	149.42	Yes	Yes	September 2020

1.3 Rainfall and river flows

Daily rainfall for the Mackay region is shown on Figure 1.2. The rainfall onset is calculated as the date when the rainfall total reaches 50mm since 1st September. The 2020-2021 wet season rainfall total was 1002.4 mm, placing it well below the median wet season rainfall for 1912-1913 to 2019-2020 (Figure 1.3).

A)



B)

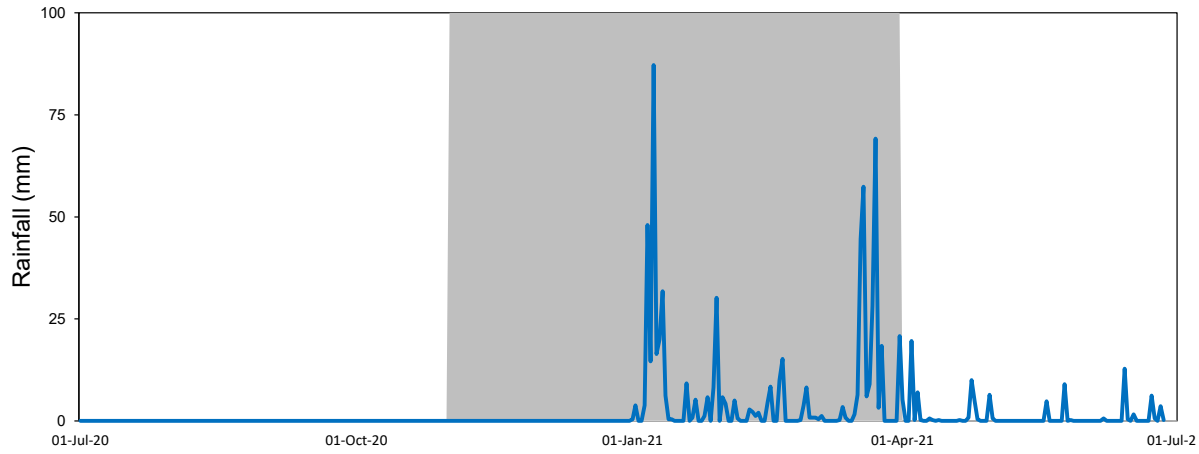


Figure 1.2 Rainfall recorded at: A) Mackay Aero (station 033045); and B) Plane Creek Sugar Mill (station 033059) for the 2020-2021 reporting period. The nominal wet season period is shaded grey. Data source: http://www.bom.gov.au/climate/data/

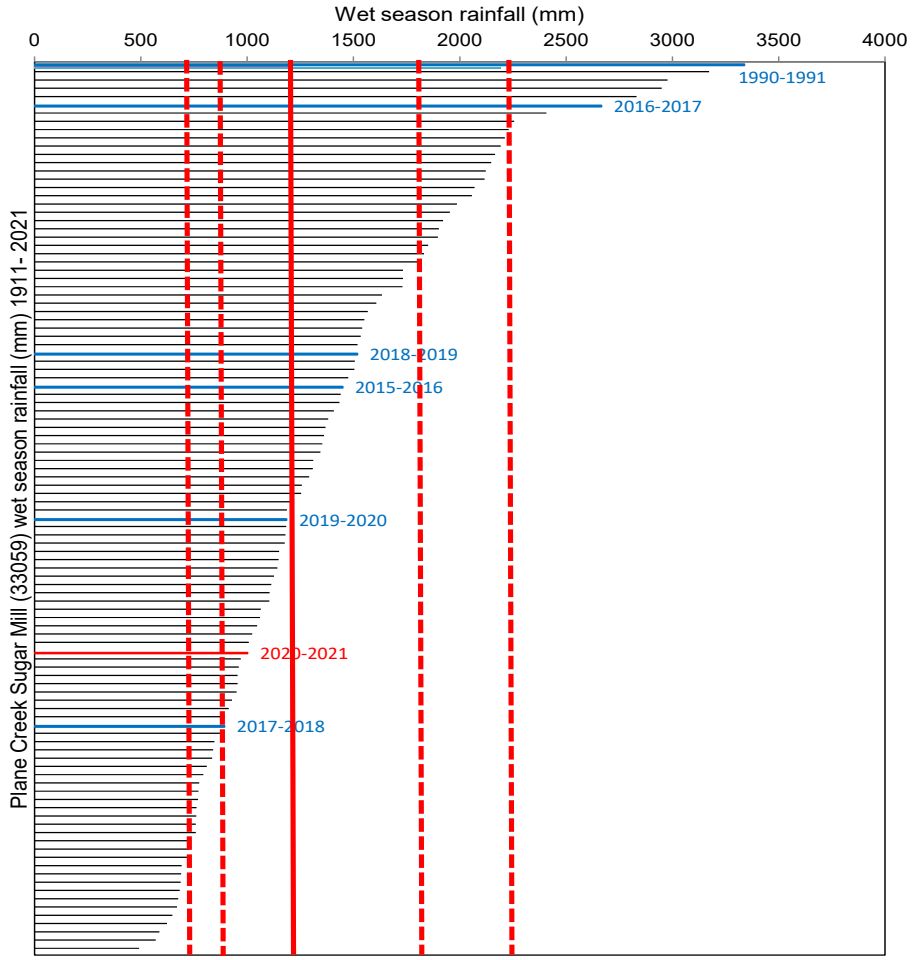


Figure 1.3 Wet season rainfall for the Mackay region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Plane Creek Sugar Mill weather station (Station number 033059). Totals were calculated for the wet season period 1st November to 31st March for each reporting year. Red bar represents the 2020-2021 reporting period, blue bars show total rainfall over the previous four years. Solid red line represents median wet season rainfall 1910-1911 to 2020-2021, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Data source: http://www.bom.gov.au/climate/data/

Hydrographs for streams in the Pioneer Basin (Pioneer River) and Plane Basin (Sandy Creek) show onset of stream discharge on 30/12/2020 with a series of flow pulses through to February 2021. Total discharge for the 2020-2021 reporting period was 365 GL (Pioneer River) and 55 GL (Sandy Creek). Total discharge for the 2020-2021 reporting period was 365 GL (Pioneer River) and 55 GL (Sandy Creek).

1.4 Project objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region within and adjacent to Port of Mackay and Hay Point. This report provides a review and analysis of data collected between 01/07/2020 and 30/06/2021. These data are part of a long 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 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 were examined here using passive samplers.

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 were analysed by Australian Laboratory Service (ALS). Passive samplers for pesticide/herbicides were analysed by the Queensland Alliance for Environmental Health Sciences (University of Queensland).

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		
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
Ultra Trace Metals		
Arsenic, Cadmium, Copper, Lead, Nickel, Silver, Zinc, Mercury	3125B ORC/ICP/MS	0.05 to 100 µg/L

2.2 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 2.2). 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.

2.2.1 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.

2.2.2 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.

2.2.3 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.

2.2.4 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)

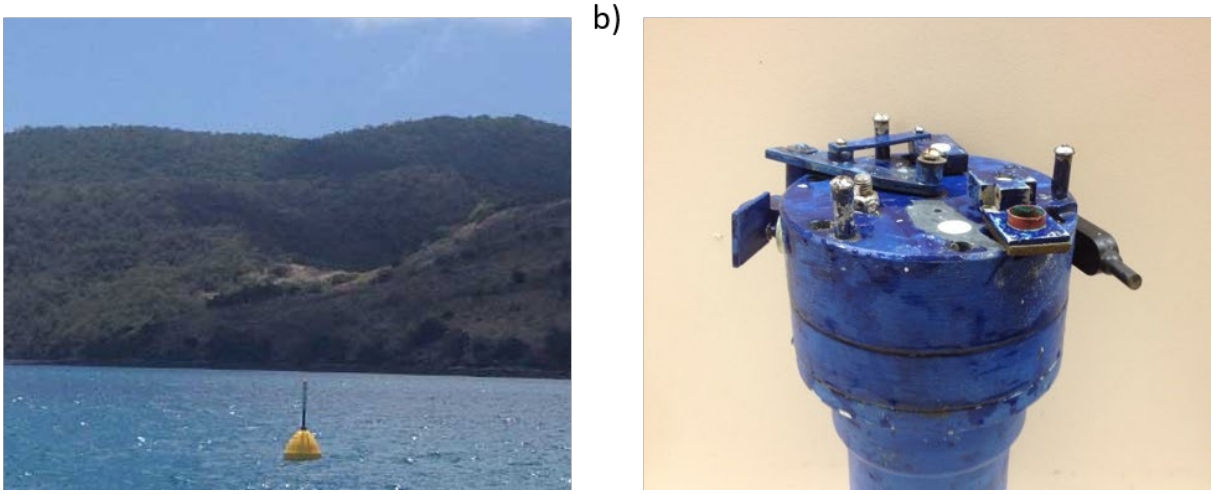


Figure 2.2 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

2.2.5 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} day^{-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.

2.1 Marotte HS current meter instruments

The Marotte HS (High Sampling Rate) is a drag-tilt current meter invented at the Marine Geophysics Laboratory (**Error! Reference source not found.**). 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.

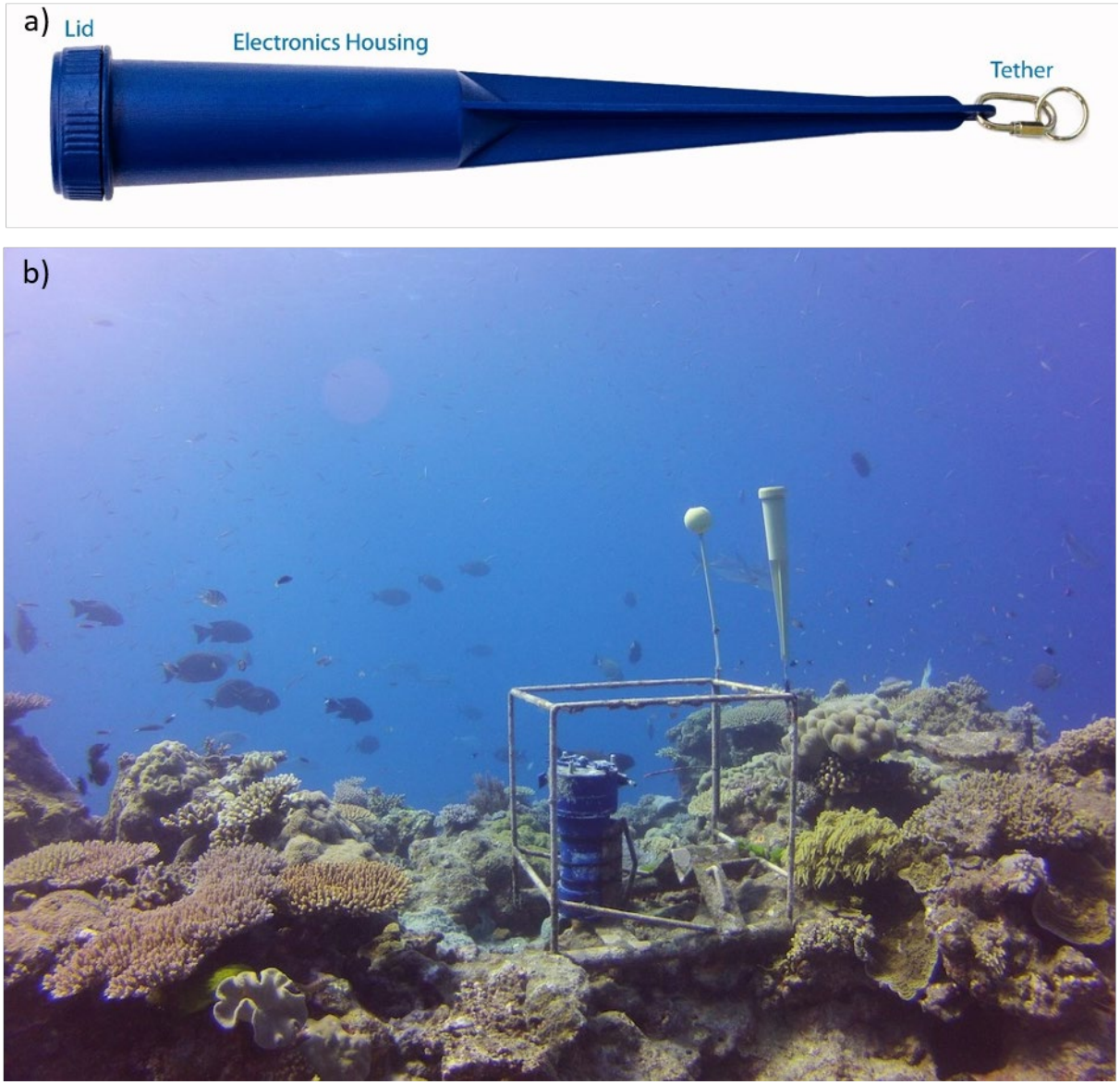


Figure 2.3 a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte tethered to a nephelometer frame at Moore Reef. Image courtesy of Eric Fisher

3 RESULTS AND DISCUSSION

There were seven sampling and maintenance trips in the 2020-2021 reporting period (Table 3.1).

Table 3.1 Summary of instrument maintenance and water quality surveys completed during the 2020/2021 reporting period. Note that the dry season metal sampling was completed September 2021.

Date	Nutrients, Chlorophyll-*a*	Ultra trace metals	Logger
06/09/2020	Yes	-	Yes
30/10/2020	Yes	-	Yes
02/12/2020	Yes	-	Yes
26/01/2021	Yes	Yes	Yes
10/03/2021	Yes	-	Yes
21/4/2021	Yes	-	Yes*
15/06/2021	Yes	-	Yes#

3.1 Ambient water quality

3.1.1 Physio-chemical measurements

Water temperature ranged from 20.45 to 28.98 °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. 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 from 50.5 to 56.0 mS cm^{-1} and was in the range typical of seawater (Figure 3.2). Dissolved oxygen ranged from 68.9 to 107.3 %sat (Figure 3.3). pH ranged from 7.93 to 8.75 (Figure 3.4).

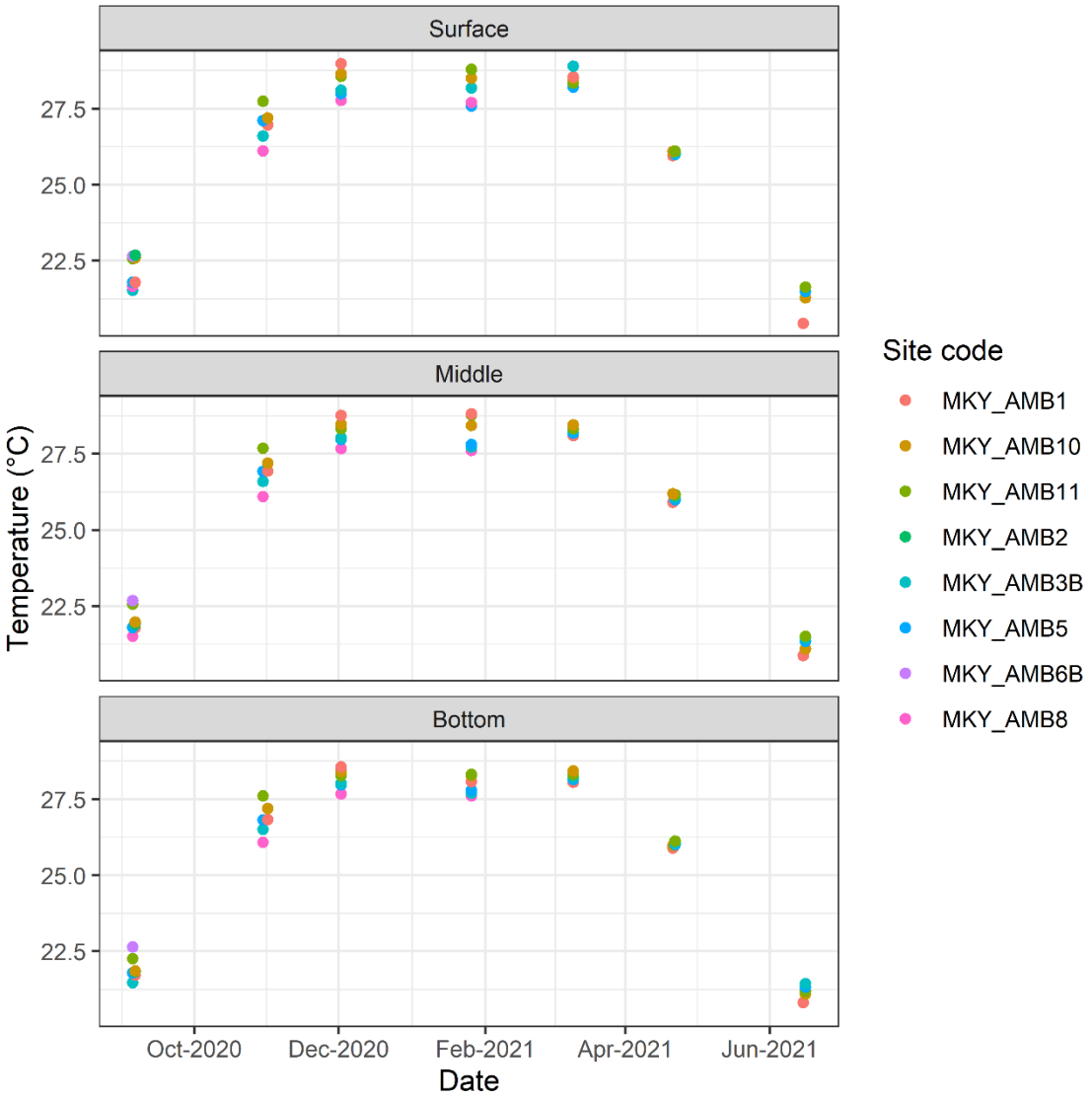


Figure 3.1 Water temperature recorded at three depths at the water quality sites throughout the reporting period.

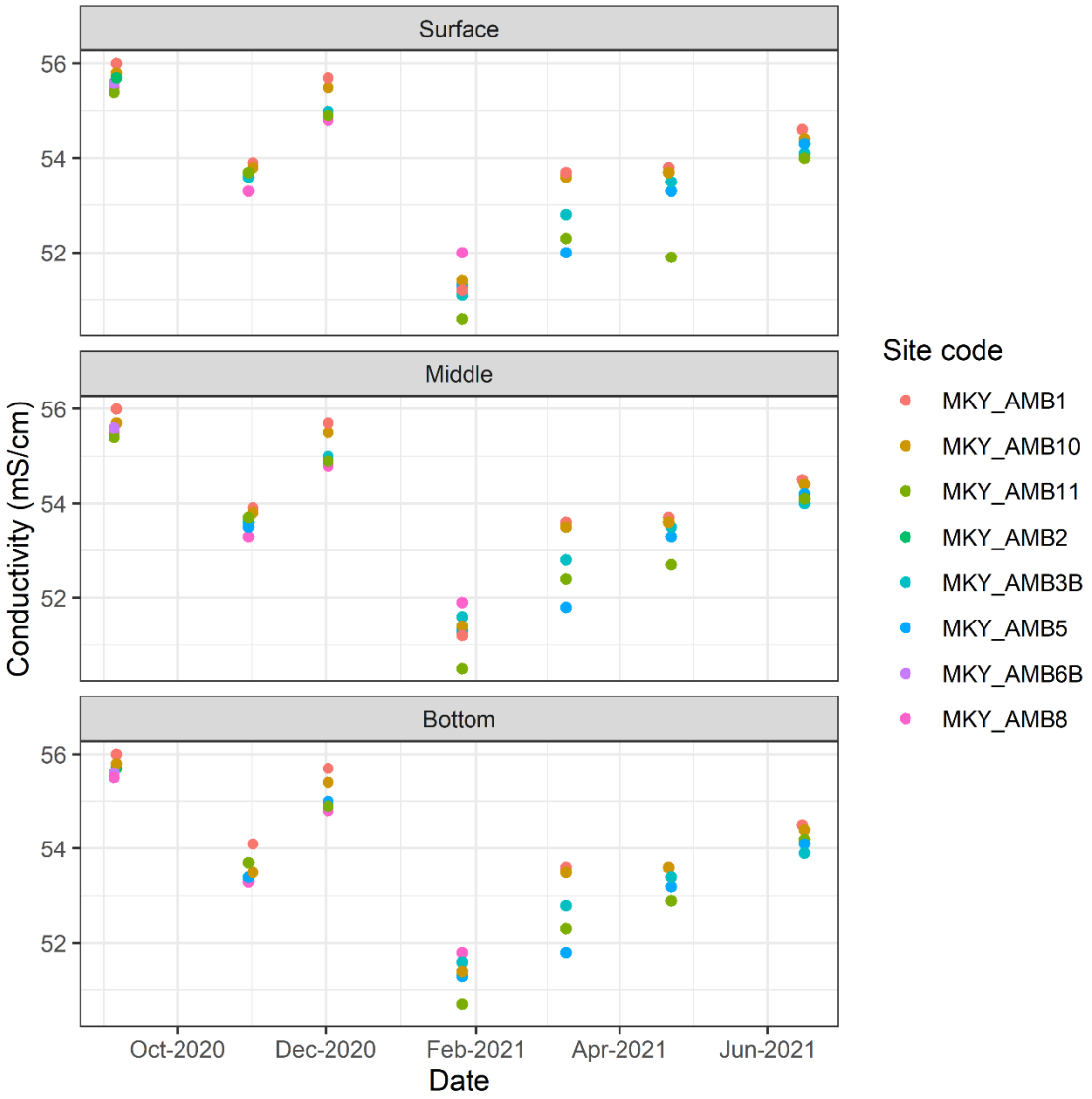


Figure 3.2 Electrical conductivity recorded at three depths at the water quality sites throughout the reporting period.

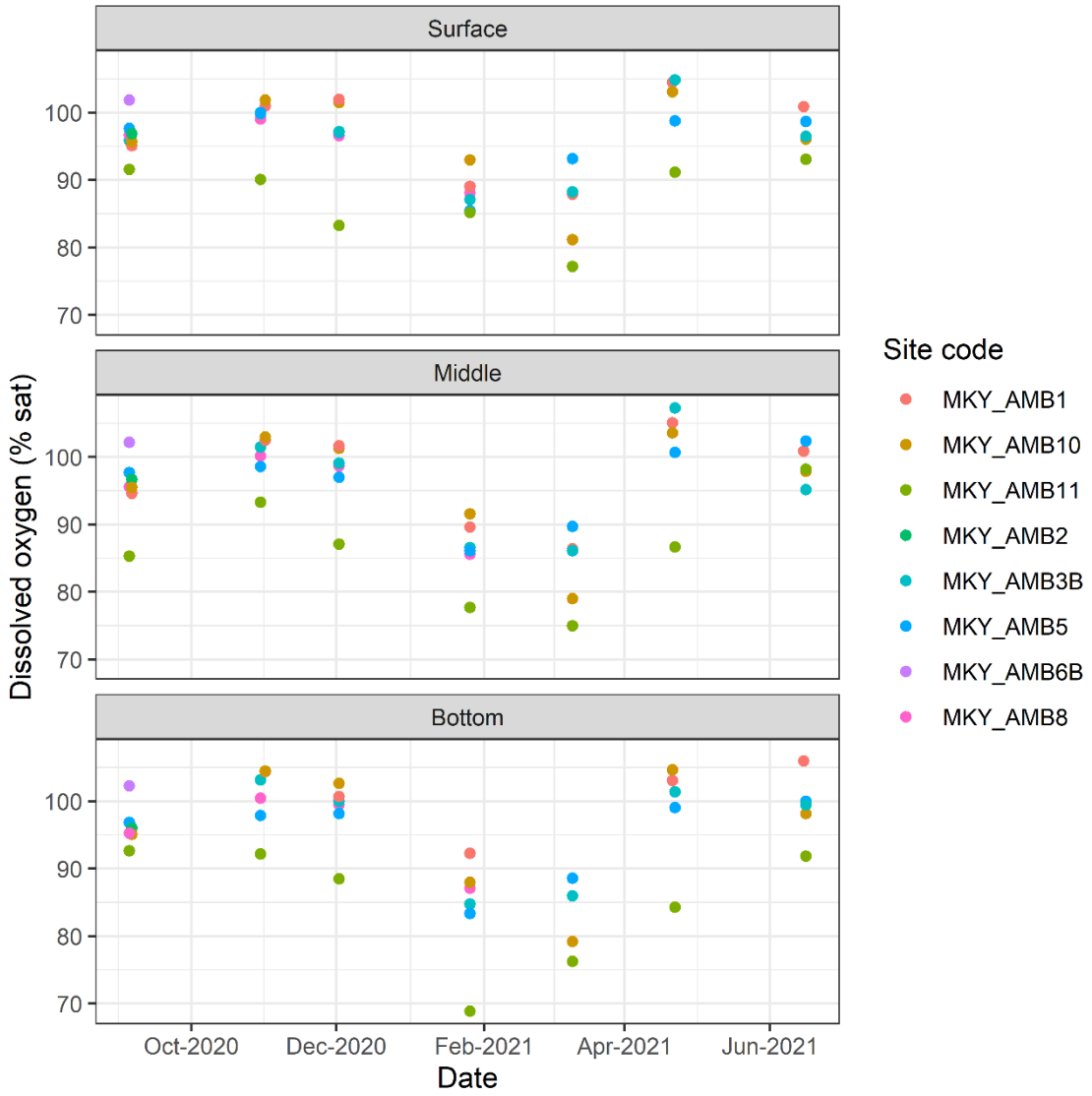


Figure 3.3 Dissolved oxygen (%sat) recorded at three depths at the water quality sites throughout the reporting period.

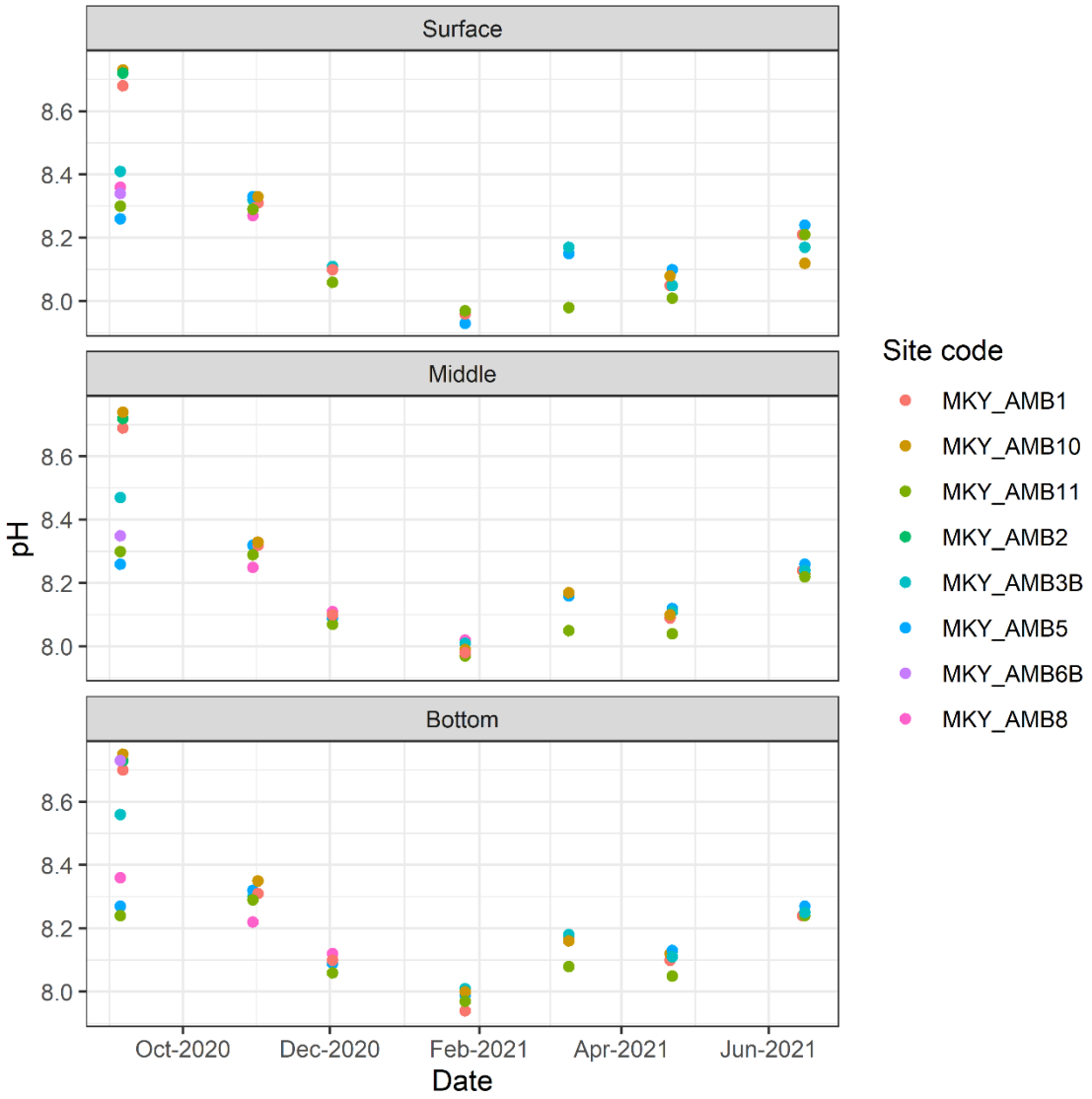


Figure 3.4 pH recorded at three depths at the water quality sites throughout the reporting period.

3.1.2 Nutrients, water clarity and chlorophyll-*a*

Particulate nitrogen (PN) concentrations ranged from 2 to 162 µg L^{-1} (Figure 3.5). Mean PN across the nine sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} for all sampling events with the exception of September to December 2020, and March and June 2021. Particulate phosphorus (PP) concentrations ranged from <1 to 11 µg L^{-1} (Figure 3.6). Mean PP exceeded the GBRMPA guideline trigger value of 2.8 µg L^{-1} in June, November, and December 2020, and March and June 2021.

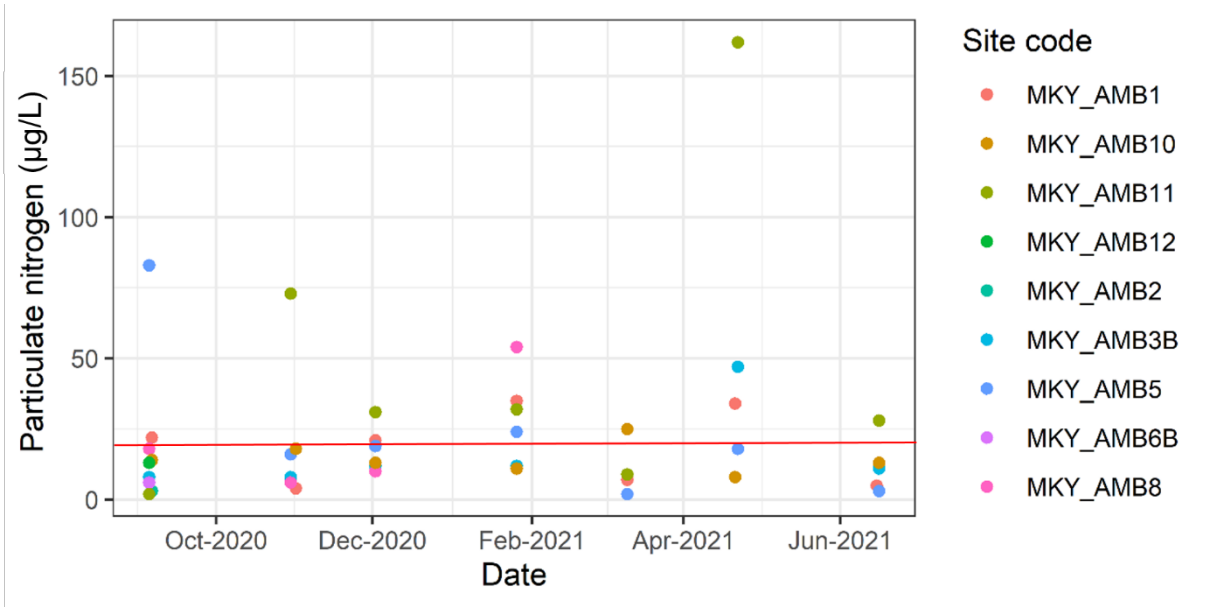


Figure 3.5 Particulate nitrogen (PN) concentrations measured in water samples collected from the nine water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

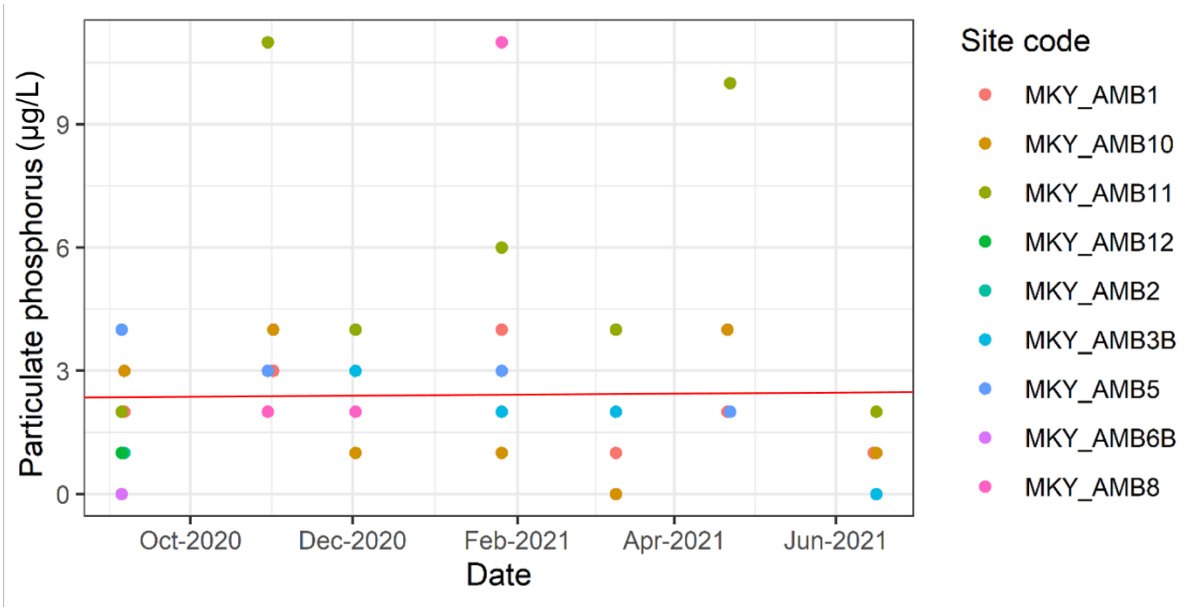


Figure 3.6 Particulate phosphorus (PP) concentrations measured in water samples collected from the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

Total suspended solids ranged from 0.89 to 7.8 mg L^{-1} (Figure 3.7). Mean TSS across the sites exceeded the GBRMPA guideline trigger value of 2.0 mg L^{-1} for all sampling events with the exception of June 2021 (1.82 mg L^{-1}). Secchi depth ranged from 1.5 to 10.0 m (Figure 3.8). Chlorophyll-*a* concentrations ranged from 0.24 to 4.46 µg L^{-1} (Figure 3.9). Mean Chlorophyll-*a* concentrations exceeded the GBRMPA guideline trigger value for all sampling events.

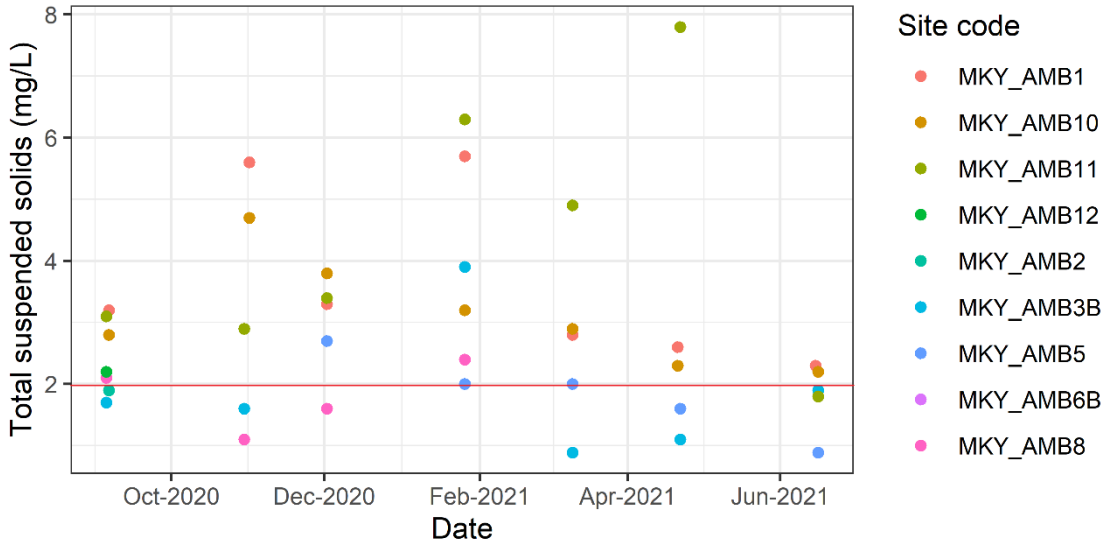


Figure 3.7 Total suspended solids (TSS) measured in water samples at the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

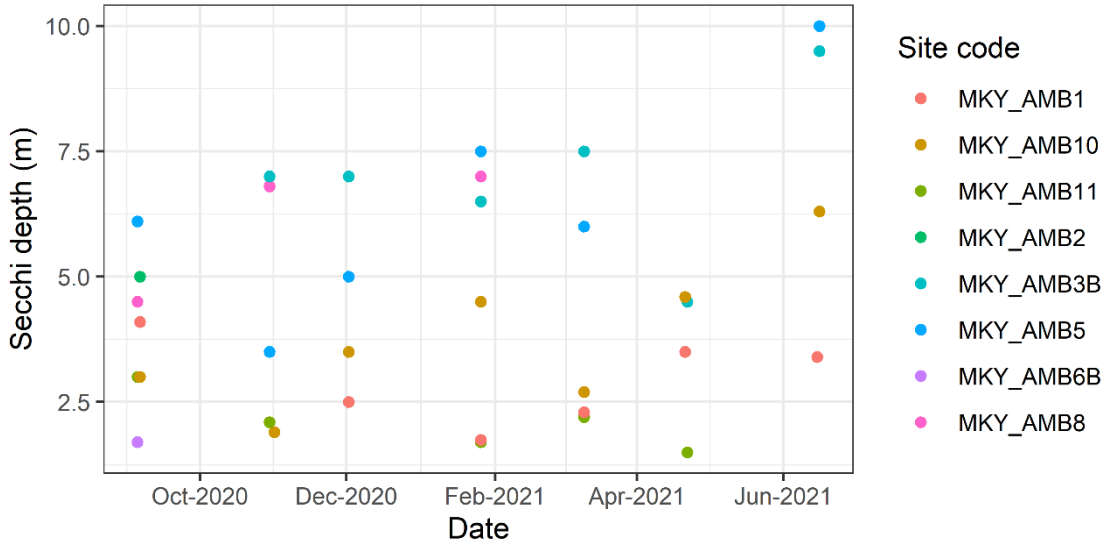


Figure 3.8 Secchi disk depth recorded at the water quality sites throughout the reporting period.

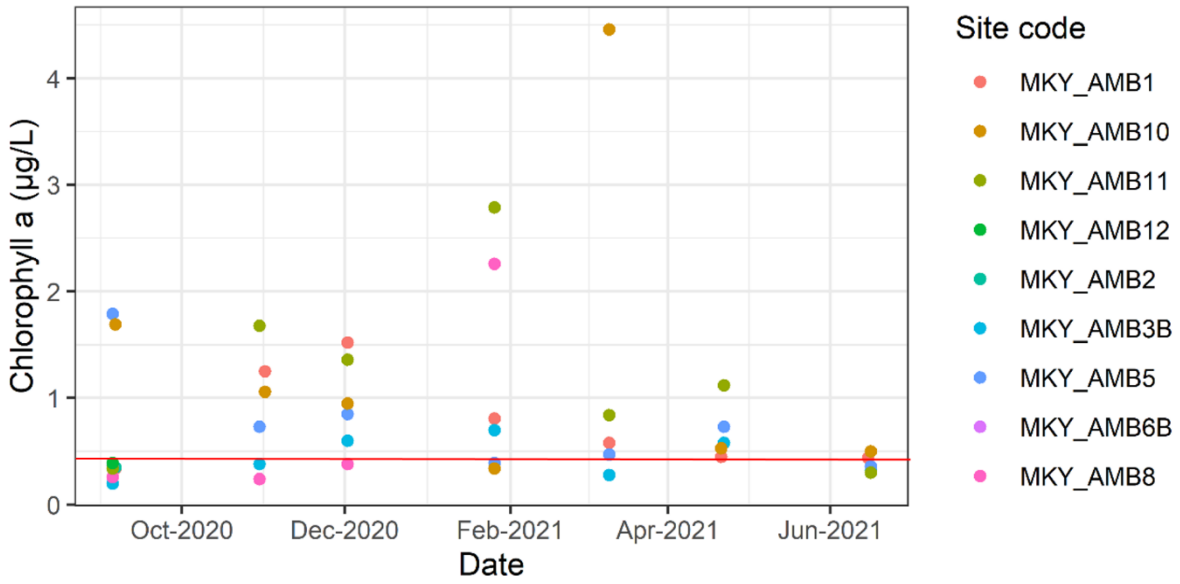


Figure 3.9 Chlorophyll-*a* concentrations measured in water samples collected from the nine water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

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, Nickel, Zinc, and Mercury were not detected (< LOD). Copper was detected at AMB 3B (Round Top) during January 2021, and at all sites during the September 2021 campaign (which is strictly outside this reporting period). The elevation in copper has not been recorded previously in the monitoring. It either represents a true detection, or in fact could be due to a contamination issue (i.e at the laboratory, or in the field). TropWATER are looking further into this and will report in the next annual report. Lead was detected in August 2019 at MKY_AMB5 (Slade Point), and MKY_AMB8 (Dudgeon Point) but was at concentrations below guideline values. Arsenic was detected at low concentrations (1.3 to 2.0 µg L^{-1}) – which is actually much lower than the previous reporting period (1.5 to 2.2 µg L^{-1}). Note that ANZECC guidelines do not have a trigger value for arsenic. A low reliability marine guideline trigger value of 4.5 µg L^{-1} for As (V) and 2.3 µg L^{-1} for As (III) has been derived (ANZECC, 2000), however, these trigger guidelines are only an indicative interim working level. 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 nine 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
Jan-2021	26/01/2021	MKY_AMB1	Freshwater Point	<0.1	<0.2	<1	<0.2	<0.5	1.8	<5	<0.0001
	26/01/2021	MKY_AMB3B	Round Top Island	<0.1	<0.2	2	<0.2	0.5	1.6	5	<0.0001
	26/01/2021	MKY_AMB5	Slade Island	<0.1	<0.2	<1	<0.2	<0.5	2	<5	<0.0001
	26/01/2021	MKY_AMB8	Spoil Grounds	<0.1	<0.2	<1	<0.2	<0.5	1.9	<5	<0.0001
	26/01/2021	MKY_AMB10	Victor Islet	<0.1	<0.2	<1	<0.2	<0.5	1.9	<5	<0.0001
	26/01/2021	MKY_AMB11	Mackay Harbour	<0.1	<0.2	1	<0.2	<0.5	2	<5	<0.0001
Sept-2021	12/09/2021	MKY_AMB1	Freshwater Point	<0.1	<0.2	2	<0.2	<0.5	1.4	<5	<0.0001
	12/09/2021	MKY_AMB3B	Round Top Island	<0.1	<0.2	2	<0.2	<0.5	1.4	<5	<0.0001
	12/09/2021	MKY_AMB5	Slade Island	<0.1	<0.2	2	<0.2	<0.5	1.3	<5	<0.0001
	12/09/2021	MKY_AMB10	Victor Islet	<0.1	<0.2	2	<0.2	<0.5	1.3	<5	<0.0001
	12/09/2021	MKY_AMB11	Mackay Harbour	<0.1	<0.2	3	<0.2	<0.5	1.5	<5	<0.0001

3.1.4 Pesticides

Pesticide concentrations are presented in Table 3.3. Concentrations were reported as less than values, with the exception of Atrizine, DEET, Diuron, Hexazinone and Metolachlor (S+R) which were detected above limit of detection. When comparing to the draft GBRMPA guidelines, Metolachlor (S+R) is close to the 99% guidelines for species protection, all other are below the guidelines (King et al., 2017a, b).

Table 3.3 Pesticide concentrations measured in passive samples deployed at AMB 5. Deployment periods were 30 and 33 days respectively.

MKY AMB5	GBRMPA 99% (2018)	2/12/2020	10/03/2021
unit	µg/L	ng/L	ng/L
2,4-D	1000	*<0.870*	*<0.670*
Ametryn	0.1	*<1.56*	*<1.21*
Atrazine		*<0.210*	**0.360**
Atrazine desethyl		*<0.250*	*<0.190*
Bromacil		*<0.140*	*<0.110*
Carbendazim		*<0.250*	*<0.190*
DEET		**9.39**	**2.82**
Diazinon		*<0.210*	*<0.160*
Diclofenac		*<0.030*	*<0.020*
Diuron	0.43	*<0.250*	**4.67**
Fipronil	0.0034	*<0.090*	*<0.070*
Fluometuron	20	*<0.150*	*<0.120*
Haloxyfop	590	*<0.110*	*<0.080*
Hexazinone	1.8	*<0.200*	**2.27**
Hydrochlorthiazide		*<0.190*	*<0.150*
MCPA	1	*<0.630*	*<0.490*
Metolachlor (S+R)	0.0002	*<0.200*	**0.190**
Prometryn	0.11	*<0.340*	*<0.260*
Propoxur		*<0.170*	*<0.130*
Simazine	28	*<0.140*	*<0.110*
Tebuthiuron	4.7	*<0.160*	*<0.120*
Terbuthylazine	0.4	*<0.190*	*<0.150*
Terbutryn	0.079	*<1.33*	*<1.03*
Triclopyr	0.36	*<0.520*	*<0.400*
Trimethoprim		*<0.080*	*<0.070*

3.2 Multiparameter water quality logger

Instruments were deployed at seven sites from July 2020 until July 2021 – the exception was that sites AMB2 (Hay Reef) and AMB12 (Keswick Island) were decommissioned in September 2020, while AMB8 (Sediment relocation sites) was decommissioned March 2021 – however the data collected is still presented here for completeness (Table 1.1). Using standard statistics, we describe observed trends and differences between sites and discuss the driving forces in these environments. Several loggers were not retrieved or flooded leading to gaps in data, including July at Freshwater, Jan – Feb at Roundtop, Nov – Dec at Slade, Nov- Dec and Feb at Spoil Grounds. Additionally, data are missing from all sites for the time period April – May/June, corresponding directly to COVID-19 related deployment restrictions. See time series in the appendices for exact dates.

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

3.2.1 RMS water height

AMB12 had lower RMS values than all other sites with a median of 0.005 m and the lowest variance in RMS values (Figure 3.10,Table 3.4). Results are similar to the previous year's (2019-2020) findings and are due to the site being positioned in the lee of Keswick and St Bees Islands that shelter it from wind and waves. AMB1, AMB2, AMB3, AMB8 and AMB10 have median RMS ≤0.022; AMB5 had the highest median RMS ≤0.046.

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

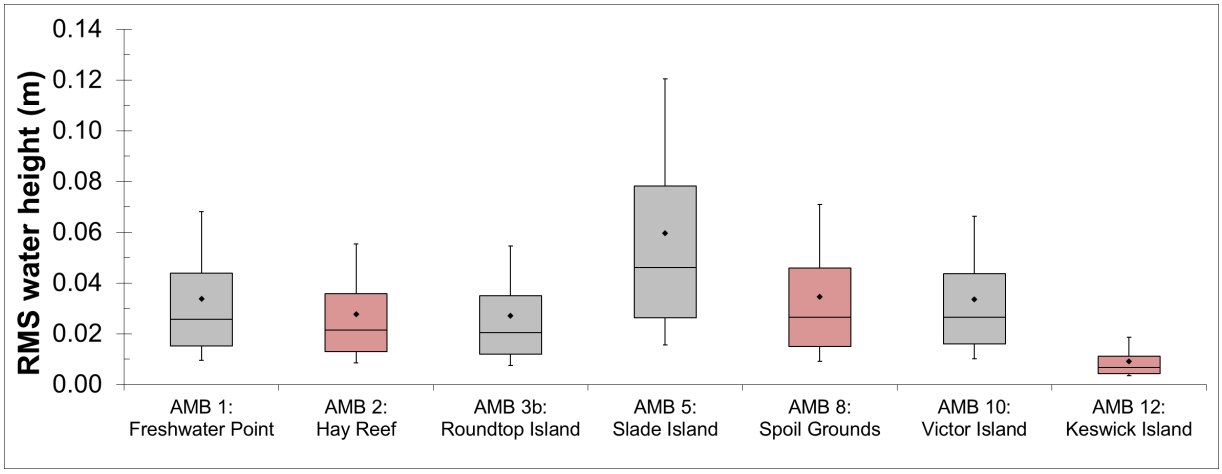


Figure 3.10 Box plot of root mean square (RMS) of water height (m) from July 2019 to July 2020. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamonds represent the mean values. Boxes shaded red highlight the sites, which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

Table 3.4 Summary of RMS water height (m) from July 2010 until July 2021.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil Grounds	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	0.034	0.028	0.027	0.060	0.035	0.034	0.009
median	0.026	0.021	0.020	0.046	0.026	0.026	0.007
min	0.000	0.000	0.000	0.000	0.000	0.000	0.000
lower quartile	0.015	0.013	0.012	0.026	0.015	0.016	0.004
upper quartile	0.044	0.036	0.035	0.078	0.046	0.044	0.011
max	0.366	0.258	0.271	0.645	0.349	0.362	0.105
90th percentile	0.068	0.055	0.054	0.120	0.071	0.066	0.019
10th percentile	0.010	0.008	0.007	0.016	0.009	0.010	0.003
n (recordings)	**45,499**	**9,712**	**52,546**	**52,529**	**20,018**	**52,543**	**9,558**
f (year obtained)**	**0.866**	**0.185**	**1.000**	**0.999**	**0.381**	**1.000**	**0.182**
St. Dev	0.027	0.022	0.022	0.049	0.028	0.025	0.008
St. Error	0.000	0.000	0.000	0.000	0.000	0.000	0.000

**f = fraction of the total 2020 July-2021 July recording period obtained (a maximum of 52560 possible recordings [10 min interval data]); note that any original recordings which were masked or excluded during the Quality Assurance (QA) process, are not counted in 'n' or 'f'.

3.2.2 NTUe/SSC

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

AMB3b, AMB5, AMB8 and AMB12 had median SSC values below 1 mg L^{-1} and the least variance in SSC. AMB2 also had median SSC values below 1 mg L^{-1}, but the second-highest variance (Figure 3.11, Table 3.5). Several factors contribute to low SSC at AMB3, including that the site is sheltered from the trade south east weather systems which could result in less re-suspension of sediments by wave energy and that the coarse sediment at this site is not resuspended easily. AMB1 and AMB10 had higher median SSC (2.0 – 2.4 mg L^{-1}). These sites are closer to the coast and are likely affected by coastal currents moving across shallow areas with high resuspension rates (Macdonald et al. 2013).

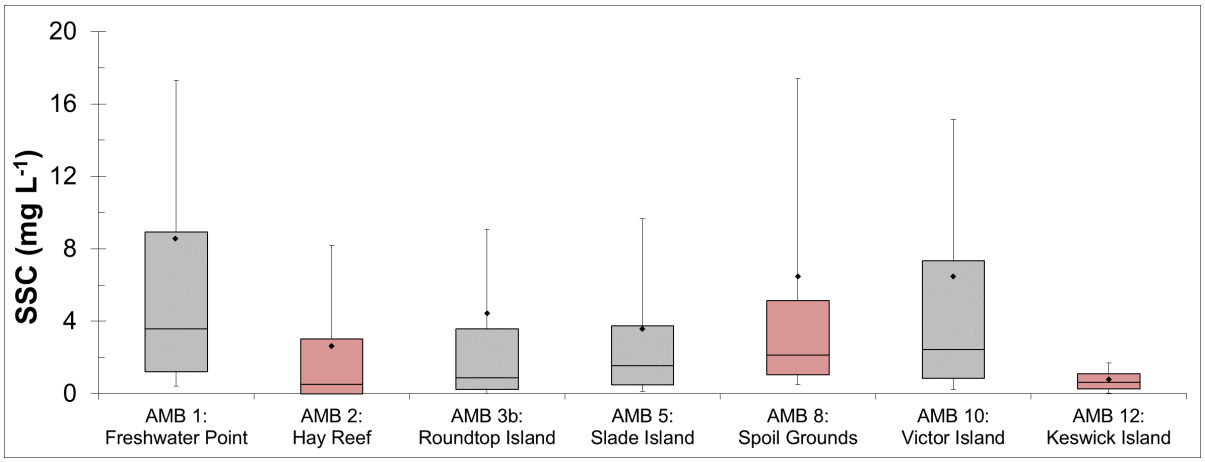


Figure 3.11 Box plot of suspended sediment concentration (SSC; mg L^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value. Boxes shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

Table 3.5 Summary of suspended sediment concentration (mg L^{-1}) from July 2020 to July 2021.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil Grounds	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	8.55	2.63	4.45	3.59	6.47	6.49	0.81
median	3.59	0.51	0.89	1.55	2.14	2.43	0.64
min	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower quartile	1.20	0.00	0.25	0.49	1.06	0.85	0.26
upper quartile	8.93	3.04	3.58	3.75	5.14	7.35	1.11
max	345.82	86.66	379.29	74.18	166.21	344.82	9.84
90th percentile	17.30	8.20	9.07	9.68	17.40	15.14	1.70
10th percentile	0.43	0.00	0.00	0.13	0.50	0.23	0.03
n (recordings)	**24,737**	**9,709**	**28,442**	**27,763**	**19,266**	**39,589**	**9,493**
f (year obtained)**	**0.471**	**0.185**	**0.541**	**0.528**	**0.367**	**0.753**	**0.181**
St. Dev	18.01	4.99	14.54	5.82	12.35	13.71	0.81
St. Error	0.11	0.05	0.09	0.03	0.09	0.07	0.01

**f = fraction of the total 2020 July-2021 July recording period obtained (a maximum of 52560 possible recordings [10 min interval data]); note that any original recordings which were masked or excluded during the Quality Assurance (QA) process, are not counted in 'n' or 'f'.

3.2.3 Deposition

Deposition of sediment is a natural process in all coastal marine waters. Suspended sediment deposits in environments where wave energy is not sufficient to keep sediment suspended in the water column. The time series of deposition rates indicate that deposition peaks following RMS events but with a lag so that peak deposition occurs when RMS has decreased to near background levels (Appendix A2). An explanation for this lag is that, as waves resuspend sediment, little deposition occurs because the energy in the system keeps sediment in suspension. However, when waves decrease and there is no longer enough energy in the system to keep sediment in suspension 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 (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.

AMB1 had the highest median, mean and upper quartile deposition rate while AMB5 had the lowest deposition rates (Figure 3.12, Table 3.6). The most deposition occurred in September at AMB3b and AMB10 and in October at AMB1, AMB8 and AMB12. Deposition was highest in March at AMB2 (Appendix A3).

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

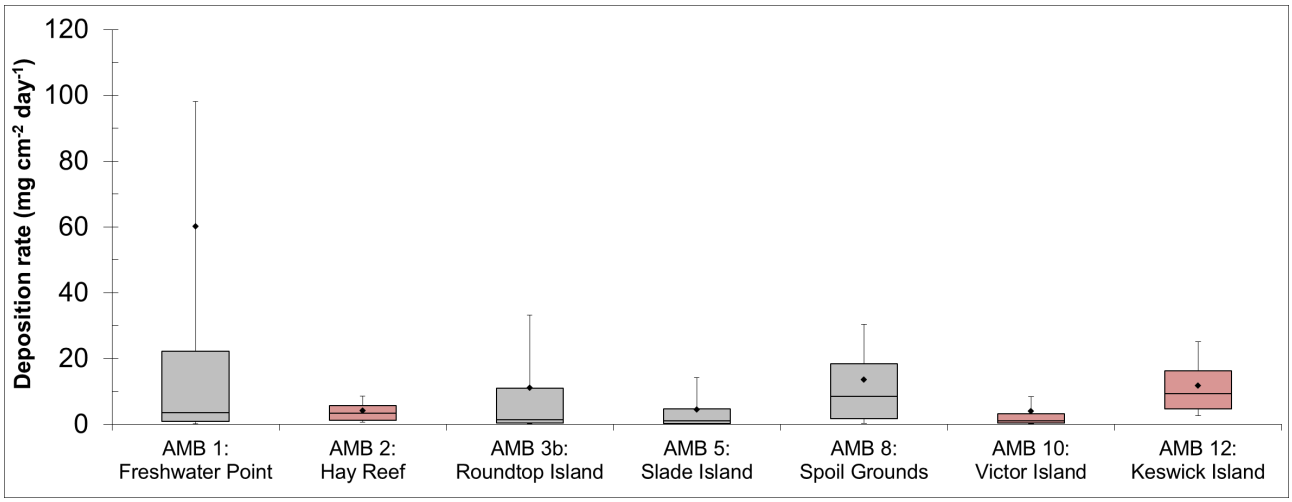


Figure 3.12 Box plot of hourly deposition rate (mg cm^{-2} day^{-1}) at the seven sites for the monitoring period July 2020 to July 2021. Boxes shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

Table 3.6 Summary of the mean daily deposition rate (mg cm^{-2} day^{-1}) statistics from July 2020 to July 2021.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil Grounds	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	60.16	4.28	11.23	4.59	13.61	4.02	11.87
median	3.50	3.33	1.34	1.05	8.46	1.14	9.31
min	0.01	0.18	0.01	0.00	0.02	0.01	1.43
lower quartile	0.93	1.31	0.39	0.22	1.82	0.44	4.73
upper quartile	22.28	5.78	10.92	4.68	18.46	3.18	16.30
max	1135.83	20.65	119.05	65.22	78.81	83.71	45.42
90th percentile	98.12	8.56	33.15	14.27	30.47	8.48	25.06
10th percentile	0.22	0.67	0.13	0.05	0.29	0.17	2.65
n (recordings)	**283**	**68**	**255**	**248**	**135**	**246**	**64**
f (year obtained)**	**0.775**	**0.186**	**0.699**	**0.679**	**0.370**	**0.674**	**0.175**
St. Dev	179.02	4.25	22.31	8.74	16.84	8.98	9.51
St. Error	10.64	0.52	1.40	0.56	1.45	0.57	1.19

**f = fraction of the total 2020 July-2021 July recording period obtained (a maximum of 365 possible recordings [daily interval data]); note that any original recordings which were masked or excluded during the Quality Assurance (QA) process, are not counted in 'n' or 'f'.

3.2.4 Water temperature

Water temperature was similar among all sites (Figure 3.13, Table 3.7). Mean monthly temperature peaked between December and March at approximately 30 °C (Appendix A2); a factor that was also observed in the field in-situ water temperature surveys. The lowest mean monthly temperatures were observed between May to July, where values dropped to approximately 20 °C (Appendix A3). Decreases in temperature over short time periods match with increases in RMS water depth. Water temperature is generally not considered to be a compliance condition for approval operations, however the temperature data presented here holds importance in future interpretation of ecological processes in the region, and across the GBR (e.g. Johanson et al., 2015).

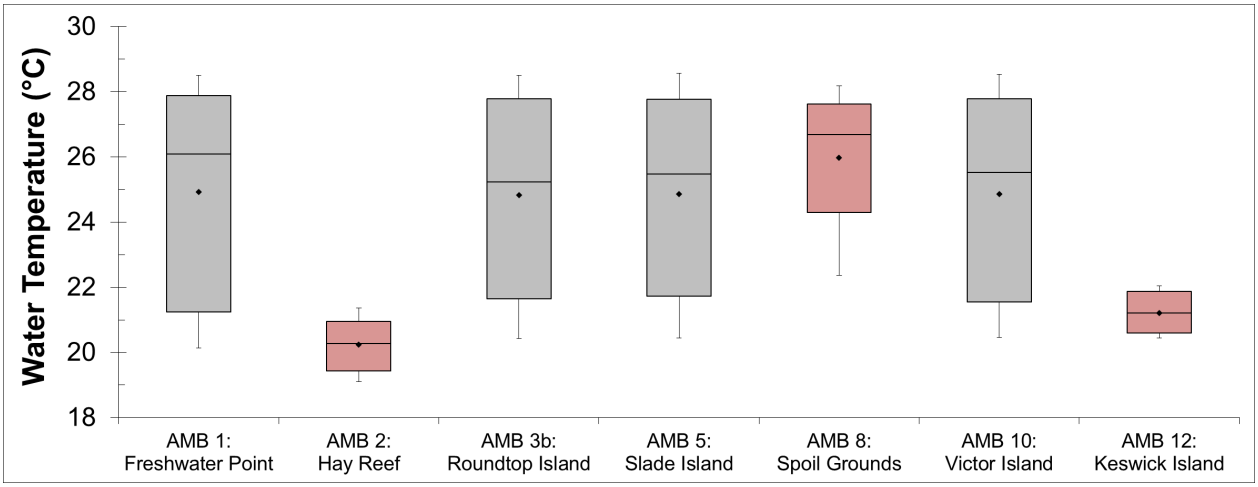


Figure 3.13 Box plot of the water temperature (°C) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value. Boxes shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

Table 3.7 Summary of water temperature (°C) for the monitoring period from July 2020 to July 2021.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil Grounds	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	24.93	20.25	24.83	24.87	25.97	24.86	21.22
median	26.09	20.27	25.24	25.47	26.69	25.53	21.21
min	18.30	18.68	19.18	19.29	21.54	18.96	20.18
lower quartile	21.25	19.44	21.65	21.73	24.29	21.55	20.60
upper quartile	27.88	20.96	27.79	27.77	27.63	27.79	21.87
max	30.46	22.16	29.92	30.19	29.41	30.12	22.22
90th percentile	28.51	21.36	28.50	28.57	28.19	28.54	22.04
10th percentile	20.14	19.11	20.43	20.44	22.37	20.46	20.44
n (recordings)	**37,561**	**9,712**	**52,327**	**52,514**	**20,005**	**52,519**	**9,558**
f (year obtained)**	**0.715**	**0.185**	**0.996**	**0.999**	**0.381**	**0.999**	**0.182**
St. Dev	3.35	0.83	3.11	3.13	2.09	3.17	0.63
St. Error	0.02	0.01	0.01	0.01	0.01	0.01	0.01

**f = fraction of the total 2020 July-2021 July recording period obtained (a maximum of 52560 possible recordings [10 min interval data]); note that any original recordings which were masked or excluded during the Quality Assurance (QA) process, are not counted in 'n' or 'f'.

3.2.5 Photosynthetically active radiation (PAR)

Benthic PAR was influenced by water depth, as the lowest PAR was measured at deepest site (AMB 8; Figure 3.14, Table 3.8). The highest median PAR was measured at AMB3B, and it has the highest upper quartile of 2.44 mol m^{-2} d^{-1} (excluding the decommissioned sites) (Figure 3.11). One site had an upper quartiles ≥2.0 mol m^{-2} d^{-1} (AMB5), indicating that 25 % of days at these sites had greater than 2.0 mol m^{-2} d^{-1}.

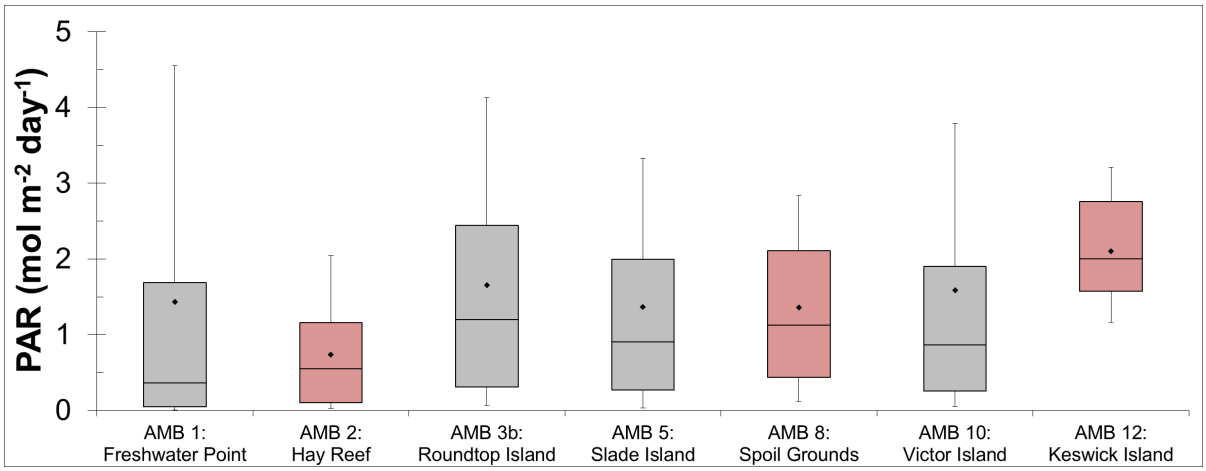


Figure 3.14 Box plot of PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles, respectively. The diamond represents the mean value. Boxes shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

Table 3.8 Summary of PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021.

Site	AMB 1: Freshwater Point	AMB 2: Hay Reef	AMB 3b: Roundtop Island	AMB 5: Slade Island	AMB 8: Spoil Grounds	AMB 10: Victor Island	AMB 12: Keswick Island
Mean	1.43	0.74	1.66	1.37	1.36	1.59	2.10
median	0.36	0.55	1.20	0.90	1.13	0.86	2.00
min	0.00	0.00	0.00	0.00	0.00	0.00	0.23
lower quartile	0.05	0.10	0.31	0.27	0.44	0.25	1.57
upper quartile	1.69	1.16	2.44	2.00	2.11	1.90	2.76
max	14.19	2.66	7.96	8.86	4.77	14.63	3.82
90^{th} percentile	4.55	2.04	4.13	3.33	2.83	3.79	3.21
10^{th} percentile	0.00	0.03	0.07	0.03	0.12	0.05	1.16
n (recordings)	317	68	322	355	141	364	67
f (year obtained)**	**0.868**	**0.186**	**0.882**	**0.973**	**0.386**	**0.997**	**0.184**
St. Dev	2.39	0.77	1.62	1.44	1.14	2.22	0.82
St. Error	0.13	0.09	0.09	0.08	0.10	0.12	0.10

**f = fraction of the total 2020 July-2021 July recording period obtained (a maximum of 365 possible recordings [daily interval data]); note that any original recordings which were masked or excluded during the Quality Assurance (QA) process, are not counted in 'n' or 'f'.

Benthic PAR was highly variable throughout the year, which is a common pattern in the region. For most sites, PAR was highest in July-September and in March (Figure 3.15). Semi-regular oscillations between low and high PAR were overridden by larger episodic events caused by storms or rainfall (Figure 3.16).

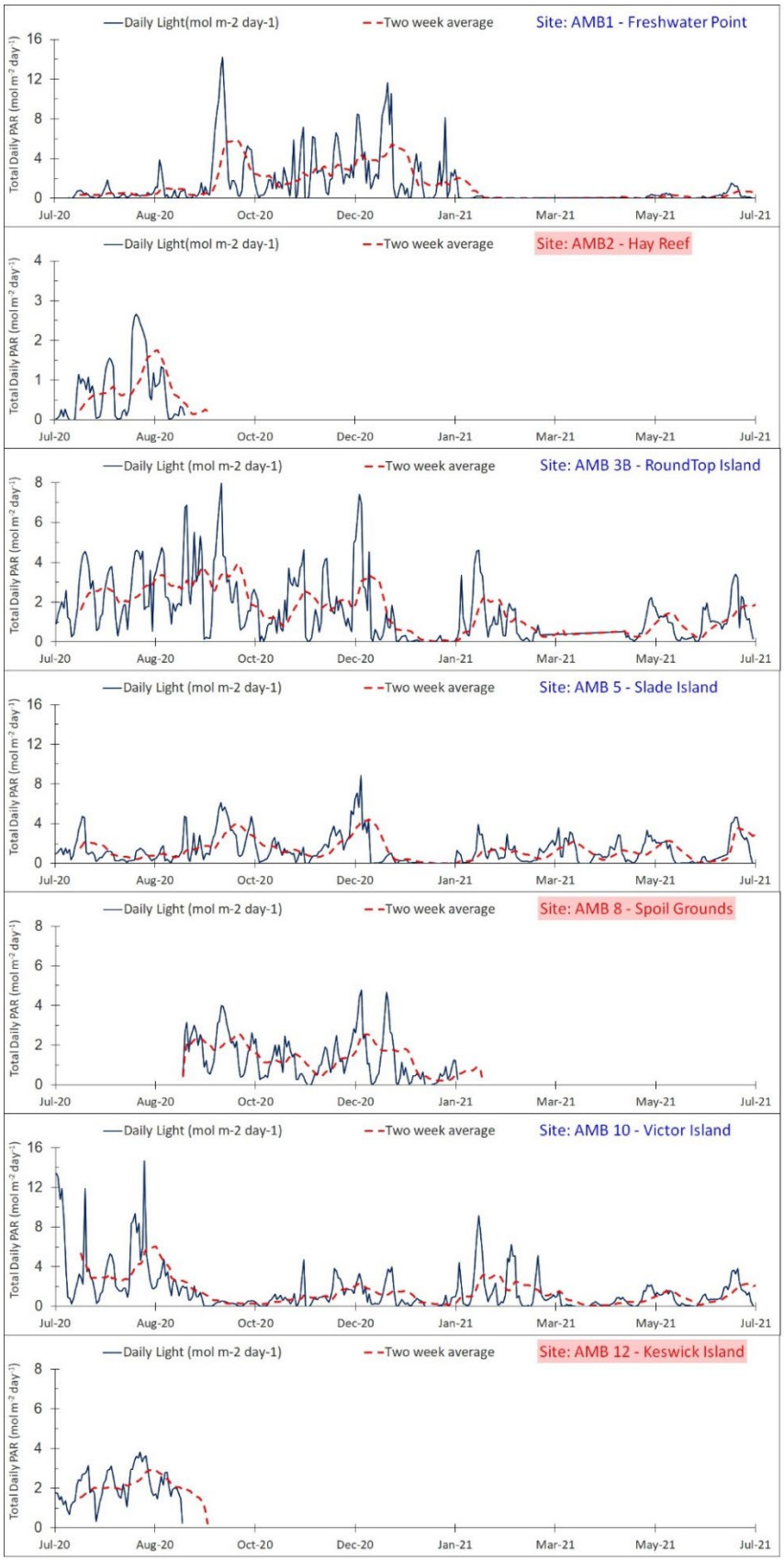


Figure 3.15 Time series of daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. Daily PAR is plotted in blue and a 2-week moving average of daily PAR is plotted in red. Site names shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites.

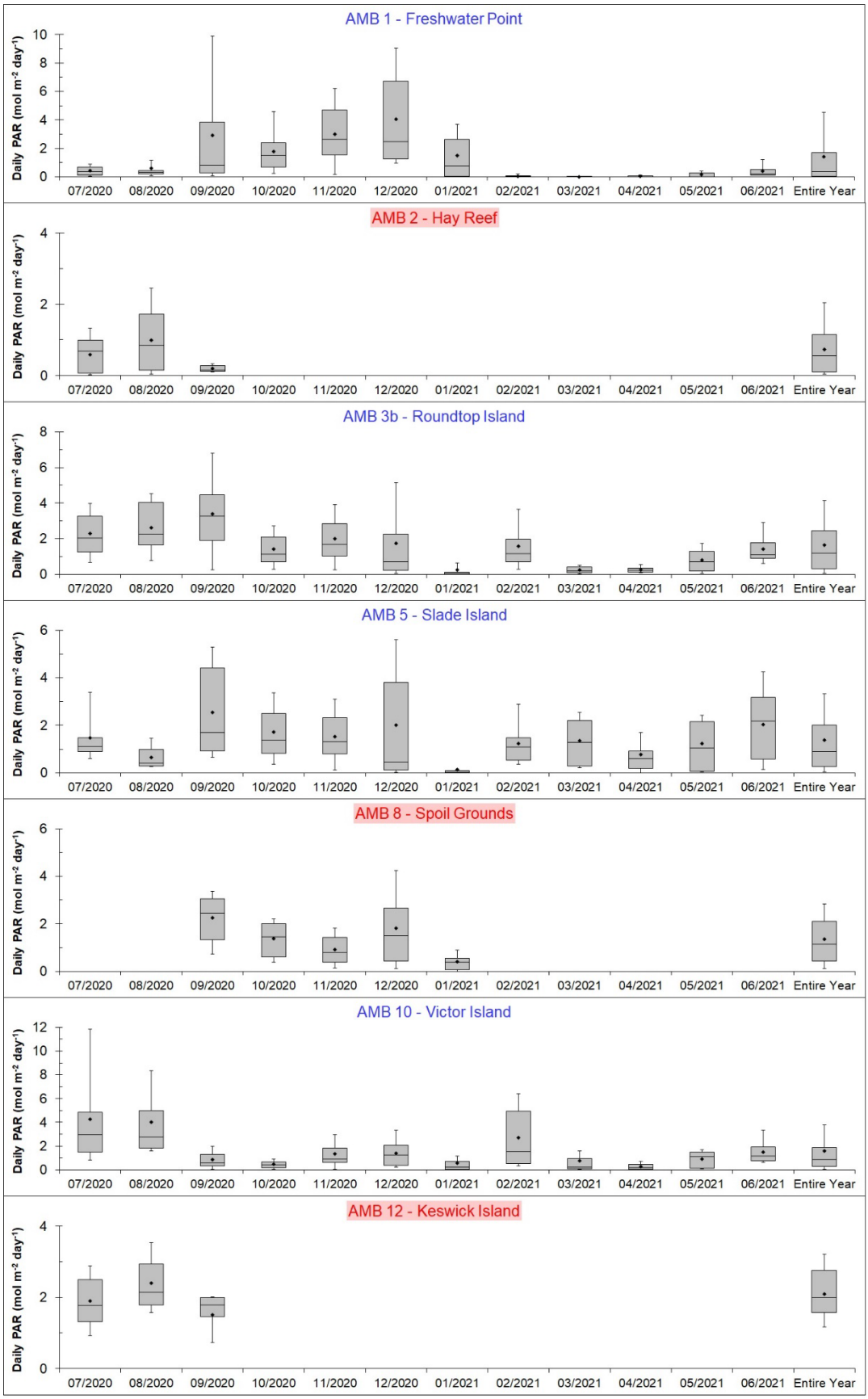


Figure 3.16 Monthly boxplots of total daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles, respectively. The diamond represents the mean value.

3.2.6 Similarities in patterns of PAR among sites

There are no significant correlations between the benthic PAR at any pairwise comparisons (Figure 3.17). No association were found above $R^2 = 0.43$ for the sites that remained in the program. This is in contrast to the previous annual periods where associations of $R^2 > 0.65$ have been shown. These analyses assist in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region. Sites that were decommissioned are also shown for completeness.

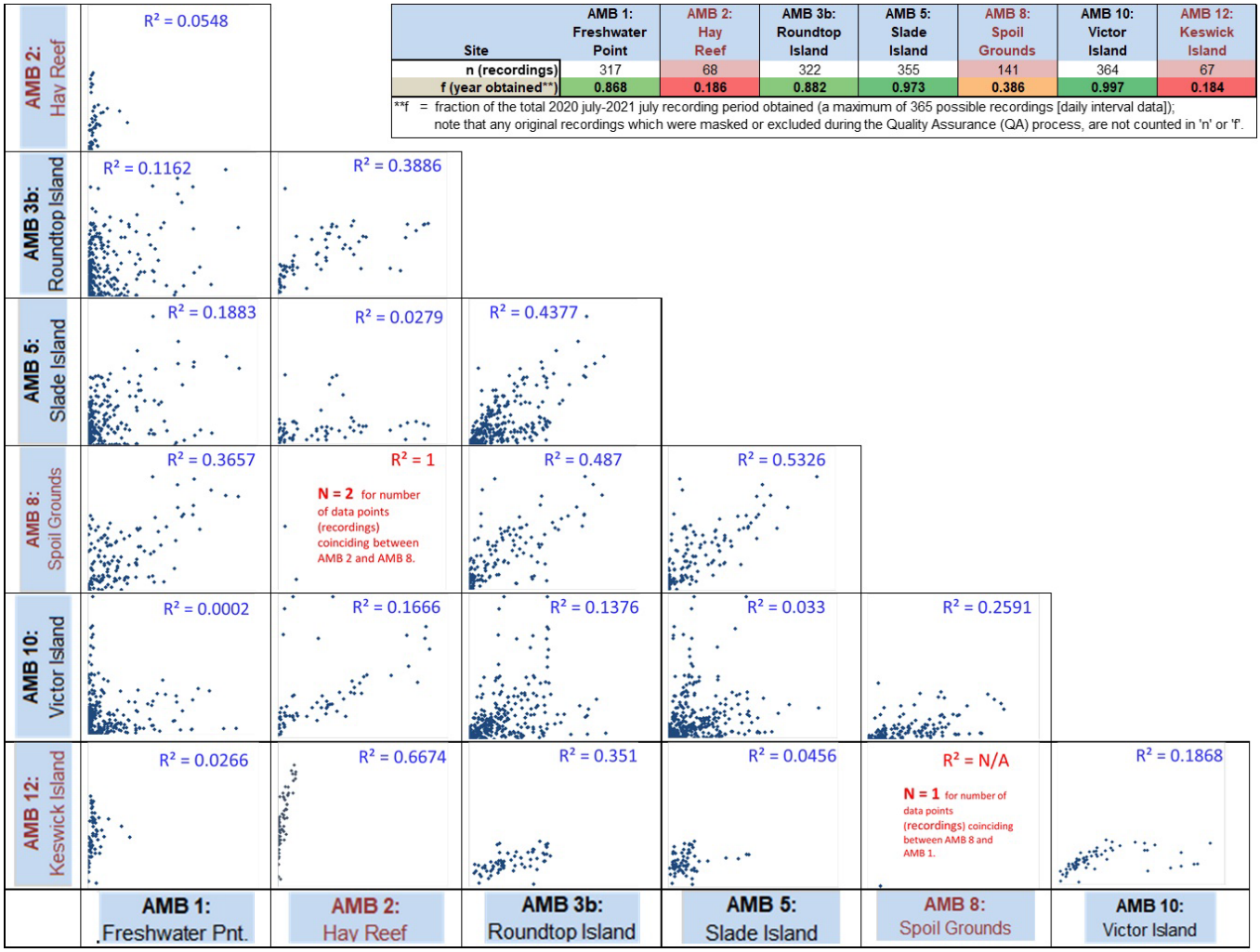


Figure 3.17 Scatterplots of the pairwise comparisons among sites indicating the strength of the relationships between patterns of daily PAR. R^2 values are presented for each comparison.

3.2.7 Annual site comparison

Comparison of the data 2014-2021 provides a perspective of trends in the monitored environment. Weather can induce small variations between years, but consistent differences between sites suggest characteristic differences in aquatic environments.

RMS water height

RMS water height values are expected to change each year if there are changes to the locations where data was located or a change in weather events for the year. RMS values in 2019-2020 largely reflected the differences observed in previous years (Figure 3.18). Slight differences in RMS are most likely due to variation in weather between years.

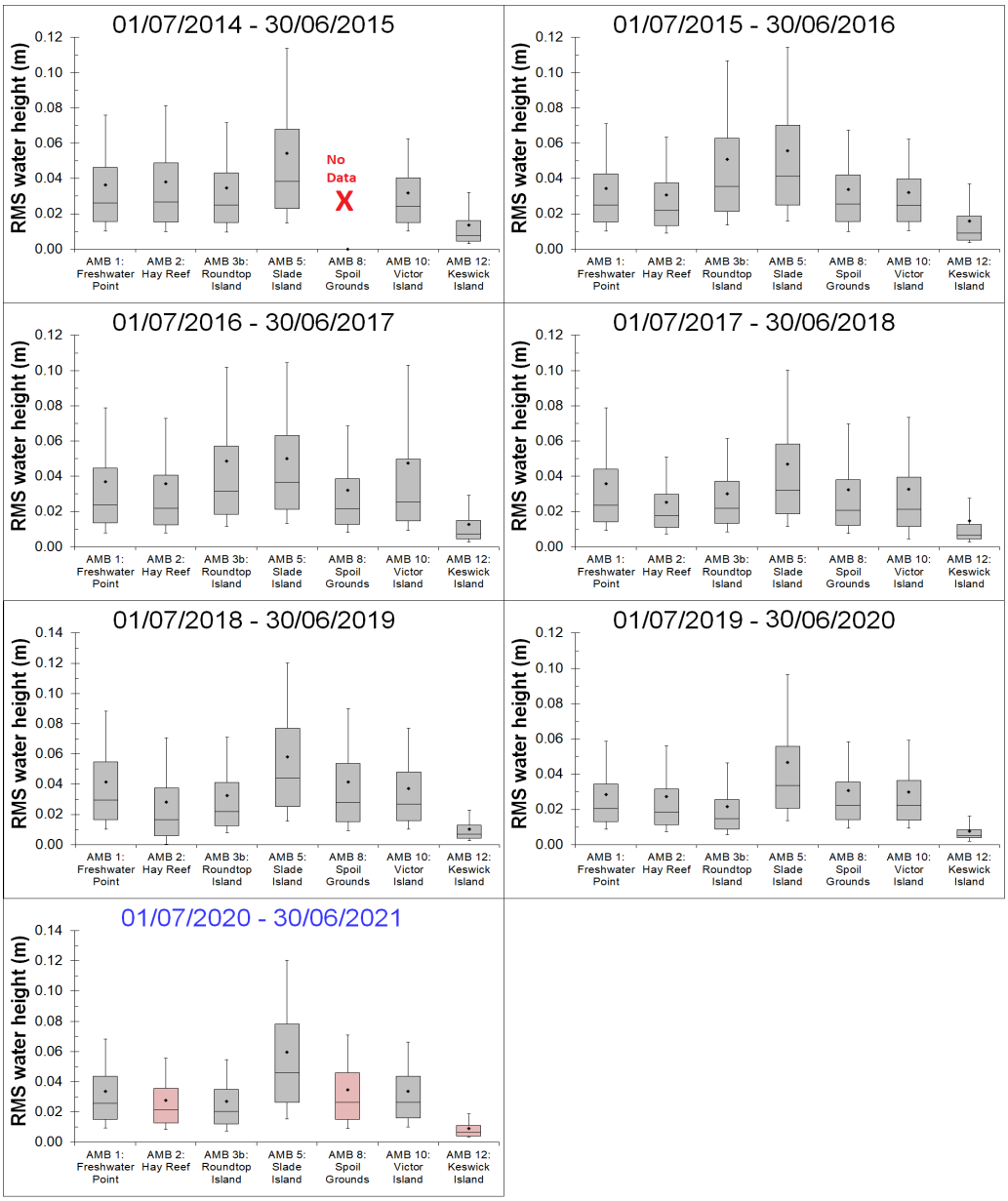


Figure 3.18 Annual summaries of RMS water height (m) from 2014-2020. Note that the sites are numerically ordered for 2020-2021. In the 2020-2021 plot, boxes shaded red highlight the sites which were decommissioned during this year and hence have relative low number of recordings compared to other sites. 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.

NTUe/SSC

Differences in SSC between sites are largely consistent between years (Figure 3.19). AMB12 and AMB3 consistently had the lowest SSC, while AMB1, AMB2, and AMB10 typically had high SSC. Large SSC events can be associated with large weather systems, such as Tropical Cyclone Debbie in 2017 which can mobile large amounts of benthic sediment in these coastal areas. Interestingly, the current reporting period generally had the lowest SSC results relative to previous years.

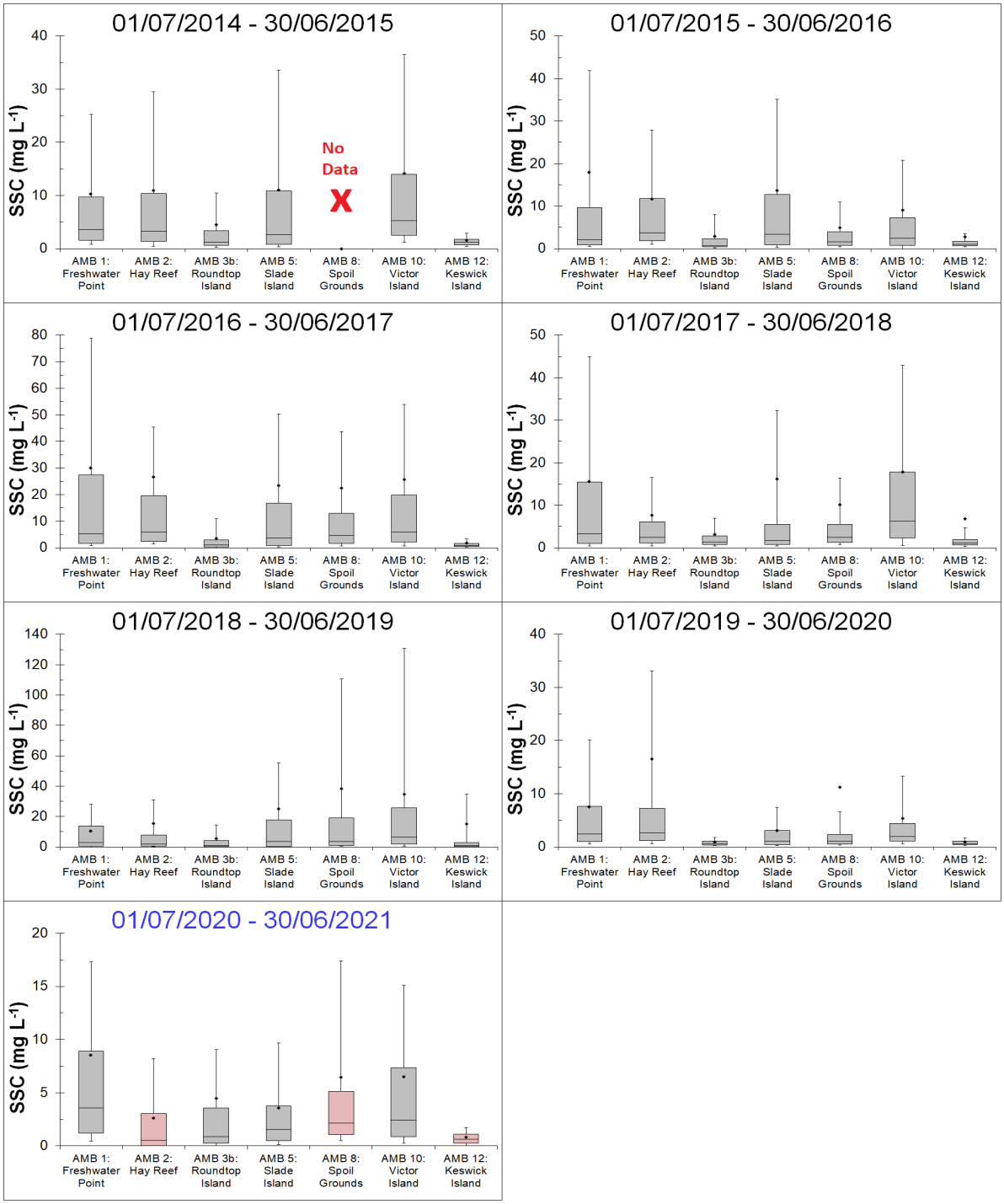


Figure 3.19 Annual summaries of suspended sediment concentration (SSC) from 2014-2020. Note that different scales are used between years. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Deposition rate

Deposition rates can vary among sites and different times of the year (Figure 3.20). AMB1 and AMB5 generally display the highest deposition rates relative to all others sites.

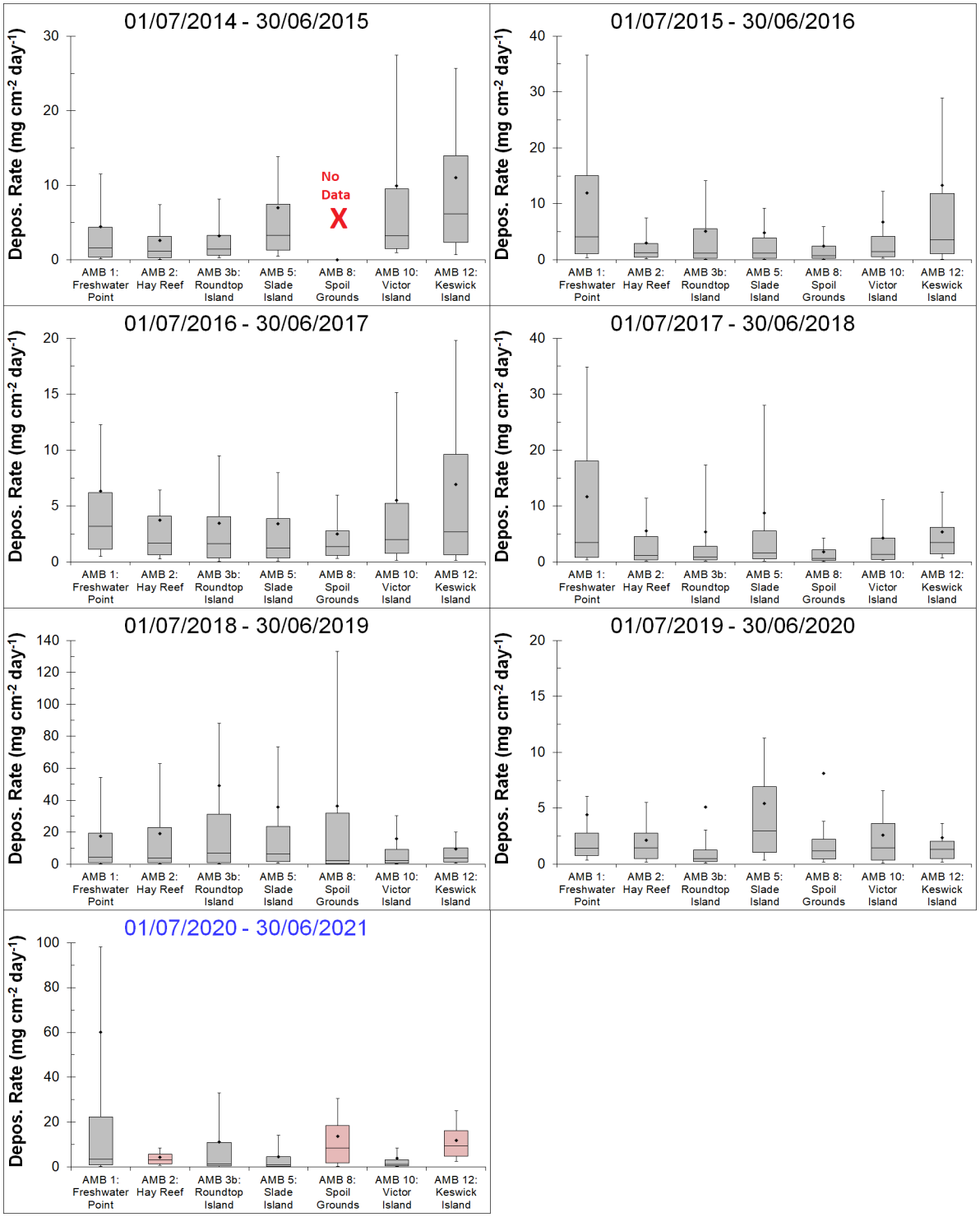


Figure 3.20 Annual summaries of daily deposition (mg cm^{-2} day^{-1}) from 2014-2020. Note that different scales are used between years. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles, respectively. The diamond represents the mean value.

3.2.8 Seasonal variation: wet vs dry

A comparison of wet and dry season water quality (2014-2021) suggests that the wet season coincides with increased suspended sediments, increased sediment deposition, and decreased irradiance at some sites. Temperatures were higher in the wet season at all sites. No clear seasonal pattern was observed for RMS across all sites.

Note: Supplementary table added below about maximum (and also general) seasonal data coverage across all sites, in case further details are useful, I did not add table with numbering; so as not to upset the numbering of tables across all pages.

Related Year	Wet Season Period		Dry Season Period	
	Start	end	Start	end
2014	01/11/2014	31/03/2015	06/07/2014	31/10/2014
2015	01/11/2015	31/03/2016	01/04/2015	31/10/2015
2016	01/11/2016	31/03/2017	01/04/2016	31/10/2016
2017	01/11/2017	31/03/2018	01/04/2017	31/10/2017
2018	01/11/2018	31/03/2019	01/04/2018	31/10/2018
2019	01/11/2019	31/03/2020	01/04/2019	31/10/2019
2020	01/11/2020	31/03/2021	01/04/2020	31/10/2020
2021	N/A	N/A	01/04/2021	30/06/2021

Sites AMB1 and AMB2, exhibited the strongest seasonal differences, including increased SSC (Figure 3.22) and decreased PAR (Figure 3.24). Interestingly, the remaining sites AMB3b, AMB5, AMB8, AMB10 and AMB12 exhibited similar suspended sediments across both seasons. All sites exhibited weak seasonal differences in sediment deposition for the 2019-2020 period (Figure 3.23).

RMS water height

Wet seasons are associated with large storms, wind and rain. It is often assumed that there is a large difference in wave energy between the wet and dry seasons in the Mackay region, but the combined data from 2014-2021 indicate that there is not a large difference in RMS between seasons (Figure 3.21, all years). For 2020-2021, there was slightly higher median and upper quartile RMS during the wet season at AMB1 and AMB10, however, the difference between seasons was generally weak at all other sites.

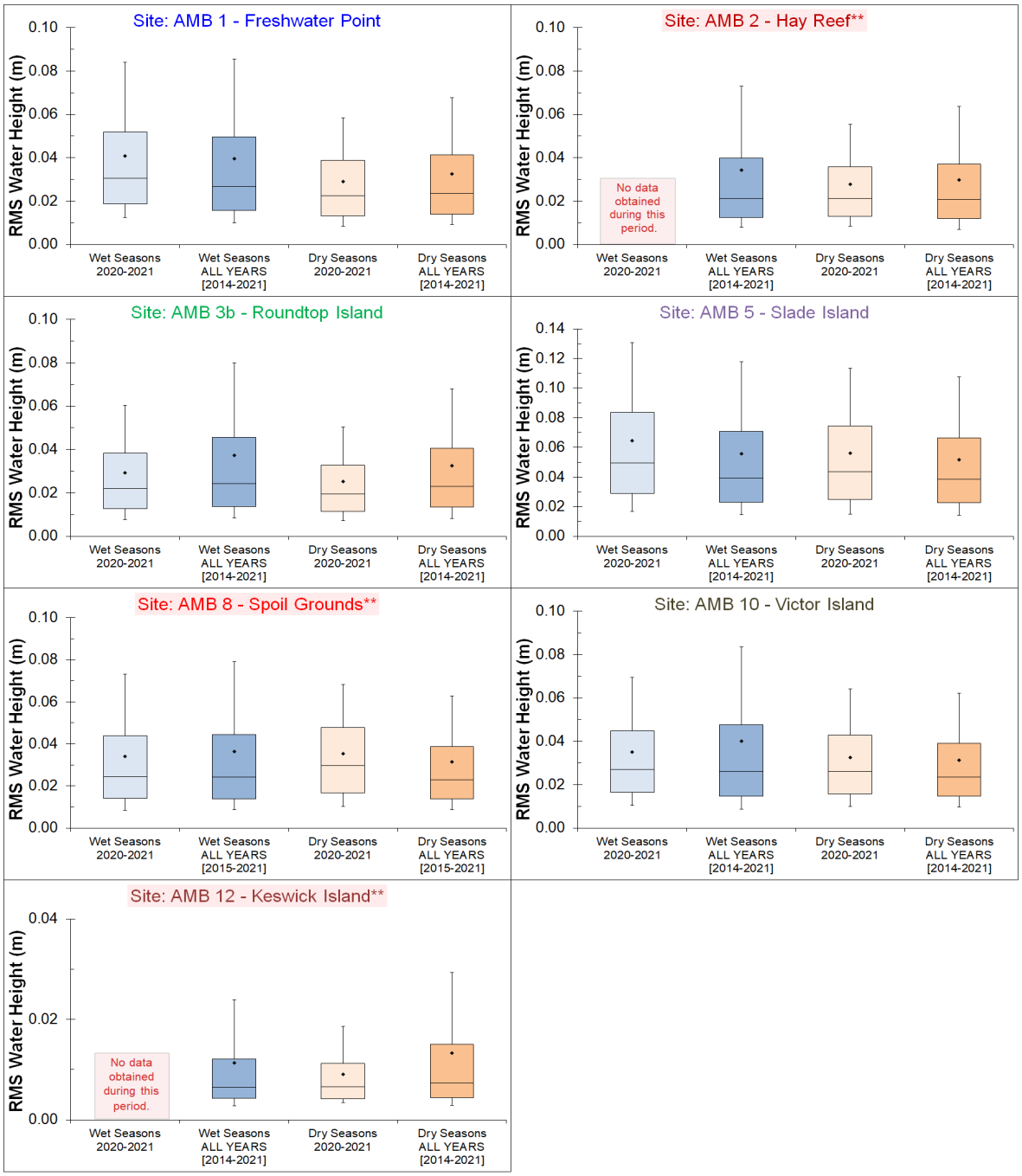


Figure 3.21 RMS water height box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2020-2021) or all available wet seasons (2014-2021). Note that a different scale is used for AMB12 compared to the other sites. 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.

SSC

For most sites, suspended sediment concentrations (SSC) were slightly higher during the wet season, however, the difference was less than previous years (Figure 3.22). AMB 3b showed decreased SSC during the wet season, when compared to dry season in the current reporting period, which is different to other sites.

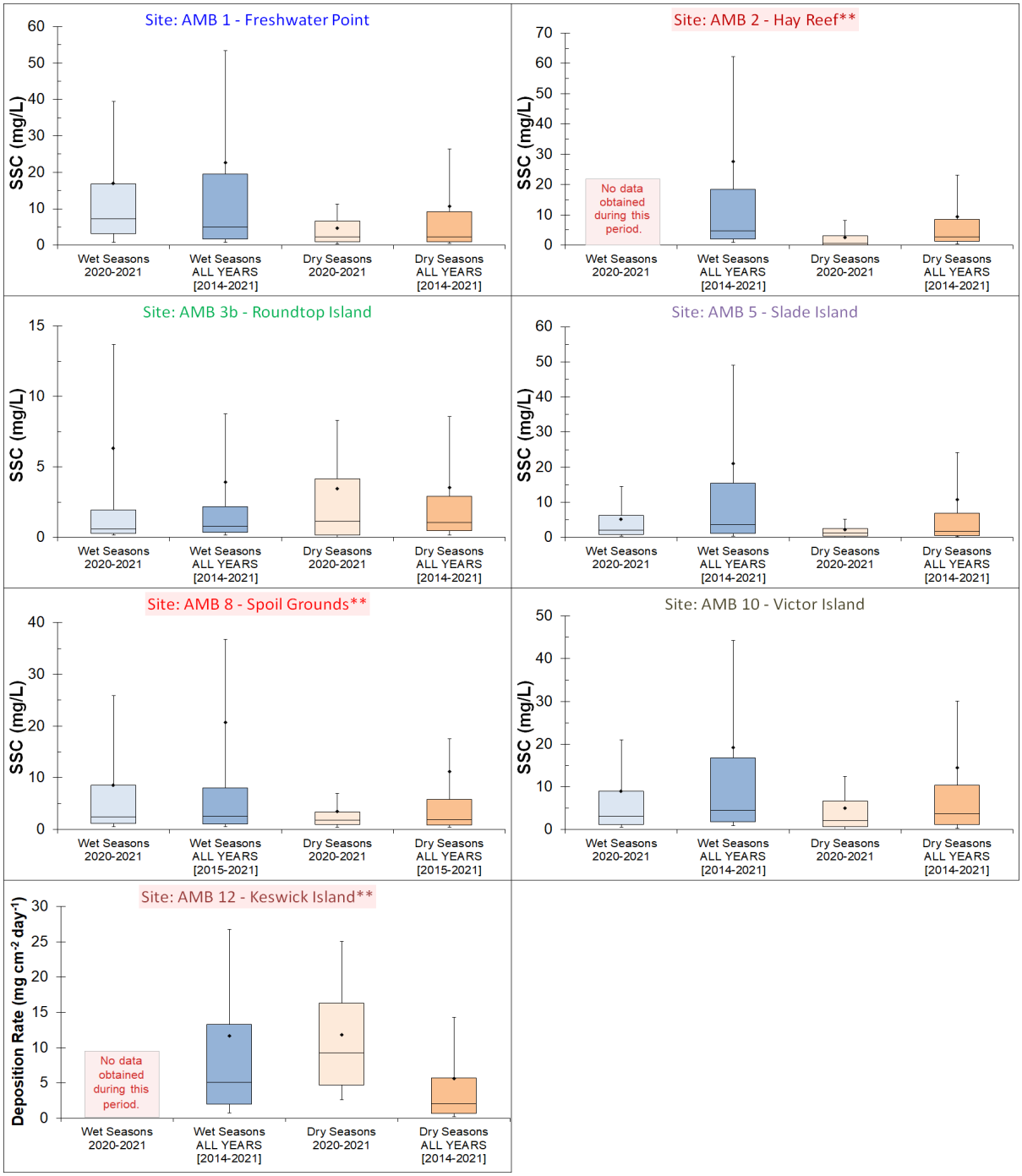


Figure 3.22 Suspended sediment concentration (SSC) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2020-2021) or all available wet seasons (2014-2021). Note that different scales are used for different sites. 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.

Hourly deposition rate

For the 2020-2021 monitoring year, median and upper quartile sediment deposition rates in the wet season were lower than the dry at all sites, with the exception of AMB3b. This is in contrast to the previous year, which showed an overall increase in deposition rates during the wet season. The mechanism behind this change is unclear, however, this could be linked to the reduced levels of SSC during this period (see rainfall total for this year in Figure 1.3 which shows below average rainfall).

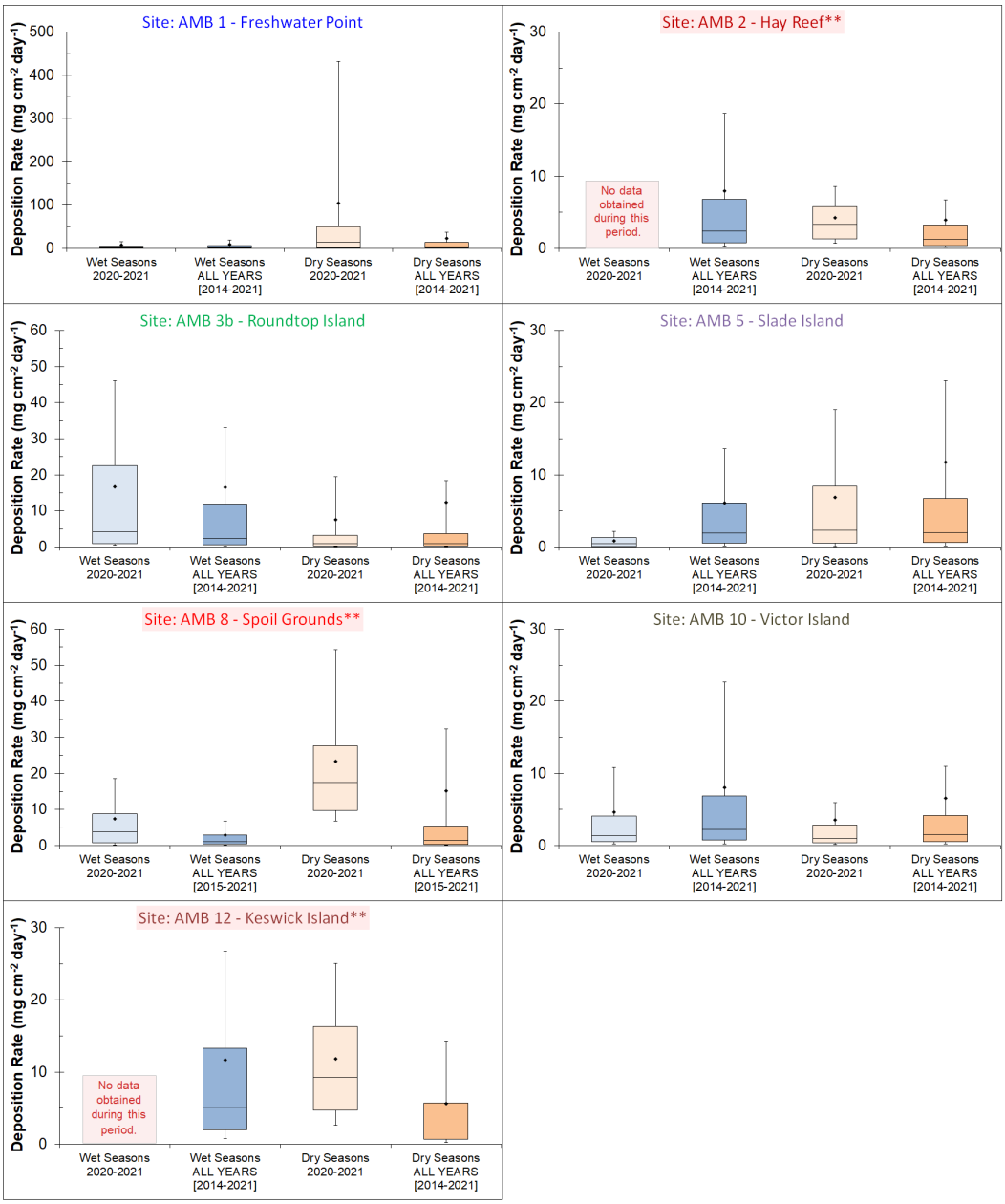


Figure 3.23 Sediment deposition rates (mg cm^{-2} day^{-1}) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2020-2021) or all available wet seasons (2014-2021). The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles, respectively. The diamond represents the mean value.

Total daily PAR

Most sites had similar photosynthetically available radiation statistics across the wet and dry seasons as the previous year. The usual profile of reduced PAR during the wet compared to the dry season was observed (Figure 3.24). The pattern of lower PAR during wet season is probably related to rainfall events and higher SSC (Figure 3.22), or more cloud cover which would also be responsible for reduced benthic PAR during the wet season.

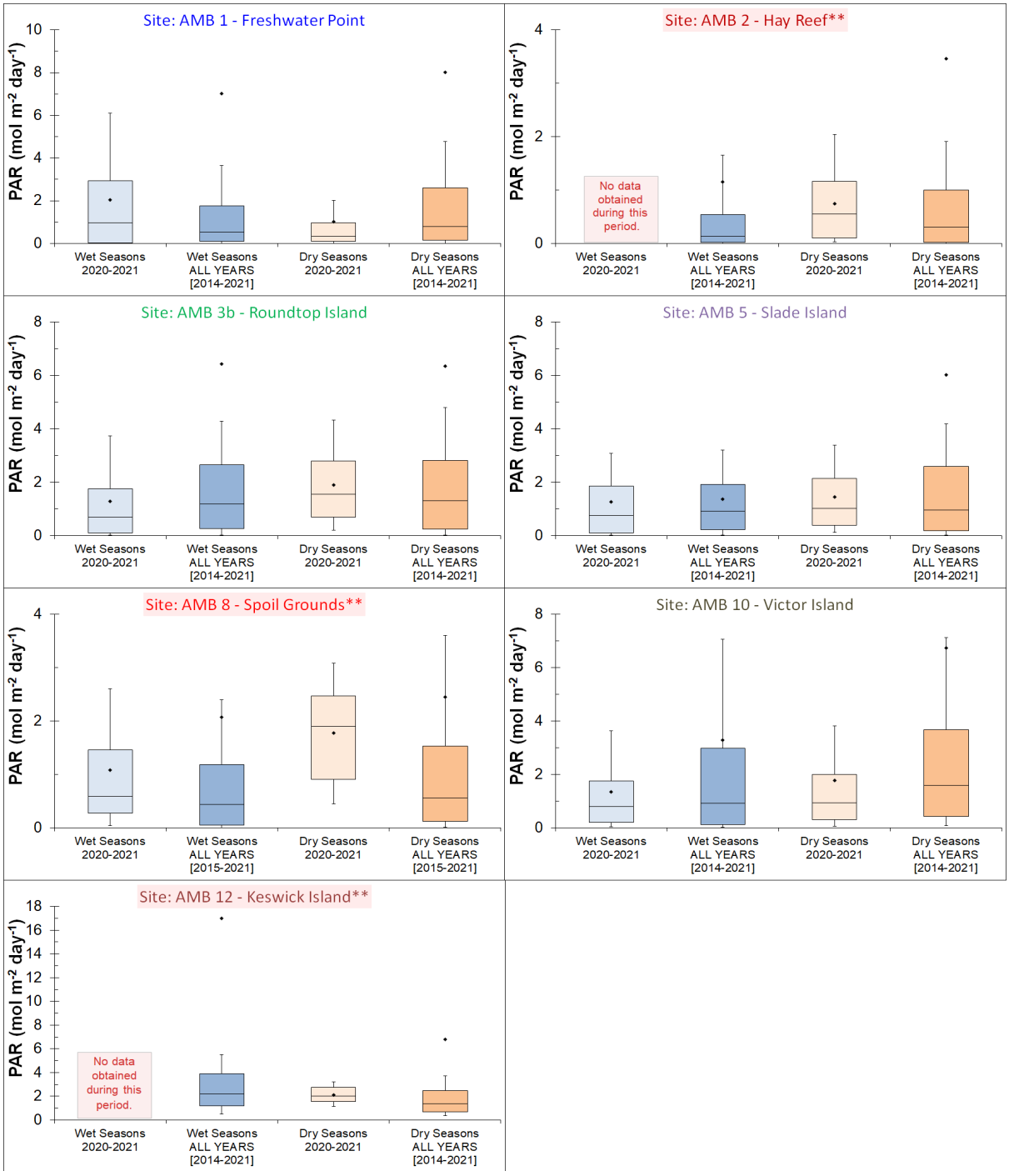


Figure 3.24 Photosynthetically available radiation (mol m^{-2} day^{-1}) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2020-2021) or all available wet seasons (2014-2021). Note the doubled y-axis scale for some sites. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10^{th}, 25^{th}, 50^{th}, 75^{th} and 90^{th} percentiles, respectively. The diamond represents the mean value.

Water temperature

Median temperatures during the wet season (28-29 °C) are notably higher than in the dry season (22-24 °C; Figure 3.25). Notably, the range in water temperature in the current reporting period is generally more similar to the long term distribution of water temperatures.

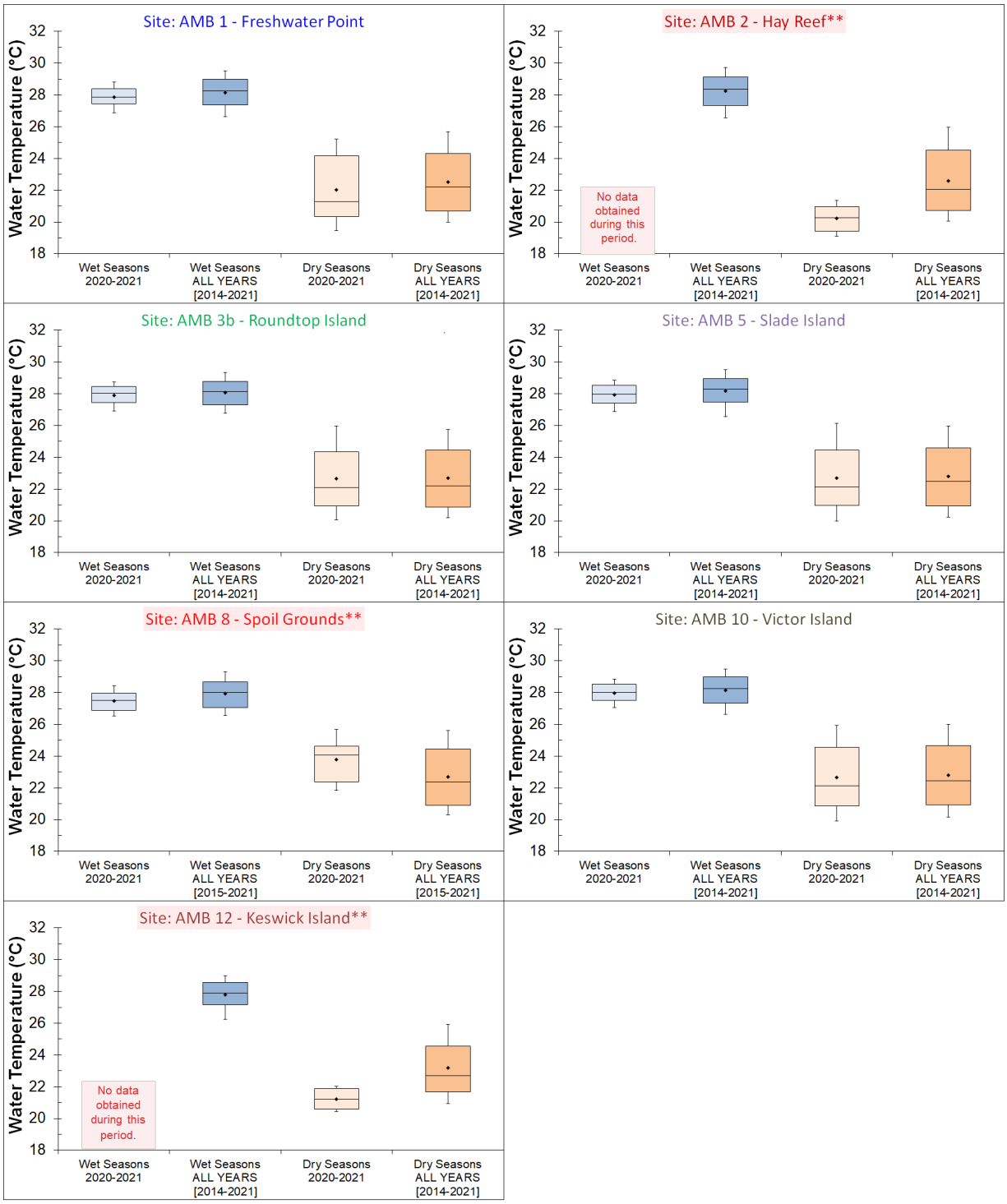


Figure 3.25 Temperature (°C) box plots for each monitoring site. Boxes represent the wet (1 November-31 March) and dry seasons (1 April-31 October) using either one wet season (2019-2020) or all available wet seasons (2014-2020). The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

3.2.9 Marotte HS current meter

Marotte HS current meter instruments were deployed throughout the monitoring period of July 2020 to July 2021, for Mackay sites AMB 1,3b, 5 and 10. However, following September 2020, current meter instruments were temporarily decommissioned for usage in Mackay deployments and then later re-applied for ongoing deployments from January 2021 and onwards; except for sites AMB2, AMB 8 and AMB 12 which were entirely decommissioned for deployments beyond September 2020 as per other sections of this report. The reason for the breaks in data series was either flooding of the instruments or the units were missing because of fouling and units breaking free. The obtained current meter data indicates the prominent current direction, current speed, and water temperature at each site. Data shows that coastal current, tidal current or a combination of both influence current direction and magnitude. The figures presented display the current meter data in current rose which provide a visual representation of the frequency of current speed, direction, and temperature. On the proceeding pages the presented results of obtained current meter data indicate the prominent water current direction, water current speed (m/s), and water temperature (°C) at each Mackay location.

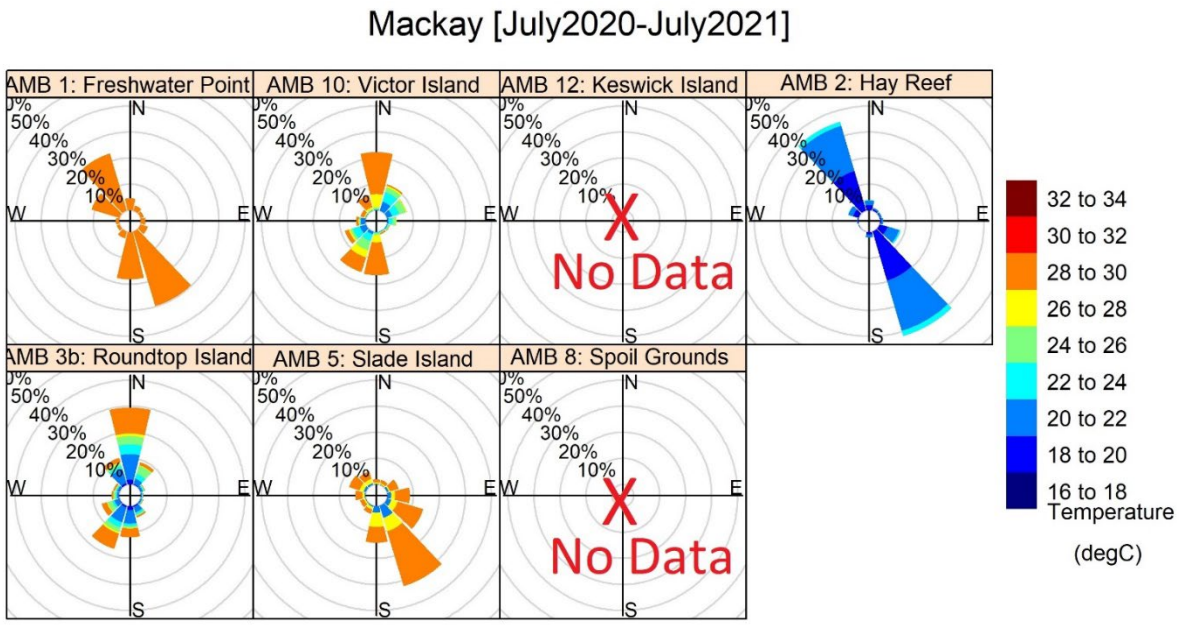


Figure 3.26 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction (heading), for each of the Seven Mackay sites and covering the monitoring period July 2020 to July 2021.

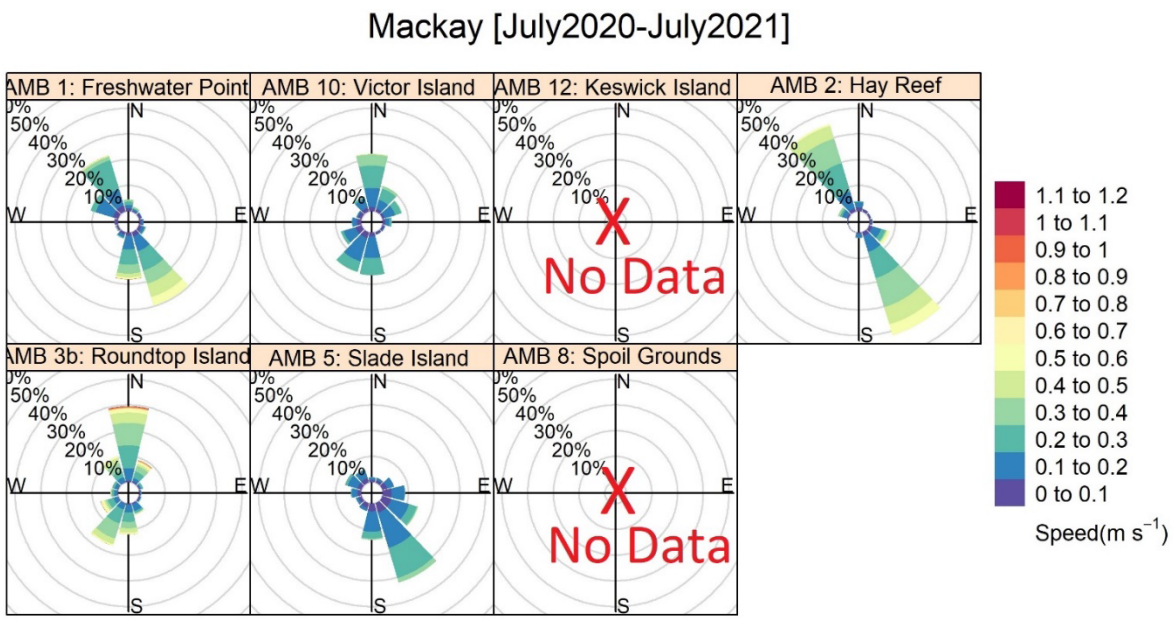


Figure 3.27 Rose-plots displaying the frequency of recorded current speed (m/s) with respect to current direction (heading), for each of the Seven Mackay sites and covering the monitoring period July 2020 to July 2021.

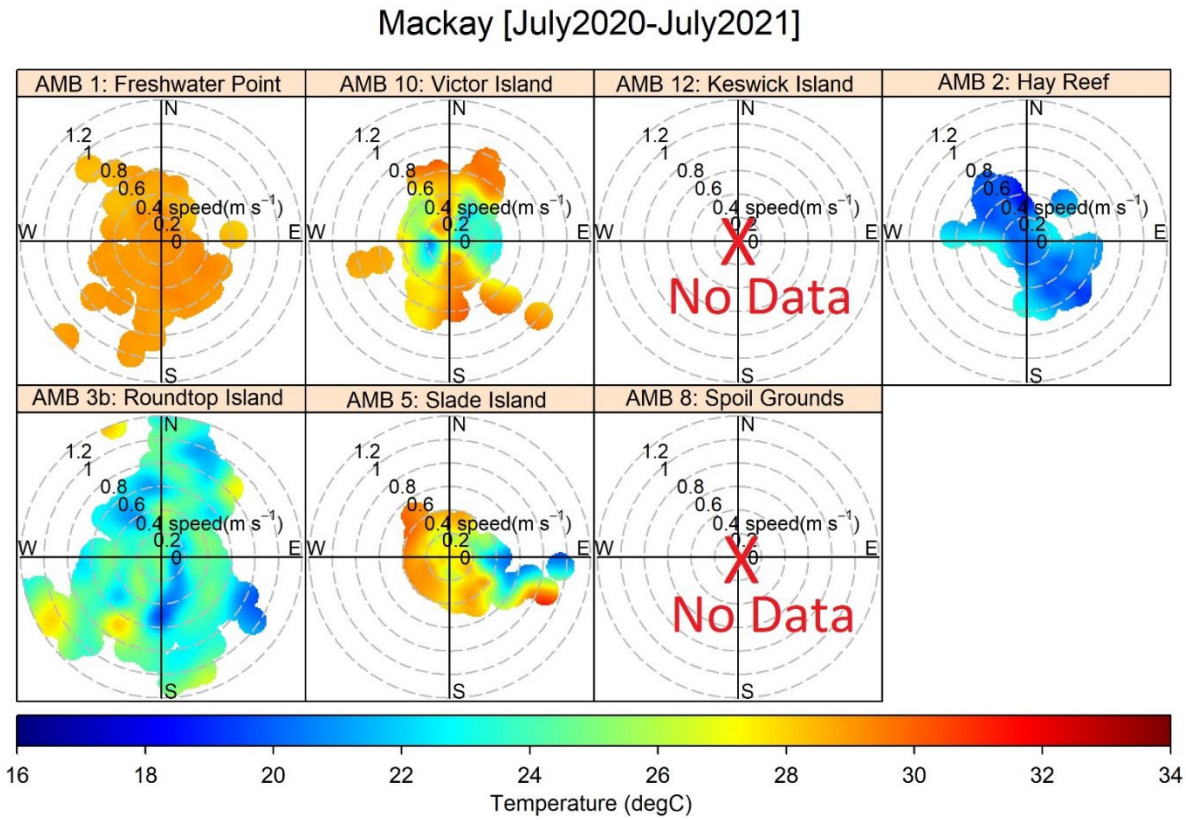


Figure 3.28 For each of the Seven Mackay sites and covering the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). The position of the data, within each plot, indicates current direction and the distance from the origin indicates current speed (m/s). Data points are coloured according to calculated average water temperature (°C).

Current meter data during the Dry Season (April – October)

Below is a summary of current meter data that was collected during months of the dry season period (April-October). This includes, a) Rose-plots displaying the frequency of recorded water temperature (°C) with respect to current direction (heading*) (Figure 3.29). b) Rose-plots displaying the frequency of recorded current speeds (m/s) with respect to current direction (heading*) (Figure 3.30). c) Bi-variate plots presenting averaged water temperature (°C) calculated with respect to current speed (m/s) and current direction (heading*) (Figure 3.31).

*heading is defined by degrees (angle) rotating clockwise from facing North.

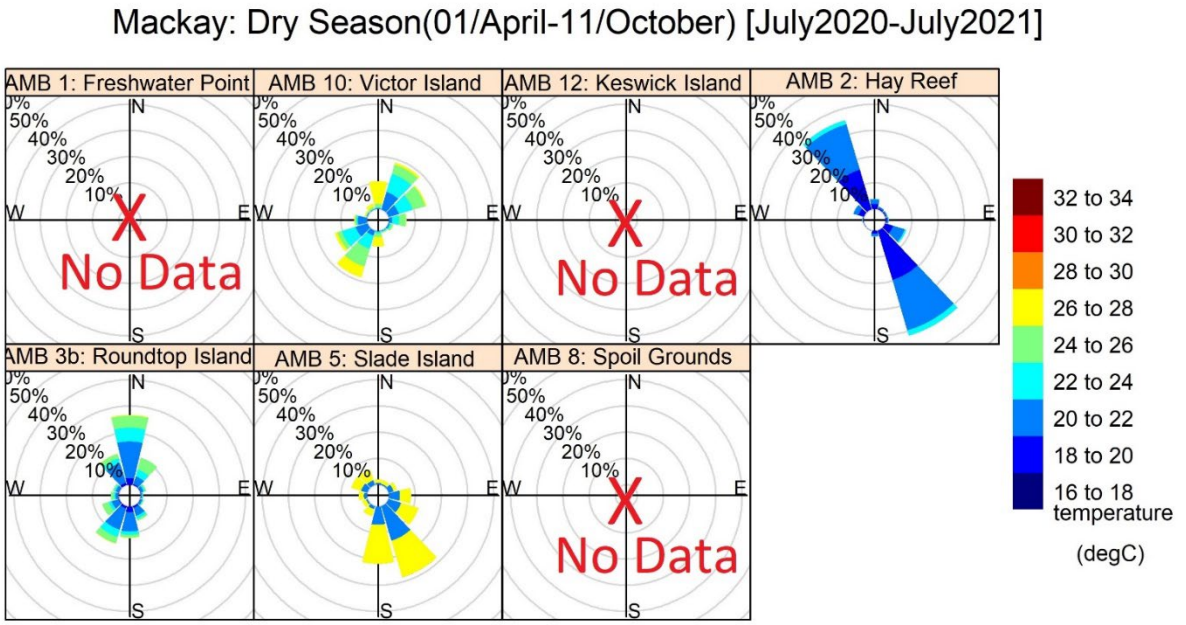


Figure 3.29 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction (heading), for each of the Seven Mackay sites during the dry season months (April-October) across the monitoring period July 2020 to July 2021.

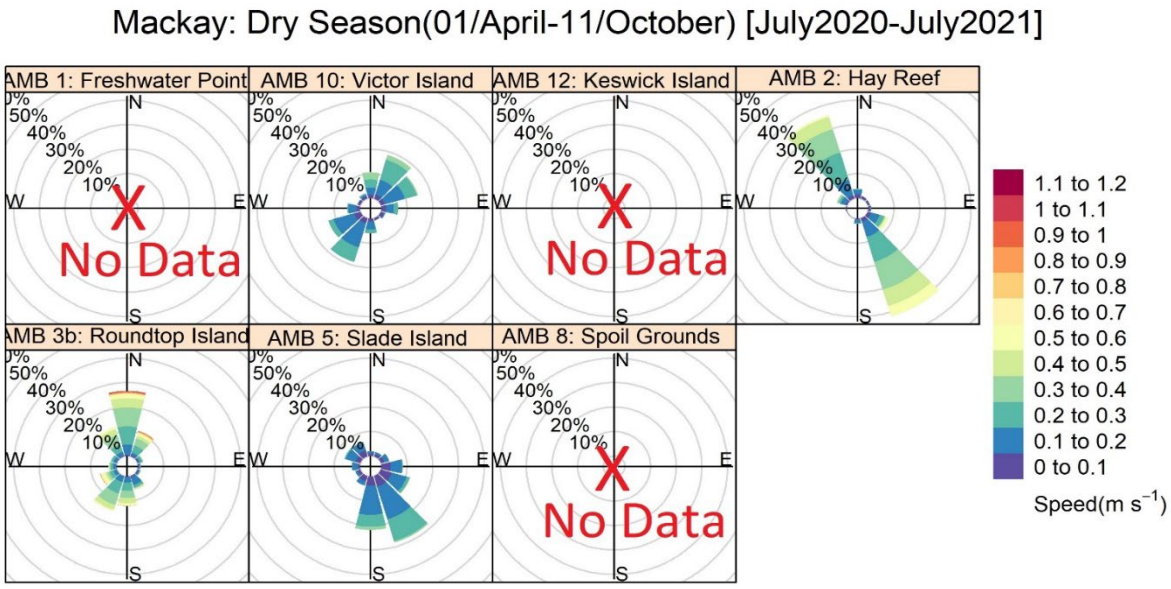


Figure 3.30 Rose-plots displaying the frequency of recorded current speed (m/s) with respect to current direction (heading), for each of the Seven Mackay sites during the dry season months (April-October) across the monitoring period July 2020 to July 2021.

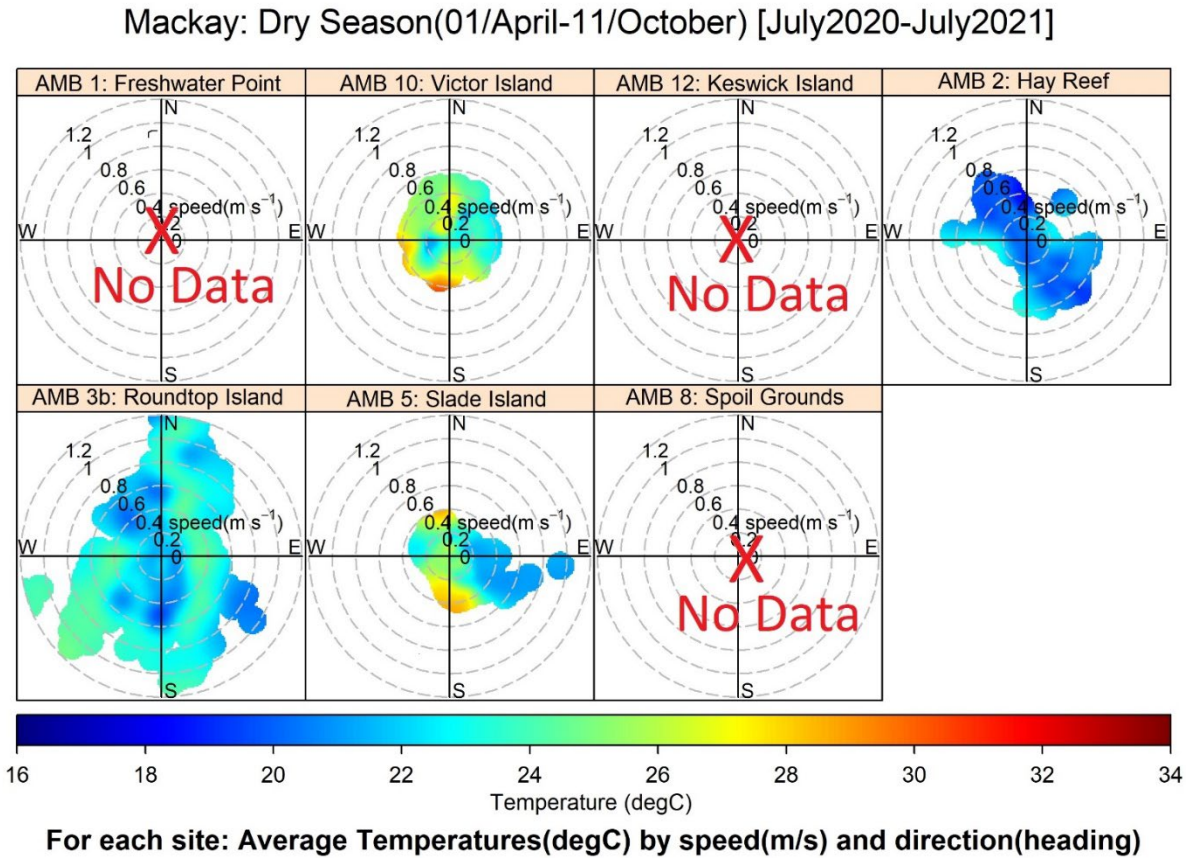


Figure 3.31 For each of the Seven Mackay sites during the dry season months (April-October) across the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). The position of the data, within each plot, indicates current direction and the distance from the origin indicates current speed (m/s). Data points are coloured according to calculated average water temperature (°C).

Current meter data during the Wet Season (November-March)

Current meter data that was collected during months of the wet season period (November-March) is summarised below. a) Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction (heading*) (Figure 3.32). b) Rose-plots displaying the frequency of recorded current speeds (m/s) with respect to current direction (heading*) (Figure 3.33). c) Bi-variate plots presenting averaged water temperature (°C) calculated with respect to current speed (m/s) and current direction (heading*) (Figure 3.34).

*heading is defined by degrees (angle) rotating clockwise from facing North.

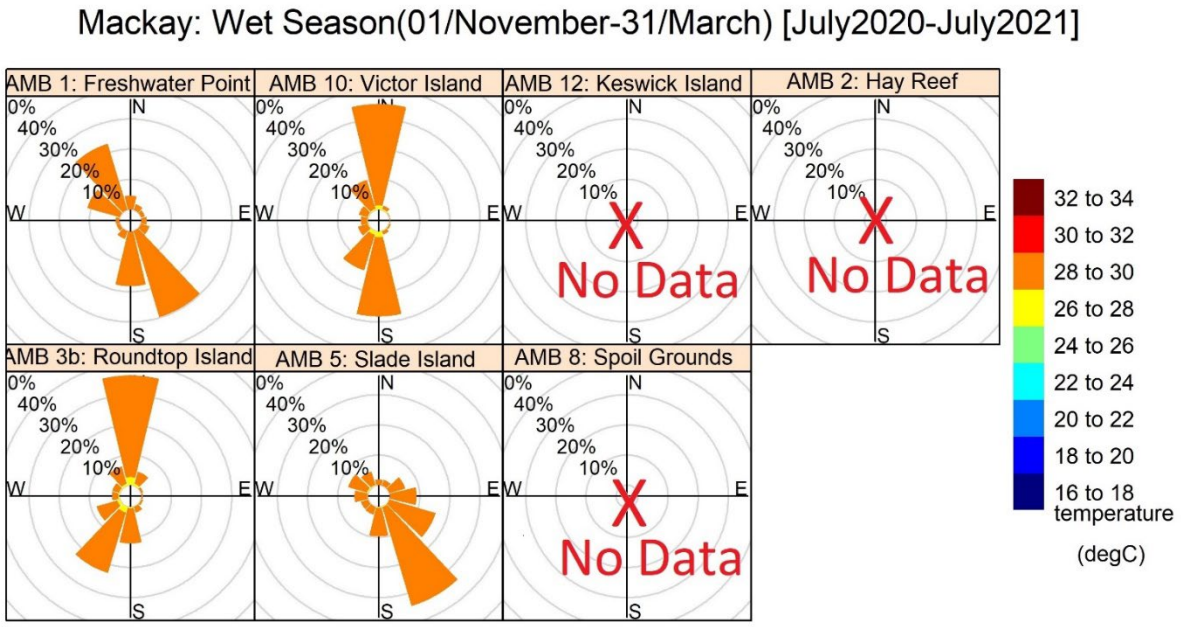


Figure 3.32 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction (heading), for each of the Seven Mackay sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021.

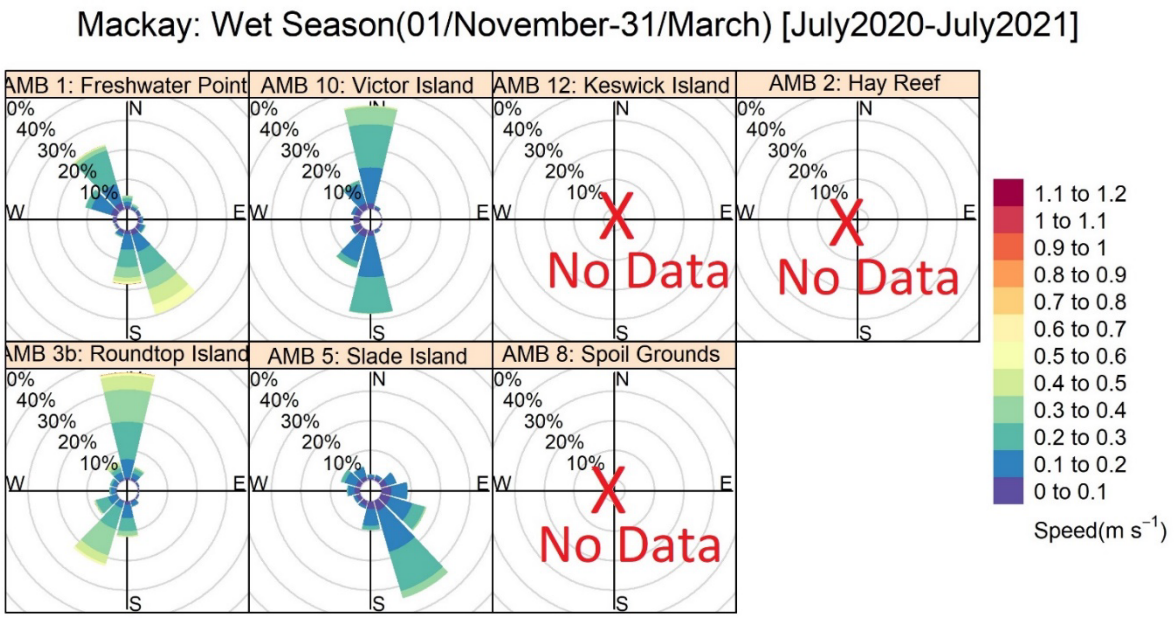


Figure 3.33 Rose-plots displaying the frequency of recorded current speed (m/s) with respect to current direction (heading), for each of the Seven Mackay sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021

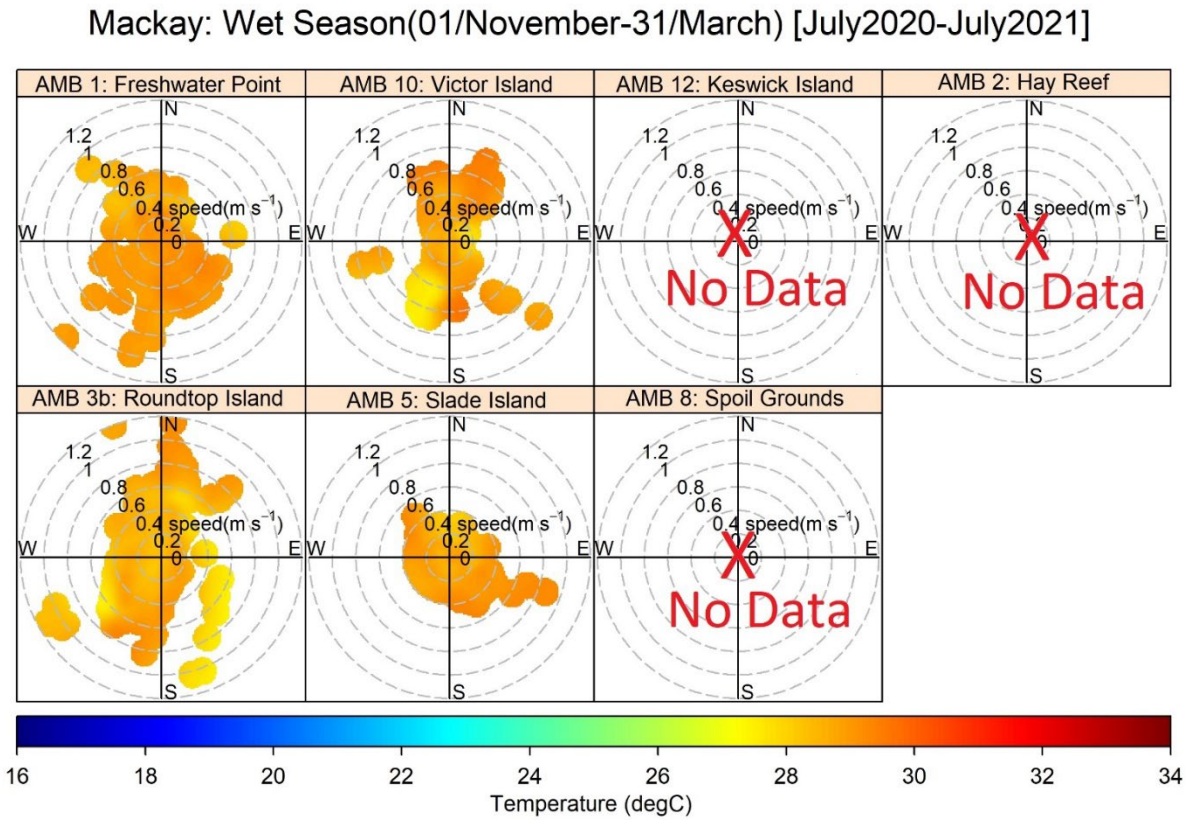


Figure 3.34 For each of the Seven Mackay sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). The position of the data, within each plot, indicates current direction and the distance from the origin indicates current speed (m/s). Data points are coloured according to calculated average water temperature (°C).

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

4.1.1 Climatic conditions

1. The total 2010-2021 wet season rainfall at Plane Creek Sugar Mill (17 km linear from Hay Point) is below the long-term average wet season total, proximal to the 40th percentile of long-term rainfall wet season totals.
2. The wet season rainfall contributed to at least four flow periods, but most notably during late December 2020 and early January 2021, where rainfall and river discharge was highest.

4.1.2 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 continues to be highest during the summer and coolest during the winter months. Similar to previous years, dissolved oxygen levels and pH remain similar among the three depth horizons, which provides some evidence, that the water column is largely well mixed. The same appears for electrical conductivity.
3. Particulate nitrogen concentrations exceeded the guidelines throughout most of the 2020-2021 monitoring period. This continues to be a regular occurrence and might require further investigation into the guidelines for the region.
4. Chlorophyll-a concentrations exceeded the GBRMPA guideline trigger value for all sampling. This continues to be the case each year, and suggests the need to consider the development of locally specific guidelines that reflect the natural range of conditions experience in the region.
5. Metals targeted for analysis were not detected above the 95% level of protection trigger values for marine waters. Silver, Cadmium, Nickel, Zinc, and Mercury were not detected. Copper was detected here (unlike in previous years), and we are not sure for this detection, either it could be attributed to laboratory contamination, or possible some contamination from the copper tape used on the new loggers that was transferred to our samples. We have introduced additional steps during field sampling as an extra precaution to ensure that if this is a cross contamination, it is not repeated.
6. This reporting period we transitioned to using passive samplers to monitor pesticide and herbicide concentrations. Pesticides targeted for analysis using passive samplers were not detected above the trigger values for the GBR. While some pesticide/herbicides were detected, these samples were below the GBRMPA draft guidelines for 99% species protection.

4.1.3 High frequency loggers

1. Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment, and this has been most notable here given the links drawn between RMS water depth and NTUe/SSC. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week. This is similar to the pattern observed in long term annual data sets at these sites.
2. Another important finding here was that deposition data did not indicate large deposits occurring at any of the monitored sites, and this is likely attributed to re-suspension of sediment by wave energy. SSC continues to regularly exceed relevant water quality guidelines at all sites, indicating that the development of local water quality guidelines is prudent. As

part of this local water quality guideline development, it is recommended that the guidelines apply to benthic waters, adjacent to sensitive receptor habitats, rather than the current approach of surface water guidelines that can be well away from important habitats.

3. The comparison of wet and dry season shows some slight differences in SSC for most sites, with lower mean and median values compared to previous years.
4. Fine-scale patterns of photosynthetically active radiation (PAR) continue to be driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids – this trend was particularly the case given the extended wet season rainfall and runoff in the region following the monsoon that covered the region in February 2019.
5. Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter. Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites.
6. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations, the relationship between these two parameters is not always strong. At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats, such as seagrass, algae and corals, it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats. For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.
7. Overall the difference between wet and dry season PAR levels remained similar to previous years. This is probably not surprising given that the total wet season rainfall for this reporting period was within the 40th percentile of historical rainfall patterns in the region. This supports the need for on-going monitoring to further characterise water quality responses to rainfall particularly under future changing climate predictions.

4.2 Recommendations

1. The program this reporting period has been reduced, consisting of four monitoring sites, which allows us to continue characterising water quality in the Mackay region. The remaining sites are Freshwater Point, Victor Islet, Roundtop Island and Slade Island; which covers approximately 50kms of coastline. This network of sites remains an important configuration given that is spans areas to the north and south of the facilities, and have been sites in place since the inception of the program in 2014.
2. The use of passive samplers has been an important advancement in the program. This sampling approach provides a more time integrated assessment of the exposure risk, rather than more traditional approaches where rely on a single water grab sample. This is the first year to use this approach, and in future years more detailed comparisons will be made to examine trends.
3. The elevated copper result recorded in the marina in August 2019 were below the guideline in the May 2020 survey, this result might be an anomaly, however, should be further checked for an emerging problem.

LITERATURE SOURCED

ANZECC and ARMCANZ (2000) Australian Water Quality Guidelines for Fresh and Marine Waters. Australia and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Brodie, J. E., Kroon, F. J., Schaffelke, B., Wolanski, E. C., Lewis, S. E., Devlin, M. J., Bohnet, I. C, Bainbridge, Z. T., Waterhouse, J., Davis, A. M. (2012) Terrestrial pollutant runoff to the Great Barrier Reef: an update of issues, priorities and management responses. Marine Pollution Bulletin, 65, 81-100.

Bunt, J., Larcombe, P., Jago, C. F. (1999) Quantifiying the response of optical backscatter devices and transmissiometers to variations in suspended particulate matter (SPM). Continental Shelf Research 19: 1199-1220

Capone, D. G., Zehr, J. P., Paerl, H. W., Bergman, B., Carpenter, E. J. (1997). Trichodesmium, a globally significant marine cyanobacterium. Science, 276, 1221-1229.

Chartrand, K. M., Ralph, P. J., Petrou, K., Rasheed, M. A. (2012) Development of a light-based seagrass management approach for the Gladstone Western Basin dredging program. DEEDI Publication, Fisheries Queensland, Cairns.

Commonwealth of Australia. (2019) Special Climate Statement 69 – an extended period of heavy rainfall and flooding in tropical Queensland. Bureau of Meteorology .

Conner, C. S., De Visser, A. M. (1992) A laboratory investigation of particle size effects on an optical backscatterance sensor. Marine Geology 108:151-159

Cook, R. D., Weisberg, S. (1982) Residuals and Influence in Regression. Chapman and Hall.

Crawley, M.J. (2007) The R Book. John Wiley and Sons, Ltd.

Devlin, M. J., McKinna, L. W., Alvarez-Romero, J. G., Petus, C., Abott, B., Harkness, P., Brodie, J. (2012) Mapping the pollutants in surface riverine flood plume waters in the Great Barrier Reef, Australia. Marine Pollution Bulletin, 65, 224-235. doi: 10.1016/j.marpolbul.2012.03.001

Drewry, J., Mitchell, C., Higham, W. (2008) Water quality improvement plan: final report for Mackay Whitsunday region. Mackay Whitsunday Natural Resource Management Group.

Erftemeijer, P. L. A., B. Riegl, B. W. Hoeksema, Todd, P. A. (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. Marine Pollution Bulletin 64, 1737-1765.

Erftemeijer, P. L. A., Lewis, R. R. R. (2006) Environmental impacts of dredging on seagrasses: a review. Marine Pollution Bulletin 52, 1553-1572.

Fabricius, K. E., G. De'ath, C. Humphrey, I. Zagorskis, Schaffelke, B. (2013) Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. Estuarine, Coastal and Shelf Science 116, 57-65.

Fox, J., Monette, G. (1992) Generalized collinearity diagnostics. JASA, 87, 178–183.

GBRMPA (2010) Water quality guidelines for the Great Barrier Reef Marine Park 2010 current edition. Great Barrier Reef Marine Park Authority.

GBRMPA (2013) Great Barrier Reef Region Strategic Assessment Report. Australian Government, Great Barrier Reef Marine Park Authority. pp. 636.

Grömping, G. (2006) Relative Importance for Linear Regression in R: The Package relaimpo. Journal of Statistical Software, 17, 1-27.

Johansen, J. L., Pratchett, M. S., Messmer, V., Coker, D. J., Tobin, A. J., Hoey, A. S. (2015) Large predatory coral trout species unlikely to meet increasing energetic demands in a warming ocean. Scientific Reports, 5.

King, O. C., Smith, R. A., Mann, R. M., Warne, M. J. (2017a) Proposed aquatic ecosystem protection guideline values for pesticides commonly used in the Great Barrier Reef catchment area: Part 1 (amended) - 2,4-D, Ametryn, Diuron, Glyphosate, Hexazinone, Imazapic, Imidacloprid, Isoxaflutole, Metolachlor, Metribuzin, Metsulfuron-methyl, Simazine, Tebuthiuron. Department of Environment and Science. Brisbane, Queensland, Australia. 296 pp.

King, O. C., Smith, R. A., Mann, R. M., Warne, M. J. (2017b). Proposed aquatic ecosystem protection guideline values for pesticides commonly used in the Great Barrier Reef catchment area: Part 2 - Bromacil, Chlorothalonil, Fipronil, Fluometuron, Fluroxypyr, Haloxyfop, MCPA, Pendimethalin, Prometryn, Propazine, Propiconazole, Terbutryn, Triclopyr and Terbuthylazine. Department of Science, Information Technology and Innovation. Brisbane, Queensland, Australia.

Kirk, J. T. O. (1985) Effects of suspendiods (turbidity) on penetration of solar rediation in aquatic ecosystems. Hydrobiologia, 125, 195-208.

Kroon, F. J., Kuhnert, P. M., Henderson, B. L., Wilkinson, S. N., Kinsey-Henderson, A., Abbott, B., Brodie. J. E., Turner, R. D. (2012) River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Marine Pollution Bulletin, 65, 167-181.

Larcombe P, Ridd PV, Prytz A, Wilson, B. (1995) Factors controlling suspended sediment ion inner-shelf coral reefs, Townsville, Australia. Coral Reefs 14:163-171

Lewis, S. E., Brodie, J. E., Bainbridge, Z. T., Rohde, K. W., Davis, A. M., Masters, B. L., Maughan, M., Devlin, M. J., Mueller, J. F., Schaffelke, B. (2009) Herbicides: A new threat to the Great Barrier Reef. Environmental Pollution, 157, 2470-2484.

Logan, M., Fabricius, K., Weeks, S., Rodriguez, A., Lewis, S., Brodie, J. (2014) Tracking GBR water clarity over time and demonstrating the effects of river discharge events. Progress Report: Southern and Northern NRM Regions. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (53pp.).

Ludwig, K. A., Hanes, D. M. (1990) A laboratory explanation of optical backscatterance suspended solids sensors exposed to sand-mud mixtures. Mar Geol 94:173-179

Orpin, A. R., Ridd, P. V. (2012) Exposure of inshore corals to suspended sediments due to wave-resuspension and river plumes in the central Great Barrier Reef: A reappraisal. Continental Shelf Research 47, 55-67.

R Core Team (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Ridd, P.V., Day, G., Thomas, S., Harradence, J., Renagi, O., Fox, D., Bunt, J., Renagi, O., Jago, C. (2001) Measurement of sediment deposition rates using an Optical Backscatter Sensor. Estuarine Coastal and Shelf Science, 52, 155-163.

Schaffelke, B., Carleton, J., Skuza, M., Zagorskis, I., Furnas, M. J. (2012) Water quality in the inshore Great Barrier Reef lagoon: Implications for long-term monitoring and management. Marine Pollution Bulletin, 65(4), 249-260.

Sofonia, J. J., Unsworth, R. K. F. (2010) Development of water quality thresholds during dredging for the protection of benthic primary producer habitats. Journal of Environmental Monitoring 12:159-163.

Standards Australia (1998) Water Quality – Sampling. Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. AS/NZS 5667.1:1998. Standards Australia, Homebush.

Thomas, S., Ridd, P. V., Renagi, O. (2003) Laboratory investigation on the effect of particle size, water flow and bottom surface roughness upon the response of an upward- pointing optical backscatter sensor to sediment accumulation. Continental Shelf Research. 23, 1545-1557.

TropWATER (2015) Assessment of the contamination risk posed by sampling consumables to the detection and monitoring of filterable metals in water samples. Internal report. Centre for Tropical Water and Aquatic Ecosystem Research, James Cook University.

Wolanski, E., Delesalle, B., Gibbs, R. (1994) Carbonate mud in Mataiva Atoll, French Polynesia: Suspension and export. Marine Pollution Bulletin 29:36-41.

A1 CALIBRATION PROCEDURES

A1.1 Turbidity/Deposition Calibration

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

A1.2 SSC Calibration

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

A1.3 Light Calibration

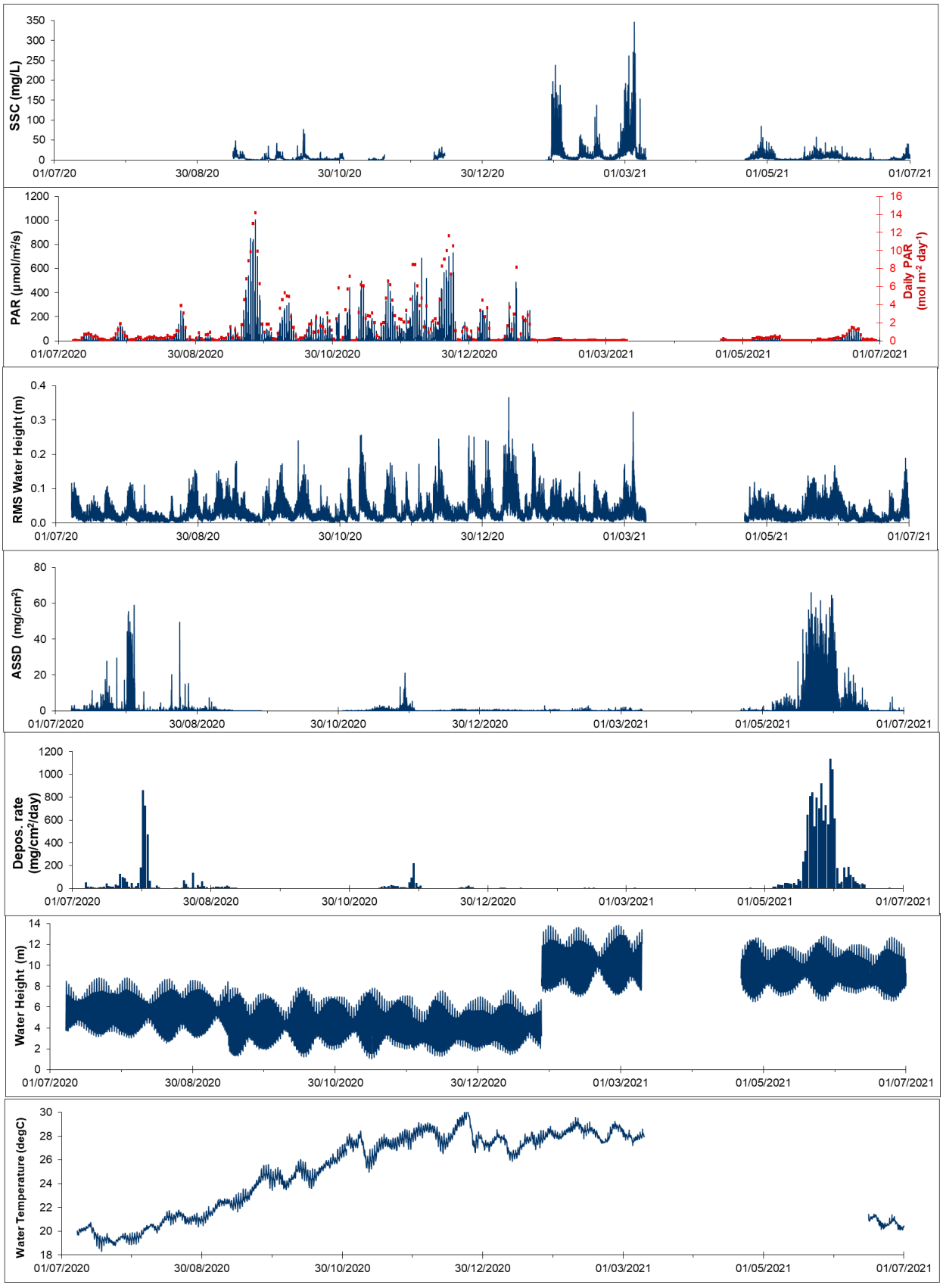
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration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

A1.4 Pressure Sensor Calibration

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

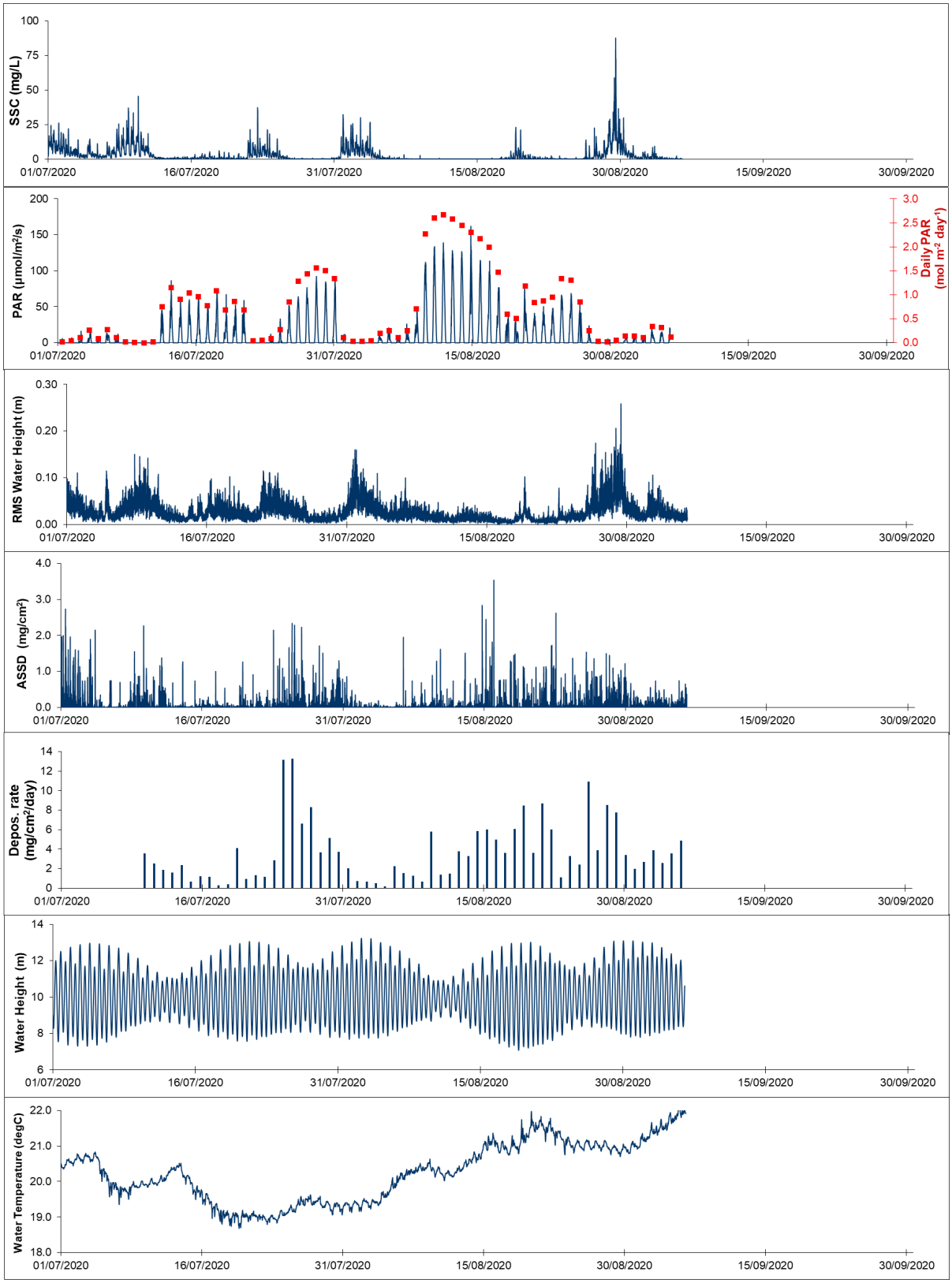
A2 TIME SERIES DATA

A2.1 AMB1: Freshwater Point

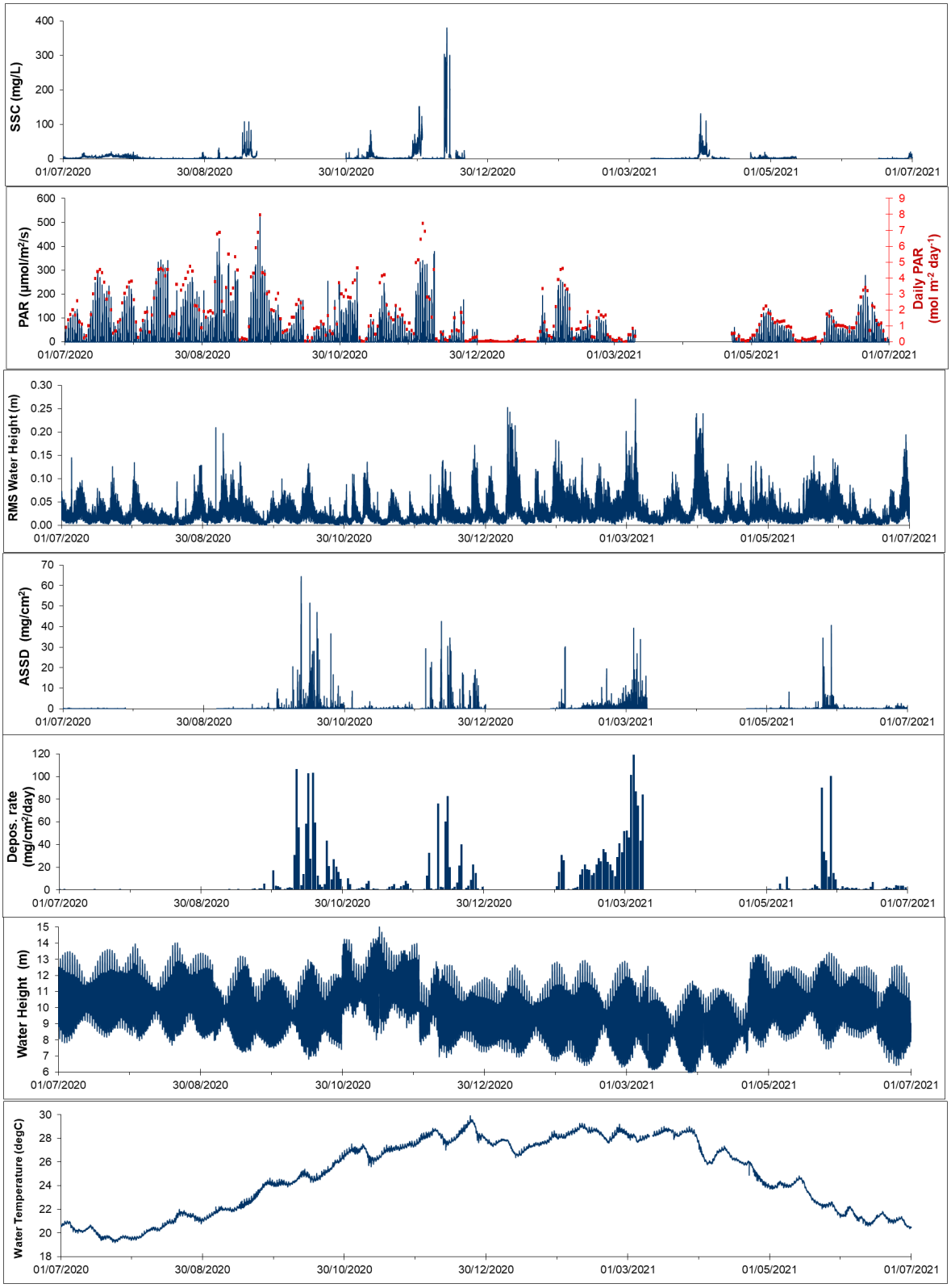


A2.2 AMB2: Hay Reef

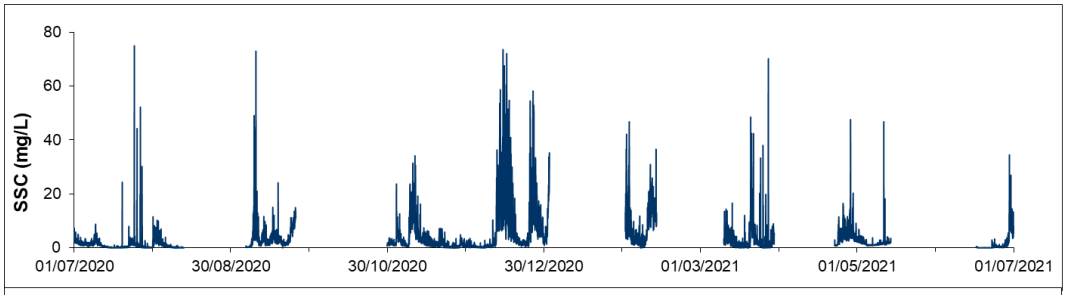
Neph deployments for this site were decommissioned in September 2020, so horizontal axis limits have been zoomed in time-wise.

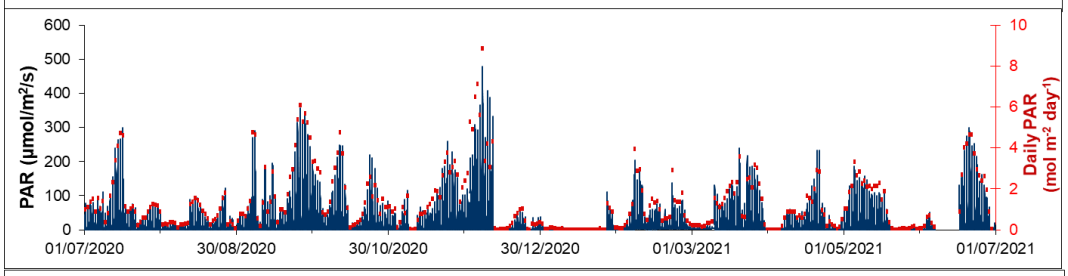


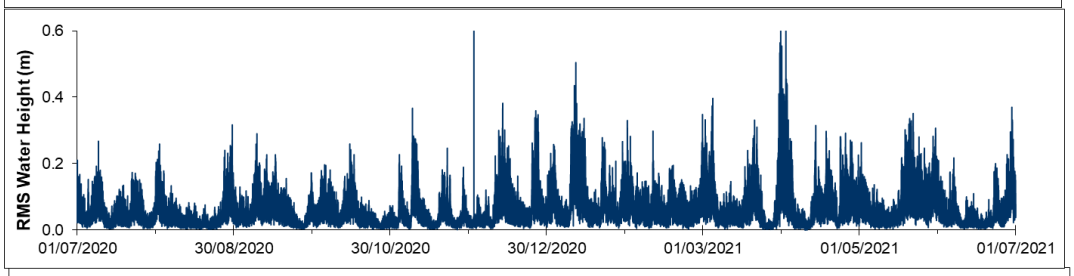
A2.3 AMB3: Round Top Island

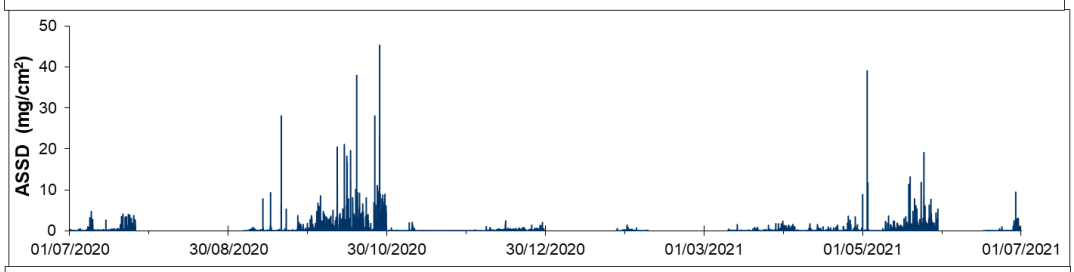


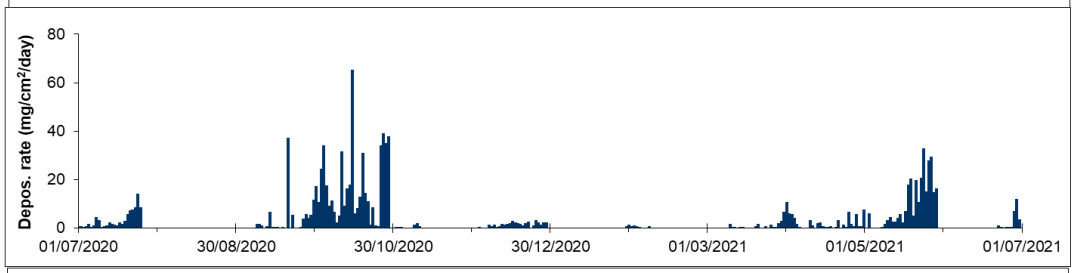
A2.4 AMB5: Slade Island

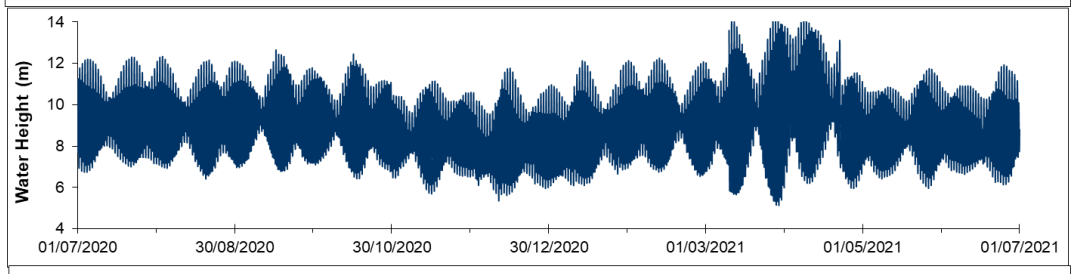


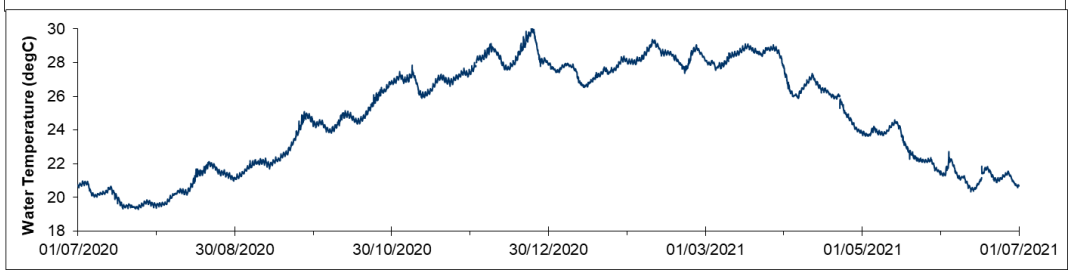




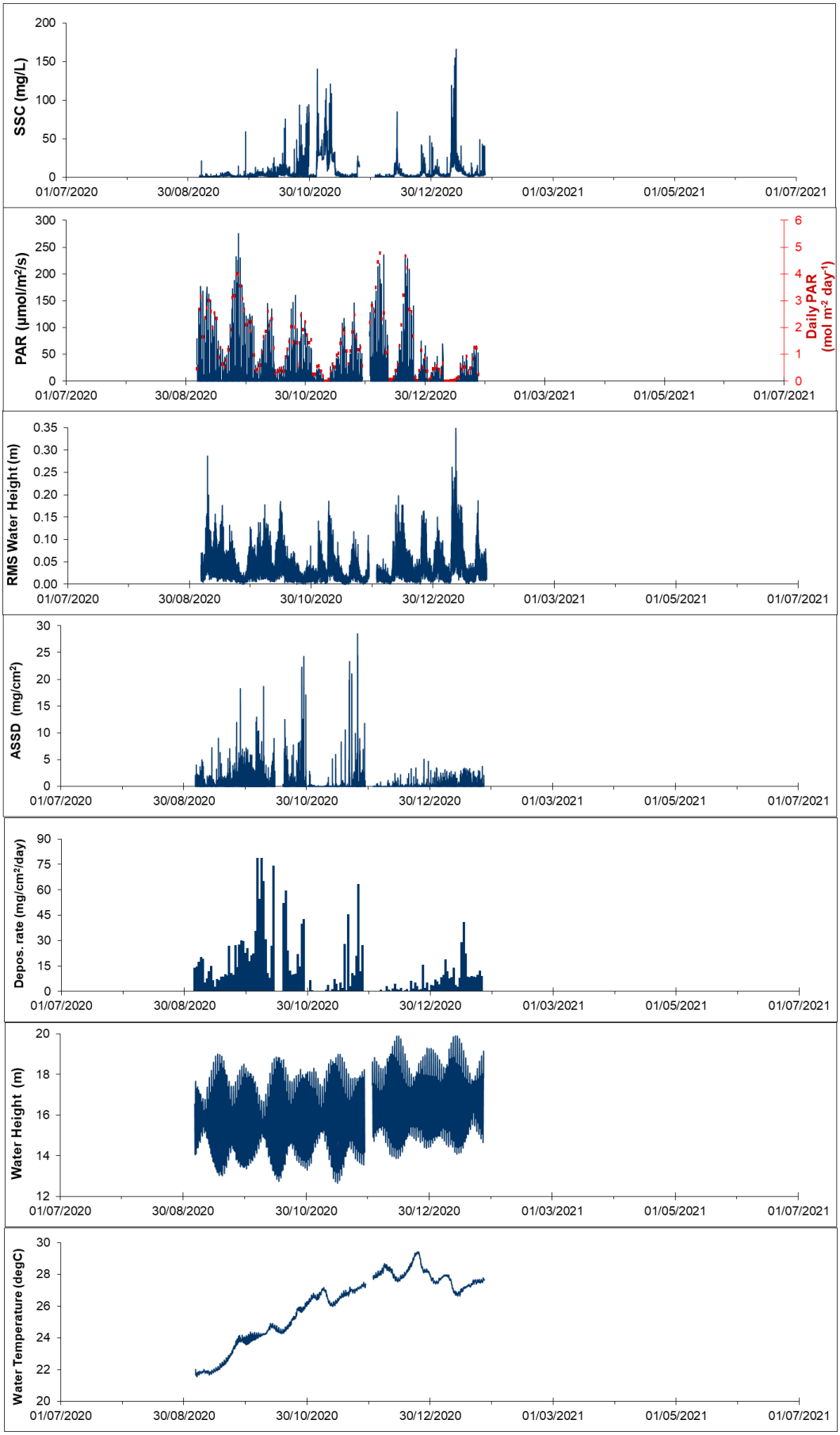




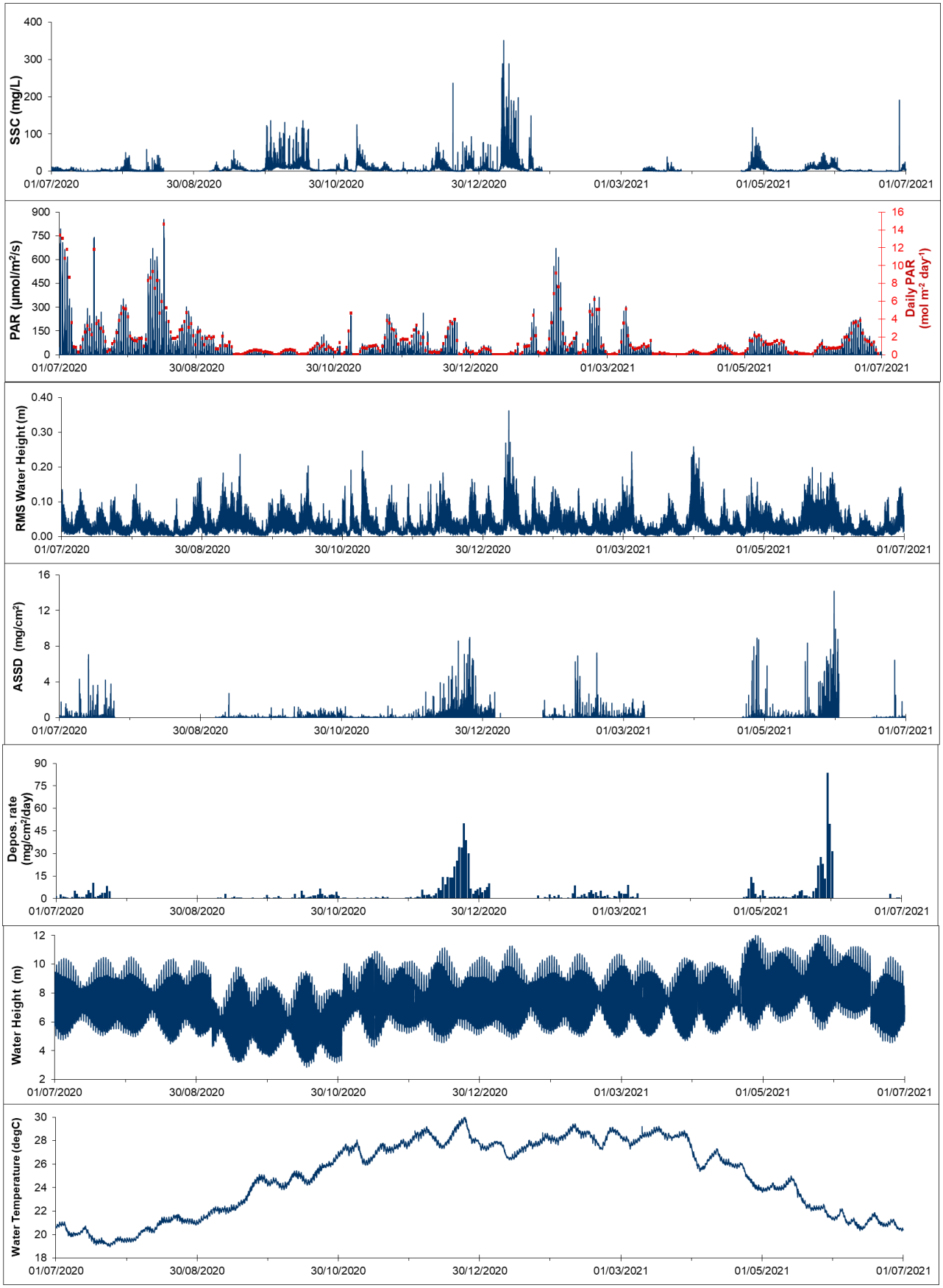




A2.5 AMB8: Spoil ground

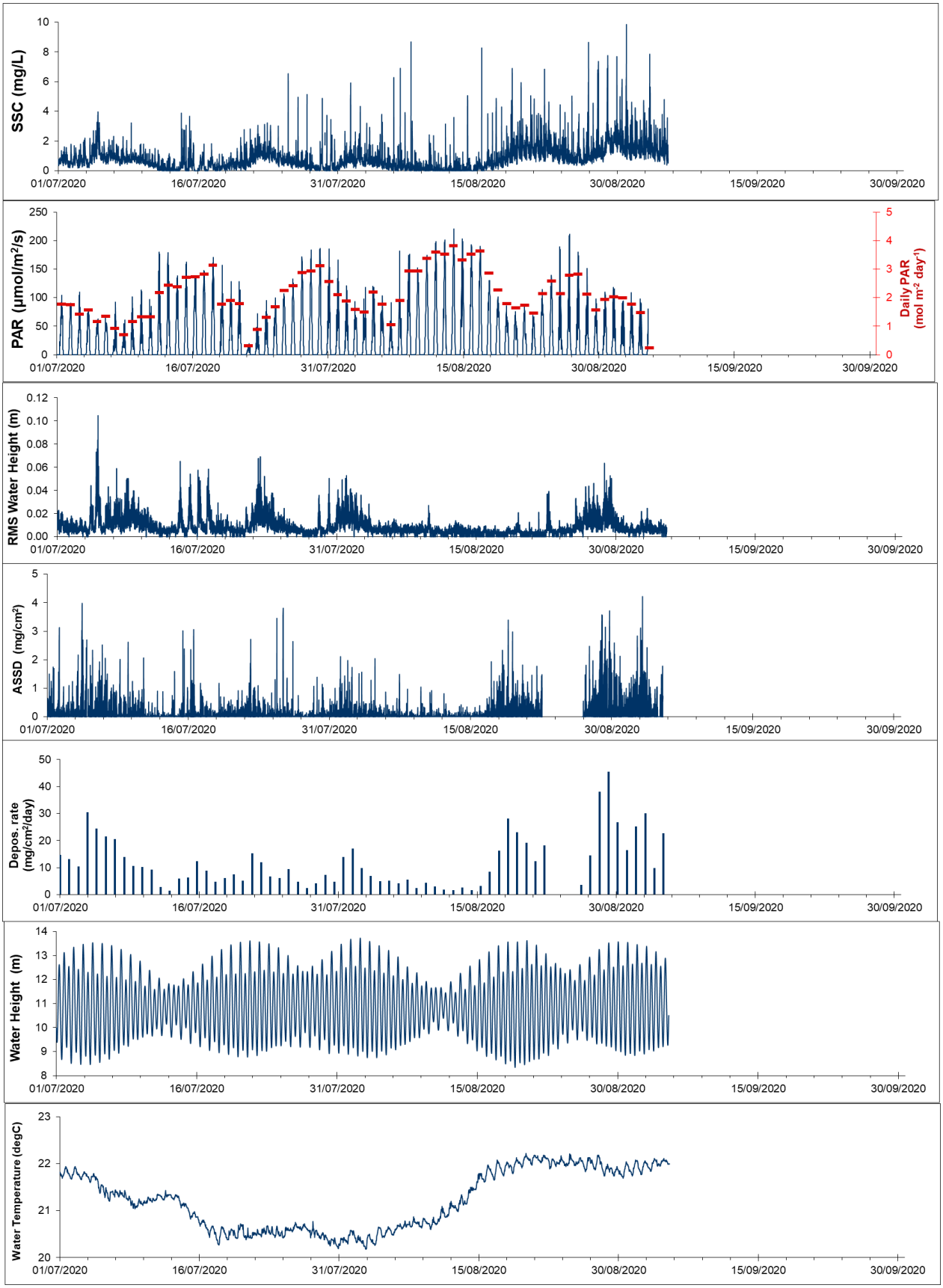


A2.6 AMB10: Victor Island



A2.7 AMB12: Keswick Island

Neph deployments for this site were decommissioned in September 2020, so horizontal axis limits have been zoomed in time-wise.



A3 SUMMARY OF MONTHLY STATISTICS

AMB1: Freshwater Point

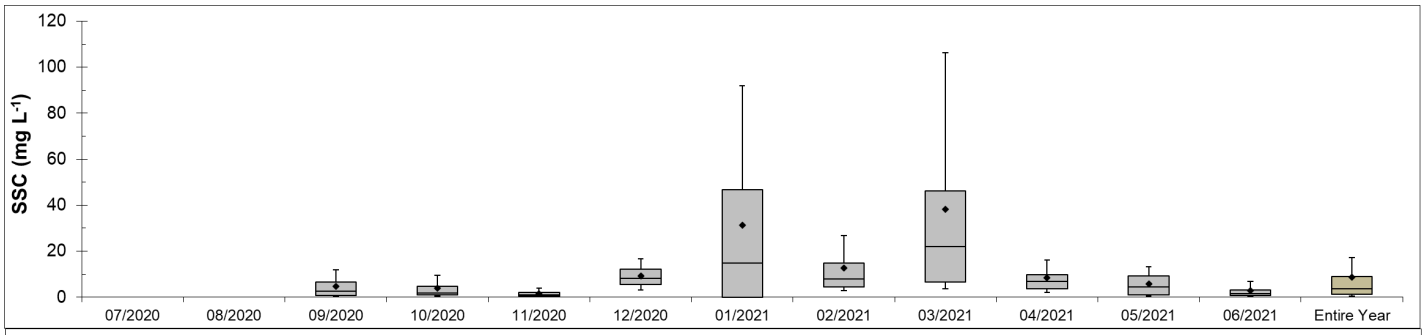
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean			4.80	3.86	1.58	9.32	31.33	12.61	38.23	8.42	5.87	2.75	8.55
median			2.64	1.83	0.90	8.24	14.88	7.93	22.02	6.73	4.42	1.58	3.59
min			0.00	1.21	0.00	26.53	0.00	0.00	0.00	0.00	0.00	0.00	7.00
lower			0.77	1.08	0.43	5.53	0.00	4.38	6.55	3.53	1.02	0.59	1.20
upper			6.61	4.62	2.14	12.25	46.66	14.83	46.23	9.76	9.20	3.19	8.93
max			48.37	77.22	13.40	32.61	236.58	187.14	345.82	84.90	57.65	40.61	345.82
90th percentile			11.84	9.36	3.96	16.70	91.88	26.82	106.41	16.03	13.26	6.76	17.30
10th percentile			0.32	0.53	0.20	3.14	0.00	2.72	3.50	2.13	0.51	0.14	0.43
n(recordings obtained)	0	0	2277	4458	1060	702	769	4017	1336	1348	4464	4306	24737
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.000	0.000	0.527	0.999	0.245	0.157	0.172	0.996	0.299	0.312	1.000	0.997	0.471
St. Dev			6.15	5.60	1.71	5.45	43.95	15.32	47.78	7.99	5.78	3.82	18.01
St. Error			0.13	0.08	0.05	0.21	1.58	0.24	1.31	0.22	0.09	0.06	0.11

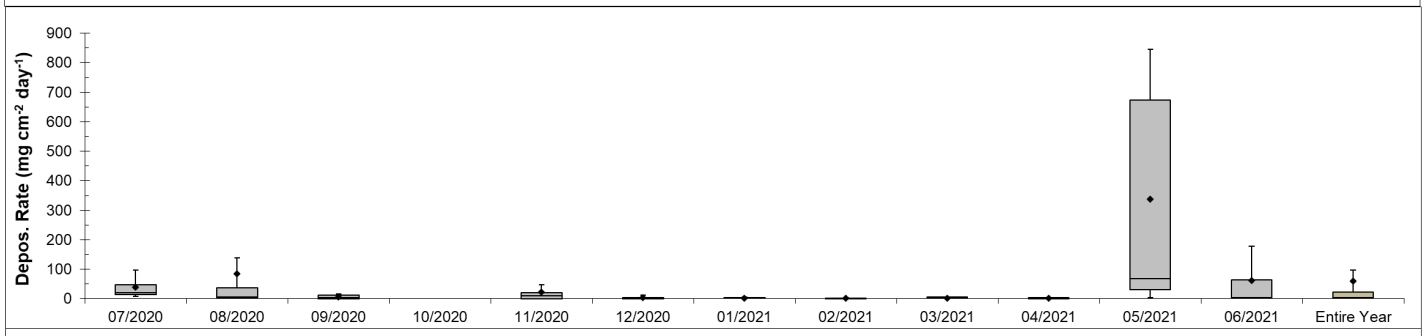
Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	40.11	85.02	5.71		22.34	4.22	2.36	1.52	2.91	1.66	336.76	61.17	60.16
median	20.04	6.90	2.98		10.90	0.83	1.95	0.90	3.31	1.56	68.13	3.90	3.50
min	5.06	0.91	0.01		0.12	0.01	0.29	0.04	0.15	0.25	0.33	0.10	0.01
lower	15.13	4.16	0.12		0.62	0.38	1.02	0.29	2.00	0.87	30.96	1.08	0.93
upper	48.46	36.72	11.64		21.57	4.15	2.70	1.96	3.48	1.77	673.45	63.16	22.28
max	185.98	860.45	23.54		223.32	26.17	8.08	5.33	6.16	4.58	1135.83	616.22	1135.83
90th percentile	97.35	139.03	16.04		48.55	11.88	5.23	3.64	4.52	2.76	845.79	178.93	98.12
10th percentile	8.25	1.90	0.03		0.31	0.05	0.53	0.14	0.53	0.68	3.05	0.46	0.22
n(recordings obtained)	25	31	27	0	30	31	31	28	9	10	31	30	283
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.806	1.000	0.900	0.000	1.000	1.000	1.000	1.000	0.290	0.333	1.000	1.000	0.775
St. Dev	44.01	209.06	7.16		43.30	6.84	1.94	1.54	1.82	1.21	379.40	120.30	179.02
St. Error	8.80	37.55	1.38		7.91	1.23	0.35	0.29	0.61	0.38	68.14	21.96	10.64

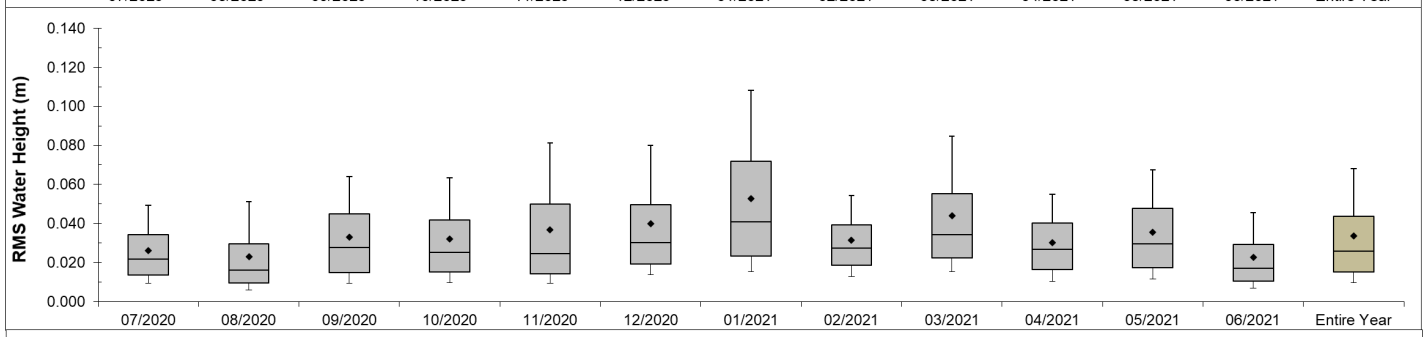
RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0262	0.0231	0.0330	0.0321	0.0368	0.0398	0.0528	0.0314	0.0439	0.0303	0.0355	0.0228	0.0338
median	0.0217	0.0160	0.0276	0.0252	0.0247	0.0303	0.0409	0.0272	0.0342	0.0269	0.0296	0.0172	0.0257
min	0.0022	0.0010	0.0019	0.0022	0.0022	0.0027	0.0046	0.0028	0.0037	0.0024	0.0024	0.0000	0.0000
lower	0.0136	0.0096	0.0150	0.0153	0.0143	0.0193	0.0232	0.0186	0.0224	0.0163	0.0175	0.0106	0.0152
upper	0.0344	0.0296	0.0449	0.0419	0.0499	0.0496	0.0719	0.0394	0.0552	0.0403	0.0476	0.0294	0.0438
max	0.1176	0.1530	0.1794	0.2400	0.2551	0.2520	0.3658	0.1495	0.3235	0.1185	0.1678	0.1889	0.3658
90th percentile	0.0492	0.0513	0.0640	0.0635	0.0813	0.0801	0.1081	0.0543	0.0847	0.0551	0.0675	0.0457	0.0682
10th percentile	0.0094	0.0060	0.0093	0.0096	0.0095	0.0136	0.0152	0.0130	0.0154	0.0104	0.0115	0.0069	0.0096
n(recordings obtained)	3484	4464	4320	4464	4317	4462	4462	4032	1364	1349	4464	4317	45499
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.780	1.000	1.000	1.000	0.999	1.000	1.000	1.000	0.306	0.312	1.000	0.999	0.866
St. Dev	0.0169	0.0204	0.0234	0.0237	0.0324	0.0302	0.0395	0.0183	0.0326	0.0183	0.0234	0.0180	0.0272
St. Error	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0006	0.0003	0.0009	0.0005	0.0004	0.0003	0.0001

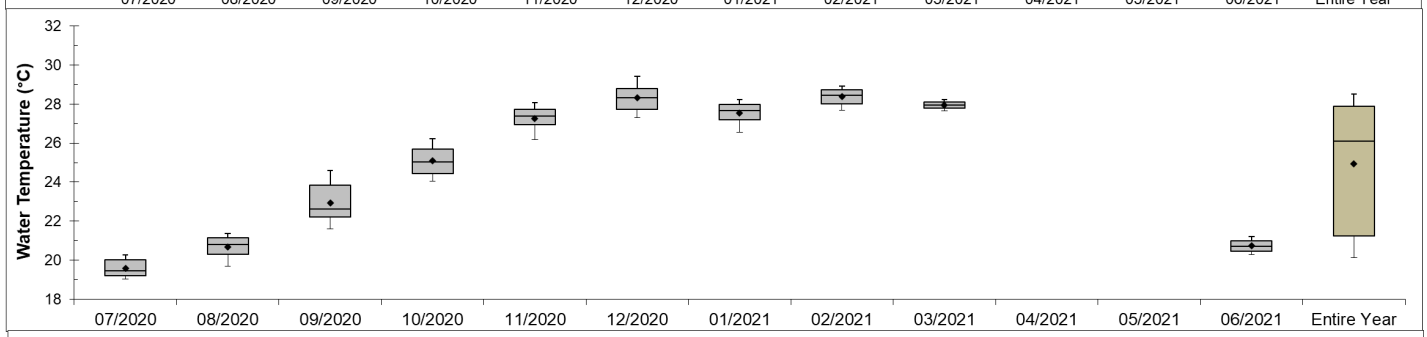
Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	19.58	20.67	22.94	25.09	27.26	28.31	27.54	28.38	27.96			20.73	24.93
median	19.47	20.82	22.61	25.02	27.38	28.32	27.65	28.44	27.96			20.70	26.09
min	18.30	18.91	20.71	23.49	24.97	26.53	25.88	27.40	27.21			20.11	18.30
lower	19.22	20.30	22.20	24.45	26.94	27.72	27.20	28.01	27.80			20.46	21.25
upper	20.01	21.15	23.84	25.69	27.74	28.80	27.98	28.72	28.10			21.01	27.88
max	20.74	21.77	25.62	27.35	28.67	30.46	28.84	29.58	28.60			21.44	30.46
90th percentile	20.28	21.37	24.61	26.22	28.07	29.43	28.24	28.92	28.24			21.20	28.51
10th percentile	19.04	19.68	21.60	24.05	26.19	27.30	26.56	27.68	27.65			20.30	20.14
n(recordings obtained)	3484	4464	4320	4464	4317	4458	4456	4032	1364	0	0	2202	37561
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.780	1.000	1.000	1.000	0.999	0.999	0.998	1.000	0.306	0.000	0.000	0.510	0.715
St. Dev	0.47	0.62	1.11	0.82	0.71	0.78	0.60	0.45	0.24			0.34	3.35
St. Error	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01			0.01	0.02

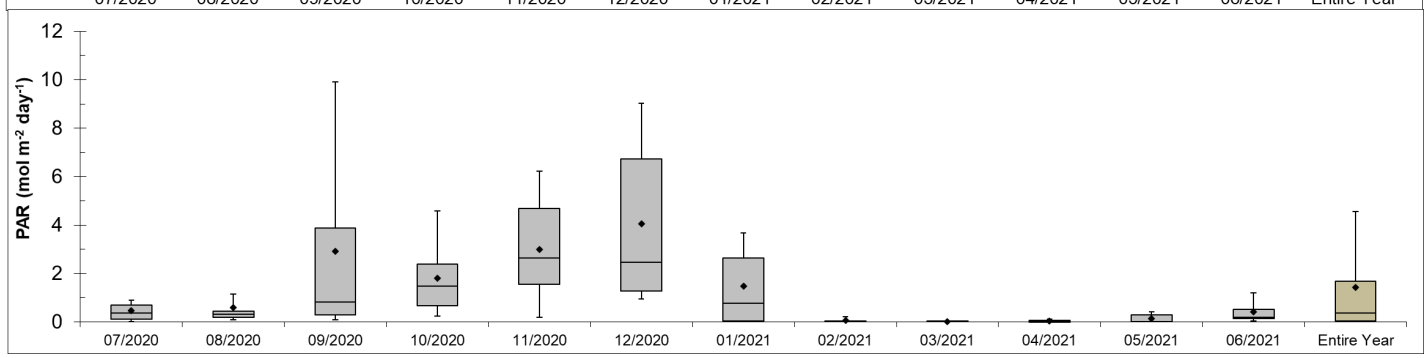
Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	0.46	0.59	2.92	1.80	2.99	4.06	1.49	0.06	0.02	0.05	0.15	0.41	1.43
median	0.36	0.33	0.81	1.48	2.63	2.46	0.77	0.02	0.01	0.01	0.02	0.20	0.36
min	0.00	0.03	0.03	0.13	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lower	0.12	0.18	0.28	0.68	1.55	1.27	0.05	0.01	0.00	0.00	0.00	0.13	0.05
upper	0.70	0.45	3.87	2.38	4.68	6.74	2.65	0.05	0.02	0.06	0.29	0.53	1.69
max	1.87	3.88	14.19	5.31	7.15	11.62	8.16	0.27	0.05	0.23	0.53	1.51	14.19
90th percentile	0.91	1.16	9.90	4.57	6.21	9.03	3.67	0.21	0.05	0.12	0.41	1.21	4.55
10th percentile	0.02	0.08	0.10	0.25	0.18	0.96	0.00	0.00	0.00	0.00	0.00	0.05	0.00
n(recordings obtained)	25	31	30	31	30	31	31	28	10	10	31	29	317
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.806	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.323	0.333	1.000	0.967	0.868
St. Dev	0.45	0.85	4.21	1.51	2.22	3.47	1.87	0.08	0.02	0.07	0.18	0.45	2.39
St. Error	0.09	0.15	0.77	0.27	0.41	0.62	0.34	0.01	0.01	0.02	0.03	0.08	0.13


SSC (mg L-1)
120
100
80
60
40
20
0
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year


Depos. Rate (mg cm-2 day-1)
900
800
700
600
500
400
300
200
100
0
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year


RMS Water Height (m)
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year


Water Temperature (°C)
32
30
28
26
24
22
20
18
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year


PAR (mol m-2 day-1)
12
10
8
6
4
2
0
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 2 – Hay Reef

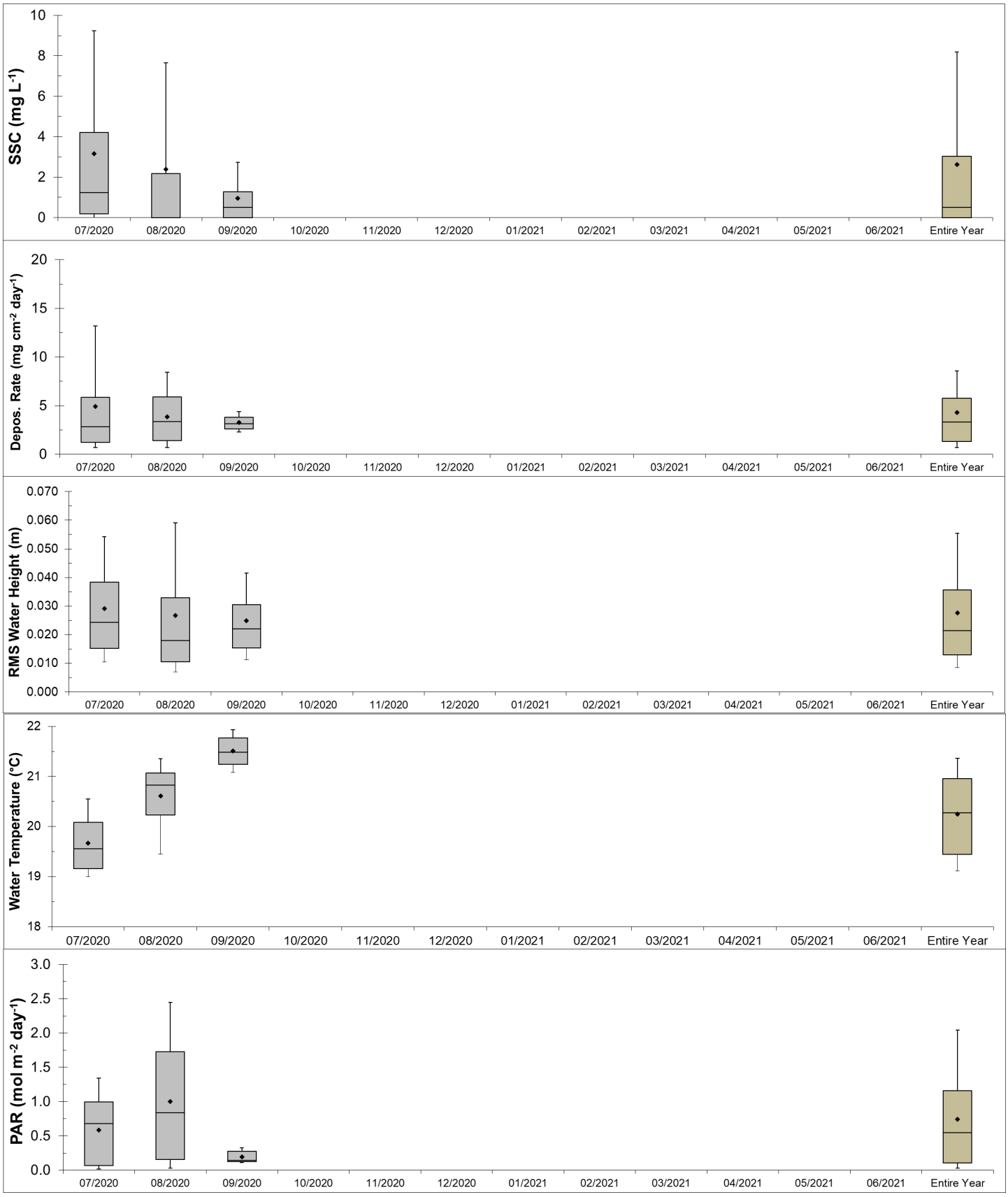
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	3.17	2.39	0.96										2.63
median	1.23	0.00	0.50										0.51
min	0.00	0.00	0.00										7.00
lower	0.18	0.00	0.00										0.00
upper	4.21	2.17	1.27										3.04
max	45.36	86.66	9.76										86.66
90th percentile	9.24	7.65	2.73										8.20
10th percentile	0.00	0.00	0.00										0.00
n(recordings obtained)	4463	4463	783	0	0	0	0	0	0	0	0	0	9709
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.185
St. Dev	4.61	5.63	1.39										4.99
St. Error	0.07	0.08	0.05										0.05

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	4.89	3.87	3.26										4.28
median	2.83	3.37	3.12										3.33
min	0.30	0.18	1.99										0.18
lower	1.22	1.42	2.60										1.31
upper	5.87	5.91	3.82										5.78
max	20.65	10.91	4.88										20.65
90th percentile	13.17	8.43	4.39										8.56
10th percentile	0.67	0.68	2.28										0.67
n(recordings obtained)	31	31	6	0	0	0	0	0	0	0	0	0	68
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.186
St. Dev	5.57	2.88	1.06										4.25
St. Error	1.00	0.52	0.43										0.52

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0292	0.0267	0.0249										0.0277
median	0.0243	0.0180	0.0221										0.0214
min	0.0027	0.0000	0.0048										0.0000
lower	0.0152	0.0106	0.0153										0.0129
upper	0.0383	0.0329	0.0305										0.0357
max	0.1502	0.2584	0.1061										0.2584
90th percentile	0.0543	0.0590	0.0415										0.0555
10th percentile	0.0104	0.0069	0.0112										0.0084
n(recordings obtained)	4464	4464	784	0	0	0	0	0	0	0	0	0	9712
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.185
St. Dev	0.0187	0.0250	0.0134										0.0215
St. Error	0.0003	0.0004	0.0005										0.0002

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	19.66	20.61	21.51										20.25
median	19.56	20.83	21.48										20.27
min	18.68	19.13	20.91										18.68
lower	19.16	20.23	21.24										19.44
upper	20.08	21.07	21.77										20.96
max	20.83	21.97	22.16										22.16
90th percentile	20.55	21.35	21.93										21.36
10th percentile	19.00	19.45	21.08										19.11
n(recordings obtained)	4464	4464	784	0	0	0	0	0	0	0	0	0	9712
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.181	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.185
St. Dev	0.56	0.65	0.32										0.83
St. Error	0.01	0.01	0.01										0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	0.59	1.00	0.19										0.74
median	0.68	0.84	0.14										0.55
min	0.00	0.02	0.10										0.00
lower	0.07	0.16	0.12										0.10
upper	1.00	1.73	0.27										1.16
max	1.56	2.66	0.34										2.66
90th percentile	1.34	2.45	0.33										2.04
10th percentile	0.02	0.03	0.11										0.03
n(recordings obtained)	31	31	6	0	0	0	0	0	0	0	0	0	68
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.186
St. Dev	0.53	0.93	0.11										0.77
St. Error	0.10	0.17	0.04										0.09


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 3b – Roundtop Island

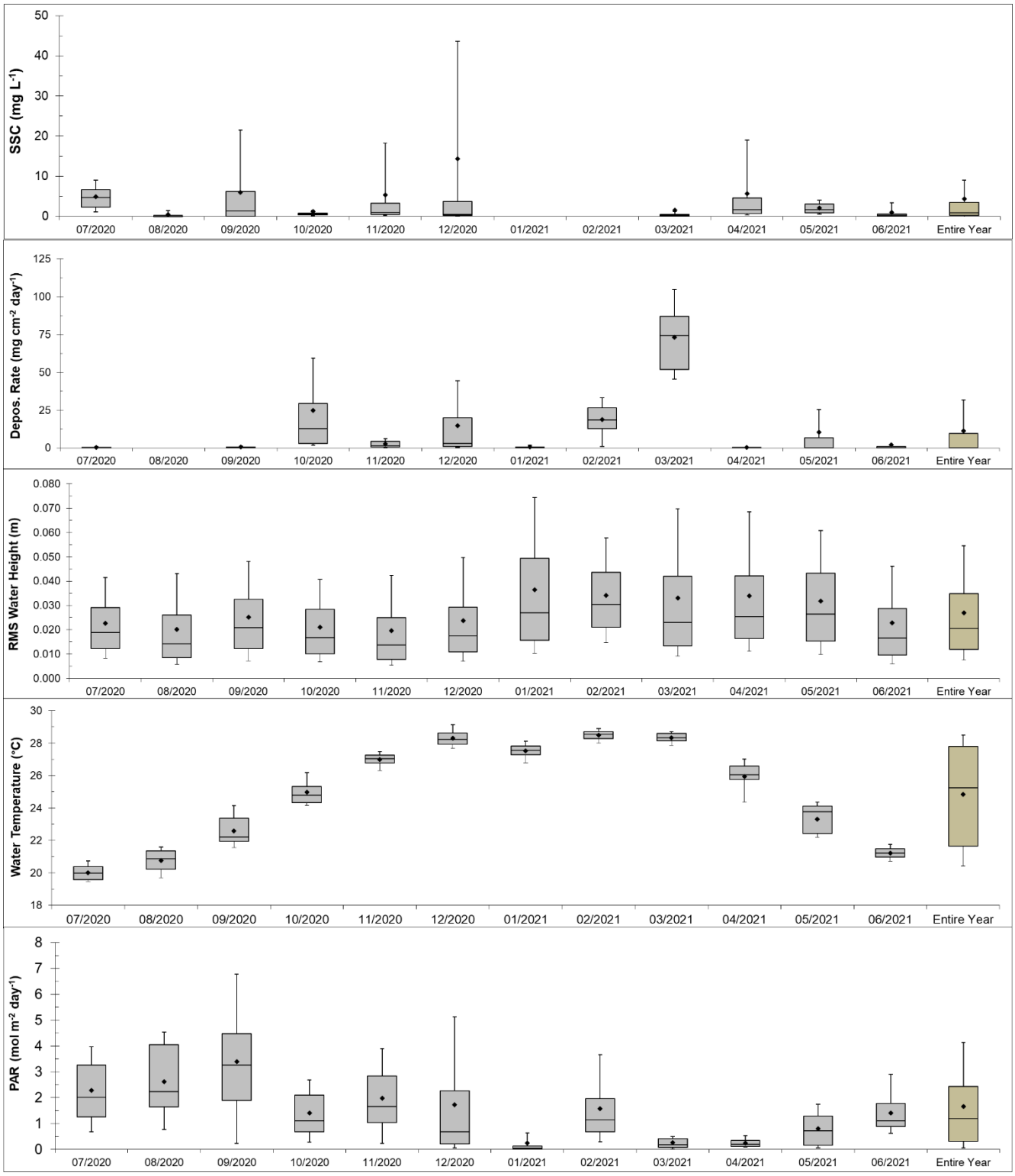
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	4.95	0.47	6.04	1.22	5.38	14.40			1.61	5.73	2.07	1.09	4.45
median	4.68	0.00	1.35	0.56	1.09	0.55			0.33	1.72	1.72	0.32	0.89
min	0.29	0.00	0.00	6.80	0.00	27.01			0.00	0.00	0.00	0.00	7.00
lower	2.39	0.00	0.12	0.40	0.53	0.26			0.20	0.69	0.93	0.18	0.25
upper	6.69	0.33	6.20	0.80	3.31	3.77			0.55	4.66	3.07	0.56	3.58
max	20.17	18.50	107.27	18.27	151.08	379.29			124.49	130.31	7.22	19.75	379.29
90th percentile	9.06	1.45	21.53	1.49	18.29	43.65			1.31	19.05	4.09	3.46	9.07
10th percentile	1.14	0.00	0.00	0.21	0.31	0.11			0.11	0.39	0.55	0.09	0.00
n(recordings obtained)	4464	4464	3017	218	4320	2329	0	0	3084	2854	1600	2092	28442
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.698	0.049	1.000	0.522	0.000	0.000	0.691	0.661	0.358	0.484	0.541
St. Dev	3.09	1.23	10.71	2.89	11.31	42.58			7.17	10.17	1.39	2.29	14.54
St. Error	0.05	0.02	0.19	0.20	0.17	0.88			0.13	0.19	0.03	0.05	0.09

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	0.28		0.68	24.78	2.68	14.59	0.73	18.63	73.27	0.28	10.44	1.96	11.23
median	0.16		0.35	12.66	1.50	2.83	0.18	18.36	74.29	0.31	0.79	1.59	1.34
min	0.02		0.07	0.22	0.10	0.02	0.11	0.23	43.56	0.01	0.09	0.05	0.01
lower	0.07		0.23	2.84	0.70	0.97	0.14	12.71	51.77	0.12	0.47	1.04	0.39
upper	0.36		0.71	29.34	4.21	19.92	0.39	26.49	86.98	0.42	7.45	2.52	10.92
max	1.10		5.42	106.64	10.41	82.58	3.35	40.95	119.05	0.53	100.28	6.93	119.05
90th percentile	0.82		1.25	59.21	6.17	44.25	1.90	33.12	104.76	0.48	26.22	3.74	33.15
10th percentile	0.04		0.13	1.64	0.49	0.46	0.12	1.04	45.62	0.01	0.20	0.48	0.13
n(recordings obtained)	27	0	26	31	29	29	6	28	9	9	31	30	255
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.871	0.000	0.867	1.000	0.967	0.935	0.194	1.000	0.290	0.300	1.000	1.000	0.699
St. Dev	0.30		1.04	31.61	2.71	22.92	1.29	11.72	26.67	0.19	23.99	1.47	22.31
St. Error	0.06		0.20	5.68	0.50	4.26	0.52	2.22	8.89	0.06	4.31	0.27	1.40

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0226	0.0201	0.0251	0.0211	0.0196	0.0237	0.0365	0.0341	0.0331	0.0340	0.0319	0.0228	0.0270
median	0.0190	0.0142	0.0208	0.0167	0.0138	0.0176	0.0270	0.0303	0.0231	0.0253	0.0264	0.0166	0.0205
min	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0027	0.0000	0.0000	0.0034	0.0010	0.0000
lower	0.0122	0.0085	0.0122	0.0102	0.0078	0.0109	0.0157	0.0211	0.0133	0.0163	0.0154	0.0097	0.0120
upper	0.0291	0.0260	0.0325	0.0284	0.0251	0.0293	0.0494	0.0436	0.0419	0.0421	0.0433	0.0287	0.0349
max	0.1449	0.1346	0.2097	0.1320	0.1357	0.1720	0.2528	0.1444	0.2707	0.2396	0.1478	0.1939	0.2707
90th percentile	0.0414	0.0430	0.0480	0.0408	0.0423	0.0496	0.0744	0.0578	0.0698	0.0685	0.0608	0.0461	0.0545
10th percentile	0.0082	0.0058	0.0072	0.0068	0.0054	0.0070	0.0104	0.0147	0.0092	0.0112	0.0099	0.0060	0.0075
n(recordings obtained)	4464	4464	4319	4459	4320	4462	4464	4032	4463	4317	4464	4318	52546
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	1.000	0.999	1.000	1.000	1.000	1.000	1.000	0.999	1.000	1.000	1.000
St. Dev	0.0144	0.0173	0.0184	0.0150	0.0174	0.0193	0.0287	0.0184	0.0299	0.0277	0.0213	0.0202	0.0221
St. Error	0.0002	0.0003	0.0003	0.0002	0.0003	0.0003	0.0004	0.0003	0.0004	0.0004	0.0003	0.0003	0.0001

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	20.00	20.75	22.59	24.96	26.98	28.31	27.52	28.48	28.34	25.93	23.32	21.23	24.83
median	19.98	20.86	22.21	24.79	27.05	28.23	27.56	28.54	28.33	26.04	23.77	21.22	25.24
min	19.18	19.40	21.09	23.89	25.60	27.01	26.37	27.60	27.08	23.82	21.30	20.36	19.18
lower	19.59	20.23	21.93	24.34	26.78	27.92	27.28	28.27	28.15	25.74	22.42	20.97	21.65
upper	20.39	21.35	23.36	25.33	27.26	28.63	27.83	28.71	28.59	26.59	24.11	21.47	27.79
max	21.02	22.00	24.64	27.10	27.93	29.92	28.65	29.28	29.01	27.51	24.83	22.25	29.92
90th percentile	20.72	21.59	24.13	26.17	27.46	29.14	28.12	28.89	28.70	27.01	24.36	21.76	28.50
10th percentile	19.45	19.69	21.56	24.15	26.31	27.68	26.79	27.99	27.87	24.36	22.19	20.73	20.43
n(recordings obtained)	4464	4464	4314	4459	4320	4457	4464	4032	4259	4317	4464	4313	52327
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.999	0.999	1.000	0.998	1.000	1.000	0.954	0.999	1.000	0.998	0.996
St. Dev	0.48	0.68	0.93	0.76	0.41	0.51	0.46	0.34	0.30	0.90	0.93	0.40	3.11
St. Error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	2.29	2.63	3.40	1.41	1.99	1.73	0.25	1.57	0.26	0.25	0.81	1.41	1.66
median	2.02	2.24	3.26	1.11	1.66	0.69	0.05	1.15	0.18	0.21	0.71	1.10	1.20
min	0.27	0.30	0.12	0.05	0.01	0.01	0.00	0.17	0.00	0.04	0.02	0.11	0.00
lower	1.25	1.65	1.89	0.69	1.04	0.21	0.00	0.69	0.08	0.12	0.17	0.88	0.31
upper	3.26	4.05	4.47	2.10	2.84	2.26	0.13	1.96	0.42	0.35	1.29	1.78	2.44
max	4.55	4.75	7.96	3.71	4.63	7.42	3.35	4.61	0.84	0.57	2.24	3.40	7.96
90th percentile	3.97	4.54	6.78	2.70	3.91	5.14	0.64	3.66	0.50	0.53	1.75	2.90	4.13
10th percentile	0.69	0.77	0.24	0.29	0.24	0.07	0.00	0.30	0.02	0.09	0.07	0.62	0.07
n(recordings obtained)	31	31	30	31	30	31	31	28	10	9	31	29	322
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.323	0.300	1.000	0.967	0.882
St. Dev	1.28	1.44	2.18	0.97	1.35	2.25	0.64	1.31	0.26	0.19	0.68	0.89	1.62
St. Error	0.23	0.26	0.40	0.17	0.25	0.40	0.11	0.25	0.08	0.06	0.12	0.16	0.09


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 5 – Slade Island

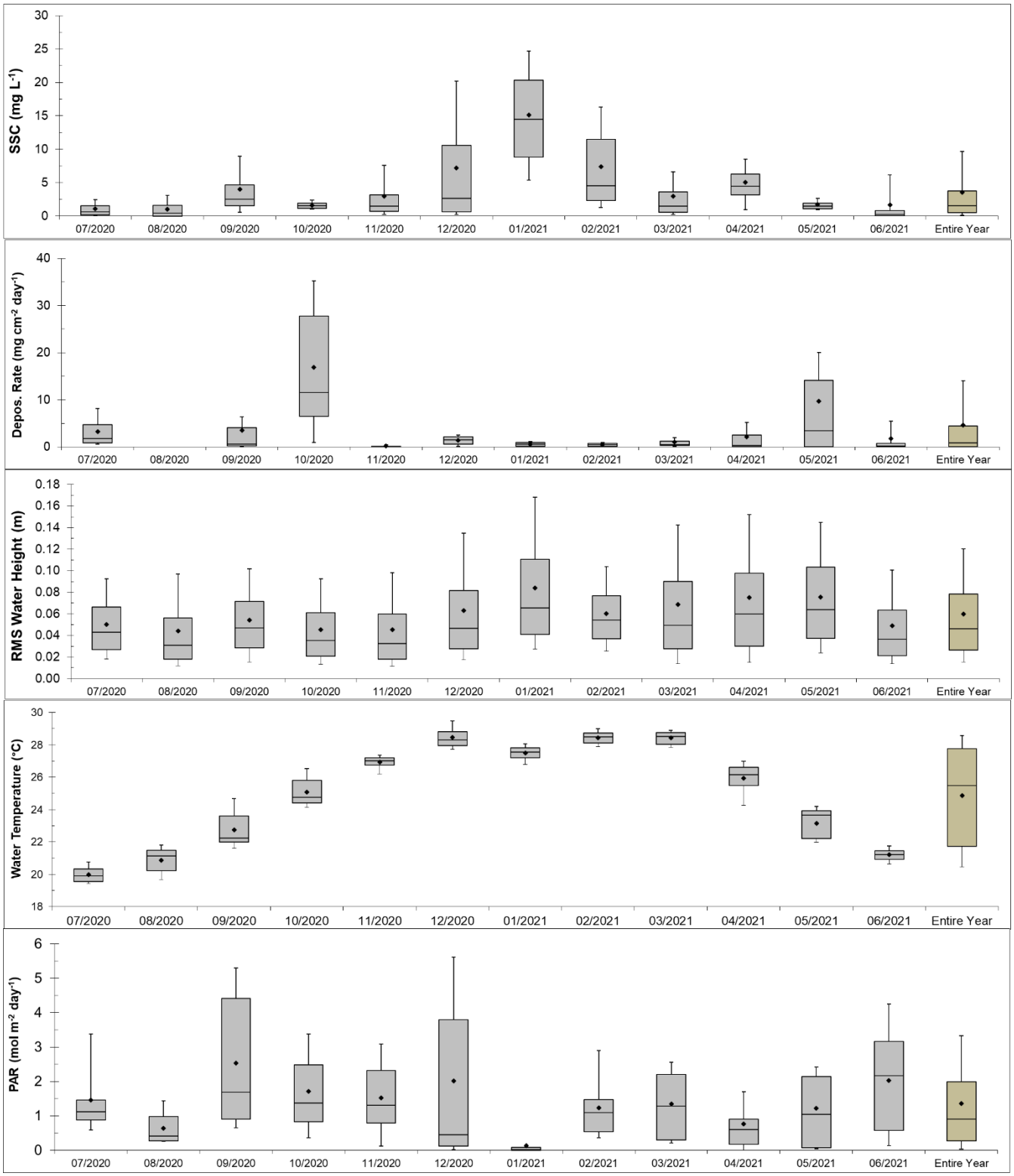
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	1.12	1.06	4.03	1.63	2.95	7.19	15.16	7.40	2.96	5.06	1.72	1.66	3.59
median	0.65	0.43	2.55	1.51	1.50	2.67	14.50	4.55	1.51	4.50	1.46	0.24	1.55
min	0.00	0.00	0.00	6.42	0.00	27.47	0.00	0.00	0.00	0.00	0.00	0.00	7.00
lower	0.18	0.00	1.52	1.17	0.70	0.64	8.84	2.34	0.57	3.16	1.09	0.02	0.49
upper	1.55	1.61	4.65	1.94	3.18	10.58	20.31	11.51	3.63	6.27	1.96	0.80	3.75
max	74.18	10.20	72.55	3.71	34.05	73.13	42.12	46.17	69.48	47.56	46.75	34.46	74.18
90th percentile	2.46	3.08	8.97	2.41	7.59	20.19	24.66	16.30	6.60	8.49	2.64	6.14	9.68
10th percentile	0.07	0.00	0.57	1.01	0.25	0.26	5.39	1.32	0.22	0.95	0.95	0.00	0.13
n(recordings obtained)	4457	1674	2790	204	4320	4438	219	1619	2820	1223	1914	2085	27763
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.998	0.375	0.646	0.046	1.000	0.994	0.049	0.402	0.632	0.283	0.429	0.483	0.528
St. Dev	2.28	1.44	4.93	0.57	4.12	9.51	7.57	6.65	4.73	3.93	1.61	3.78	5.82
St. Error	0.03	0.04	0.09	0.04	0.06	0.14	0.51	0.17	0.09	0.11	0.04	0.08	0.03

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	3.28		3.57	16.86	0.21	1.43	0.58	0.50	1.01	2.10	9.67	1.75	4.59
median	1.73		0.55	11.54	0.02	1.46	0.55	0.53	0.45	0.83	5.68	0.35	1.05
min	0.52		0.03	0.08	0.00	0.01	0.06	0.06	0.08	0.01	0.07	0.04	0.00
lower	0.88		0.22	6.44	0.01	0.61	0.12	0.14	0.26	0.54	2.23	0.10	0.22
upper	4.69		4.10	27.73	0.11	2.19	0.91	0.72	1.21	3.05	16.35	0.89	4.68
max	14.13		37.42	65.22	2.19	3.19	1.31	1.17	6.76	10.73	32.84	12.00	65.22
90th percentile	8.16		6.42	35.23	0.48	2.50	1.12	0.95	1.93	5.71	22.24	5.59	14.27
10th percentile	0.62		0.11	0.98	0.01	0.09	0.07	0.08	0.10	0.10	0.11	0.07	0.05
n(recordings obtained)	25	0	25	31	30	28	6	7	22	30	29	15	248
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.806	0.000	0.833	1.000	1.000	0.903	0.194	0.250	0.710	1.000	0.935	0.500	0.679
St. Dev	3.49		7.64	15.20	0.47	0.93	0.53	0.41	1.49	2.57	9.78	3.39	8.74
St. Error	0.70		1.53	2.73	0.09	0.18	0.21	0.16	0.32	0.47	1.82	0.88	0.56

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0502	0.0441	0.0542	0.0456	0.0456	0.0630	0.0842	0.0602	0.0687	0.0752	0.0757	0.0491	0.0597
median	0.0431	0.0308	0.0470	0.0352	0.0326	0.0465	0.0654	0.0542	0.0496	0.0597	0.0638	0.0365	0.0461
min	0.0035	0.0023	0.0033	0.0033	0.0025	0.0048	0.0064	0.0031	0.0016	0.0000	0.0035	0.0023	0.0000
lower	0.0271	0.0181	0.0283	0.0208	0.0180	0.0278	0.0409	0.0369	0.0278	0.0301	0.0372	0.0213	0.0263
upper	0.0664	0.0562	0.0717	0.0610	0.0597	0.0817	0.1105	0.0767	0.0901	0.0979	0.1034	0.0634	0.0782
max	0.2672	0.3111	0.2897	0.2575	0.3592	0.6453	0.5034	0.2978	0.6127	0.6207	0.3508	0.3675	0.6453
90th percentile	0.0924	0.0971	0.1019	0.0927	0.0981	0.1346	0.1682	0.1038	0.1426	0.1520	0.1448	0.1006	0.1204
10th percentile	0.0181	0.0116	0.0153	0.0133	0.0116	0.0176	0.0274	0.0254	0.0137	0.0151	0.0238	0.0138	0.0156
n(recordings obtained)	4464	4464	4320	4459	4320	4444	4464	4032	4462	4318	4464	4318	52529
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	1.000	0.999	1.000	0.996	1.000	1.000	1.000	1.000	1.000	1.000	0.999
St. Dev	0.0309	0.0386	0.0359	0.0342	0.0397	0.0517	0.0606	0.0321	0.0638	0.0639	0.0498	0.0408	0.0486
St. Error	0.0005	0.0006	0.0005	0.0005	0.0006	0.0008	0.0009	0.0005	0.0010	0.0010	0.0007	0.0006	0.0002

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	19.98	20.88	22.74	25.07	26.92	28.45	27.50	28.44	28.42	25.93	23.14	21.21	24.87
median	19.90	21.14	22.23	24.77	27.02	28.30	27.56	28.49	28.52	26.14	23.65	21.21	25.47
min	19.29	19.44	21.12	23.82	25.89	27.47	26.53	27.37	27.53	23.82	21.34	20.33	19.29
lower	19.54	20.22	21.98	24.41	26.74	27.96	27.20	28.12	28.03	25.49	22.21	20.92	21.73
upper	20.33	21.48	23.60	25.81	27.20	28.80	27.82	28.73	28.77	26.61	23.92	21.45	27.77
max	20.97	22.12	25.09	27.07	27.85	30.19	28.39	29.37	29.11	27.54	24.60	22.72	30.19
90th percentile	20.75	21.80	24.69	26.53	27.37	29.47	28.07	29.00	28.88	26.99	24.20	21.76	28.57
10th percentile	19.44	19.66	21.61	24.12	26.20	27.73	26.78	27.89	27.83	24.26	21.97	20.63	20.44
n(recordings obtained)	4464	4464	4317	4459	4320	4439	4464	4032	4458	4318	4464	4315	52514
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.999	0.999	1.000	0.994	1.000	1.000	0.999	1.000	1.000	0.999	0.999
St. Dev	0.48	0.77	1.12	0.89	0.42	0.63	0.45	0.42	0.40	0.94	0.93	0.43	3.13
St. Error	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	1.46	0.65	2.54	1.72	1.53	2.01	0.14	1.24	1.35	0.76	1.22	2.02	1.37
median	1.12	0.42	1.68	1.37	1.31	0.45	0.02	1.09	1.28	0.60	1.04	2.17	0.90
min	0.22	0.07	0.19	0.13	0.00	0.01	0.00	0.07	0.00	0.00	0.01	0.03	0.00
lower	0.88	0.27	0.91	0.83	0.79	0.13	0.00	0.54	0.29	0.18	0.07	0.57	0.27
upper	1.46	0.99	4.42	2.49	2.32	3.80	0.09	1.47	2.21	0.91	2.14	3.16	2.00
max	4.73	1.80	6.11	4.77	3.76	8.86	1.29	3.95	3.59	2.90	3.31	4.66	8.86
90th percentile	3.38	1.44	5.29	3.38	3.10	5.61	0.12	2.90	2.55	1.70	2.42	4.25	3.33
10th percentile	0.59	0.26	0.66	0.36	0.12	0.03	0.00	0.36	0.21	0.00	0.05	0.13	0.03
n(recordings obtained)	31	31	30	31	30	31	31	28	31	30	31	20	355
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.667	0.973
St. Dev	1.17	0.50	1.90	1.20	1.08	2.57	0.32	0.96	1.05	0.78	1.08	1.65	1.44
St. Error	0.21	0.09	0.35	0.22	0.20	0.46	0.06	0.18	0.19	0.14	0.19	0.37	0.08


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 8 – Spoil Grounds

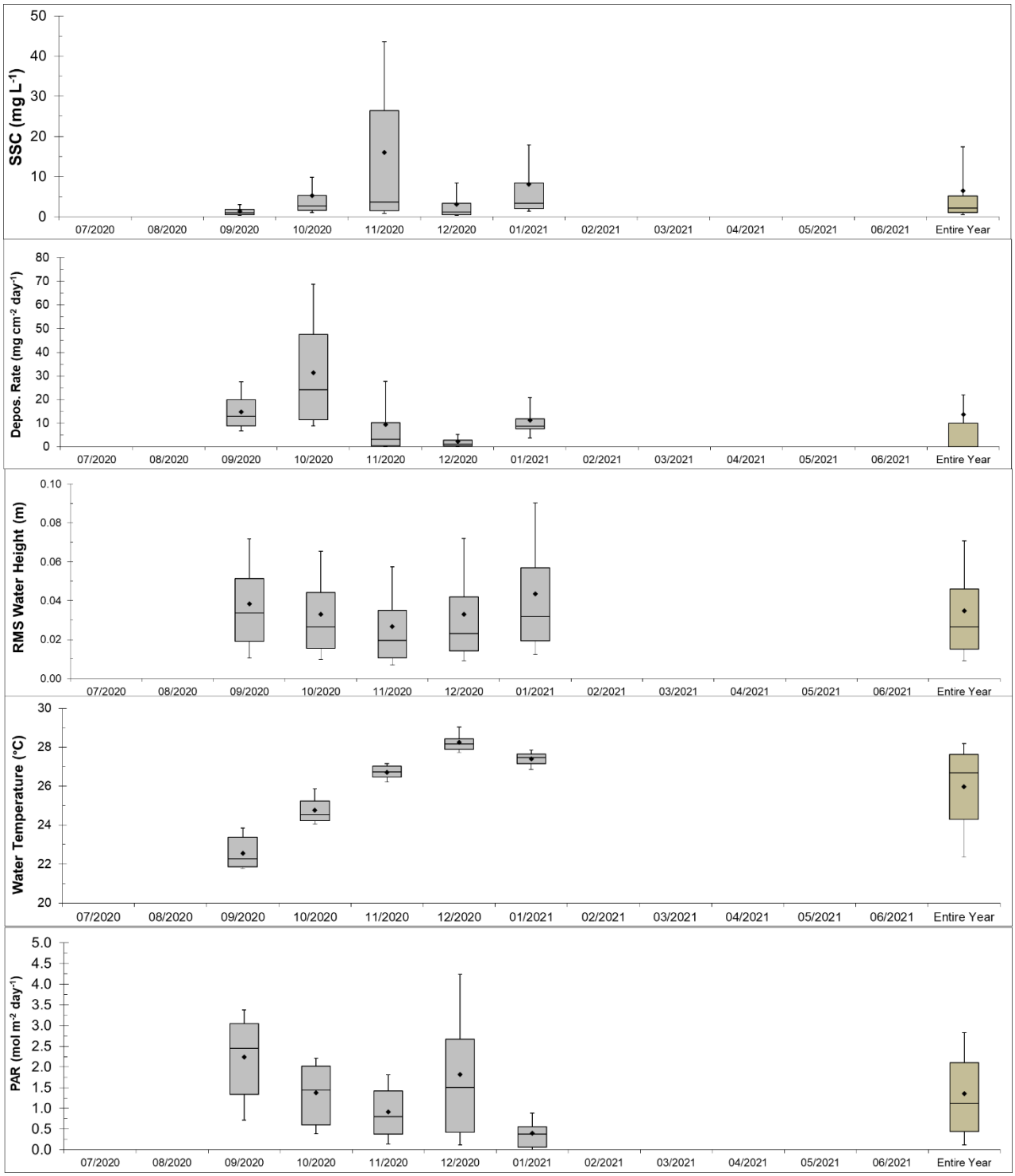
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean			1.38	5.26	15.97	3.10	8.12						6.47
median			0.99	2.73	3.65	1.21	3.33						2.14
min			0.00	12.74	0.00	27.53	0.00						7.00
lower			0.51	1.60	1.50	0.56	1.99						1.06
upper			1.82	5.27	26.37	3.37	8.39						5.14
max			58.88	93.96	139.82	83.93	166.21						166.21
90th percentile			2.99	9.79	43.57	8.47	17.88						17.40
10th percentile			0.25	1.10	0.88	0.26	1.42						0.50
n(recordings obtained)	0	0	3644	4354	3393	4251	3624	0	0	0	0	0	19266
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.000	0.000	0.844	0.975	0.785	0.952	0.812	0.000	0.000	0.000	0.000	0.000	0.367
St. Dev			1.70	8.86	19.74	5.41	13.63						12.35
St. Error			0.03	0.13	0.34	0.08	0.23						0.09

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean			14.83	31.42	9.49	2.19	11.24						13.61
median			12.98	24.09	3.10	1.23	8.73						8.46
min			2.87	0.06	0.06	0.02	2.86						0.02
lower			8.80	11.51	0.44	0.36	7.64						1.82
upper			19.90	47.53	10.22	2.81	11.88						18.46
max			30.11	78.81	63.53	15.63	41.00						78.81
90th percentile			27.48	68.68	27.61	5.28	20.93						30.47
10th percentile			6.63	8.93	0.17	0.16	3.80						0.29
n(recordings obtained)	0	0	26	27	27	30	25	0	0	0	0	0	135
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.000	0.000	0.867	0.871	0.900	0.968	0.806	0.000	0.000	0.000	0.000	0.000	0.370
St. Dev			8.24	23.99	15.44	3.08	8.57						16.84
St. Error			1.62	4.62	2.97	0.56	1.71						1.45

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean			0.0384	0.0330	0.0268	0.0329	0.0436						0.0347
median			0.0338	0.0264	0.0197	0.0232	0.0319						0.0265
min			0.0000	0.0000	0.0000	0.0000	0.0027						0.0000
lower			0.0191	0.0155	0.0107	0.0142	0.0194						0.0150
upper			0.0513	0.0442	0.0350	0.0420	0.0570						0.0458
max			0.2863	0.1853	0.1855	0.1973	0.3489						0.3489
90th percentile			0.0717	0.0653	0.0574	0.0719	0.0903						0.0709
10th percentile			0.0105	0.0099	0.0070	0.0091	0.0122						0.0091
n(recordings obtained)	0	0	3659	4456	3982	4263	3658	0	0	0	0	0	20018
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.000	0.000	0.847	0.998	0.922	0.955	0.819	0.000	0.000	0.000	0.000	0.000	0.381
St. Dev			0.0258	0.0240	0.0228	0.0277	0.0356						0.0279
St. Error			0.0004	0.0004	0.0004	0.0004	0.0006						0.0002

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean			22.56	24.76	26.72	28.25	27.41						25.97
median			22.25	24.55	26.73	28.16	27.48						26.69
min			21.54	23.58	25.97	27.53	26.63						21.54
lower			21.86	24.24	26.46	27.89	27.16						24.29
upper			23.38	25.23	27.02	28.44	27.66						27.63
max			24.17	26.48	27.50	29.41	27.96						29.41
90th percentile			23.85	25.87	27.17	29.03	27.86						28.19
10th percentile			21.76	24.04	26.21	27.73	26.85						22.37
n(recordings obtained)	0	0	3654	4452	3982	4258	3659	0	0	0	0	0	20005
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.000	0.000	0.846	0.997	0.922	0.954	0.820	0.000	0.000	0.000	0.000	0.000	0.381
St. Dev			0.81	0.69	0.36	0.47	0.35						2.09
St. Error			0.01	0.01	0.01	0.01	0.01						0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean			2.24	1.38	0.92	1.82	0.40						1.36
median			2.45	1.44	0.80	1.51	0.37						1.13
min			0.45	0.28	0.00	0.01	0.00						0.00
lower			1.33	0.60	0.38	0.42	0.07						0.44
upper			3.05	2.02	1.42	2.67	0.55						2.11
max			4.00	2.62	2.48	4.77	1.26						4.77
90th percentile			3.38	2.21	1.81	4.24	0.89						2.83
10th percentile			0.72	0.38	0.13	0.11	0.00						0.12
n(recordings obtained)	0	0	26	31	28	30	26	0	0	0	0	0	141
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.000	0.000	0.867	1.000	0.933	0.968	0.839	0.000	0.000	0.000	0.000	0.000	0.386
St. Dev			1.05	0.74	0.66	1.50	0.36						1.14
St. Error			0.21	0.13	0.13	0.27	0.07						0.10


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 10 – Victor Island

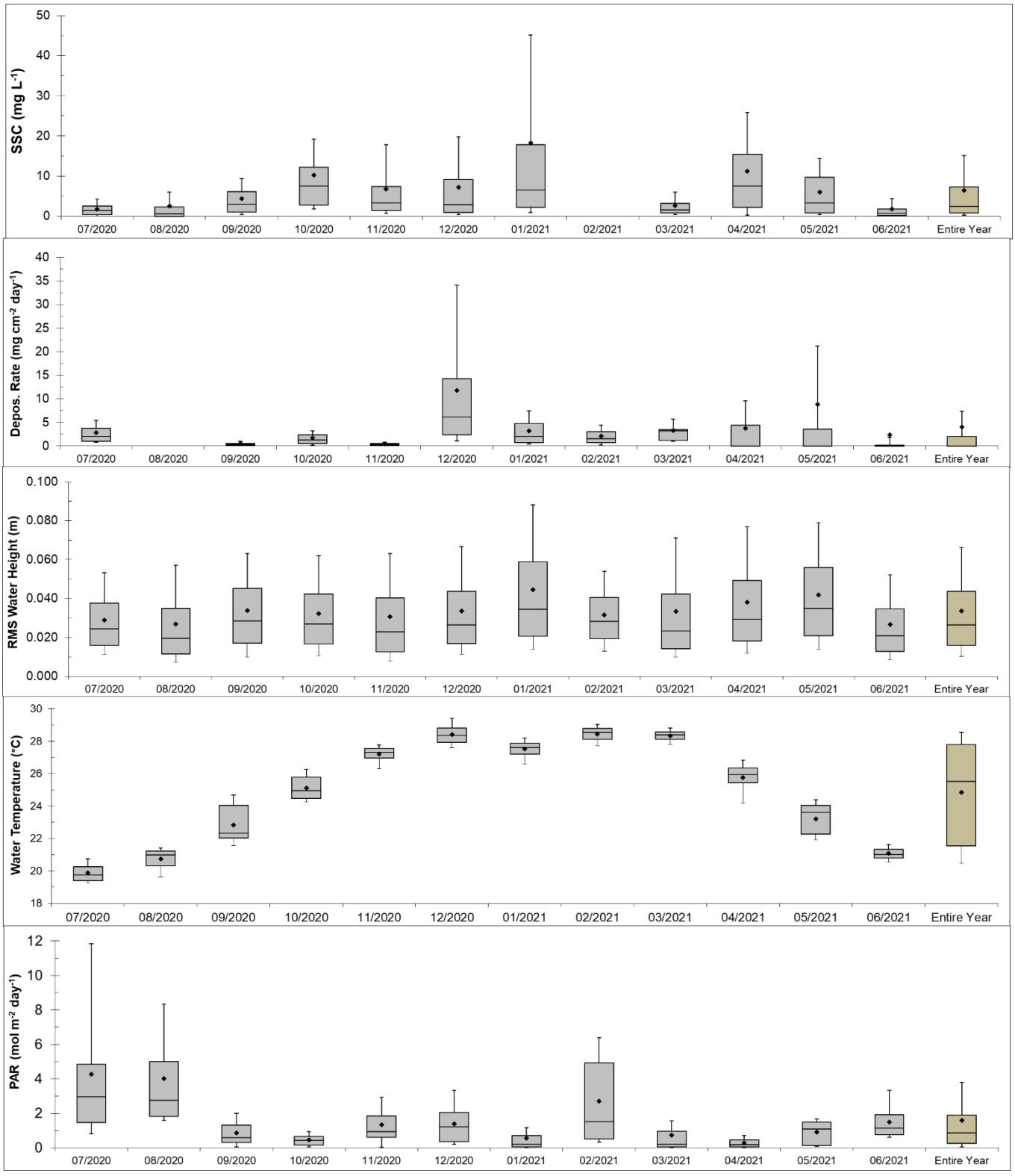
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	1.85	2.50	4.36	10.22	6.74	7.27	18.25		2.64	11.21	6.05	1.85	6.49
median	1.43	0.62	2.98	7.57	3.33	2.87	6.62		1.63	7.57	3.29	0.77	2.43
min	0.00	0.00	0.00	2.85	0.00	27.19	0.00		0.00	0.00	0.00	0.00	7.00
lower	0.41	0.00	1.01	2.73	1.52	0.98	2.26		0.79	2.19	0.79	0.20	0.85
upper	2.54	2.29	6.09	12.22	7.42	9.14	17.85		3.18	15.42	9.69	1.84	7.35
max	13.35	57.38	121.69	135.35	124.84	236.17	344.82		38.86	116.84	49.80	189.53	344.82
90th percentile	4.31	5.98	9.39	19.27	17.84	19.83	45.12		6.07	25.90	14.36	4.36	15.14
10th percentile	0.00	0.00	0.41	1.79	0.74	0.42	0.92		0.40	0.31	0.38	0.00	0.23
n(recordings obtained)	4452	2431	3538	4315	4314	4452	3586	0	2384	1341	4461	4315	39589
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.997	0.545	0.819	0.967	0.999	0.997	0.803	0.000	0.534	0.310	0.999	0.999	0.753
St. Dev	1.90	5.48	5.25	12.78	9.87	11.40	33.88		3.21	12.89	6.60	5.45	13.71
St. Error	0.03	0.11	0.09	0.19	0.15	0.17	0.57		0.07	0.35	0.10	0.08	0.07

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	2.84		0.57	1.74	0.43	11.80	3.19	2.15	3.32	3.78	8.80	2.36	4.02
median	2.00		0.38	1.27	0.34	6.19	2.06	1.58	3.19	1.21	1.95	0.14	1.14
min	0.26		0.08	0.01	0.05	0.35	0.24	0.18	0.66	0.04	0.43	0.07	0.01
lower	1.01		0.20	0.59	0.21	2.42	0.77	0.75	1.20	0.31	0.97	0.10	0.44
upper	3.77		0.58	2.35	0.56	14.28	4.79	3.00	3.50	5.60	5.49	0.36	3.18
max	10.33		3.00	6.62	1.24	50.18	10.11	8.68	8.95	14.37	83.71	31.61	83.71
90th percentile	5.45		1.01	3.22	0.79	34.12	7.49	4.38	5.73	10.79	23.12	1.96	8.48
10th percentile	0.79		0.13	0.16	0.11	1.14	0.42	0.30	1.01	0.11	0.64	0.09	0.17
n(recordings obtained)	24	0	25	31	30	31	11	28	9	10	31	16	246
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.774	0.000	0.833	1.000	1.000	1.000	0.355	1.000	0.290	0.333	1.000	0.533	0.674
St. Dev	2.55		0.68	1.58	0.31	13.25	3.27	1.95	2.52	5.01	17.53	7.84	8.98
St. Error	0.52		0.14	0.28	0.06	2.38	0.99	0.37	0.84	1.59	3.15	1.96	0.57

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0290	0.0269	0.0337	0.0324	0.0307	0.0337	0.0446	0.0316	0.0335	0.0381	0.0419	0.0266	0.0336
median	0.0244	0.0195	0.0285	0.0268	0.0228	0.0264	0.0345	0.0283	0.0232	0.0294	0.0348	0.0208	0.0264
min	0.0023	0.0000	0.0025	0.0019	0.0018	0.0020	0.0034	0.0029	0.0015	0.0000	0.0037	0.0009	0.0000
lower	0.0159	0.0114	0.0170	0.0166	0.0126	0.0168	0.0206	0.0193	0.0141	0.0183	0.0208	0.0128	0.0160
upper	0.0377	0.0348	0.0452	0.0424	0.0402	0.0436	0.0588	0.0404	0.0422	0.0491	0.0559	0.0346	0.0437
max	0.1354	0.1689	0.2369	0.2036	0.2461	0.1813	0.3624	0.1696	0.2581	0.2410	0.1990	0.1428	0.3624
90th percentile	0.0533	0.0570	0.0631	0.0620	0.0632	0.0666	0.0881	0.0539	0.0711	0.0770	0.0789	0.0522	0.0663
10th percentile	0.0112	0.0072	0.0101	0.0107	0.0081	0.0113	0.0140	0.0130	0.0098	0.0119	0.0137	0.0085	0.0102
n(recordings obtained)	4464	4464	4319	4464	4316	4461	4462	4032	4462	4318	4464	4317	52543
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	1.000	1.000	0.999	0.999	1.000	1.000	1.000	1.000	1.000	0.999	1.000
St. Dev	0.0178	0.0223	0.0231	0.0217	0.0258	0.0238	0.0337	0.0172	0.0297	0.0286	0.0276	0.0197	0.0253
St. Error	0.0003	0.0003	0.0004	0.0003	0.0004	0.0004	0.0005	0.0003	0.0004	0.0004	0.0004	0.0003	0.0001

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	19.87	20.74	22.84	25.12	27.21	28.42	27.53	28.45	28.35	25.76	23.22	21.08	24.86
median	19.74	20.99	22.32	24.94	27.32	28.35	27.61	28.54	28.38	25.95	23.62	21.02	25.53
min	18.96	19.35	21.01	23.83	25.91	27.19	26.37	27.24	27.26	23.74	21.26	20.31	18.96
lower	19.41	20.30	22.02	24.46	26.97	27.94	27.20	28.13	28.11	25.43	22.27	20.80	21.55
upper	20.25	21.22	24.05	25.79	27.57	28.82	27.89	28.79	28.59	26.36	24.04	21.33	27.79
max	21.08	21.72	25.13	27.18	28.13	30.12	28.68	29.44	29.23	27.31	25.00	22.20	30.12
90th percentile	20.74	21.40	24.68	26.28	27.77	29.40	28.19	29.02	28.81	26.83	24.40	21.62	28.54
10th percentile	19.24	19.62	21.56	24.24	26.32	27.61	26.61	27.74	27.81	24.18	21.91	20.53	20.46
n(recordings obtained)	4464	4464	4312	4464	4316	4457	4458	4032	4463	4312	4464	4313	52519
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.998	1.000	0.999	0.998	0.999	1.000	1.000	0.998	1.000	0.998	0.999
St. Dev	0.55	0.63	1.16	0.80	0.51	0.65	0.53	0.49	0.37	0.90	1.01	0.41	3.17
St. Error	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	4.26	4.01	0.87	0.45	1.35	1.40	0.57	2.71	0.75	0.28	0.91	1.49	1.59
median	2.95	2.77	0.58	0.44	0.93	1.23	0.21	1.52	0.21	0.17	1.10	1.15	0.86
min	0.29	0.93	0.03	0.02	0.00	0.03	0.00	0.15	0.00	0.01	0.01	0.10	0.00
lower	1.48	1.83	0.31	0.16	0.62	0.35	0.05	0.52	0.06	0.05	0.14	0.77	0.25
upper	4.85	5.00	1.32	0.65	1.85	2.05	0.72	4.92	0.97	0.45	1.50	1.93	1.90
max	13.41	14.63	2.65	1.24	4.67	3.96	4.44	9.15	5.14	0.95	2.21	3.83	14.63
90th percentile	11.84	8.34	1.99	0.93	2.94	3.33	1.15	6.40	1.58	0.71	1.67	3.33	3.79
10th percentile	0.82	1.60	0.04	0.05	0.04	0.22	0.01	0.33	0.02	0.01	0.09	0.60	0.05
n(recordings obtained)	31	31	30	31	30	31	31	28	31	30	31	29	364
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.967	0.997
St. Dev	3.96	3.14	0.75	0.35	1.21	1.21	0.89	2.60	1.13	0.29	0.72	1.03	2.22
St. Error	0.71	0.56	0.14	0.06	0.22	0.22	0.16	0.49	0.20	0.05	0.13	0.19	0.12


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Monthly Stats – AMB 12 – Kewick Island

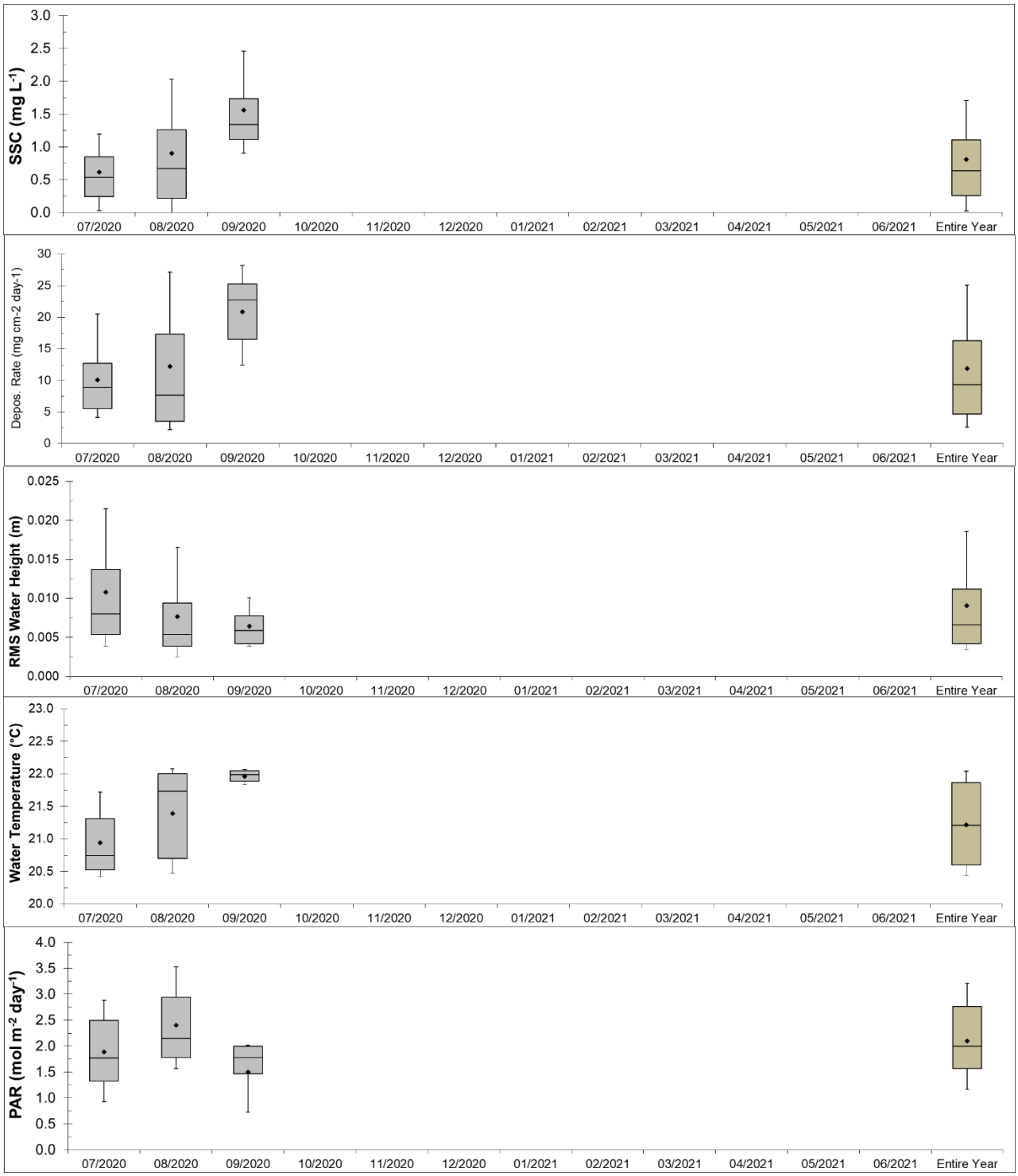
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	0.61	0.90	1.56										0.81
median	0.54	0.67	1.34										0.64
min	0.00	0.00	0.00										7.00
lower	0.24	0.22	1.12										0.26
upper	0.85	1.26	1.73										1.11
max	6.49	9.84	7.85										9.84
90th percentile	1.20	2.03	2.46										1.70
10th percentile	0.03	0.00	0.90										0.03
n(recordings obtained)	4448	4419	626	0	0	0	0	0	0	0	0	0	9493
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.996	0.990	0.145	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.181
St. Dev	0.53	0.96	0.77										0.81
St. Error	0.01	0.01	0.03										0.01

Deposition Rate (mg/[cm^2 day])	Dep. Rate 07/2020	Dep. Rate 08/2020	Dep. Rate 09/2020	Dep. Rate 10/2020	Dep. Rate 11/2020	Dep. Rate 12/2020	Dep. Rate 01/2021	Dep. Rate 02/2021	Dep. Rate 03/2021	Dep. Rate 04/2021	Dep. Rate 05/2021	Dep. Rate 06/2021	Dep. Rate Entire Year
Mean	10.10	12.22	20.88										11.87
median	8.92	7.69	22.75										9.31
min	1.43	1.56	9.76										1.43
lower	5.51	3.49	16.49										4.73
upper	12.72	17.37	25.30										16.30
max	30.52	45.42	30.10										45.42
90th percentile	20.48	27.18	28.18										25.06
10th percentile	4.11	2.20	12.45										2.65
n(recordings obtained)	31	28	5	0	0	0	0	0	0	0	0	0	64
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	0.903	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.175
St. Dev	6.76	11.49	7.92										9.51
St. Error	1.21	2.17	3.54										1.19

RMS Water Height (M)	RMS 07/2020	RMS 08/2020	RMS 09/2020	RMS 10/2020	RMS 11/2020	RMS 12/2020	RMS 01/2021	RMS 02/2021	RMS 03/2021	RMS 04/2021	RMS 05/2021	RMS 06/2021	RMS Entire Year
Mean	0.0108	0.0077	0.0065										0.0091
median	0.0080	0.0054	0.0059										0.0066
min	0.0000	0.0000	0.0000										0.0000
lower	0.0054	0.0039	0.0042										0.0042
upper	0.0137	0.0094	0.0078										0.0112
max	0.1046	0.0635	0.0246										0.1046
90th percentile	0.0215	0.0165	0.0101										0.0186
10th percentile	0.0039	0.0025	0.0039										0.0034
n(recordings obtained)	4464	4464	630	0	0	0	0	0	0	0	0	0	9558
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.146	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.182
St. Dev	0.0087	0.0068	0.0029										0.0077
St. Error	0.0001	0.0001	0.0001										0.0001

Water Temperature (degC)	Temp 07/2020	Temp 08/2020	Temp 09/2020	Temp 10/2020	Temp 11/2020	Temp 12/2020	Temp 01/2021	Temp 02/2021	Temp 03/2021	Temp 04/2021	Temp 05/2021	Temp 06/2021	Temp Entire Year
Mean	20.94	21.39	21.97										21.22
median	20.75	21.74	21.99										21.21
min	20.19	20.18	21.74										20.18
lower	20.53	20.70	21.89										20.60
upper	21.31	22.00	22.05										21.87
max	21.94	22.22	22.11										22.22
90th percentile	21.72	22.08	22.07										22.04
10th percentile	20.42	20.47	21.83										20.44
n(recordings obtained)	4464	4464	630	0	0	0	0	0	0	0	0	0	9558
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	1.000	1.000	0.146	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.182
St. Dev	0.48	0.66	0.09										0.63
St. Error	0.01	0.01	0.00										0.01

Daily PAR (mol m-2 day-1)	Light 07/2020	Light 08/2020	Light 09/2020	Light 10/2020	Light 11/2020	Light 12/2020	Light 01/2021	Light 02/2021	Light 03/2021	Light 04/2021	Light 05/2021	Light 06/2021	Light Entire Year
Mean	1.89	2.41	1.50										2.10
median	1.77	2.15	1.78										2.00
min	0.31	1.05	0.23										0.23
lower	1.32	1.78	1.47										1.57
upper	2.50	2.94	2.00										2.76
max	3.13	3.82	2.03										3.82
90th percentile	2.88	3.53	2.02										3.21
10th percentile	0.93	1.57	0.73										1.16
n(recordings obtained)	31	31	5	0	0	0	0	0	0	0	0	0	67
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	1.000	1.000	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.184
St. Dev	0.76	0.78	0.74										0.82
St. Error	0.14	0.14	0.33										0.10


SSC (mg L-1)
Depos. Rate (mg cm-2 day-1)
RMS Water Height (m)
Water Temperature (°C)
PAR (mol m-2 day-1)
07/2020
08/2020
09/2020
10/2020
11/2020
12/2020
01/2021
02/2021
03/2021
04/2021
05/2021
06/2021
Entire Year

Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER)

ATSIP Building
James Cook University
Townsville Qld 4811

Phone: 07 4781 4262
Fax: 07 4781 5589
Email: TropWATER@jcu.edu.au

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