Port of Weipa Ambient Marine Water Quality Monitoring Program: Annual Report 2020-2021

Nathan Waltham, Jordan Iles, Jamie Johns

Report No. 21/73

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A Report for North Queensland Bulk Ports Corporation

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EXECUTIVE SUMMARY

Background

1. North Queensland Bulk Ports has implemented an ambient marine water quality monitoring program surrounding the Port of Weipa. The objectives of the program are to establish a long-term water quality dataset to characterise marine water quality conditions within the waters within and around the port operation. These data are also used to support future planned activities.
2. This program has incorporated a combination of spot field measurements and high frequency continuous data loggers, laboratory analysis for a range of nutrient, and heavy metals.

Climatic conditions

1. Total wet season rainfall during the 2020-2021 monitoring period was 1449 mm, which is slightly below the long-term 75% percentile. Most of the rainfall was recorded during the wet season, with little to no rainfall occurring during the dry winter months.
2. The daily average wind speed and direction recorded at the Weipa airport was predominantly from the south east and east, reaching speeds up to and above 25 km h^{-1}

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. The water column is well mixed, with depth profiles for dissolved oxygen, temperature, electrical conductivity and pH showing only minor gradients of change.
3. Particulate nitrogen (PN) concentrations exceed guideline values during all surveys at all sites. Particulate phosphorus (PP) concentrations occasionally exceeded guideline values and were much more variable than PN over the reporting period.
4. Chlorophyll-*a* concentrations exceed guideline values during all surveys at all sites.
5. Trace metals were generally well below guideline values throughout the reporting year, similar to previous years, which suggests that their likely a low risk of contamination in the region, which does require some caution given the limited spatial and temporal monitoring as part of this program.

Sediment deposition and turbidity

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 experienced is likely in relation to re-suspension of sediment. Large peaks in NTUe/SSC and RMS water depth were recorded over periods longer than a week, giving rise to the notion that the re-suspension events can occur over extended periods.
2. Sediment deposition rates around Weipa seem slightly higher than measured in previous years, which only reflects certain periods of the data (during the wet season). This result could be a response to the wet season rainfall distribution, compared to previous years, where in the current reporting period there were three rainfall events above 100mm in a day, which could be very different to previous years (acknowledging that the total wet season rainfall was within the 75% percentile of long term records). As the data set here continues to increase, assessment of the rainfall patterns (frequency and duration) can be examined, providing more detailed insight into the rainfall and water quality relationships in this port area.

Photosynthetically active radiation (PAR)

1. Patterns of light were similar among all the coastal sites. Generally, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites and sites of closer proximity to one another were more similar than distant sites.

2. 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.

Recommendations

This monitoring program has been underway for four years (2017 to present) and should remain in place to continue to characterise, and build, a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities, but will also assist with future strategic planning and management. For example, while the total wet season rainfall during the current program was within the 75% percentile of long term records, the distribution of rainfall during the season becomes important and future assessment of these patterns should be made within sufficient data and confidence.

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1 INTRODUCTION

1.1 Port operations

The Port of Weipa is situated on the western side of Cape York Peninsula in northern Queensland (Figure 1.1). It is located within the township of Weipa, where the Embley, Mission and Pine River's converge and discharge into the Gulf of Carpentaria. The port has a series of operational and associated loading/unloading facilities. The port is operated by North Queensland Bulk Ports Corporation (NQBP). Along with other NQBP ports in Queensland, Port of Weipa requires routine maintenance dredging to maintain declared navigational depths within the swing basin and berth areas, departure path and aprons. Any dredging activity necessary in the operating ports in the region are undertaken in accordance with Commonwealth and State approvals.

1.2 Program outline

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 to an ambient marine water quality monitoring program in and around the coastal waters of Weipa (Table 1.1). As part of this program, water quality parameters are being investigated at a range of sites to build on 19 years of seagrass monitoring and three years of monitoring of photosynthetically active radiation (PAR) that has already been undertaken by NQBP. 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 habitat, predominately seagrass.

Figure 1.1 Location of water quality monitoring sites (green circles) and the decommissioned site (orange circle) utilised in the 2020-2021 reporting period. Also shown are meteorological stations (red square) referred to in this report.

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

Site name	Site code	Latitude	Longitude	Water quality	Logger
WQ1	WP_AMB1	-12.668283	141.846133	Yes	Yes
WQ2	WP_AMB2	-12.673778	141.777081	Yes	Yes
WQ3	WP_AMB3	-12.94905	141.59835	Yes	(Decommissioned)
WQ4	WP_AMB4	-12.701431	141.8667	Yes	Yes

1.3 Program objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region within and adjacent to Port of Weipa. 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, to support future planned asset management and protection of this coastal port.

2 METHODOLOGY

2.1 Ambient water quality

Spot water quality samples were collected at sites approximately on a 6-week basis (Table 3.1) from a research vessel. At each site, a calibrated multiprobe is used to measure water temperature, salinity, dissolved oxygen (%), pH, and turbidity (Figure 2.1). In addition to spot measurements, secchi disk depth is recorded, as a measure of the optical clarity of the water column, along with light attenuation using a LiCor meter. These field in-situ measurements are recorded at three depth horizons: a) surface (0.25m); b) mid-depth; and c) bottom horizon.

In aligning with the ambient marine water quality monitoring in other NQBP ports (Ports of Mackay and Hay Point, and Port of Abbott Point) the water quality program design below was completed. The list of parameters examined consisted:

- Ultra-trace dissolved metals : arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn);
- Nutrients (total and particulate nitrogen and phosphorus); and
- Chlorophyll-*a*.

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 (i.e., DERM 2009b; APHA 2005; Standards Australia 1998). Field collected water samples were stored on ice in eskies immediately during field trips aboard the vessel, and transported back to refrigeration, before delivery to the TropWATER laboratory. For chlorophyll analysis, water was placed into a 1L dark plastic bottle and placed on ice for transportation back to refrigeration. For dissolved metals and nutrients, water was passed through a 0.45 µm disposable membrane filter (Sartorius), fitted to a sterile 60 mL syringe (Livingstone), and placed into 60 mL bottles (metals) and 10 mL bottles (nutrients) for posterior analysis in the laboratory. (The use of these field sampling equipment and procedures have been previously shown to reduce the risk of contamination of samples, contributing to false positive results for reporting; TropWATER (2015). Unfiltered sample for total nitrogen and total phosphorus analysis were frozen in a 60 mL tube. All samples are kept in the dark and cold until processing in the laboratory, except nutrients which are stored frozen until processing.

Water for chlorophyll determination was filtered through a Whatman 0.45 µm GF/F glass-fibre filter with the addition of approximately 0.2 mL of magnesium carbonate within (less than) 12 hours after collection. Filters are then wrapped in aluminium foil and frozen. Pigment determinations from acetone extracts of the filters were completed using spectrophotometry, method described in 'Standard Methods for the Examination of Water and Wastewater, 10200 H. Chlorophyll'.

Water samples are analysed using the defined analysis methods and detection limits outlined in Table 2.1. 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 are analysed by Australian Laboratory Service (ALS).

Table 2.1 Water analyses performed during the program

	Parameter	APHA method number	Reporting limit
Routine water quality analyses			
	pH	4500-H+ B	-
	Conductivity (EC)	2510 B	5 µS cm^{-1}
	Total Suspended Solids (TSS)	2540 D @ 103 - 105°C	0.2 mg L^{-1}
	Salinity		
	Dissolved Oxygen		
Nutrients			
	Total Nitrogen and Phosphorus (TN, TP)	Simultaneous 4500-NO3- F and 4500-P F analyses after alkaline persulphate digestion	25 µg N L^{-1}, 5 µg P L^{-1}
	Filterable nutrients (nitrate, nitrite, ammonia)	4500-NO3- F	1 µg N L^{-1}
	Ammonia	4500- NH3 G	1 mg N L^{-1}
	Filterable Reactive Phosphorus (FRP)	4500-P F	1 µg P L^{-1}
	Chlorophyll	10200-H	0.1 µg L^{-1}
Trace Metals			

	Arsenic, Cadmium, Copper, Lead, Nickel, Silver, Zinc, Mercury	3125B ORC/ICP/MS	0.05 to 100 µg L^{-1}

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

It must be noted the international turbidity standard ISO7027 defines NTU only for 90 degree scatter, however, the Marine Geophysics Laboratory instruments obtain an NTUe value using 180 degree backscatter as it allows for much more effective cleaning. Because particle size influences the angular scattering functions of incident light (Ludwig and Hanes 1990; Conner and De Visser 1992; Wolanski et al., 1994; Bunt et al., 1999), instruments using different scattering angles can provide different measurements of turbidity (in NTU). This has to be acknowledged if later comparison between instruments collecting NTUe and NTU are to be made. To enhance the data, all sites were calibrated to provide a measure of SSC (mg L^{-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 two 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 1 m 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.

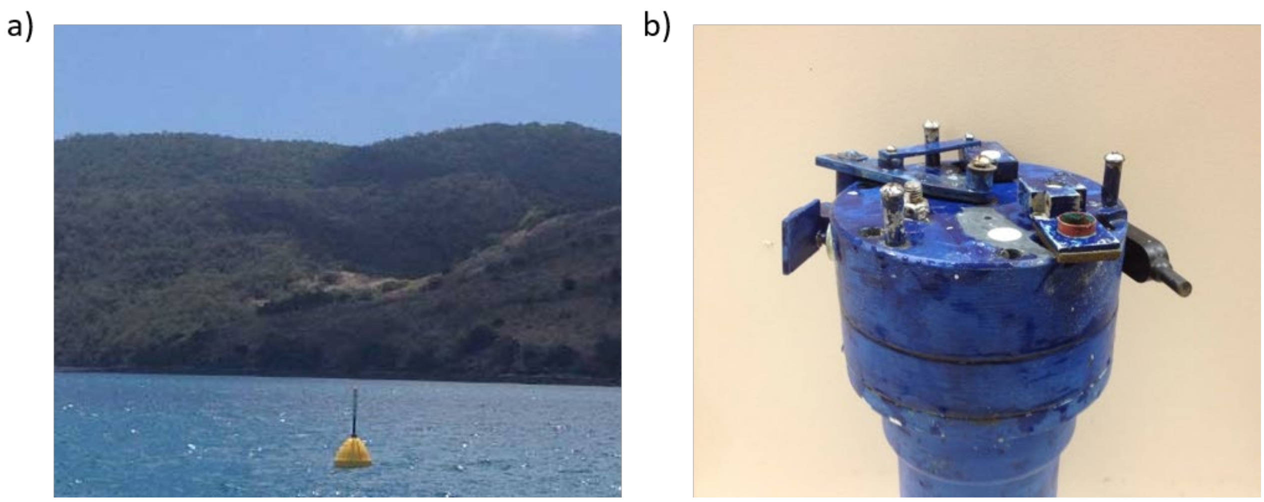


Figure 2.2 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

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.

2.3 Marotte HS current meter instruments

The Marotte HS (High Sampling Rate) is a drag-tilt current meter invented at the Marine Geophysics Laboratory (Figure 2.3). 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.

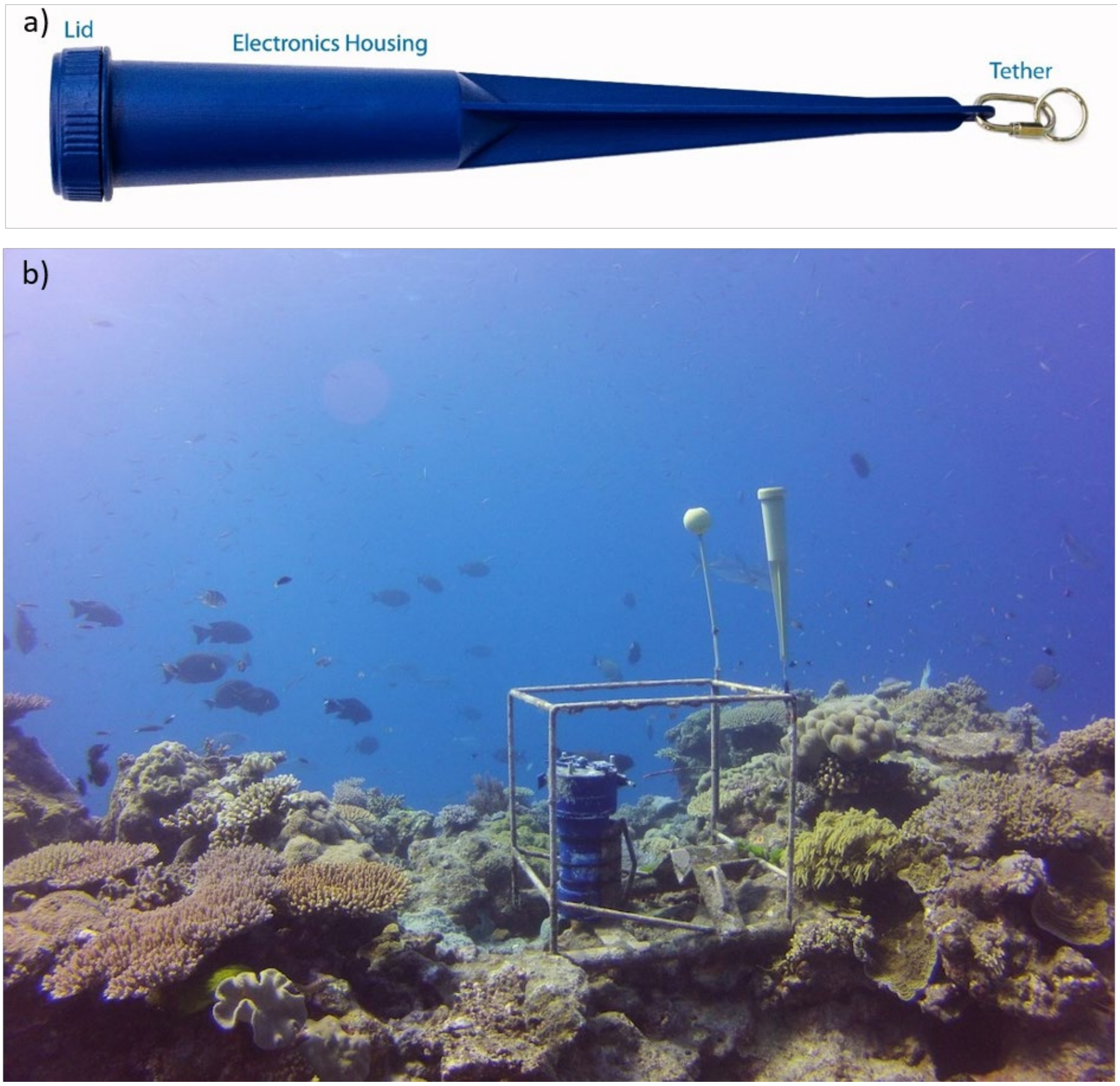


Figure 2.3 a) Basic schematic of Marotte HS current meter; and b) Marotte HS alongside Marotte tethered to a nephelometer frame at Moore Reef. Image courtesy of Eric Fisher

3 RESULTS AND DISCUSSION

There were seven sampling and maintenance trips in the 2020-2021 reporting period (Table 3.1). Travel restrictions due to COVID-19 meant we were unable to complete water sampling between May and September 2020.

Table 3.1 Summary of instrument maintenance and water quality surveys completed during the reporting period. Note a second round of metal sampling was completed August 2021 which are reported here in Section 3.2.3

Date	Nutrients, Chlorophyll-*a*	Metals	Logger maintenance
01/09/2020	Yes	-	Yes
16/10/2020	Yes	-	Yes
16/12/2020	Yes	-	Yes
09/02/2021	Yes	Yes	Yes
10/04/2021	Yes	-	Yes
10/05/2021	Yes	-	Yes

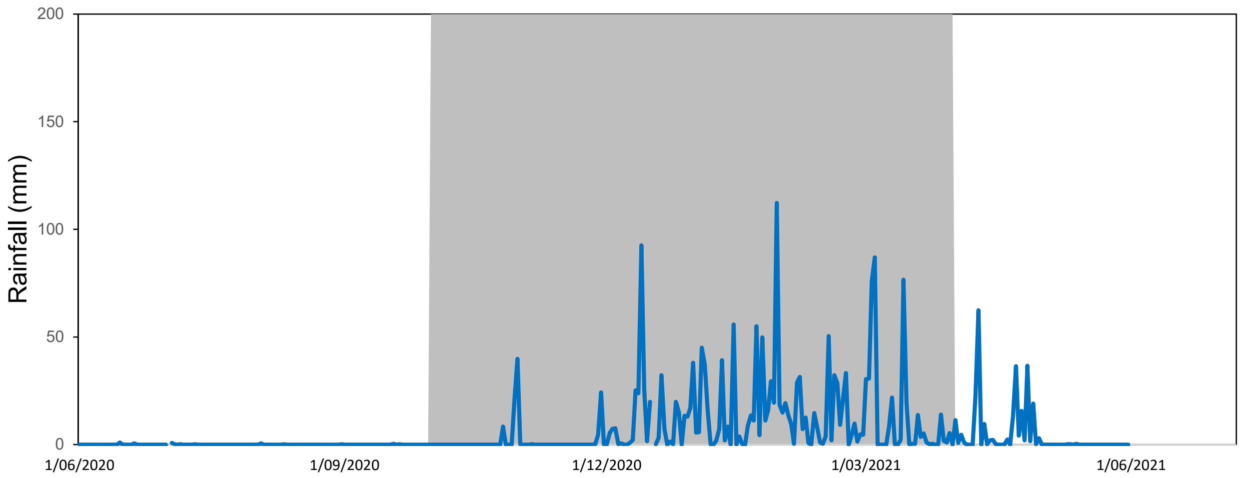
3.1 Climatic conditions

Weather observations and hydrological data were compiled from the Bureau of Meteorology and the State of Queensland.

3.1.1 Rainfall

Daily rainfall for the Weipa region is shown on

A)



B)

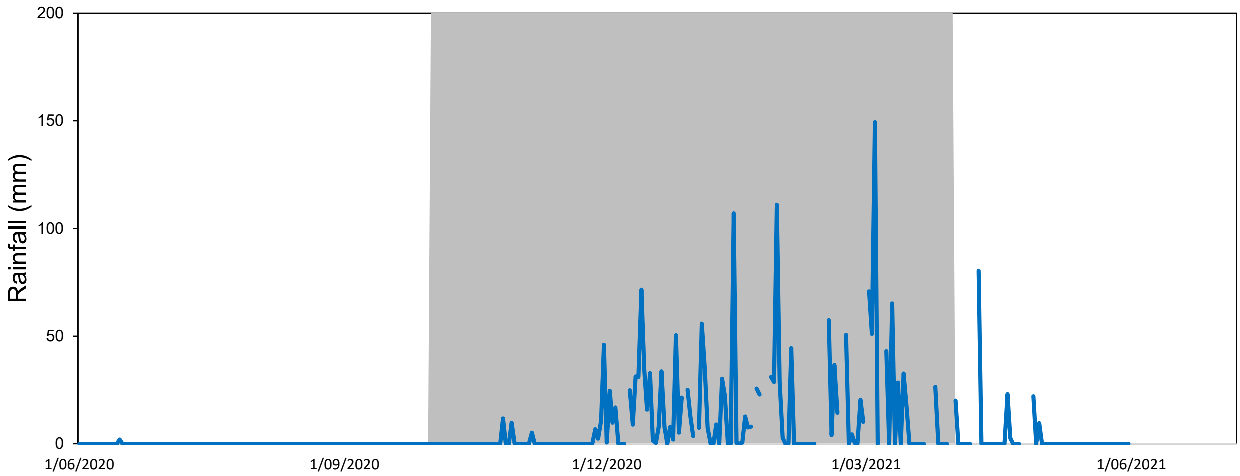
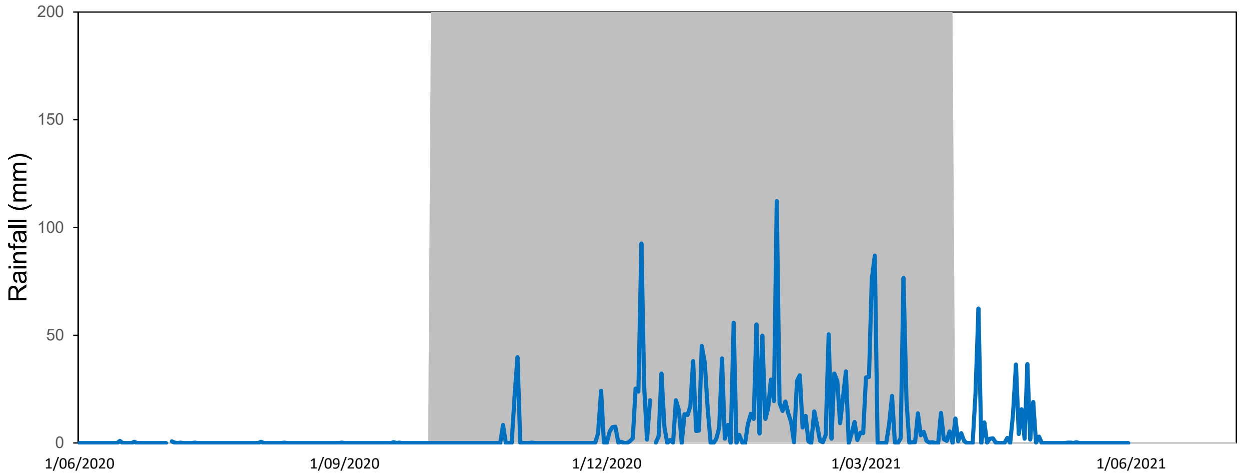


Figure 3.1. The first rainfall greater than 5 mm for the year occurred on 29/10/2020, with the rainfall onset occurring on 13/12/2020. The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. The 2020-2021 wet season rainfall total was 1910.2 mm (Weipa East Ave), which was proximal to the 75th percentile of season rainfall total calculated for wet seasons since 1914/15 (Figure 3.2).

A)



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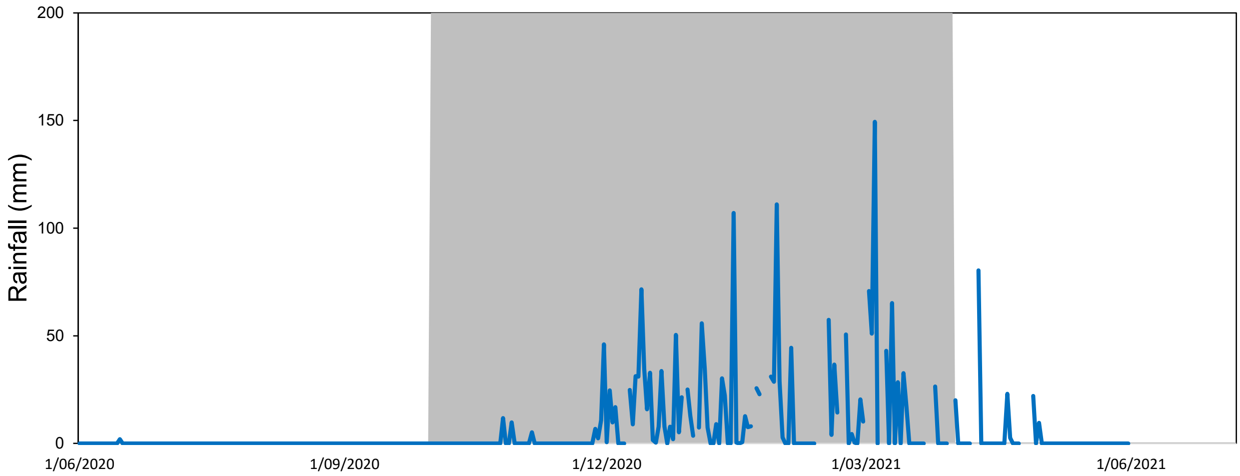


Figure 3.1 Rainfall recorded at: A) Weipa Aero (station 027045); and B) Weipa East Ave (station 027042) for the 2020-2021 reporting period. The nominal wet season period is shaded grey. Data source: http://www.bom.gov.au/climate/data/

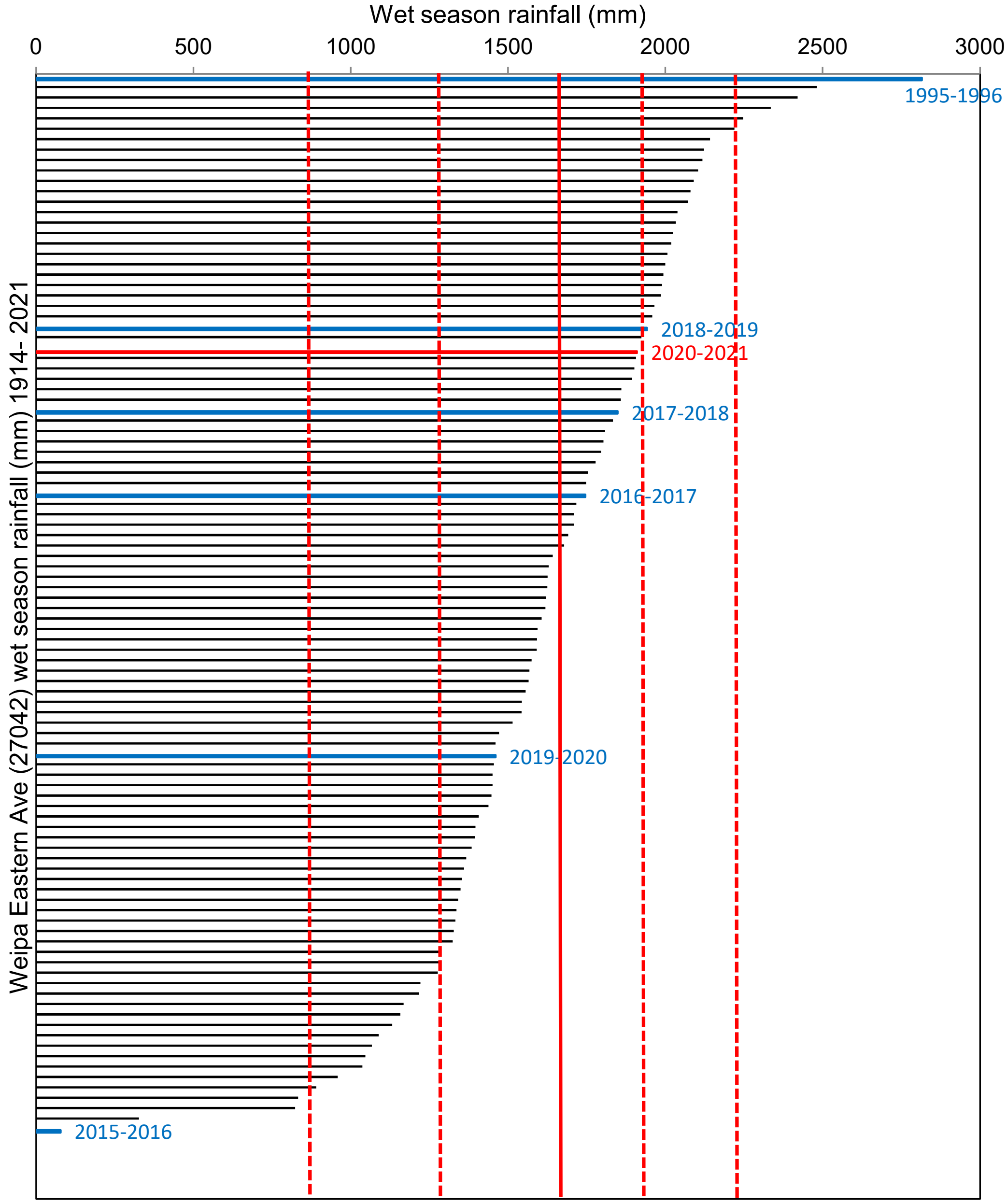


Figure 3.2 Wet season rainfall for the Weipa region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Weipa Eastern Ave weather station (station 027042). Totals were calculated for the wet season period 1st November to 31st March for each reporting 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 1913-1914 to 2020-2021, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Data source: http://www.bom.gov.au/climate/data/

3.1.2 River flows

The only local river gauging station near to Weipa is on the Watson River, which is located ~75 km south and does not discharge into the Mission River system where the Port is located. Therefore, although Watson River discharge has been used throughout this report to provide context for Port water quality conditions, results regarding the influence of water discharge on water quality variability should be interpreted with caution.

The hydrograph for Watson River shows onset of stream discharge on 28/12/2020 (Figure 3.3). Total discharge for the 2020-2021 reporting period was 727 GL. There was a large discharge pulse on 14/03/2020 following rainfall. The hydrograph displays typical monsoonal rainfall patterns for this region. Weipa is located in a tropical environment where wet season rainfall can result in prolonged and elevated river discharge, particularly between November and April each year.

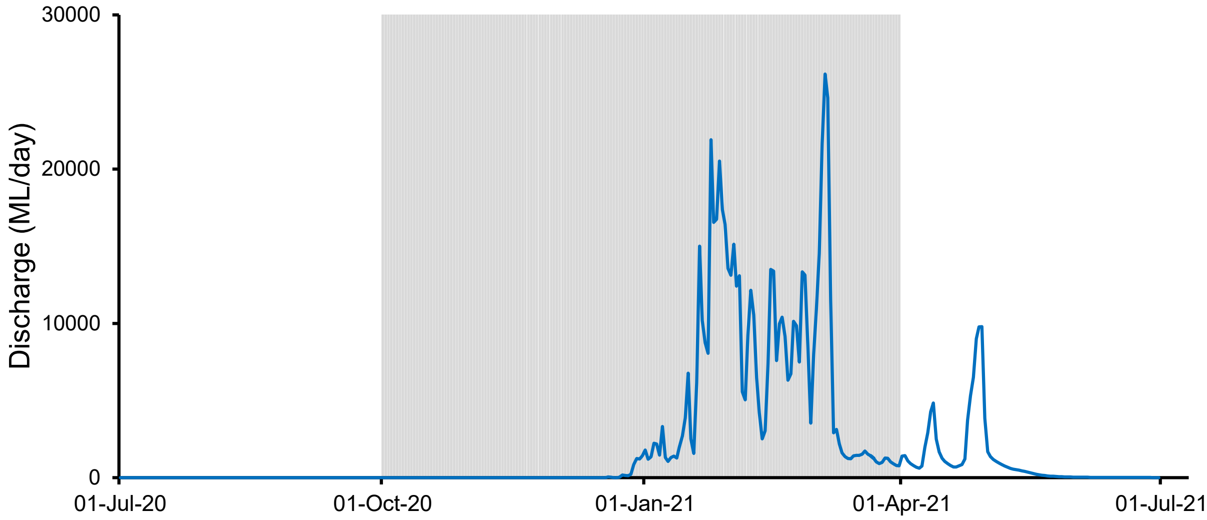


Figure 3.3 Stream discharge (GL d^{-1}) from the Watson River (station 923001A) during the 2020-2021 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/.

3.2 Ambient water quality

3.2.1 Spot water quality physio-chemical

Water temperature ranged between 25.4 and 31.3 °C (Figure 3.4). 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 29.1 and 55.1 mS cm^{-1} (Figure 3.5). Conductivity values followed seasonality with higher values occurring during summer months and lower values during winter months. There was a drop in EC during February 2021 which we attribute to rainfall and increased freshwater discharge from the Embley River. A halocline was present in March 2020 with brackish water (~35 mS cm^{-1}) overlying more saline water. This halocline was most strongly observed at the two sites within the Embley River (WP_AMB1, WP_AMB4), while the coastal sites WP_AMB2 and WP_AMB3 did not show such a strong drop in electrical conductivity. Dissolved oxygen ranged between 79.9 to 106.5 %sat (Figure 3.6). The water column was well mixed, with dissolved oxygen saturation not significantly changing through the vertical profile. pH ranged between 7.83 and 9.17 (Figure 3.7). Note we had instrument failure problems during the December 2020 survey.

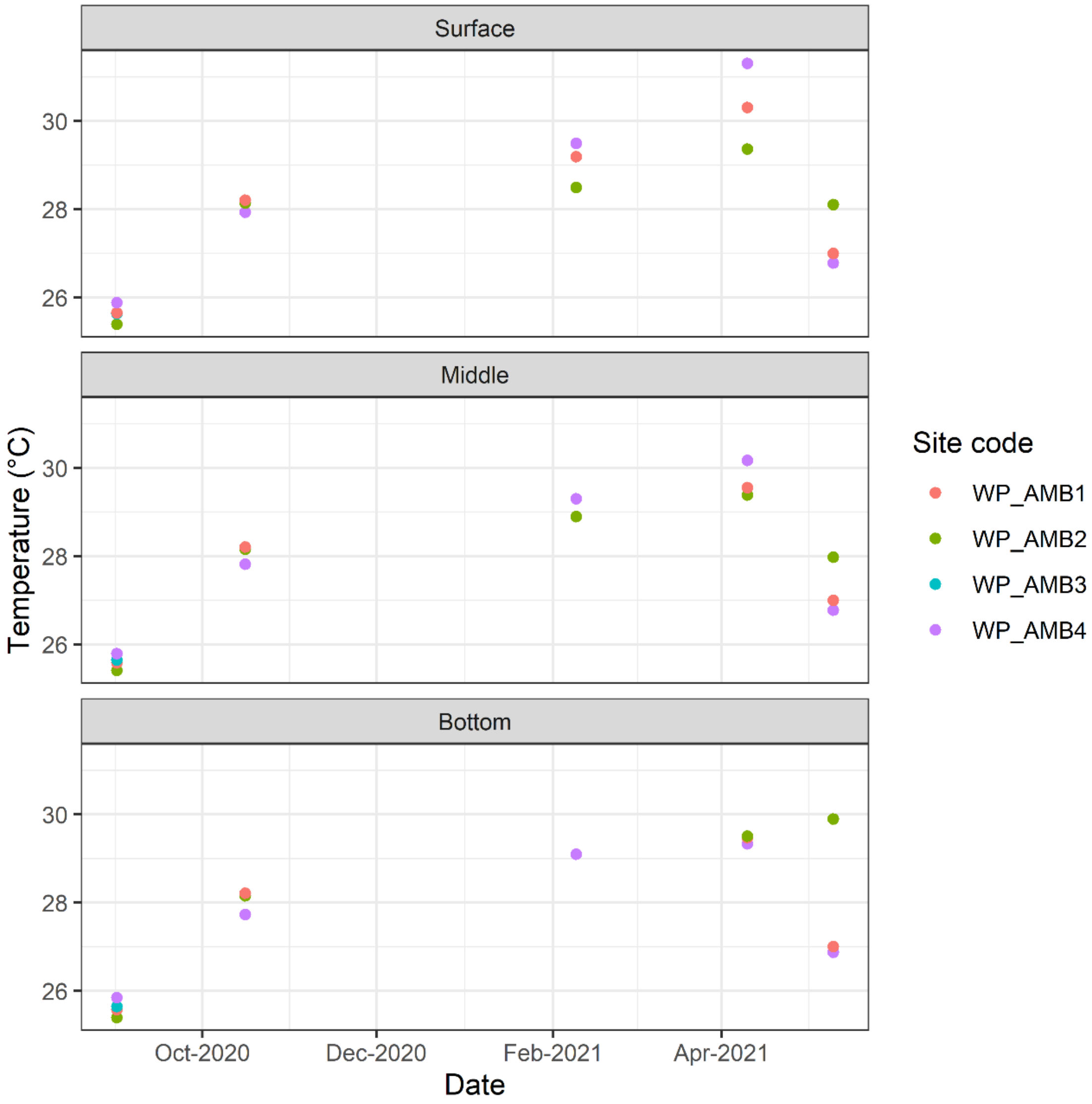


Figure 3.4 Water temperature recorded at three depths at the water quality sites throughout the reporting period.

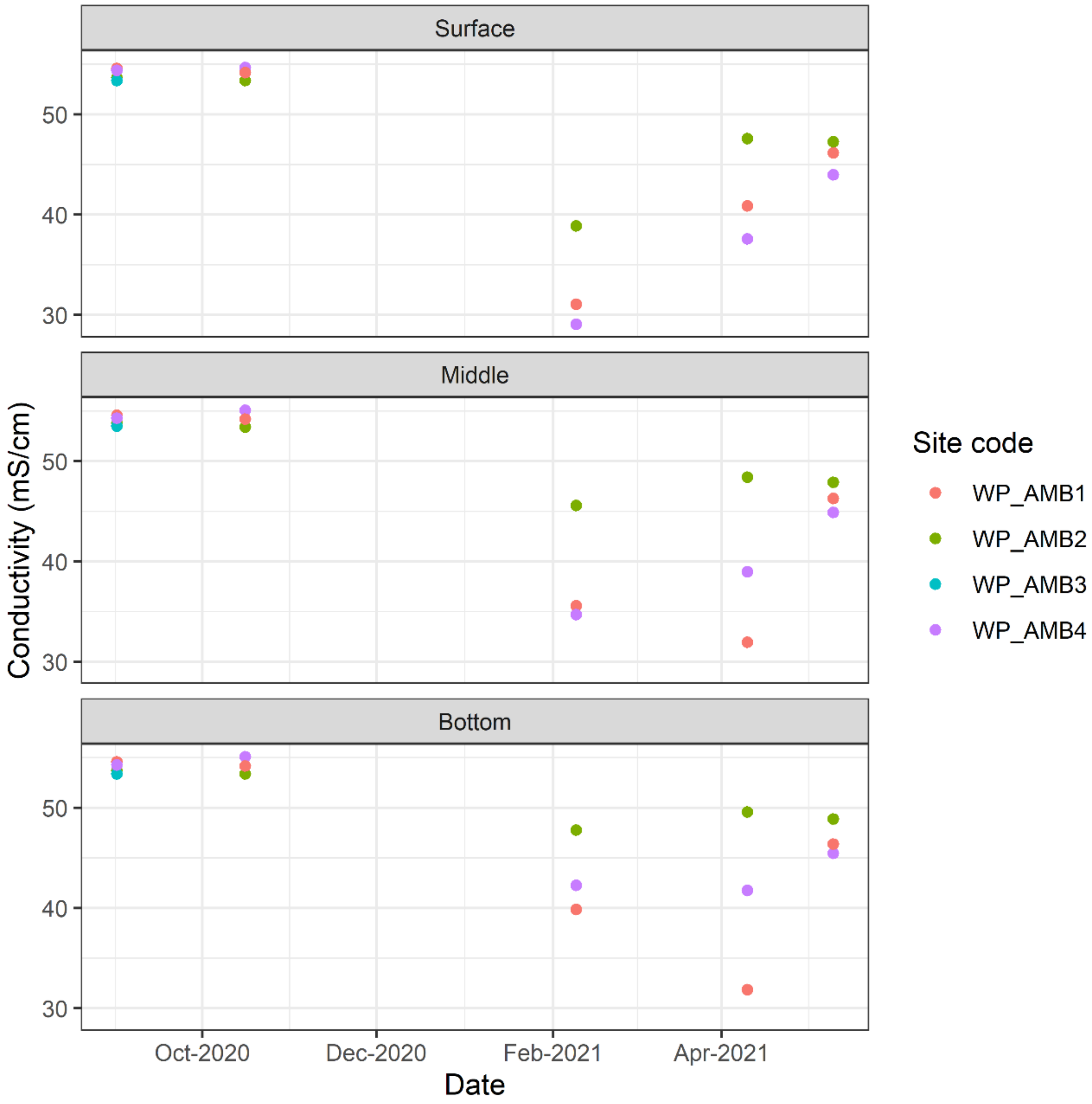


Figure 3.5 Electrical conductivity recorded at three depths at the water quality sites throughout the reporting period.

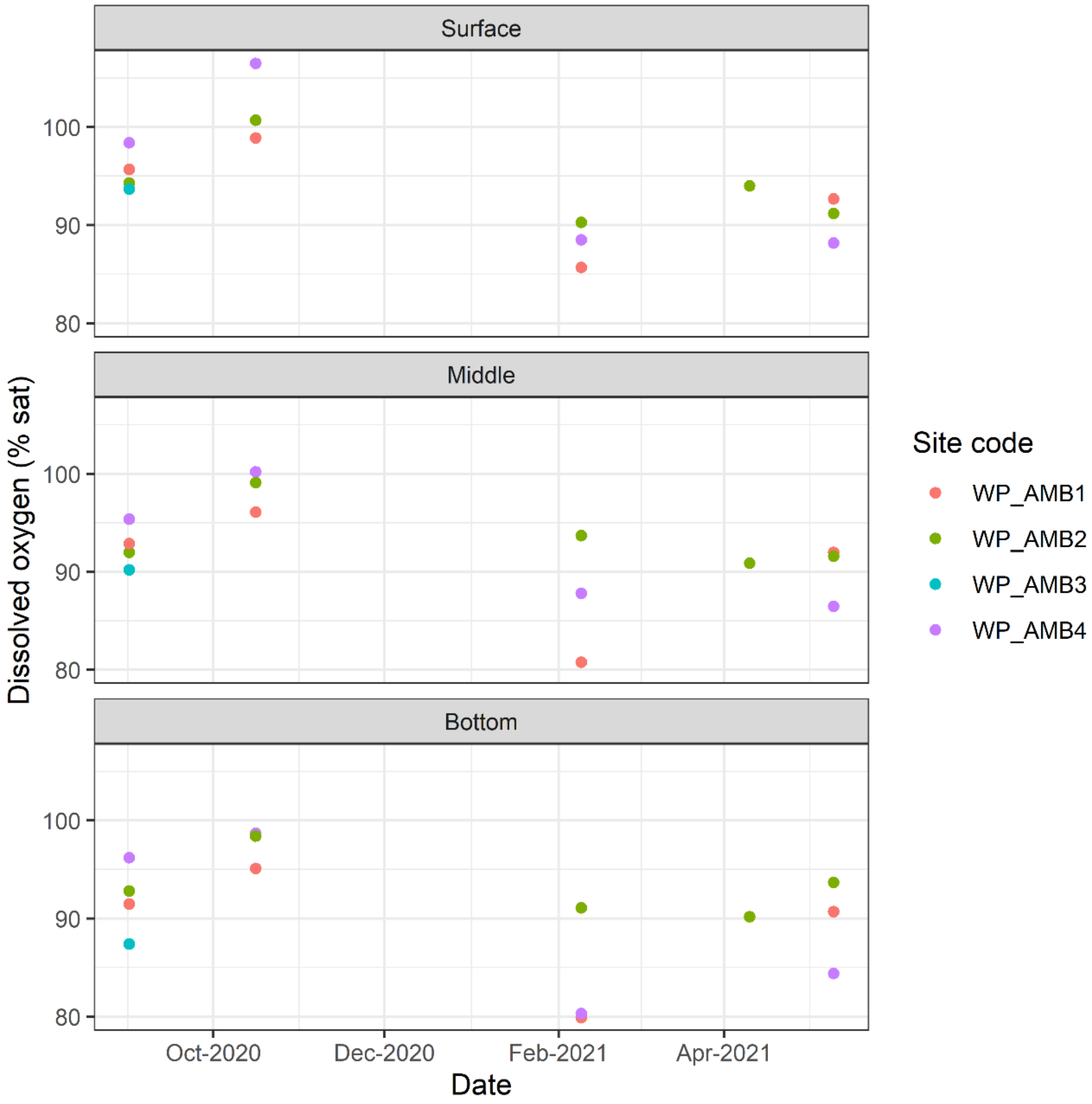


Figure 3.6 Dissolved oxygen (%sat) recorded at three depths at the water quality sites throughout the reporting period.

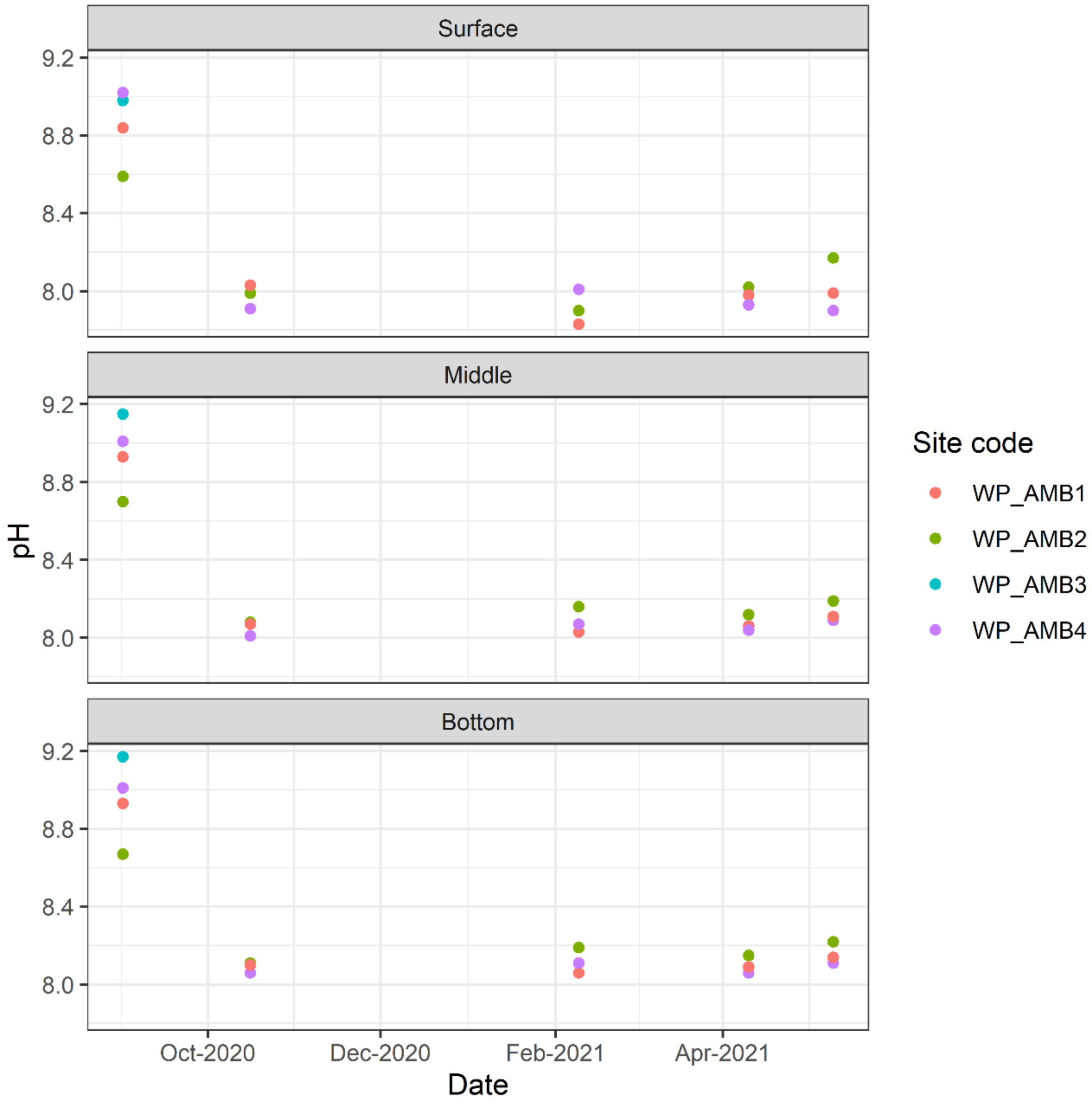


Figure 3.7 pH recorded at three depths at the water quality sites throughout the reporting period.

3.2.2 Nutrients, water clarity and chlorophyll-*a*

Particulate nitrogen (PN) and phosphorus (PP) concentrations were compared to the Water Quality Guidelines for the Great Barrier Marine Park Authority (GBRMPA, 2010) and the Queensland Water Quality Guidelines (DEHP, 2013). (Note that Weipa is not within the Great Barrier Reef World Heritage Area (GBRWHA), but GBRMPA guidelines are used in this report to provide context when comparing to NQBP's other east-coast Ports that are located adjacent to the GBRWHA).

Particulate nitrogen (PN) concentrations ranged from 4 to 212 µg L^{-1} (Figure 3.8). Mean PN across the four sites (42 µg L^{-1}) exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} for all sampling events. Particulate phosphorus (PP) concentrations ranged from 2 to 12 µg L^{-1} (Figure 3.9). PP values were much more variable than PN over the reporting period.

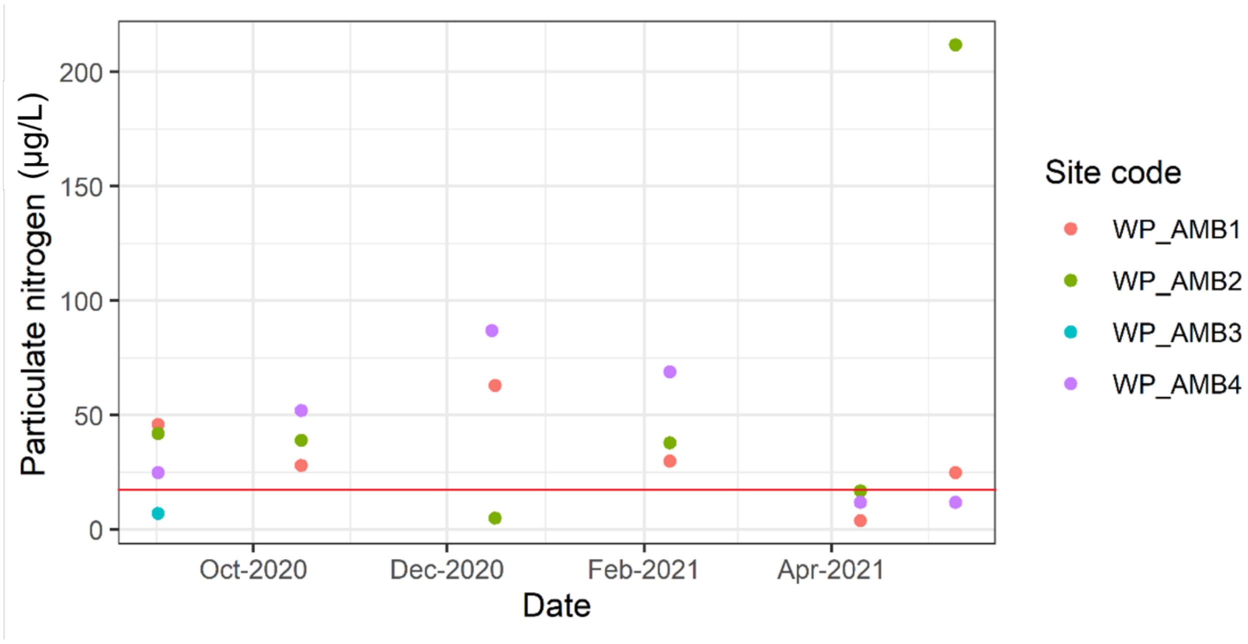


Figure 3.8 Particulate nitrogen (PN) concentrations measured in water samples collected from the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

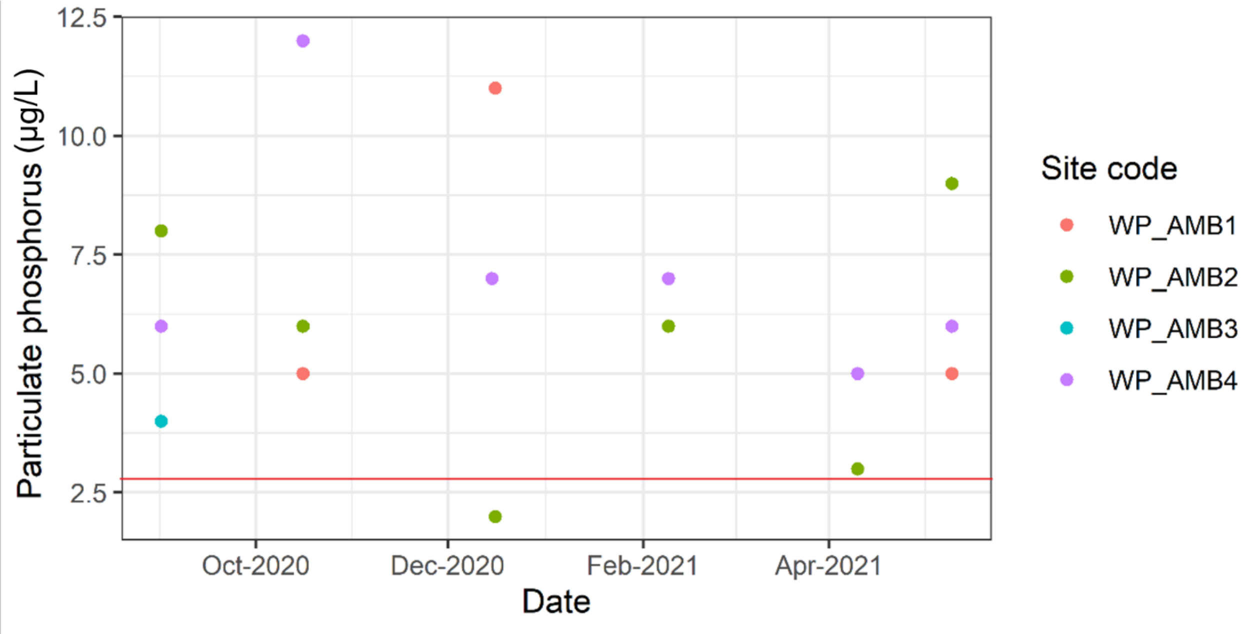


Figure 3.9 Particulate phosphorus (PP) concentrations measured in water samples collected from the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

Total suspended solids ranged from 2.2 to 29 mg L^{-1} (

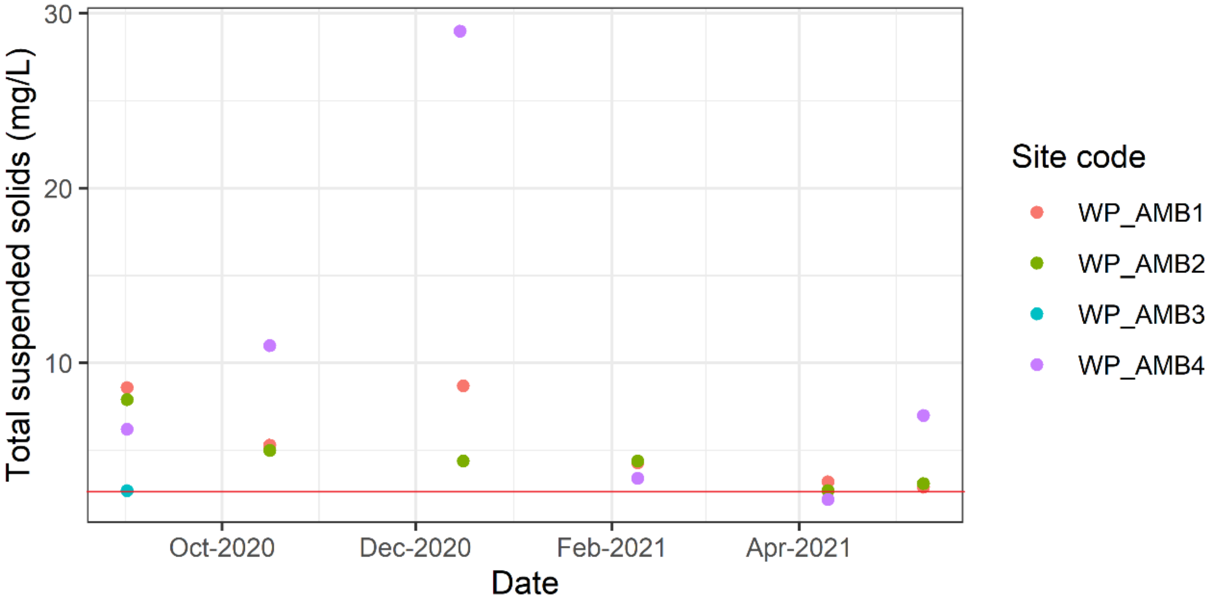


Figure **3.10**). Mean TSS across the five sites regularly exceeded the GBRMPA guideline trigger value of 2.0 mg L^{-1} for all sampling events. Secchi depth ranged from 1.0 to 4.0 m (Figure 3.11). Chlorophyll-*a* concentrations ranged from 0.65 to 2.84 µg L^{-1} (Figure 3.12). Chlorophyll-*a* concentrations exceeded the GBRMPA guideline trigger value for all sampling events.

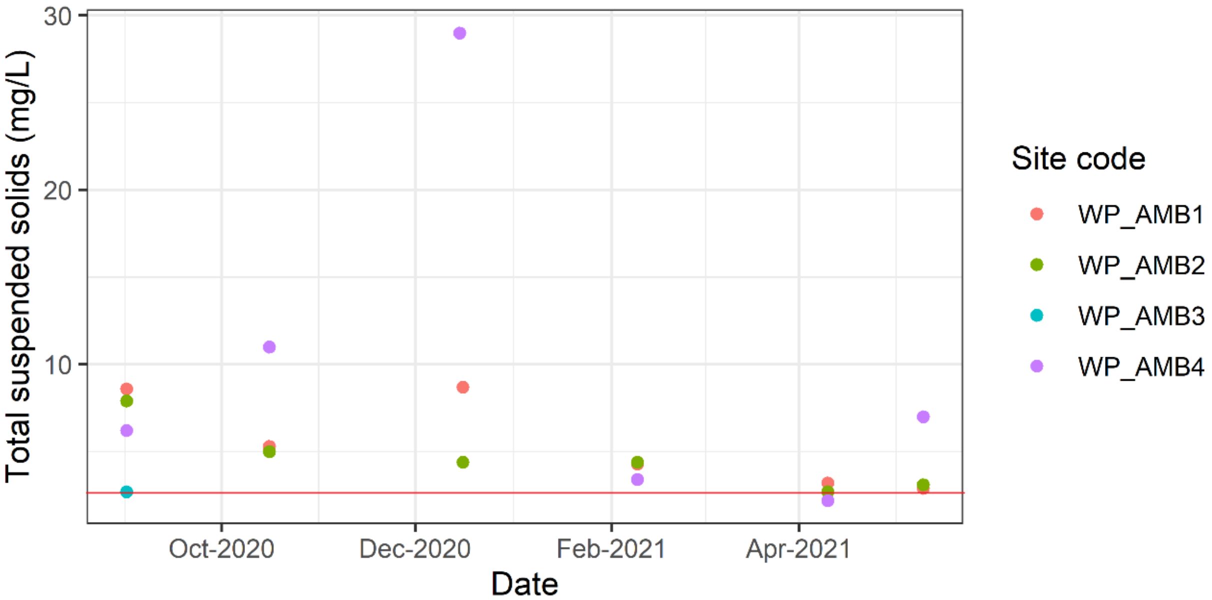


Figure 3.10 Total suspended solids (TSS) measured in water samples at the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

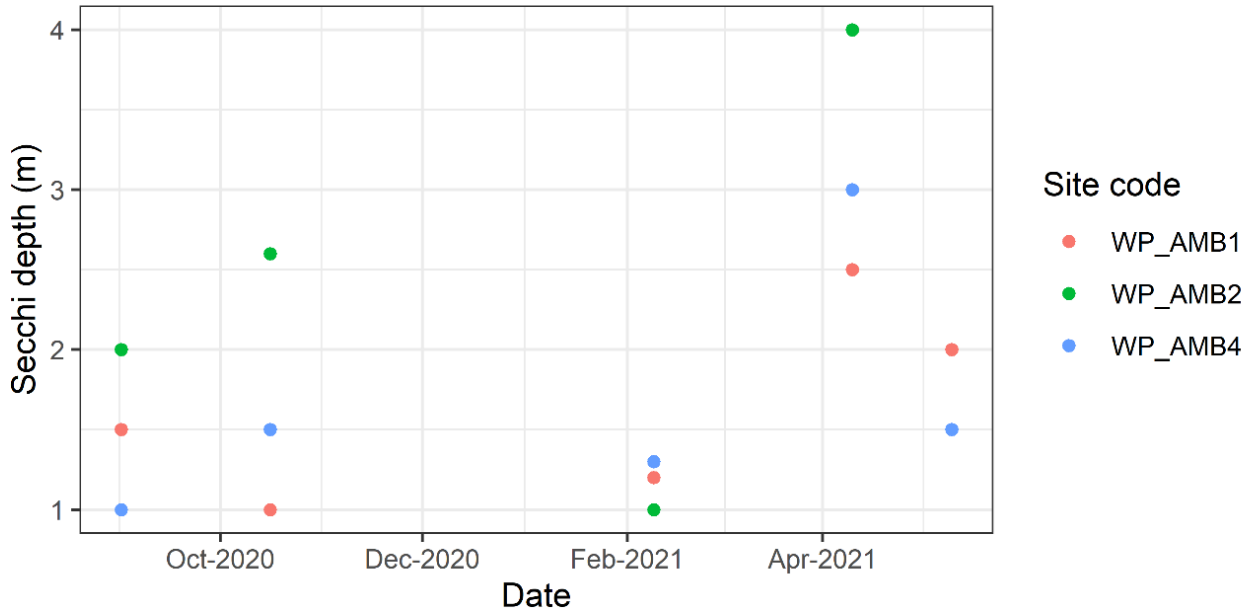


Figure 3.11 Secchi disk depth recorded at the water quality sites throughout the reporting period. Secchi disk depth was not recorded during the December 2020 campaign

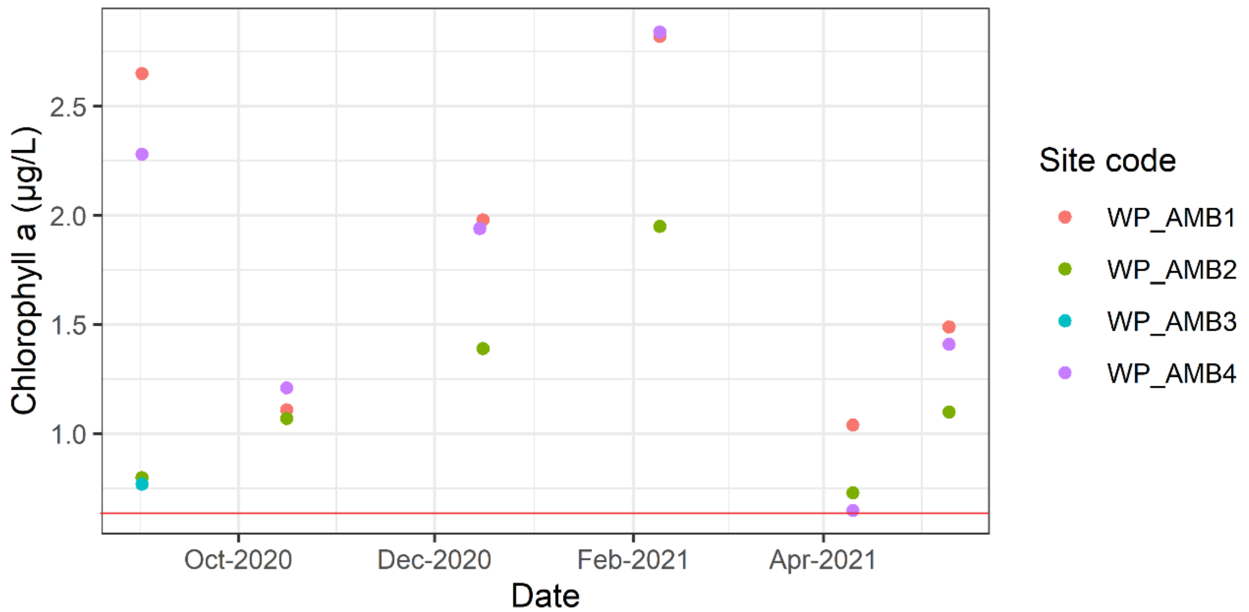


Figure 3.12 Chlorophyll-*a* concentrations measured in water samples collected from the water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

3.2.3 Heavy metals

Heavy metal concentrations are presented in Table 3.2. Concentrations were compared to the ANZECC and ARMCANZ 2000 water quality guidelines (ANZECC, 2000). Metals targeted for analysis were not detected above the 95% level of protection trigger values for marine waters. Silver, Cadmium, Copper, Nickel, Zinc, and Mercury were not detected (< LOD). Arsenic was detected at low concentrations. Note that ANZECC guidelines do not have a trigger value for arsenic. A low reliability marine guideline trigger value of 4.5 µg/L for As (V) and 2.3 µg/L for As (III) has been derived (ANZECC, 2000), however, these trigger guidelines are only an indicative interim working level.

Table 3.2 Heavy metal concentrations measured in water samples collected from the four 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
Feb - 21	9/02/2021	WP_AMB1	WQ1	<0.1	<0.2	<1	<0.2	<0.5	0.8	<5	<0.0001
	9/02/2021	WP_AMB2	WQ2	<0.1	<0.2	<1	<0.2	<0.5	1.1	<5	<0.0001
	9/02/2021	WP_AMB4	WQ4	<0.1	<0.2	<1	<0.2	<0.5	0.8	<5	<0.0001
Aug - 21	20/08/2021	WP_AMB1	WQ1	<0.1	<0.2	<1	<0.2	<0.5	2.1	<5	<0.0001
	20/08/2021	WP_AMB2	WQ2	<0.1	<0.2	<1	<0.2	<0.5	2.2	<5	<0.0001
	20/08/2021	WP_AMB4	WQ4	<0.1	<0.2	<1	<0.2	<0.5	2.1	<5	<0.0001

3.3 Multiparameter water quality logger

Instruments were deployed to three Weipa sites of WQ1, WQ2 and WQ4 from July 2020 to July 2021 (see Table 3.1). For site WQ3, instrument deployments were decommissioned at the end September 2020 and although the final WQ3 deployment was inclusively deployed between July 2020 to September 2020 (part of this reporting period); no recordings were obtained due a failure of the instrument's battery.

Hence, site WQ3 is not mentioned or included for the majority of the results and findings that are outlined and presented throughout *section 3.3*, except for, in *Section 3.3.6* which presents and compares current and past year (historical) data between Weipa sites WQ1 to WQ4.

For the results presented throughout *section 3.3*, standard statistics are applied to describe observed trends and differences between the Weipa sites and discuss the driving forces in their environments. Data is presented as an annual statistical summary of Root Mean square water height (RMS; m), Suspended Sediment Concentration (SSC; mg L^{-1}), Sediment Deposition Rate (mg cm^{-2} day^{-1}), Water Temperature (°C), and Photosynthetically Active Radiation (PAR; mol m^{-2} day^{-1}) for each site. The summary of these measured parameters 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 90^{th} and 10^{th} percentiles. Time series and monthly summaries are included in the appendices (Appendix A1.2, Appendix A1.3).

3.3.1 RMS water height

As mentioned in the methodology, Root Mean Square water height (RMS) is a proxy for wave energy or wave shear stress at the ocean floor (Macdonald, 2015). RMS is mostly driven by weather events that increase RMS simultaneously at all sites. Variation in RMS during and in-between peak events differs among sites due to differences in water depth and exposure to wave energy.

WQ1 and WQ4, located within the Embley River, had much lower RMS measurements than WQ2, which is located on the coast and outside of the Embley River. The median RMS at WQ1 and WQ4 were respectively 13% and 10% that of WQ2 (Figure 3.13, Table 3.3). The upper quartile values of WQ1 and WQ4 are approximately 11% and 8% that of WQ2, while the 90^{th} percentile values of WQ1 and WQ4 are approximately 7% and 5% that of WQ2.

Similar RMS at WQ1 and WQ4 relative to WQ2 indicates that wave energy may explain differences in water quality between the two groups of sites, but not within the two pairs of sites. The differences in RMS among the three sites has important implications for other water quality parameters. For example, a lower RMS would promote more sediment deposition and less sediment resuspension at WQ1 and WQ4 (in the Embley River) compared to WQ2 (on the coast). However, differences in water quality between WQ1 and WQ4, or between WQ2 could be due to different currents, depths, or benthic geologies, all or a combination of each of these processes could influence conditions.

Across all sites together, the highest RMS values were observed between December 2020 and March 2021 (Appendix A1.2, Appendix A1.3); which is during the wet season of 2020-2021 period. In section 3.3.6, which outlines the seasonal variation (wet vs dry season) of the various logger instrument measurements and also makes a comparison between each Weipa site for both this and previous observational periods/years (cumulatively); Figure 3.21 demonstrates that significantly higher values of RMS are consistently experienced during the wet season periods in comparison to the dry season periods.

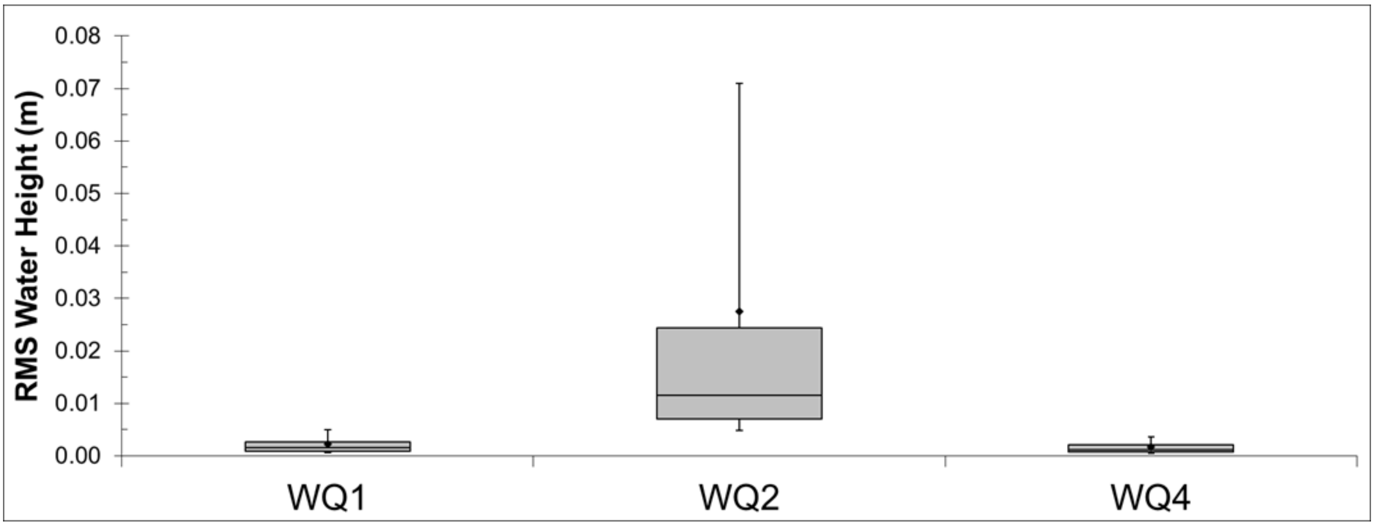


Figure 3.13 Box plot of root mean square (RMS) of water height (m) at the three sites for the monitoring period from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean values.

Table 3.3 Summary of RMS water height (m) from July 2020 to July 2021.

Site	WQ1	WQ2	WQ4
Mean	0.002	0.027	0.002
median	0.002	0.011	0.001
min	0.000	0.000	0.000
lower quartile	0.001	0.007	0.001
upper quartile	0.003	0.024	0.002
max	0.078	0.467	0.035
90th percentile	0.005	0.071	0.004
10th percentile	0.001	0.005	0.000
n (recordings)	**52,201**	**52,189**	**43,522**
f (year obtained)**	**0.993**	**0.993**	**0.828**
St. Dev	0.003	0.043	0.002
St. Error	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'.

3.3.2 NTUe/SSC

Median suspended sediment concentrations (SSC) were all ≤ 14 mg L^{-1} and 75 % (upper) quartiles were less than 36 mg L^{-1} (Figure 3.14, Table 3.4). The highest SSC was observed furthest up the Embley River (WQ4), followed by outside the river mouth (WQ2), and then inside the river mouth (WQ1). As indicated by the mean and 90th percentile values being significantly higher than its median value, WQ4 experienced frequently more extreme turbidity events in comparison to sites WQ1 and WQ2.

The SSC time series data at each site (seen in Appendix A1.2) typically follows a pattern of low background values with recurring peak events. These peak events typically occur roughly at the same time periods for each site and coincide with peaks in RMS water height (Ridd et al., 2001), and hence it is strongly notable that, across all sites, the highest values for SSC and RMS water height were both experienced between December 2020 and March 2021 (Appendix A1.3); which is during the Wet season period of 2020-2021.

Covered in section *3.3.6*, a seasonal comparison of measurements (Wet vs Dry seasonal periods), Figure 3.21 and Figure 3.22, respectively, demonstrate that both RMS water height and SSC consistently measure significantly higher during the Wet season periods across all deployment sites and previous observational periods (collectively). However, in addition to RMS water height, differences in turbidity between sites also result from variation in, site depth, benthic geology, hydrodynamics, and proximity to river mouths.

During this reporting period and prior to the 2020-2021 Wet Season Period, before November 2020, a build-up to a secondary period of notably higher SSC values is experienced for WQ1 between July and October of 2020 (during the 2020 dry season period; Appendix A1.2 and Appendix A1.3). This is unlike for sites WQ2 and WQ4 which both experienced relatively consistent and lower SSC values prior to the 2020-2021 Wet season period (Appendix A1.2 and Appendix A1.3). For site WQ1, the mean SSC value experienced during January 2021 (a wet season period month, with the highest SSC measurements overall) is approximately 1.2 times higher than the mean SSC value for the month with the second highest measurements overall (September 2020, during the 2020 Dry season period). However, in comparison, the mean SSC values for WQ2 and WQ4 are respectively (and approximately) 9.6 and 7.2 times higher when comparing the same two months of January 2021 and September 2021 for each if these two sites.

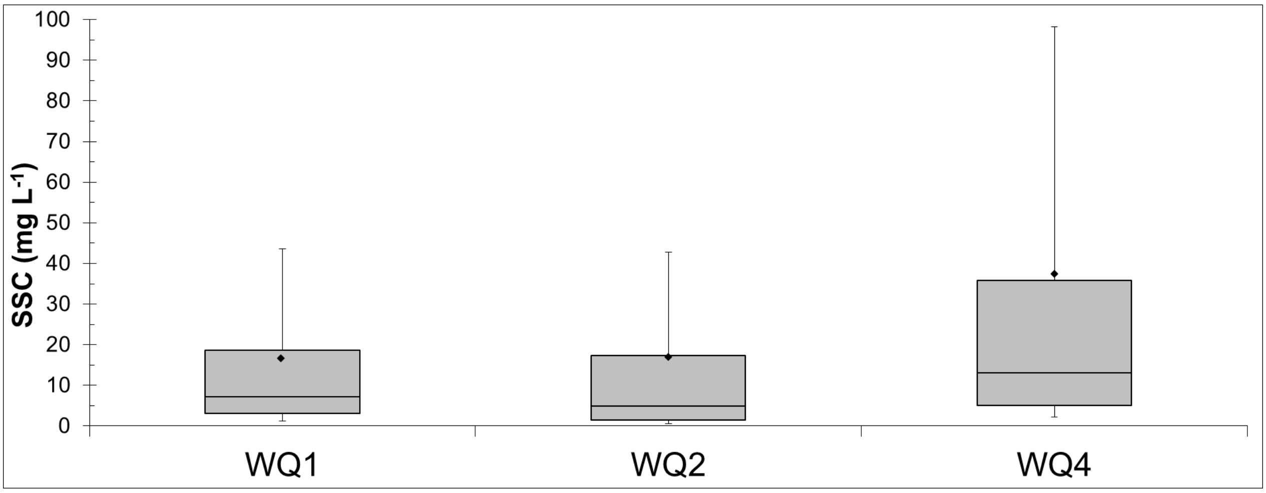


Figure 3.14 Box plot of SSC (mg L^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.4 Summary of SSC (mg L^{-1}) from July 2020 to July 2021.

Site	WQ1	WQ2	WQ4
Mean	16.753	17.005	37.413
median	7.268	4.842	13.146
min	0.000	0.000	0.000
lower quartile	3.034	1.465	5.125
upper quartile	18.634	17.300	35.844
max	299.830	481.793	817.047
90^{th} percentile	43.635	42.736	98.224
10^{th} percentile	1.281	0.545	2.140
n (recordings)	**30,231**	**36,240**	**36,916**
f (year obtained)**	**0.575**	**0.689**	**0.702**
St. Dev	26.128	34.024	68.870
St. Error	0.150	0.179	0.358

**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'.

3.3.3 Deposition

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

Considering mean, upper quartile, 90^{th} percentile and maximum values; Deposition rates were highest at WQ4 (Figure 3.15, Table 3.5) followed by WQ2 and then WQ1. However, considering Median values, deposition rates are the highest at WQ2 followed by WQ4 and then WQ1. The time-series data and monthly statistics (Appendix A1.2 and Appendix A1.3) indicates that the sites within the Embley River, WQ1 and WQ4, had the highest deposition rates during the dry seasons months (April to October), and site WQ2, outside the Embley River, had highest deposition rates during the wet season months (November to March).

Site WQ1, had higher deposition rates between July and September of 2020 (dry season period) and relatively lower and less variability of deposition rates for elsewhere throughout the 2020July-2021 July observation period. Whereas, WQ4, also within the Embley River, had notably higher deposition rates between September and November of 2020 (2020 dry season period), and also secondarily higher deposition rates in June of 2021 (during the 2021 dry season period). Outside of the Embley River, WQ2 has the highest and most variability of deposition rates between November of 2020 and march of 2021 (during the 2020-2021 Wet Season period), and also a secondary period of higher rates during the 2020 Dry season period between July and September of 2020.

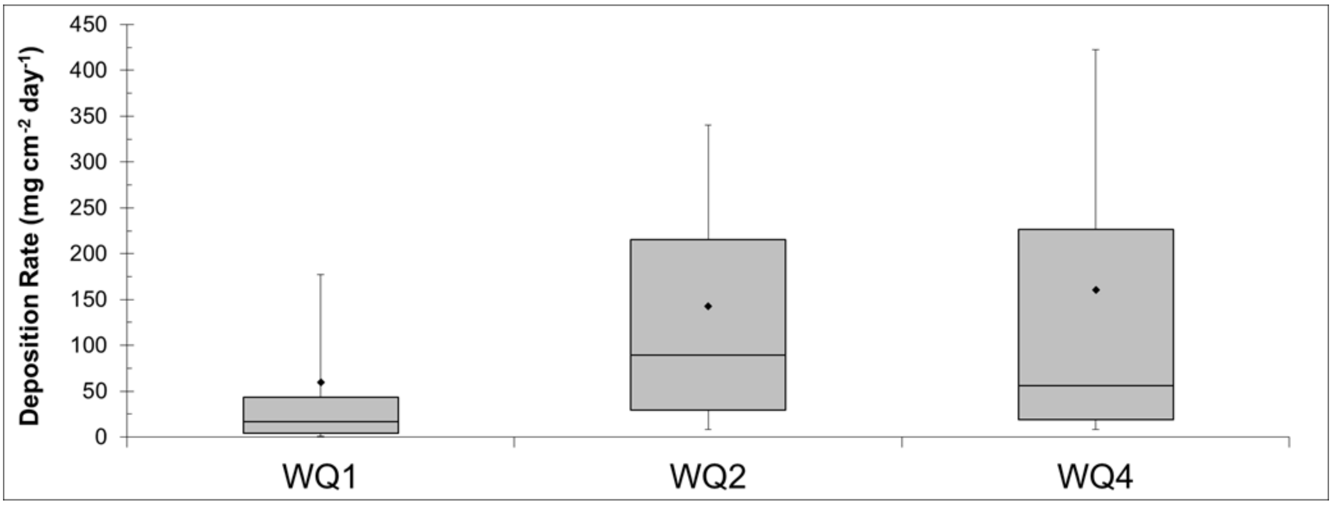


Figure 3.15 Box plot of deposition rates (mg cm^{-2} day^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.5 Summary of the mean daily deposition rate (mg cm^{-2} day^{-1}) statistics from July 2020 to July 2021.

Site	WQ1	WQ2	WQ4
Mean	59.679	142.840	160.469
median	16.612	89.466	56.216
min	0.074	0.000	0.000
lower quartile	3.962	29.481	18.740
upper quartile	43.739	215.029	226.858
max	756.283	907.954	1487.714
90th percentile	177.022	340.447	422.310
10th percentile	1.182	7.855	8.568
n(recordings)	**269**	**257**	**179**
f (year obtained)**	**0.737**	**0.704**	**0.490**
St. Dev	116.647	150.792	222.435
St. Error	7.112	9.406	16.626

**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'.

3.3.4 Water temperature

Water temperatures were relatively similar among all sites with median values of 28-29 °C, as well as, similar ranges and yearly-pattern of temperatures were experienced across the three sites (Figure 3.16, Table 3.6). Water temperatures were their highest in December-March, during the wet season period, and lowest in July-August, during the dry season period (Appendix A1.2 and Appendix A1.3).

It should be noted that water temperature is not considered to be a compliance condition for approval operations, however, the temperature data presented here holds importance in future interpretation of ecological processes in the region, and across the GBR (e.g. Johansen et al., 2015).

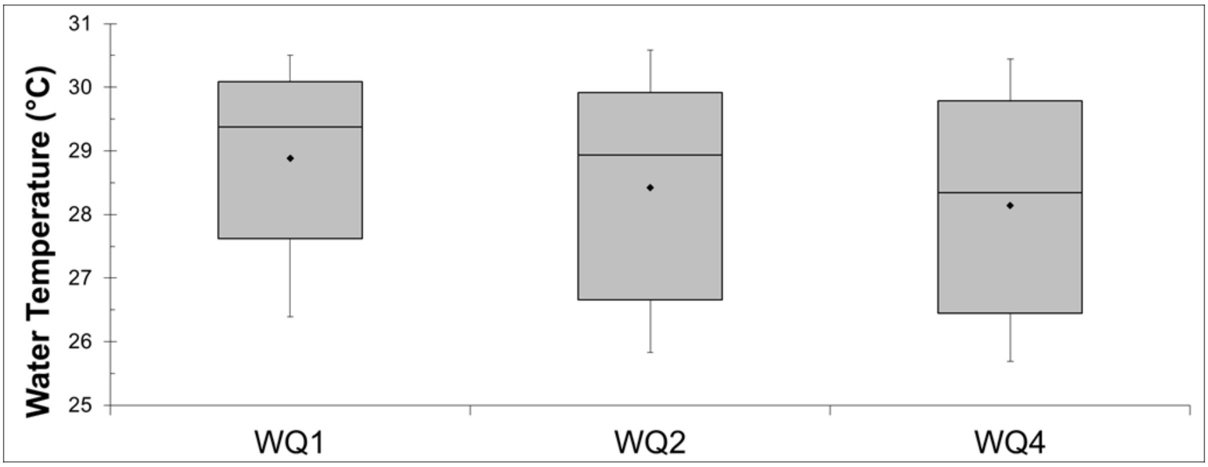


Figure 3.16 Box plot of the water temperature (°C) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.6 Summary of water temperature (°C) from July 2020 to July 2021.

Site	WQ1	WQ2	WQ4
Mean	28.881	28.422	28.141
median	29.380	28.930	28.340
min	25.640	22.860	24.390
lower quartile	27.620	26.660	26.450
upper quartile	30.090	29.920	29.790
max	32.020	32.120	31.770
90th percentile	30.500	30.580	30.440
10th percentile	26.390	25.830	25.690
n(recordings)	**43,505**	**52,173**	**43,492**
f (year obtained)**	**0.828**	**0.993**	**0.827**
St. Dev	1.502	1.813	1.817
St. Error	0.007	0.008	0.009

**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'.

3.3.5 Photosynthetically active radiation (PAR)

Mean levels of benthic photosynthetically active radiation (PAR) ranged from 1.01 to 2.57 *mol m⁻² day⁻¹* (Figure 3.17,

Table **3.7**). WQ2 had the highest median and variance in PAR. WQ4 had the lowest median and variance in PAR but also had PAR levels within the range observed at the other sites.

Across all three sites, WQ1 to WQ4, and across the entire year; PAR is at its highest between August and October of 2020 (Figure 3.18, Figure 3.19). WQ2 had the most variability throughout the year, whereas, both WQ1 and WQ4 had relatively lower and more consistent measurements outside of the August to October 2020 period of higher measurements (Appendix A1.2 and Appendix A1.3).

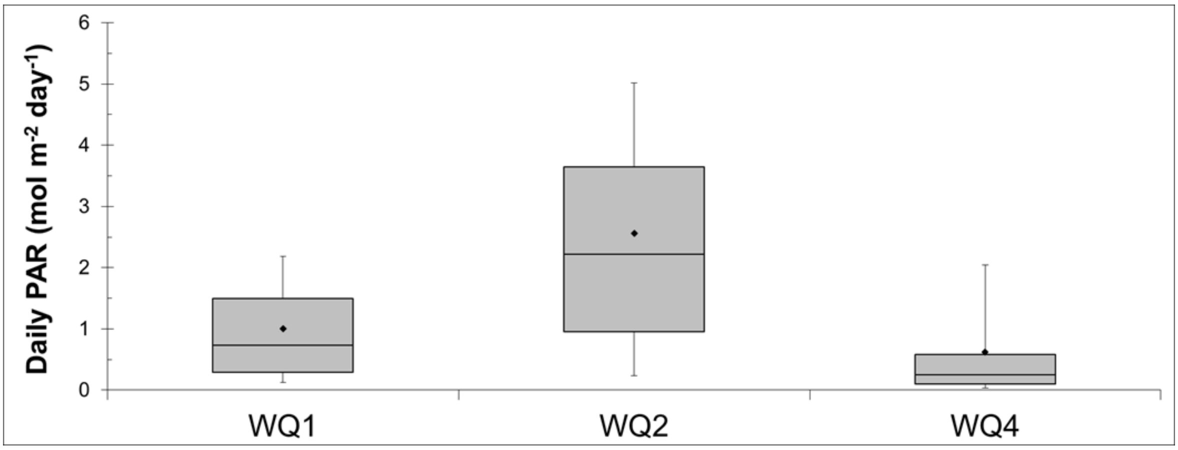


Figure 3.17 Box plot of daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value.

Table 3.7 Summary of daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021.

Site	WQ1	WQ2	WQ4
Mean	1.005	2.565	0.624
median	0.730	2.223	0.251
min	0.002	0.000	0.000
lower quartile	0.295	0.955	0.099
upper quartile	1.493	3.646	0.580
max	6.698	11.220	5.334
90th percentile	2.184	5.016	2.040
10th percentile	0.128	0.232	0.031
n(recordings)	**362**	**296**	**243**
f (year obtained)**	**0.992**	**0.811**	**0.666**
St. Dev	0.964	2.074	0.983
St. Error	0.051	0.121	0.063

**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'.

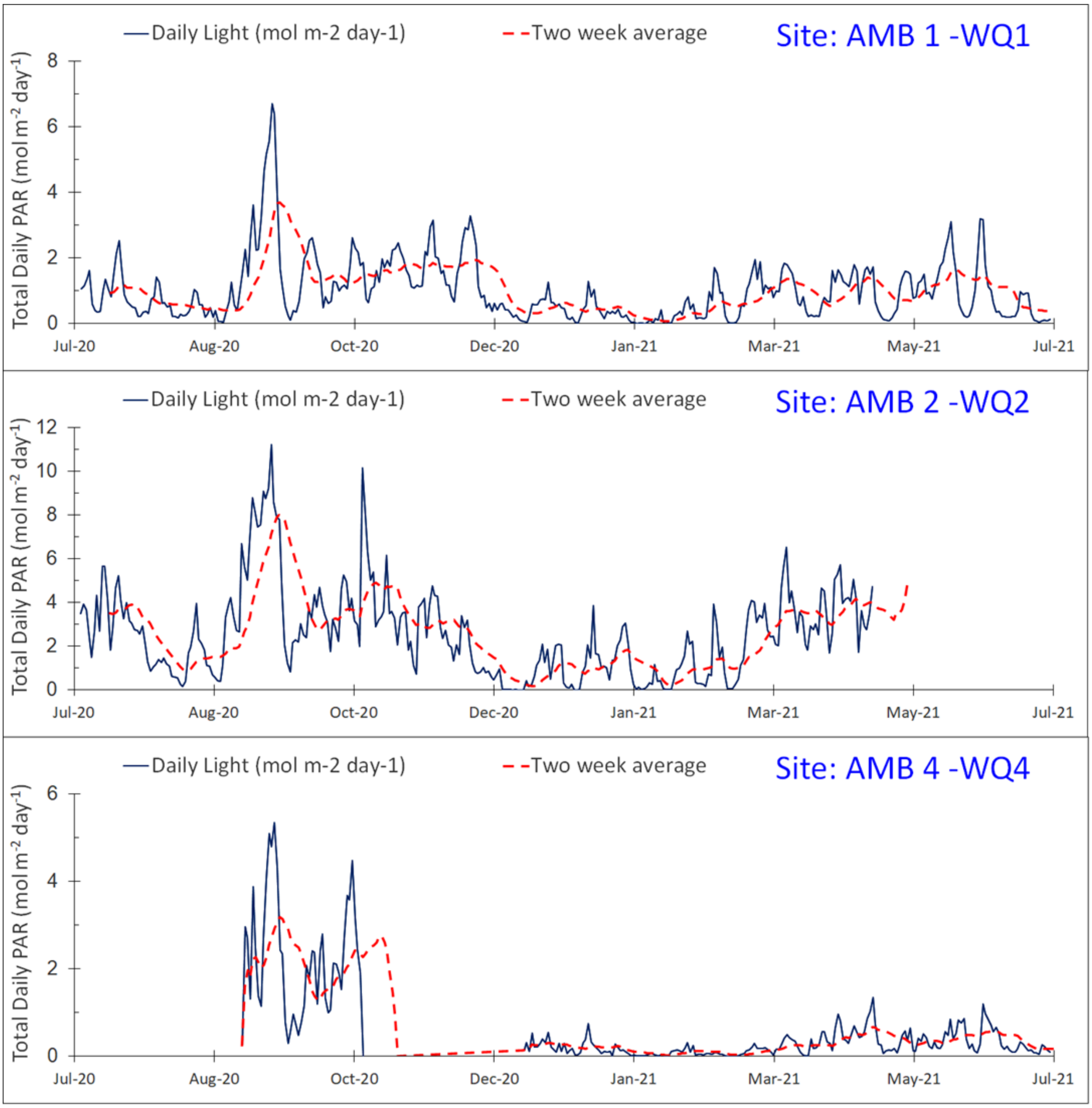


Figure 3.18 Time series of total daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. Daily mean PAR is plotted in blue and a 2-week moving average of daily mean PAR is plotted in red.

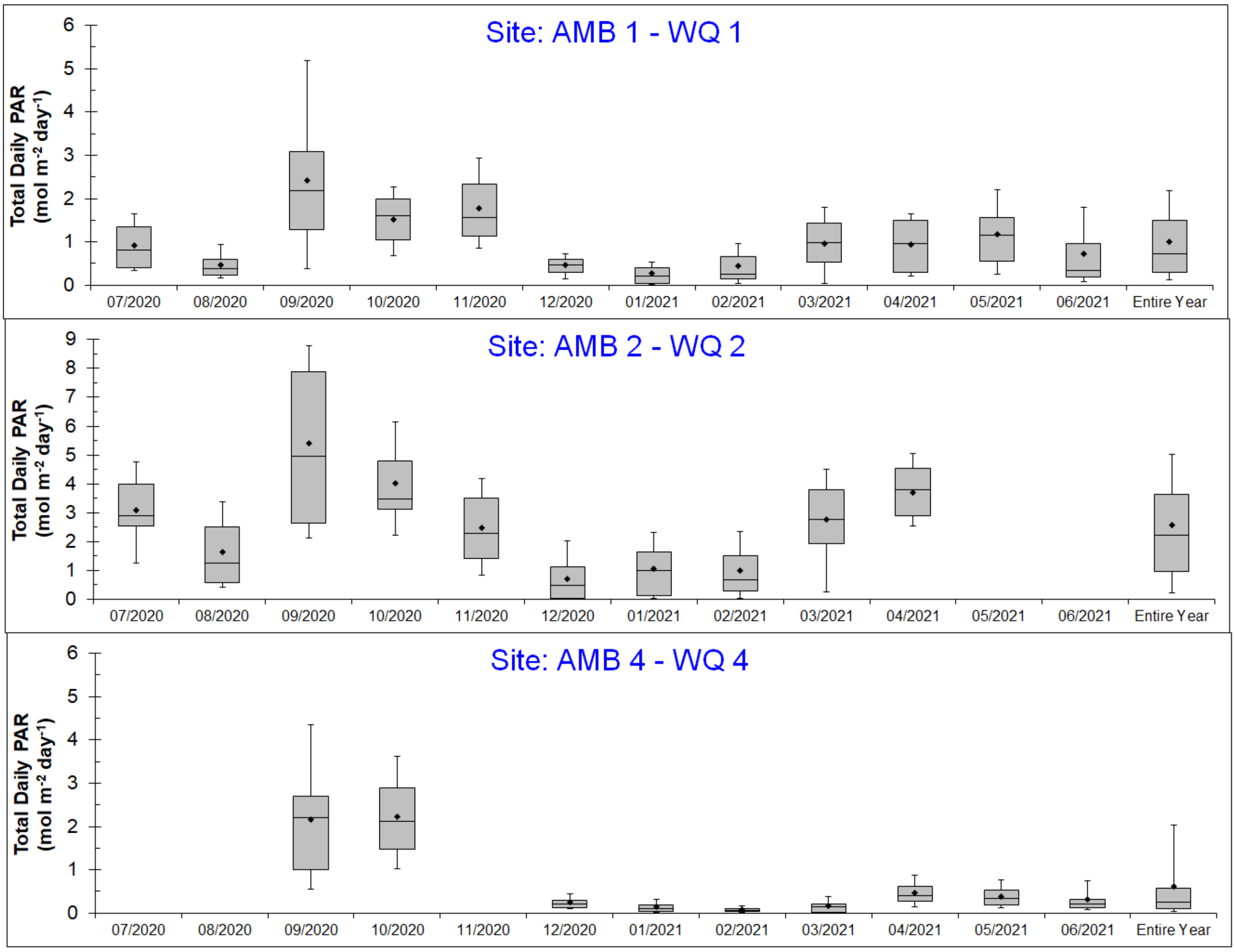
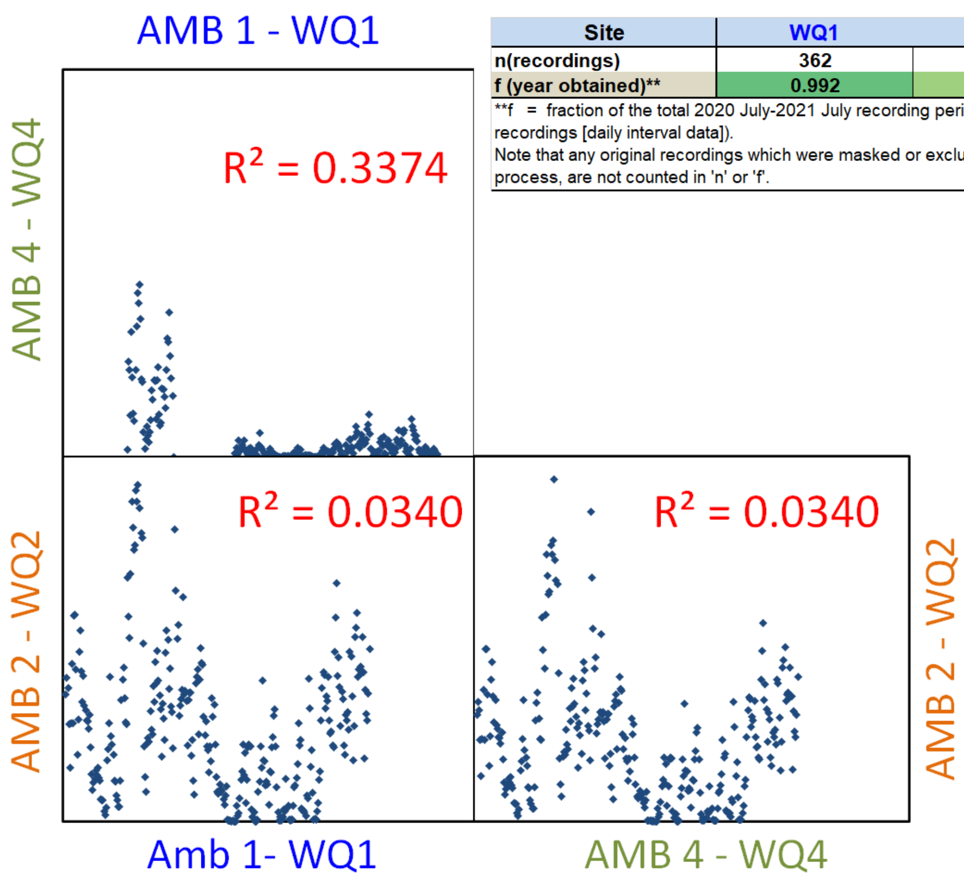


Figure 3.19 Monthly boxplots illustrating the variation in total daily PAR (mol m^{-2} day^{-1}) from July 2020 to July 2021. The lower whisker, lower edge of the box, central line, upper edge of the box and upper whisker represent the 10th, 25th, 50th, 75th and 90th percentiles, respectively. The diamond represents the mean value. Note for WQ2, the y-axis limit is double that of the other sites.

Similarities in patterns of PAR among sites

There were no significant relationships of benthic PAR found between the three sites (

Figure **3.20**), as no associations were found above R^2=0.34. It is interesting that the two plots of *WQ1 vs WQ2* and *WQ4 vs WQ2* are visually near identical and both have an equal R^2 value; the resulting plot and R^2 value (0.34) of *WQ1 vs WQ4* provides a strong indication that there is no significant relationship of PAR between the three sites altogether. On the contrary, this lack of relationship in PAR between the three sites highlights the influence of site-specific conditions (depth, turbidity, etc.) on benthic irradiance. This analysis assists in understanding site redundancy opportunities, without missing important detail in characterising water quality in the region.



Site	WQ1	WQ2	WQ4
n(recordings)	362	296	243
f (year obtained)**	0.992	0.811	0.666

**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'.

Figure 3.20 Scatterplots of PAR between sites indicating the strength of the relationships between patterns of daily PAR for July 2020 to July 2021. R^2 values are presented for each comparison.

3.3.6 Seasonal variation: wet vs dry seasons

A comparison of wet season (1 November – 31 March) and dry season (1 April – 31 October) water quality, 2017-2021, suggests that the wet season periods coincide with increased RMS (page 42), increased suspended sediments (SSC, page 43), increased water temperatures (page 46) and decreased benthic irradiance (PAR, page 45). And as for sediment deposition, page 44, no clear seasonal pattern is observed when making a comparison between all Weipa sites together. As noted on Table 1.1, page 12, the Weipa site of WQ3 was decommissioned at the end of September 2020, and although the final deployment should have obtained recordings that are inclusively part of this reporting period (July 2020 – September 2020); the instrument experienced a battery failure and hence, no data was obtained from the deployed instrument. However, for the interest of making a historical comparison between all Weipa sites together (WQ1 to WQ4); all available past deployment data (2017-2020) has been applied throughout this section for Weipa site WQ3 along with current and historical for Weipa sites WQ1, WQ2 and WQ4.

Note: Supplementary table added below about maximum (and also general) seasonal data coverage across all sites, in case further details are useful in a later draft of this report.

Related year	Wet Season		Dry Season	
	START	END	Start	END
2017	19/01/2018	31/03/2018	N/A	N/A
2018	1/11/2018	31/03/2019	1/04/2018	31/10/2018
2019	1/11/2019	31/03/2020	1/04/2019	31/10/2019
2020	1/11/2020	31/03/2021	1/04/2020	31/10/2020
2021	N/A	N/A	1/04/2021	30/06/2021

Note: as mentioned, WQ3 only has data up to 2020.

RMS water height

Median, mean and upper quartile values were higher during the wet season periods across all sites compared to the dry season periods (Figure 3.21). And notably, the expanded upper quartiles of the Wet Season bars indicate that periods of higher RMS were more frequent during the Wet Season.

In general, there was not a substantial difference in RMS between the current year 2020-2021 data and the cumulative 2017-2021 seasonal data, except for, site WQ4 which (indicatively) had notably lower RMS values throughout the 2020-2021 Wet Season compared to the cumulative 2017-2020 Wet Season data.

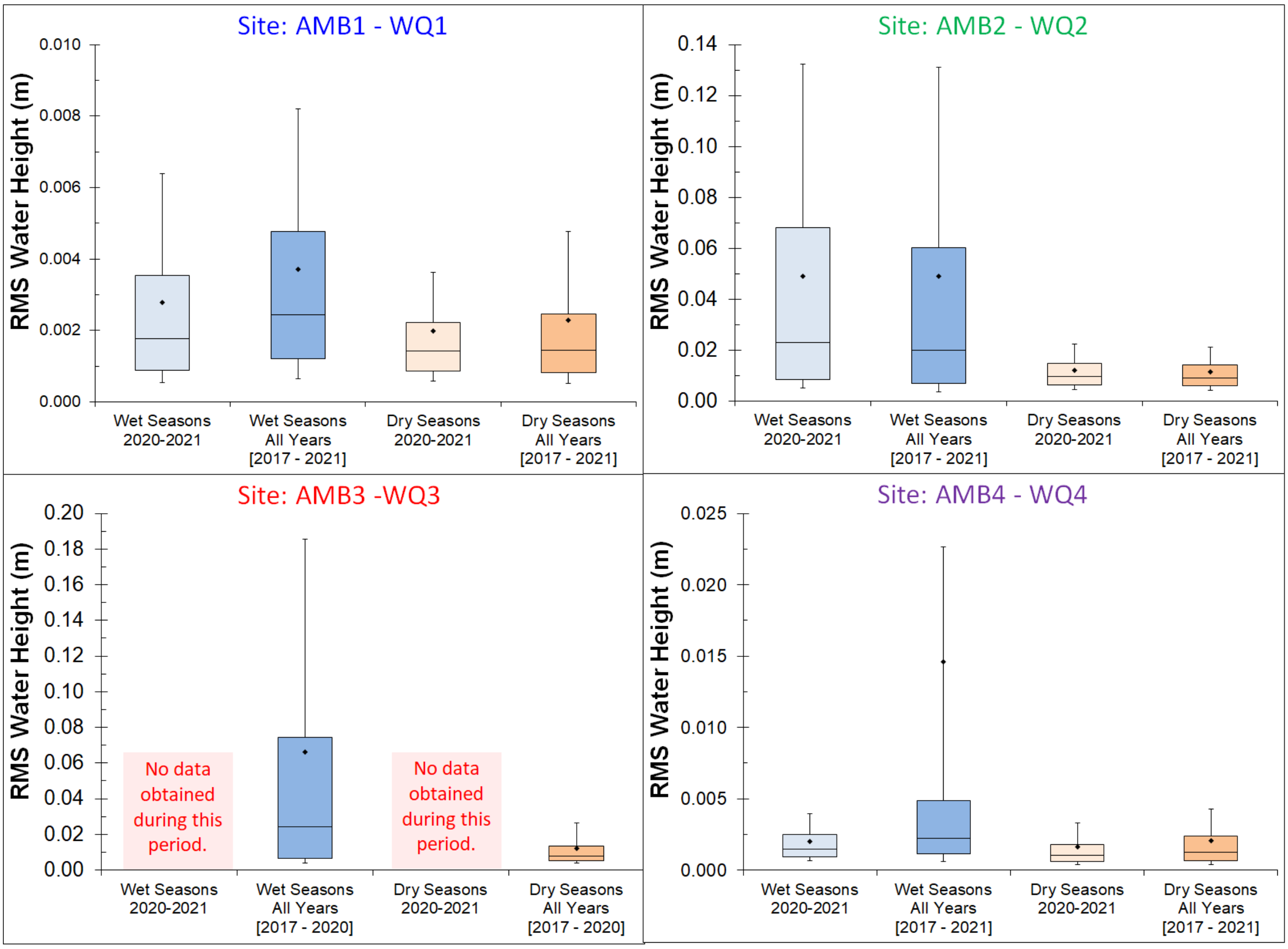


Figure 3.21 RMS box plots for WQ1-WQ4. Blue boxes represent data that is within the Wet Season period (1 November-31 March) while orange boxes represent data that is within the Dry Season period (1 April-31 October). In addition, a comparison is made between this year's observational period (2020 July -2021 July) and all available historical data (collectively, 2017-2021).

NTUe/SSC

Differences in suspended sediment concentration (SSC) between the seasons are less straightforward than for RMS. In general, for all Weipa sites, the values of median, mean and upper quartile are higher during the wet season period; indicating that extreme turbidity events were more frequent in comparison to the dry season periods (Figure 3.21). However, for site WQ1, long-term and historical data (2017-2021) indicates that the range of SSC measurements experienced between the Wet and Dry Season periods are typically not too dissimilar. From what can be observed within the 2020-2021 timeseries data and Monthly summary statistics (Appendix A1.2 and Appendix A1.3), WQ1 experienced extreme turbidity events during its 2020 dry season period that are comparable with its 2020-2021 wet season period measurements. Unlike for sites WQ2 and WQ4, which overall experienced measurements during the dry season that are relatively mild compared to their wet season period measurements.

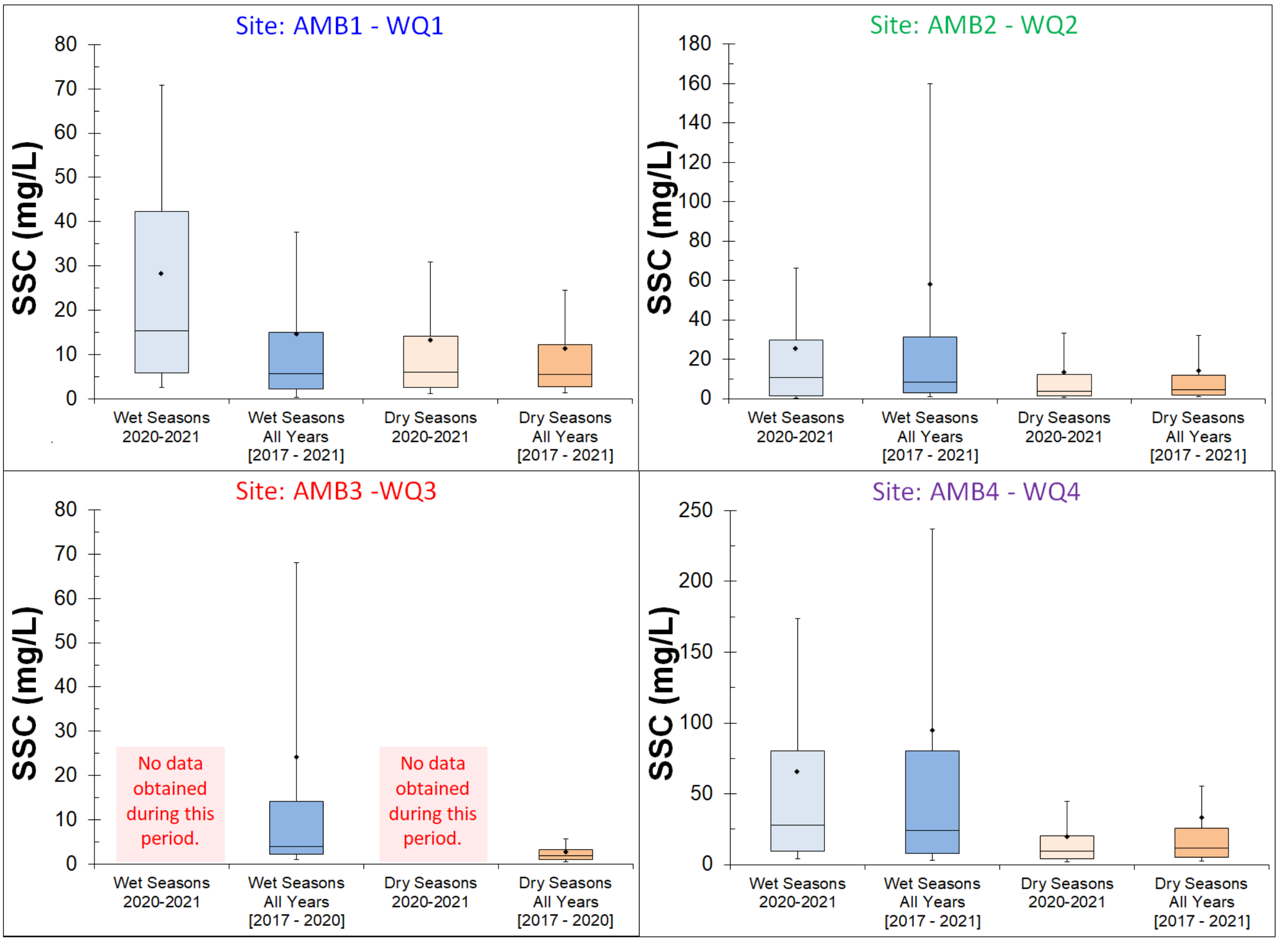


Figure 3.22 SSC box plots for WQ1-WQ4. Blue boxes represent data that is within the Wet Season period (1 November-31 March) while orange boxes represent data that is within the Dry Season period (1 April-31 October). In addition, a comparison is made between this year's observational period (2020 July -2021 July) and all available historical data (collectively, 2017-2021).

Deposition

For sites WQ1 and WQ4 that are located within the Embley River; the median, mean and upper quartile values of deposition rates were notably lower during the wet season compared to the dry season (Figure 3.23). In particular, WQ4 had notably increased variability of deposition rates during this year's dry season period compared to past year dry seasons, whereas, on the other hand, located outside of the Embley River; WQ2 had median, mean and upper quartile values of deposition rates which were exceedingly higher during the wet season for this year compared to the past wet seasons, as well as, current and past dry seasons. Although site WQ3, located outside the Embley River (on the coast at Pera Heads), is lacking present year data; historical data (2017-2020) for this site displays that higher deposition rates are typically experienced during the dry season further down the coast from the Embley River.

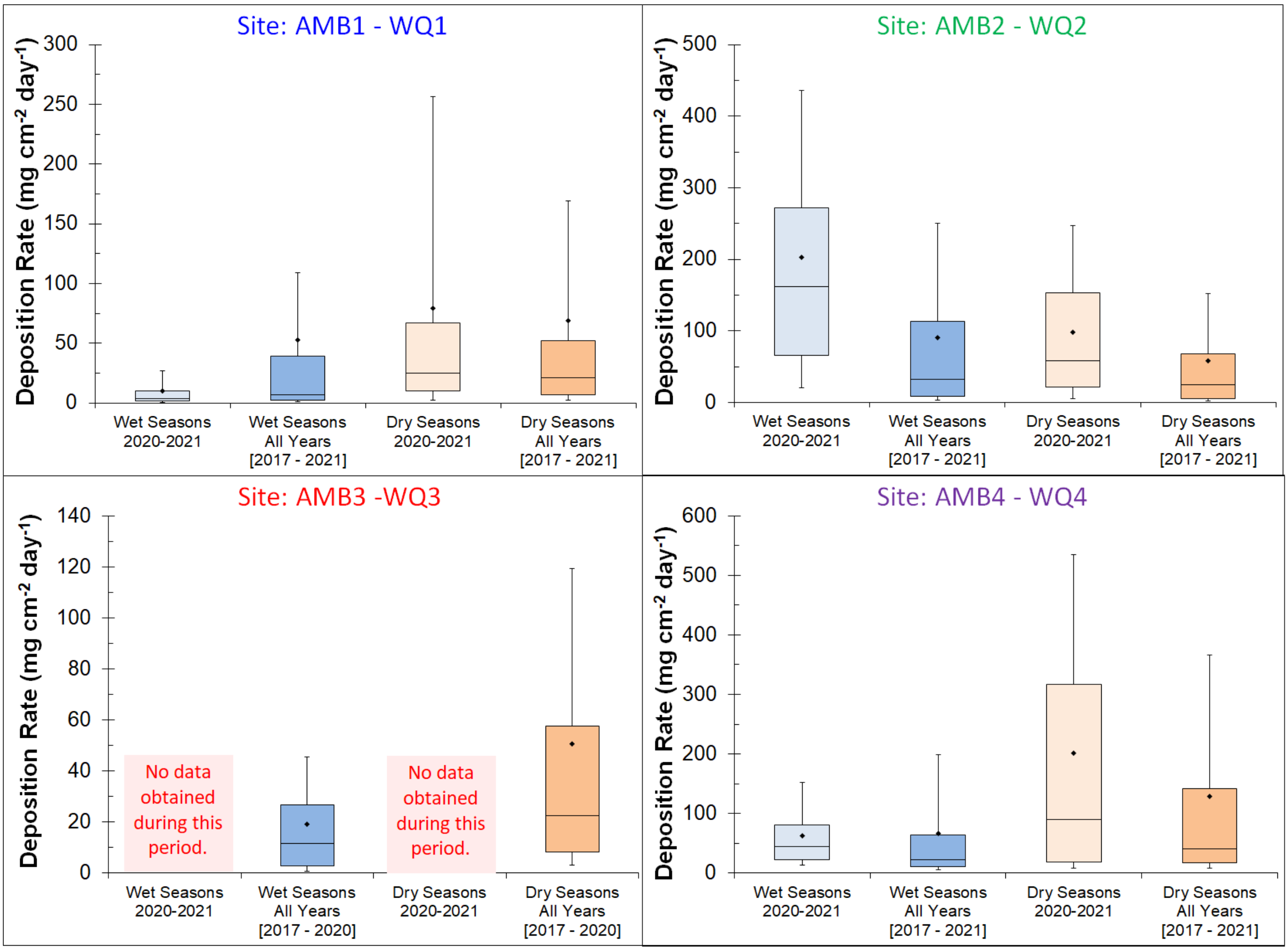


Figure 3.23 Deposition box plots for WQ1-WQ4. Blue boxes represent data that is within the Wet Season period (1 November-31 March) while orange boxes represent data that is within the Dry Season period (1 April-31 October). In addition, a comparison is made between this year's observational period (2020 July -2021 July) and all available historical data (collectively, 2017-2021).

Photosynthetically active radiation

In general, it is expected that Photosynthetically Active Radiation (PAR) could differ between seasons due to longer day length or increased cloud cover during the wet season. As displayed in Figure 3.24, PAR overall measured lower during this reporting period (2020 -2021) compared to all past years cumulatively (2017-2021) for both the Wet and Dry Seasons, and measured lower during the Wet season compared to the dry season.

Notably, sites WQ1 and WQ4 had upper quartile values that were almost lower for this year's wet season compared to the median values of the cumulative 2017-2021 Wet season data. This could suggest higher SSC and/or higher deposited sediment (November 2020 – March 2021; Appendix A1.2 and Appendix A1.3) or otherwise increased cloud coverage resulting in reduced benthic PAR during this year's wet season period.

However, it should also be noted that differences in water height (tides), distance from the coast, and distance from river mouths may also influence how PAR differs between seasons at a given location and time.

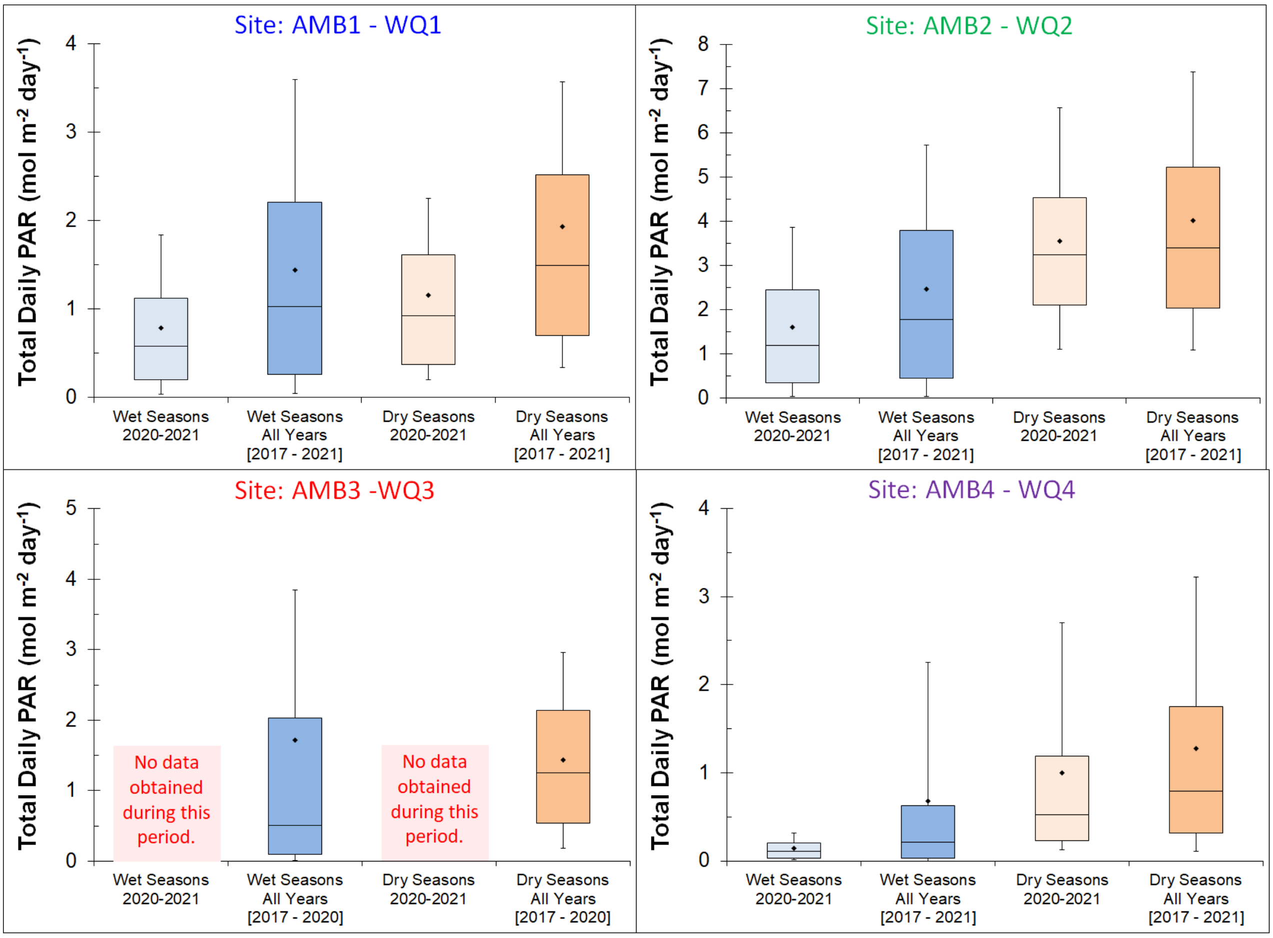


Figure 3.24 Total Daily PAR box plots for WQ1-WQ4. Blue boxes represent data that is within the Wet Season period (1 November-31 March) while orange boxes represent data that is within the Dry Season period (1 April-31 October). In addition, a comparison is made between this year's observational period (2020 July -2021 July) and all available historical data (collectively, 2017-2021).

Water temperature

Temperatures were expectedly higher during the wet season, with mean and median values at ~30.0°C for this year and ranging ~29.0-30.0°C for the 2017-2021 years data combined (including WQ3). And lower during the dry season, with mean and median values ranging 26.5-28.0°C for this year and ranging 26.5-27.0°C for the 2017-2021 years data combined (including WQ3).

Across all Weipa sites, with the exception of WQ3 (no 2020-2021 data); there is notable closeness of mean and median water temperatures between the 2020-2021 Wet Season data and the combined 2017-2021 Wet Season Data. As for the Dry season periods of this year, site WQ1 has increased mean and median water temperatures of ~0.7-0.8°C compared to the combined years, dry season data (2017-2021). WQ2 has a slighter increase of mean and median temperatures that is lesser than WQ1, whereas for site WQ4; the water temperature change between the 2020-2021 and combined 2017-2021 dry season data is further subtle.

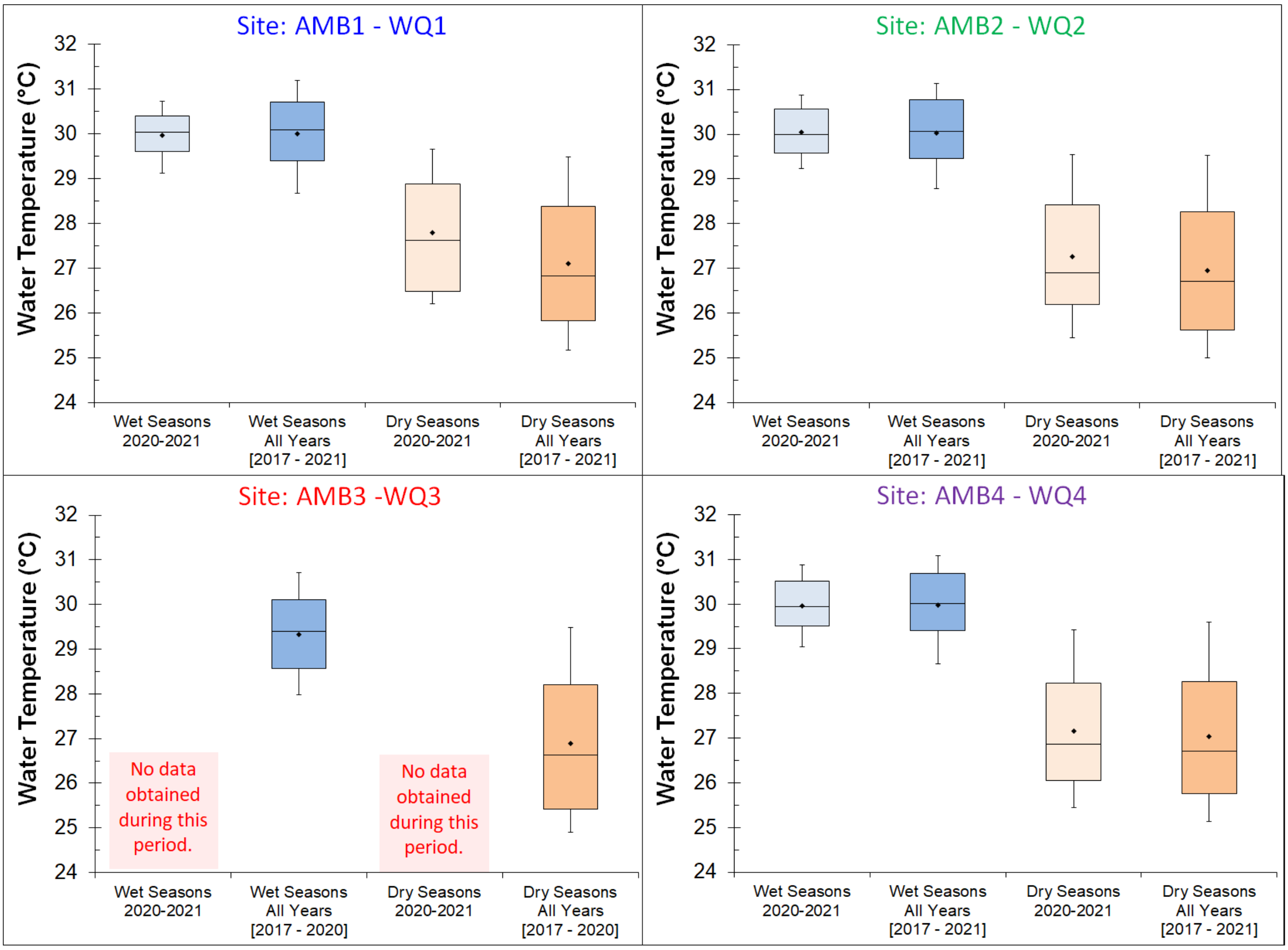


Figure 3.25 Water Temperature box plots for WQ1-WQ4. Blue boxes represent data that is within the Wet Season period (1 November-31 March) while orange boxes represent data that is within the Dry Season period (1 April-31 October). In addition, a comparison is made between this year's observational period (2020 July -2021 July) and all available historical data (collectively, 2017-2021).

3.4 Marotte HS current meter instruments

Marotte HS current meter instruments were deployed throughout the monitoring period of July 2020 to July 2021, for Weipa sites AMB 1-4. However, following September 2020, current meter instruments were temporarily decommissioned for usage in Weipa deployments and then later re-applied for ongoing deployments from February 2020 and onwards; except for sites AMB3 which were entirely decommissioned for deployments beyond September 2020 as per other sections of this report.

With the exception of the time period between September 2020 and February 2021 (where we continually had problems with the marotte units, either flooding of the instruments through leakages or the units were missing because of fouling and units breaking free), data is available throughout the (remaining) monitoring period between July 2020 to July 2021 for AMB1, AMB2 and AMB4. 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 (ºC) at each Weipa Site. In addition, the current meter data is presented separately for recordings that are obtained during the Dry Season period and the Wet season period.

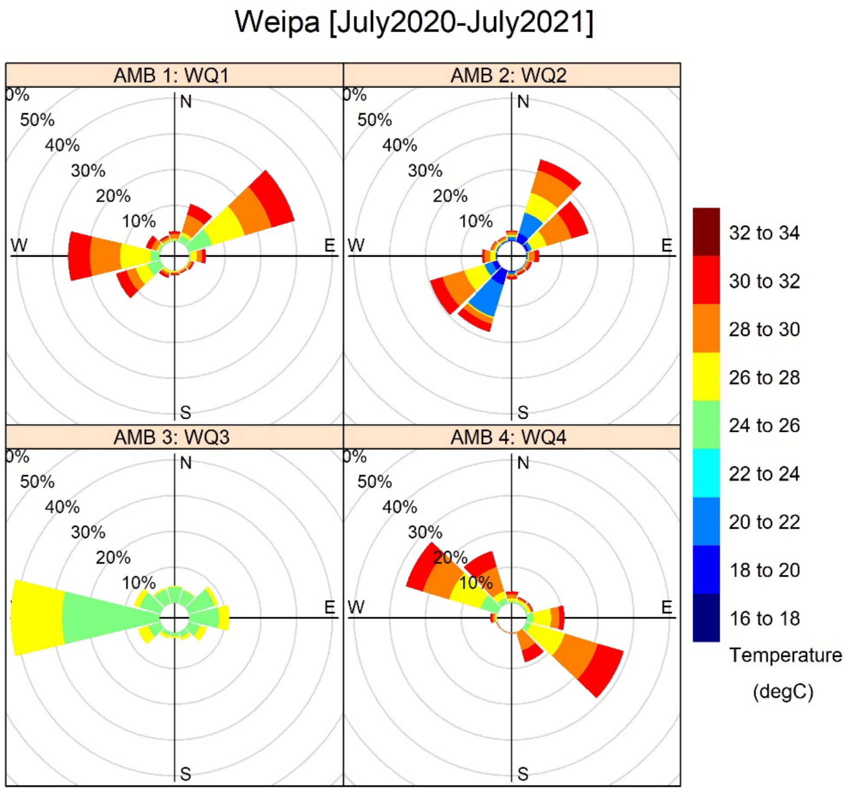


Figure 3.26 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction(heading), for each of the four sites over the monitoring period July 2020 to July 2021.

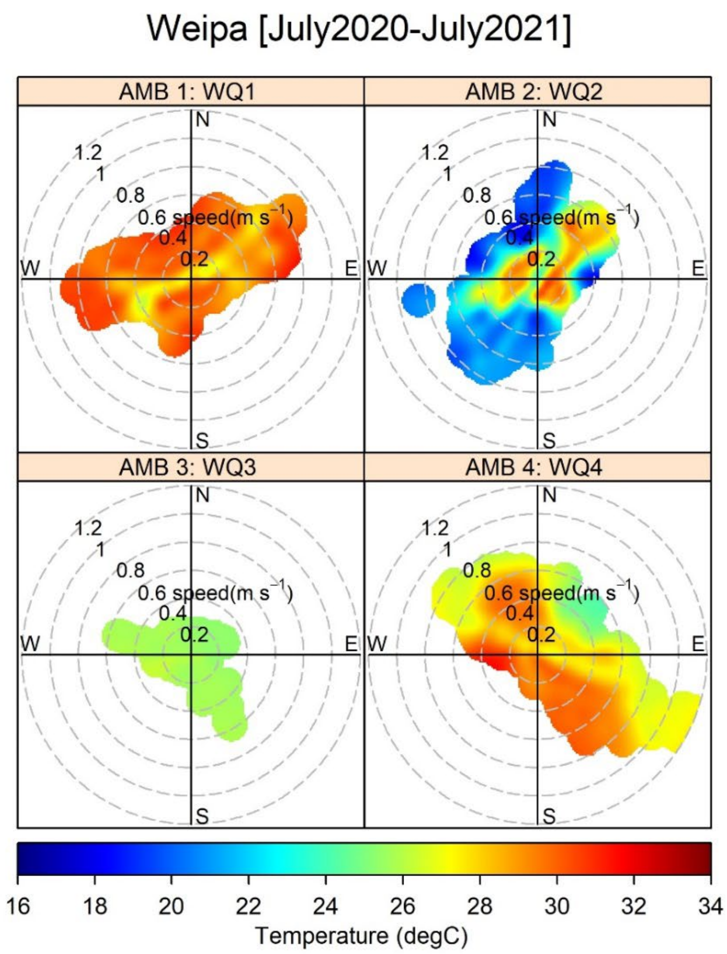


Figure 3.27 For each of the four Weipa sites and covering the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). The position of the data, within 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).

3.4.1 Dry Season (April – October)

Concerning current meter data that was collected during months of the dry season period (April-October), the three figures below and on the next page present and summarise this data.

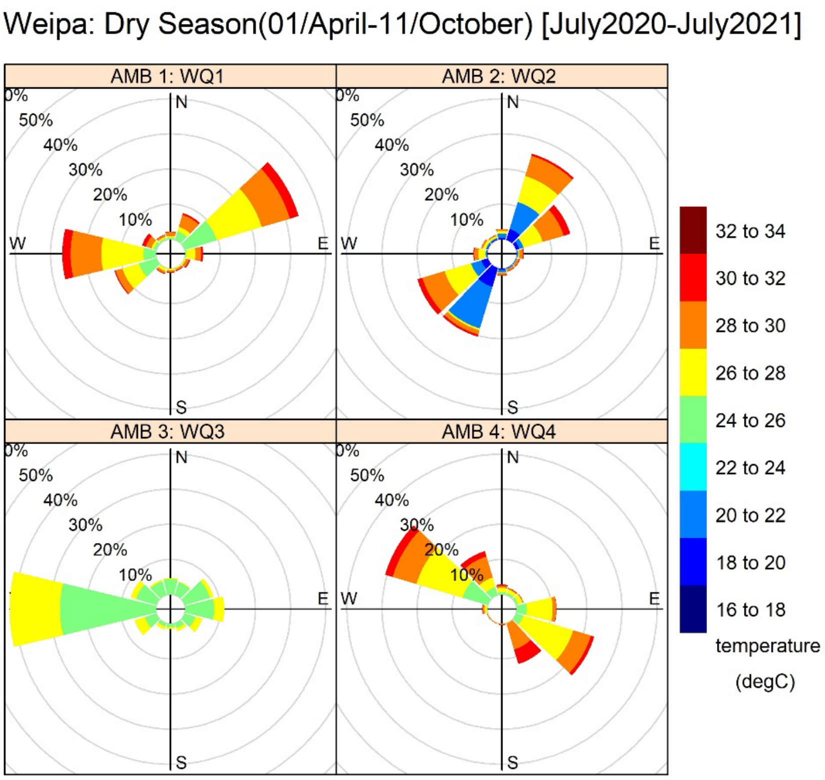


Figure 3.28 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction(heading), for each of the four sites during the dry season months (April-October) across the monitoring period July 2020 to July 2021

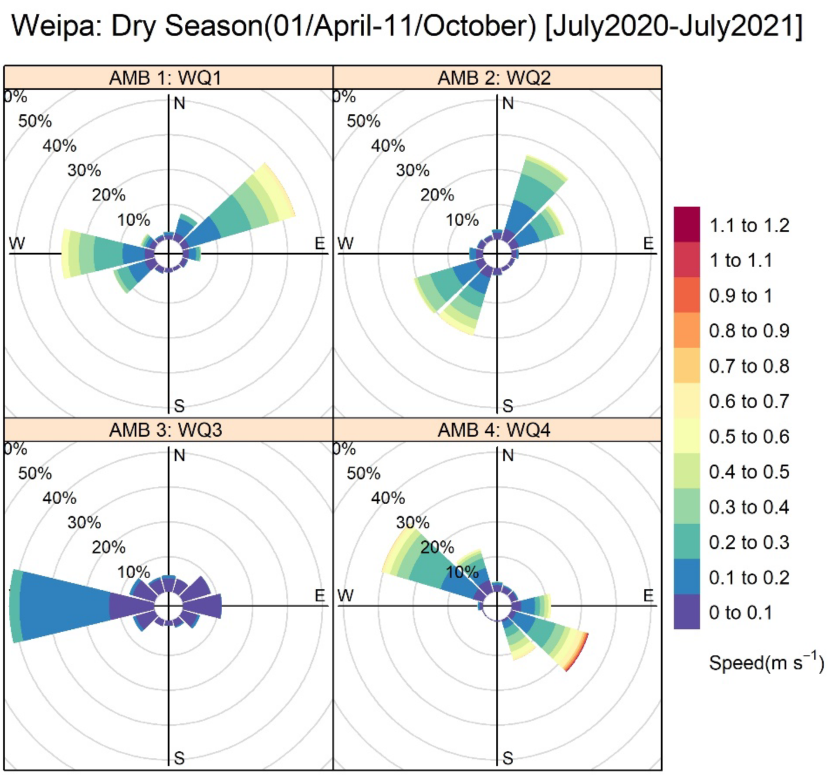


Figure 3.29 Rose-plots displaying the frequency of recorded current speed (m/s) with respect to current direction (heading), for each of the four sites during the dry season months (April-October) across the monitoring period July 2019 to July 2020

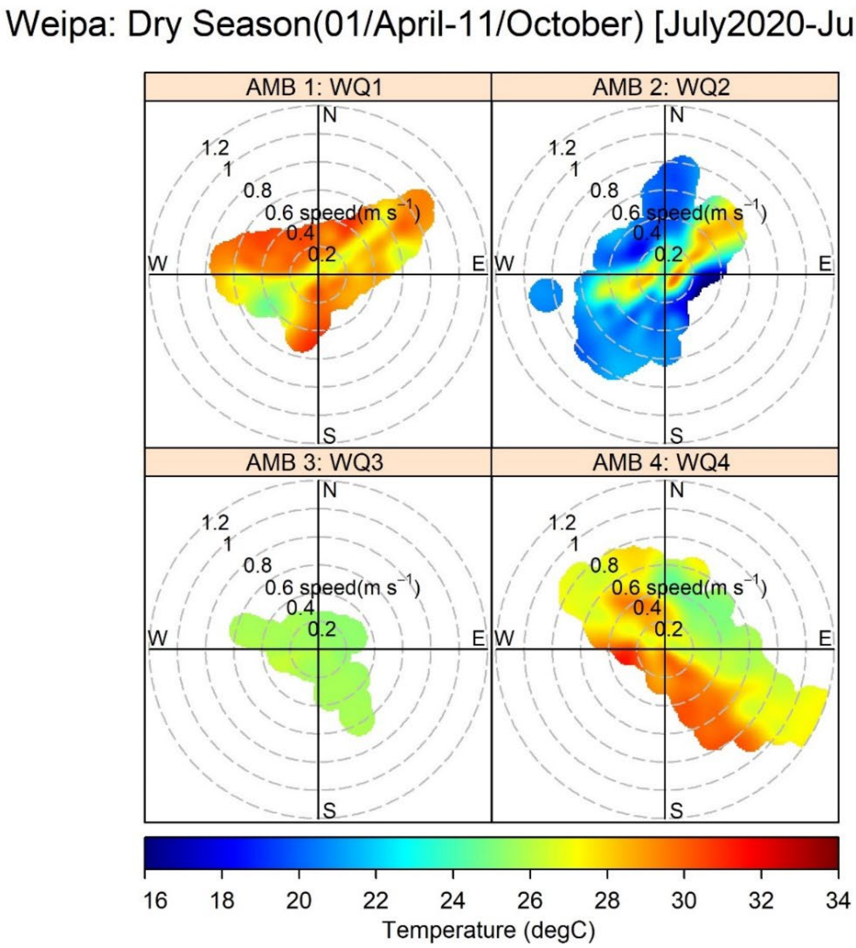


Figure 3.30 For each of the four Weipa sites during the dry season months (April-October) across the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). 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).

3.4.2 Wet season (November-March)

Concerning current meter data that was collected during months of the wet season period (November-March), the three figures below and on the next page present and summarise the data (Figure 3.31) and (Figure 3.32).

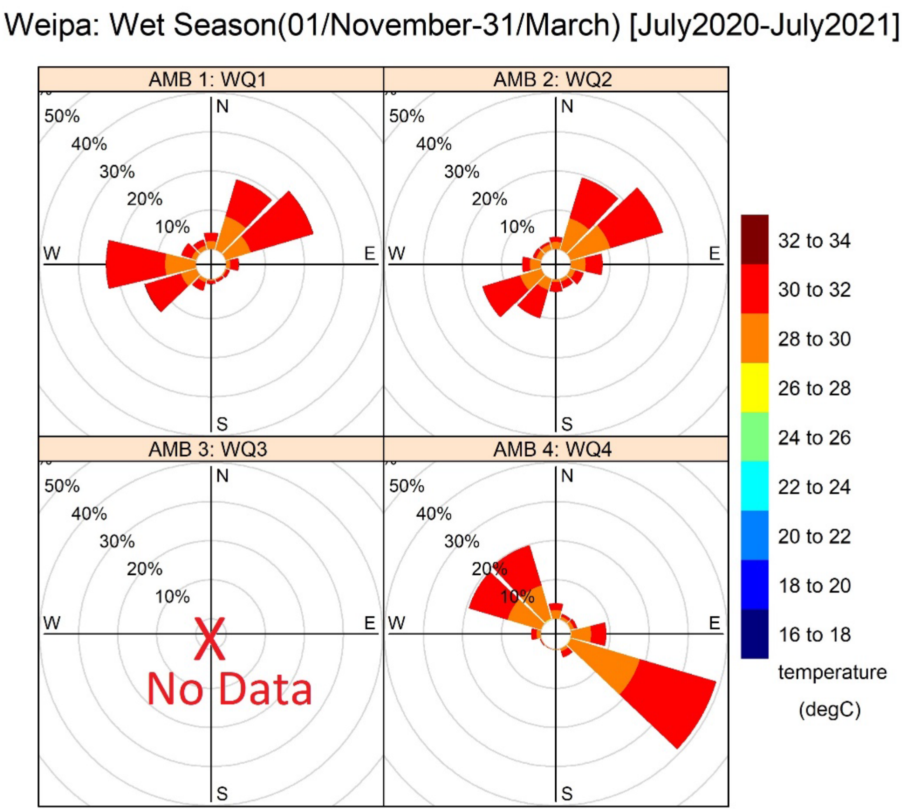


Figure 3.31 Rose-plots displaying the frequency of recorded water temperatures (°C) with respect to current direction (heading), for each of the four Weipa sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021

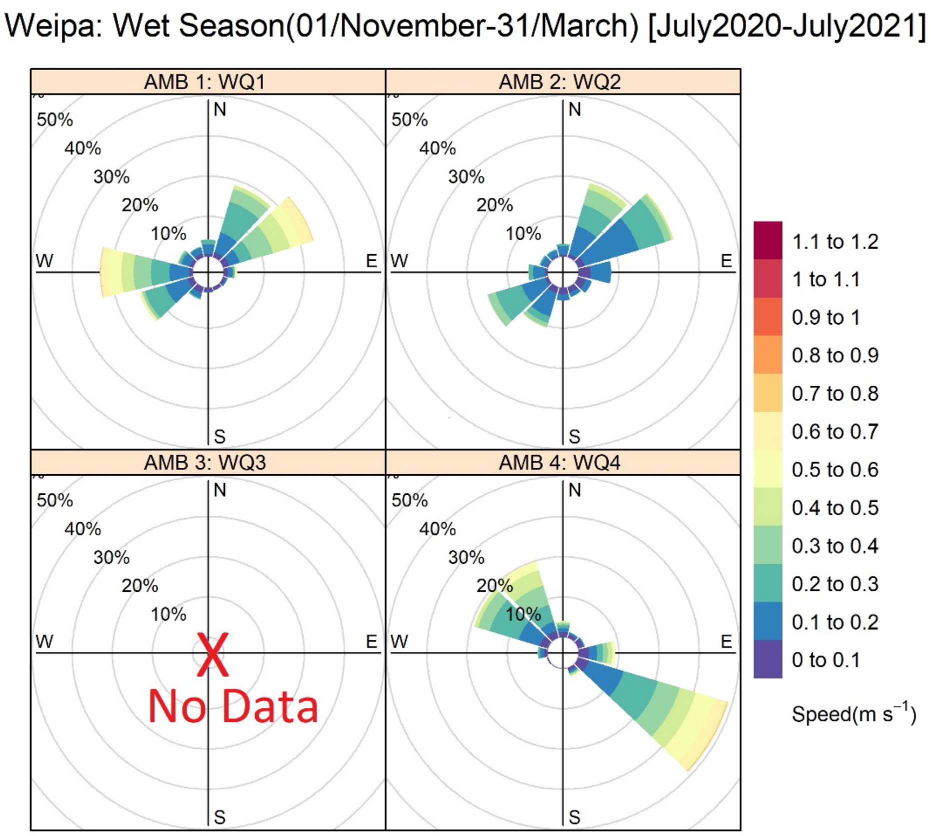


Figure 3.32 Rose-plots displaying the frequency of recorded current speed (m/s) with respect to current direction (heading), for each of the four Weipa sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021.

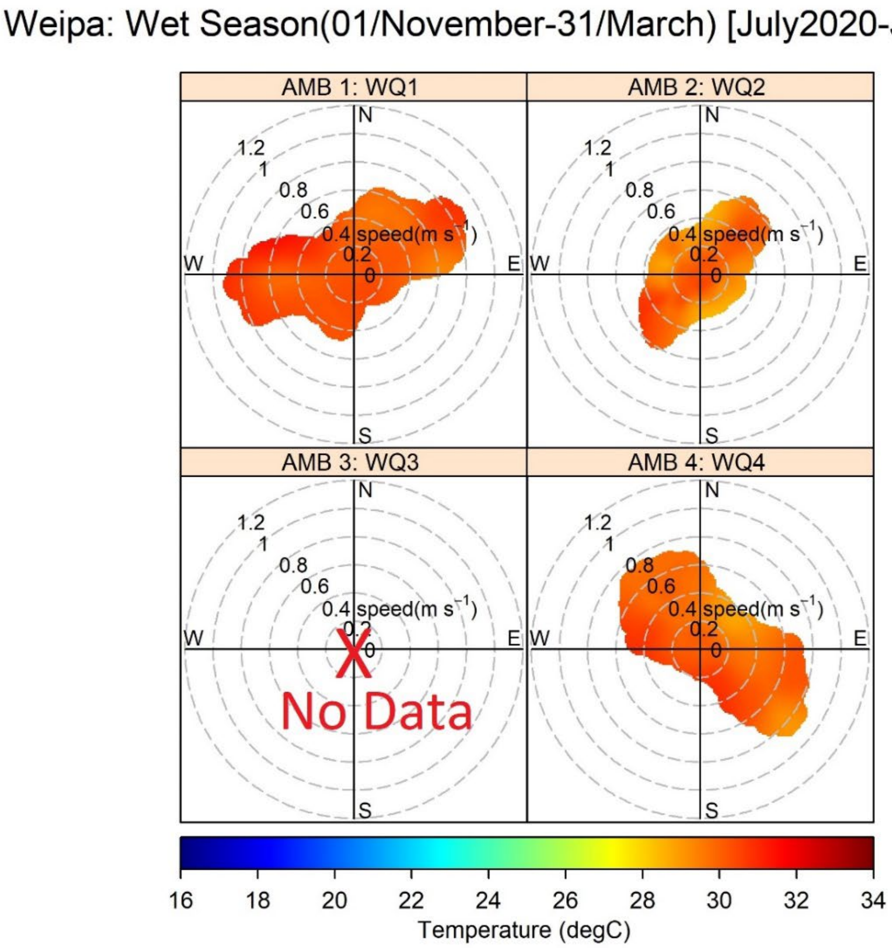


Figure 3.33 For each of the four Weipa sites during the wet season months (November-March) across the monitoring period July 2020 to July 2021, bivariate plots displaying average values for recorded water temperature (°C) that are calculated with respect to current speed (m/s) and current direction (heading). 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 2020-2021 wet season was much lower when compared to the previous year monitoring (2019-2020 wet season was in the order of the 80th percentile for rainfall in the region). This is an important factor to consider when interpreting data during this monitoring period. Comparison of these data with future years will be important to characterise ambient water quality conditions. It is important to capture monitoring data over a range of climatic conditions, which continues to be a key conclusion reported as part of this monitoring program.

4.1.2 Ambient water quality

1. There continues to be a seasonal pattern for water temperature emerging, with highest water temperatures experienced during summer months, while winter months experience cooler conditions. This pattern follows previous years, but also other port programs along the east coast of Queensland that are monitoring under this monitoring program more broadly.
2. The water column is well mixed, with depth profiles for dissolved oxygen, temperature, electrical conductivity and pH showing only minor gradients of change, a pattern that continues to be observed at all sites. This well mixing is particularly important when considering dissolved oxygen concentrations, which is known to reach critical levels for fish in coastal waters elsewhere in Queensland.
3. Particulate nitrogen (PN) and phosphorus (PP) concentrations exceed guideline values during all surveys and at all sites. This pattern continues and requires further discussion with relevant authorities to address the source of nutrient supply or, indeed, whether there is a need for local guidelines.
4. Chlorophyll-*a* concentrations exceed guideline values during all surveys and at all sites.
5. Trace metals were generally well below guideline values throughout the reporting year, similar to previous years, which suggests that their likely a low risk of contamination in the region, which does require some caution given the limited spatial and temporal monitoring as part of this program.

4.1.3 Sediment deposition and turbidity

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.
2. Sediment deposition rates around Weipa seem slightly higher than measured in previous years, which only reflects certain periods of the data (during the wet season). This result could be a response to the wet season rainfall distribution, compared to previous years, where in the current reporting period there were three rainfall events above 100mm in a day, which could be very different to previous years (acknowledging that the total wet season rainfall was within the 75% percentile of long term records). As the data set here continues to increase, assessment of the rainfall patterns (frequency and duration) can be examined, providing more detailed insight into the rainfall and water quality relationships in this port area.

4.1.4 Photosynthetically active radiation (PAR)

1. Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and lower tidal flows. Larger episodic events which lead to extended periods of low light conditions are driven by a combination of strong winds leading to increases in wave height and resuspension of particles, and rainfall events resulting from storms leading to increased catchment flows and an input of suspended solids (Fabricius et al., 2013).

2. Patterns of light were similar among all the coastal sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter (Kirk 1985; Davis-Colley and Smith 2001). Therefore variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality. Generally, however, shallow inshore sites reached higher levels of benthic PAR and were more variable than deeper water coastal sites and sites of closer proximity to one another were more similar than distant sites.
3. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations (Erftemeijer and Lewis 2006; Erftemeijer et al., 2012), the relationship between these two parameters is not always strong (Sofonia and Unsworth 2010). At many of the sites where both turbidity and benthic light were measured, the concentration of suspended solids in the water column explained less than half of the variation in PAR. As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.

4.2 Recommendations

This monitoring program has been underway for four years (2017 to present) and should remain in place to continue to characterise and build a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities, but will also assist with future strategic planning and management. For example, while the total wet season rainfall during the current program was within the 75% percentile of long term records, the distribution of rainfall during the season becomes important and future assessment of these patterns should be made within sufficient data and confidence.

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A1 APPENDIX

A1.1 Calibration procedures

A1.1.1 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 (2000) and Thomas et al (2003). Instruments are calibrated every six months or after every deployment. Sediment samples are taken at each deployment site and used to determine sediment calibration coefficients used to account for variations in grain size and shape that can alter the implied SSC value.

A1.1.2 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 r2 value equal to or greater than 0.9.

A1.1.3 Light Calibration

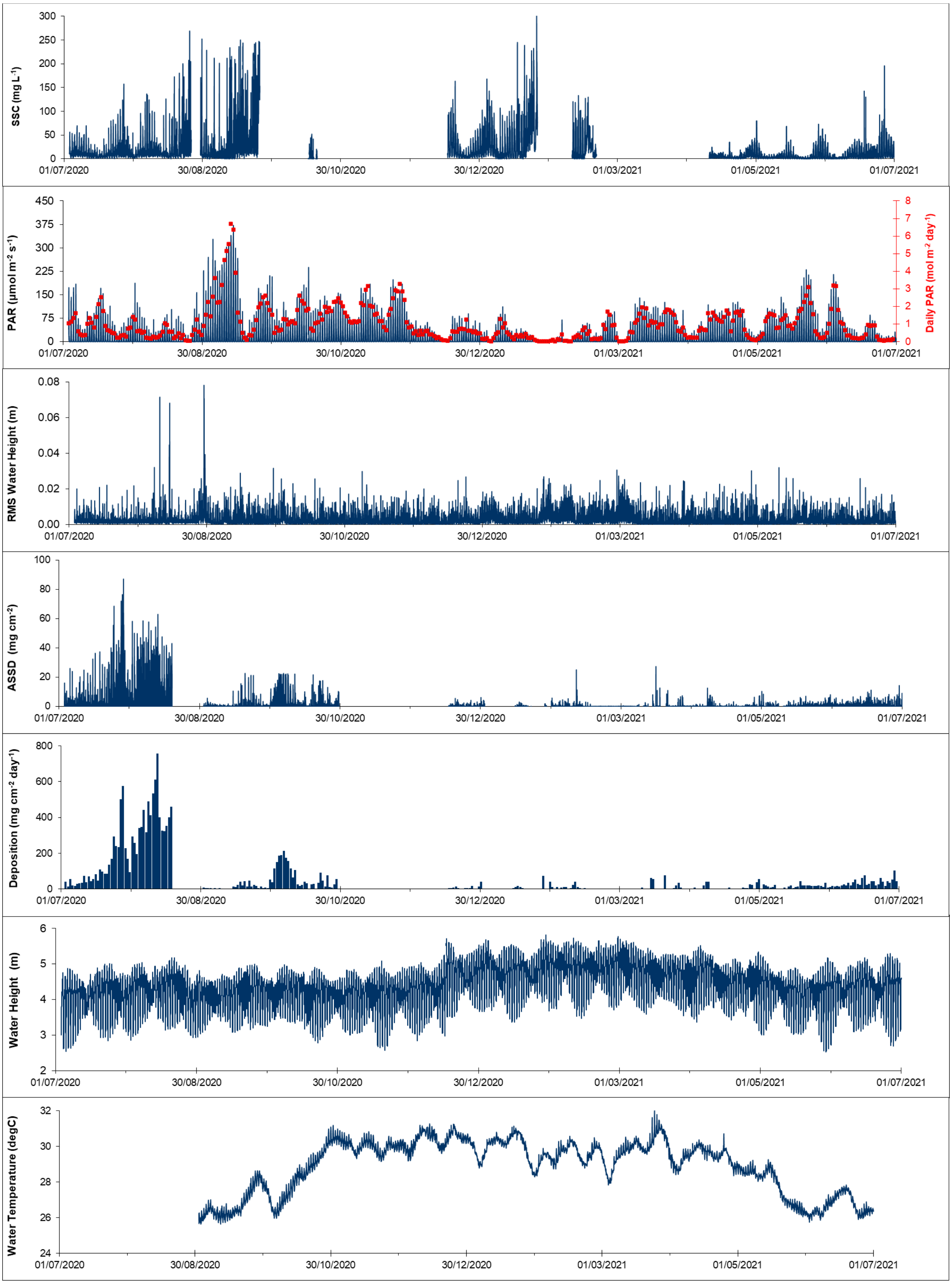
The light sensors on each logger are calibrated every six months or after every deployment. The light sensor is calibrated against a LICOR U250A submersible sensor that was calibrated in the factory within the last 12 months. The results of the logger light sensor and LICOR U250A are compared and a calibration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

A1.1.4 Pressure Sensor Calibration

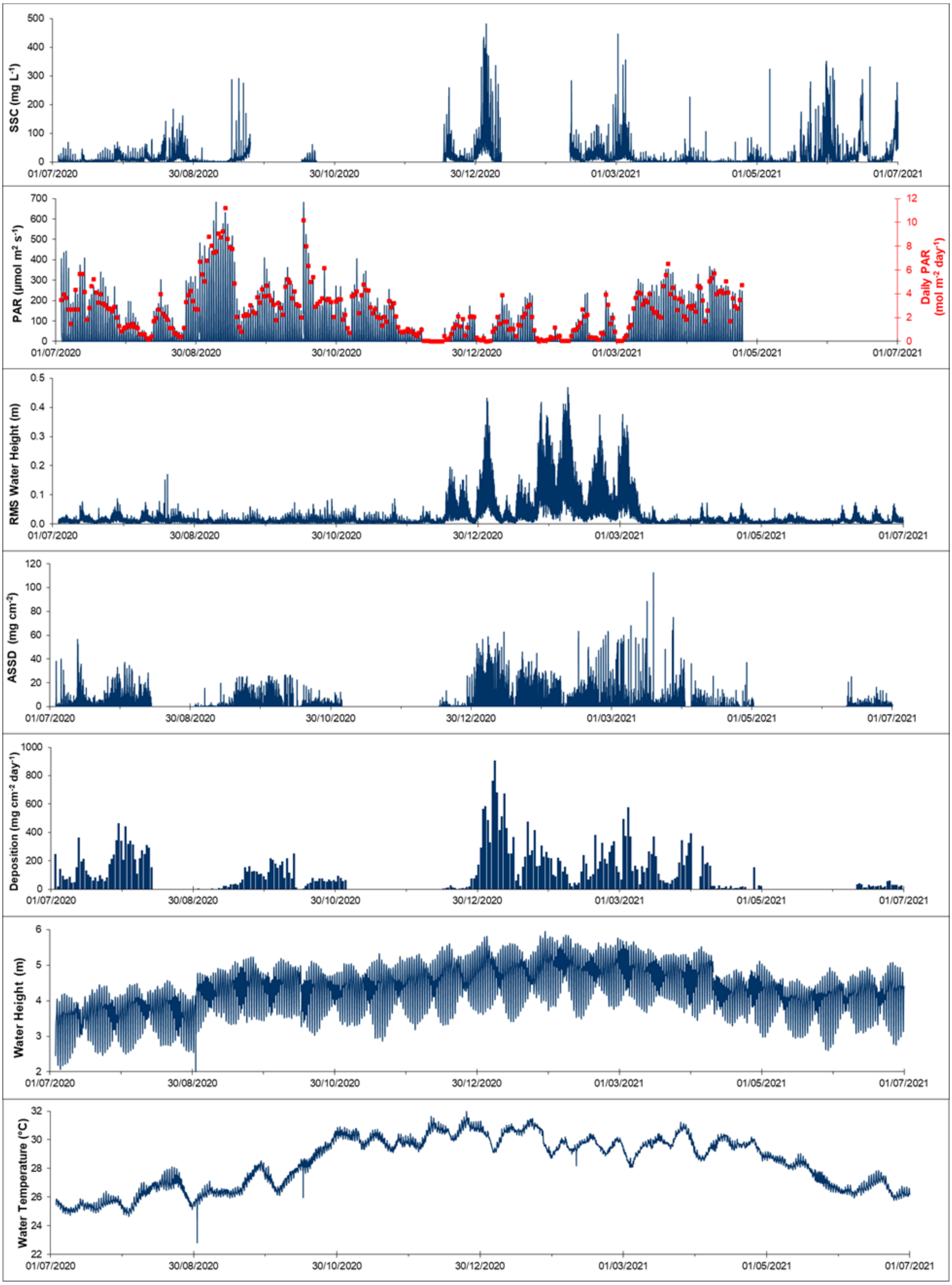
All pressure sensors are calibrated against a pressure gauge and the pressure is converted into depth in metres.

A1.2 Time Series

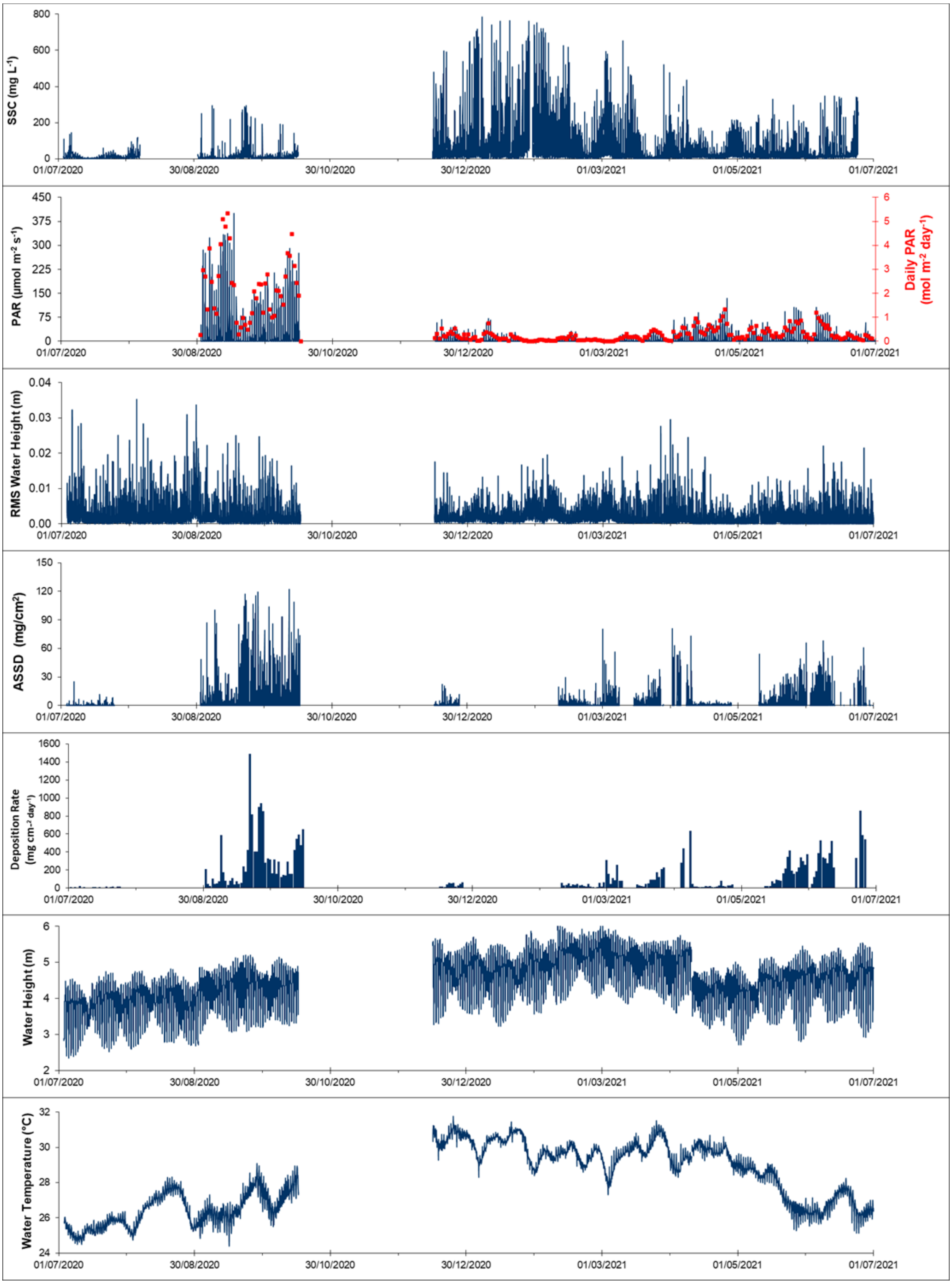
WQ1



WQ2


SSC (mg L-1)
PAR (µmol m2 s-1)
Daily PAR (mol m-2 day-1)
RMS Water Height (m)
ASSD (mg cm-2)
Deposition (mg cm-2 day-1)
Water Height (m)
Water Temperature (°C)
01/07/2020
30/08/2020
30/10/2020
30/12/2020
01/03/2021
01/05/2021
01/07/2021

WQ4


SSC (mg L-1)
PAR (µmol m-2 s-1)
Daily PAR (mol m-2 day-1)
RMS Water Height (m)
ASSD (mg/cm2)
Deposition Rate (mg cm-2 day-1)
Water Height (m)
Water Temperature (°C)
01/07/2020
30/08/2020
30/10/2020
30/12/2020
01/03/2021
01/05/2021
01/07/2021

A1.3 Monthly statistics

WQ1

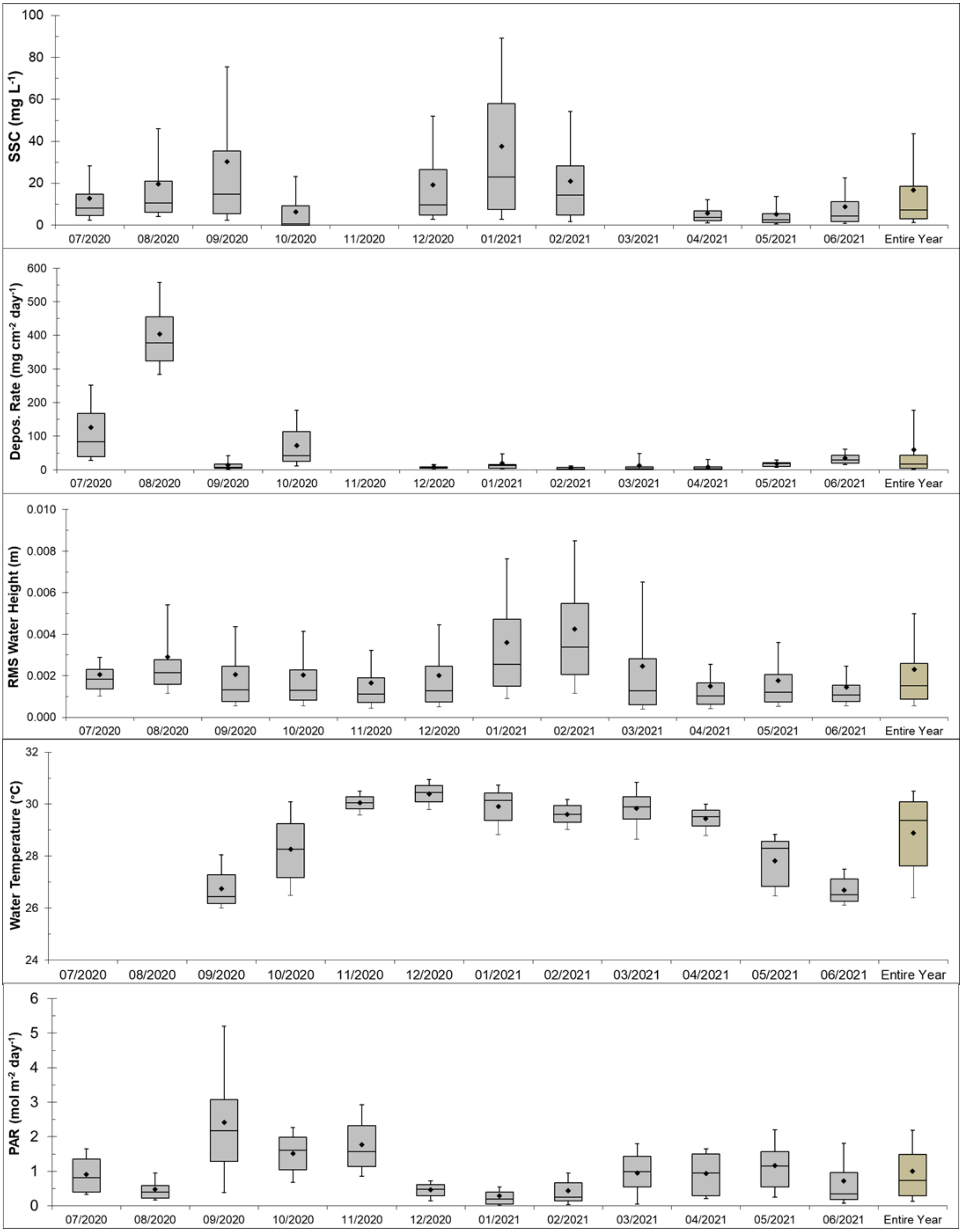
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	12.69	19.59	30.38	6.40		19.14	37.54	21.04		5.62	5.34	8.83	16.75
median	8.20	10.66	14.78	0.62		9.57	23.06	14.34		3.69	2.54	4.41	7.27
min	0.39	0.00	0.00	2.78		29.19	0.00	0.00		0.00	0.00	0.00	7.00
lower	4.67	6.23	5.45	0.00		4.83	7.43	4.85		2.13	1.28	1.72	3.03
upper	14.77	21.00	35.44	9.25		26.51	58.05	28.24		6.79	5.46	11.30	18.63
max	155.79	268.23	249.04	51.38		163.44	299.83	132.79		43.04	79.79	193.85	299.83
90th percentile	28.38	45.98	75.42	23.17		52.11	89.15	54.28		12.05	13.57	22.43	43.63
10th percentile	2.46	4.14	2.46	0.00		2.83	2.90	1.62		1.07	0.65	0.75	1.28
n(recordings obtained)	4067	3737	3299	336	0	2215	3361	1547	0	2908	4457	4304	30231
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.911	0.837	0.764	0.075	0.000	0.496	0.753	0.384	0.000	0.673	0.998	0.996	0.575
St. Dev	13.55	25.35	42.84	10.54		21.24	39.28	22.04		5.90	7.99	12.11	26.13
St. Error	0.21	0.41	0.75	0.58		0.45	0.68	0.56		0.11	0.12	0.18	0.15

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	126.70	404.00	13.68	71.96		8.94	20.11	5.33	12.81	9.15	18.22	35.44	59.68
median	83.14	377.24	6.69	42.23		5.43	12.33	1.23	2.74	2.75	17.82	29.32	16.61
min	13.66	195.19	0.77	2.40		1.20	3.62	0.09	0.07	0.39	1.31	10.45	0.07
lower	39.66	323.61	4.30	24.92		3.94	5.23	0.62	2.12	1.25	10.40	19.26	3.96
upper	168.13	454.80	16.37	114.31		9.19	16.13	7.19	8.34	8.13	21.25	43.33	43.74
max	576.57	756.28	54.14	212.09		41.48	74.09	41.07	75.59	41.55	55.01	104.03	756.28
90th percentile	251.50	557.82	42.45	177.02		15.91	47.88	10.95	49.21	30.84	29.58	61.56	177.02
10th percentile	28.01	283.21	1.18	11.74		2.85	4.36	0.31	1.10	0.83	6.76	16.05	1.18
n(recordings obtained)	29	18	30	29	0	16	9	28	24	28	28	30	269
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.935	0.581	1.000	0.935	0.000	0.516	0.290	1.000	0.774	0.933	0.903	1.000	0.737
St. Dev	136.67	133.39	14.82	64.13		9.83	23.22	8.79	21.60	13.03	11.60	20.92	116.65
St. Error	25.38	31.44	2.71	11.91		2.46	7.74	1.66	4.41	2.46	2.19	3.82	7.11

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	0.0021	0.0029	0.0021	0.0020	0.0016	0.0020	0.0036	0.0043	0.0025	0.0015	0.0018	0.0015	0.0023
median	0.0018	0.0022	0.0013	0.0013	0.0011	0.0013	0.0026	0.0034	0.0013	0.0010	0.0012	0.0011	0.0015
min	0.0003	0.0003	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
lower	0.0014	0.0016	0.0008	0.0008	0.0007	0.0007	0.0015	0.0021	0.0006	0.0006	0.0007	0.0008	0.0009
upper	0.0023	0.0028	0.0025	0.0023	0.0019	0.0025	0.0047	0.0055	0.0028	0.0016	0.0021	0.0015	0.0026
max	0.0221	0.0776	0.0316	0.0256	0.0298	0.0267	0.0267	0.0306	0.0252	0.0302	0.0319	0.0258	0.0776
90th percentile	0.0029	0.0054	0.0044	0.0041	0.0032	0.0045	0.0076	0.0085	0.0065	0.0025	0.0036	0.0025	0.0050
10th percentile	0.0010	0.0012	0.0005	0.0006	0.0004	0.0005	0.0009	0.0012	0.0004	0.0004	0.0005	0.0005	0.0006
n(recordings obtained)	4121	4464	4320	4459	4320	4462	4464	4029	4464	4317	4461	4320	52201
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.923	1.000	1.000	0.999	1.000	1.000	1.000	0.999	1.000	0.999	0.999	1.000	0.993
St. Dev	0.0015	0.0036	0.0022	0.0023	0.0018	0.0021	0.0032	0.0033	0.0031	0.0019	0.0019	0.0016	0.0026
St. Error	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000

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			26.74	28.26	30.05	30.40	29.92	29.61	29.83	29.44	27.82	26.69	28.88
median			26.43	28.27	30.06	30.45	30.14	29.61	29.89	29.51	28.29	26.51	29.38
min			25.64	25.97	29.16	29.19	28.30	28.74	27.84	28.36	26.05	25.75	25.64
lower			26.17	27.17	29.82	30.09	29.38	29.30	29.43	29.15	26.83	26.25	27.62
upper			27.27	29.24	30.29	30.71	30.42	29.94	30.29	29.76	28.56	27.12	30.09
max			28.64	31.19	30.99	31.28	31.15	30.58	32.02	30.72	29.27	27.84	32.02
90th percentile			28.05	30.09	30.50	30.94	30.73	30.17	30.84	29.99	28.83	27.50	30.50
10th percentile			25.99	26.49	29.57	29.80	28.82	29.02	28.64	28.79	26.46	26.11	26.39
n(recordings obtained)	0	0	4240	4459	4320	4462	4464	4029	4464	4294	4453	4320	43505
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	0.981	0.999	1.000	1.000	1.000	0.999	1.000	0.994	0.998	1.000	0.828
St. Dev			0.78	1.27	0.35	0.42	0.70	0.41	0.78	0.44	0.93	0.52	1.50
St. Error			0.01	0.02	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	0.91	0.48	2.42	1.51	1.77	0.47	0.28	0.44	0.95	0.93	1.17	0.71	1.00
median	0.81	0.39	2.18	1.60	1.57	0.48	0.20	0.25	0.99	0.95	1.15	0.34	0.73
min	0.22	0.03	0.10	0.49	0.65	0.05	0.00	0.01	0.01	0.08	0.17	0.04	0.00
lower	0.40	0.23	1.29	1.05	1.13	0.29	0.04	0.15	0.54	0.29	0.55	0.18	0.30
upper	1.35	0.59	3.08	1.99	2.33	0.61	0.39	0.66	1.43	1.50	1.56	0.96	1.49
max	2.52	1.26	6.70	2.61	3.29	1.25	1.28	1.70	1.95	1.78	3.10	3.19	6.70
90th percentile	1.65	0.95	5.20	2.27	2.93	0.71	0.54	0.95	1.79	1.65	2.20	1.81	2.18
10th percentile	0.33	0.17	0.38	0.68	0.86	0.14	0.01	0.03	0.05	0.21	0.25	0.07	0.13
n(recordings obtained)	29	31	30	31	30	31	31	28	31	30	31	29	362
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.935	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.967	0.992
St. Dev	0.59	0.33	1.79	0.62	0.79	0.25	0.30	0.45	0.60	0.60	0.75	0.84	0.96
St. Error	0.11	0.06	0.33	0.11	0.14	0.05	0.05	0.08	0.11	0.11	0.13	0.16	0.05


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

WQ2

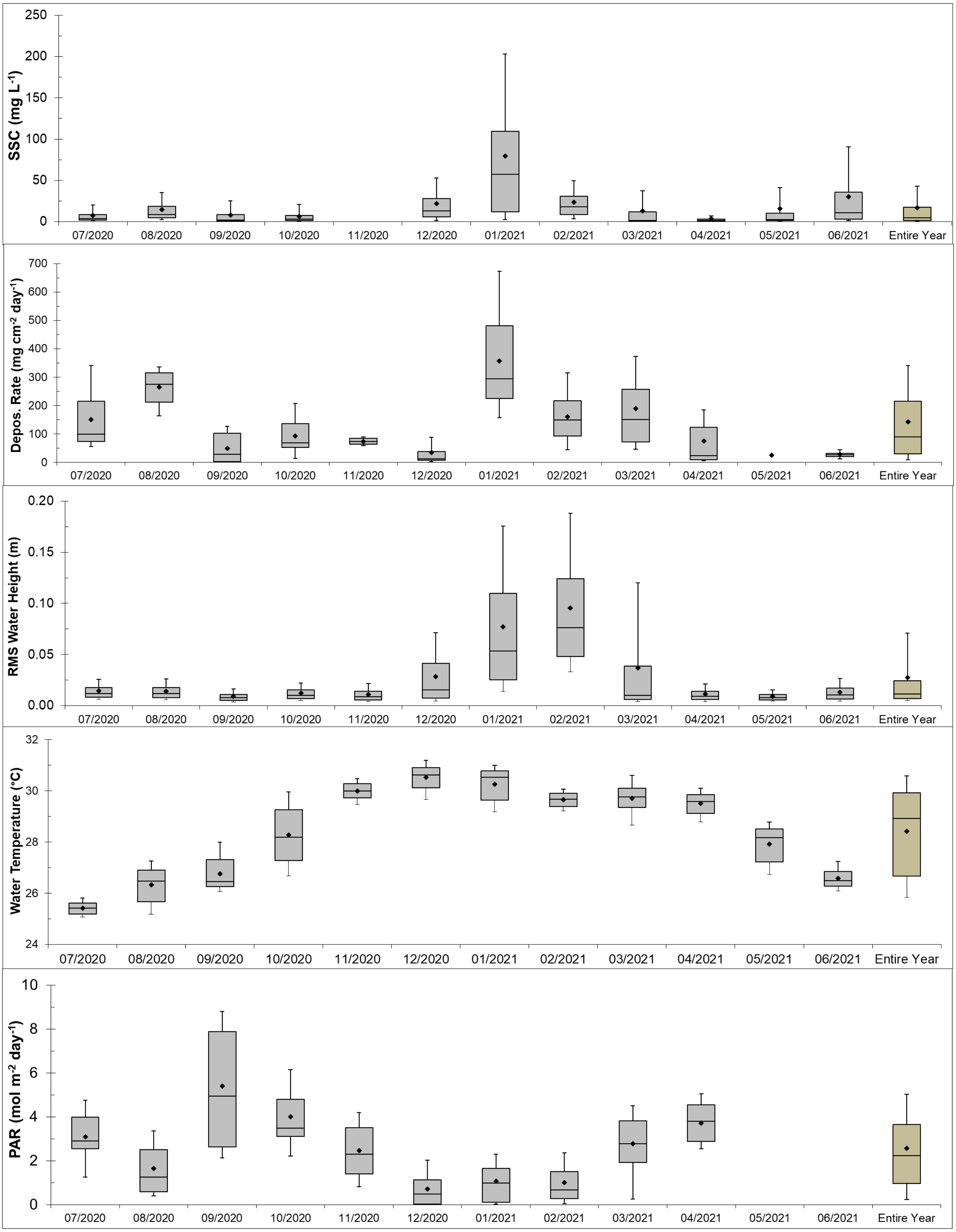
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	7.51	14.92	8.32	6.45		21.84	79.59	23.84	12.99	3.55	15.99	30.24	17.00
median	3.71	8.88	1.95	2.79		13.14	57.36	18.27	1.43	1.44	2.78	10.74	4.84
min	0.00	0.00	0.00	3.03		29.16	0.00	0.00	0.00	0.00	0.00	0.00	7.00
lower	2.07	4.73	0.78	1.20		5.85	11.77	8.41	0.49	0.63	1.21	3.27	1.47
upper	8.86	18.51	8.56	7.34		28.27	109.59	30.79	12.12	3.02	10.11	35.78	17.30
max	69.86	183.28	291.78	61.11		257.54	481.79	283.06	446.61	225.89	348.14	347.03	481.79
90th percentile	20.22	35.27	25.19	20.78		52.88	202.87	49.38	37.60	6.71	41.04	90.56	42.74
10th percentile	1.15	2.49	0.37	0.53		1.52	2.38	3.67	0.08	0.17	0.63	1.52	0.54
n(recordings obtained)	4112	4367	3345	950	0	2222	1286	2829	4449	4302	4102	4276	36240
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.921	0.978	0.774	0.213	0.000	0.498	0.288	0.702	0.997	0.996	0.919	0.990	0.689
St. Dev	9.14	17.14	16.61	8.60		25.98	84.67	23.77	29.64	8.34	37.87	46.80	34.02
St. Error	0.14	0.26	0.29	0.28		0.55	2.36	0.45	0.44	0.13	0.59	0.72	0.18

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	150.99	264.43	48.75	92.55	73.52	33.80	356.94	160.82	189.66	73.86	24.64	27.80	142.84
median	98.68	274.75	27.44	68.32	73.04	12.46	293.70	148.82	149.71	22.25	24.64	25.53	89.47
min	21.07	109.18	0.46	0.00	54.81	1.09	24.46	20.30	32.33	3.53	24.64	10.82	0.00
lower	72.26	211.11	2.83	51.62	62.93	6.58	224.60	91.55	71.85	8.44	24.64	20.16	29.48
upper	214.13	314.90	101.71	135.77	83.63	38.27	480.87	216.85	257.17	122.20	24.64	31.82	215.03
max	465.91	440.67	159.82	252.57	93.19	173.02	907.95	381.14	576.50	394.46	24.64	60.60	907.95
90th percentile	341.20	336.56	125.93	206.63	89.36	87.18	673.26	314.46	372.29	184.59	24.64	44.22	340.45
10th percentile	54.71	163.09	1.57	13.44	58.06	2.71	156.74	43.40	46.20	4.67	24.64	11.50	7.86
n(recordings obtained)	29	13	30	31	4	16	31	28	31	23	1	20	257
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.935	0.419	1.000	1.000	0.133	0.516	1.000	1.000	1.000	0.767	0.032	0.667	0.704
St. Dev	112.81	87.05	53.84	71.29	16.80	47.96	211.95	99.23	141.46	106.81		13.18	150.79
St. Error	20.95	24.14	9.83	12.80	8.40	11.99	38.07	18.75	25.41	22.27		2.95	9.41

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	0.0145	0.0142	0.0092	0.0124	0.0112	0.0283	0.0771	0.0953	0.0370	0.0115	0.0090	0.0134	0.0275
median	0.0119	0.0117	0.0077	0.0100	0.0086	0.0154	0.0534	0.0761	0.0099	0.0091	0.0078	0.0105	0.0115
min	0.0016	0.0015	0.0000	0.0013	0.0009	0.0010	0.0022	0.0063	0.0011	0.0010	0.0007	0.0010	0.0000
lower	0.0083	0.0080	0.0054	0.0069	0.0057	0.0072	0.0253	0.0483	0.0061	0.0060	0.0056	0.0066	0.0070
upper	0.0178	0.0176	0.0110	0.0156	0.0141	0.0413	0.1099	0.1242	0.0388	0.0141	0.0111	0.0173	0.0244
max	0.0867	0.1703	0.0595	0.0854	0.0858	0.1947	0.4312	0.4667	0.3740	0.0724	0.0540	0.0736	0.4667
90th percentile	0.0256	0.0263	0.0162	0.0223	0.0219	0.0711	0.1757	0.1880	0.1203	0.0212	0.0154	0.0266	0.0710
10th percentile	0.0061	0.0057	0.0035	0.0051	0.0042	0.0045	0.0139	0.0329	0.0042	0.0042	0.0043	0.0046	0.0048
n(recordings obtained)	4114	4464	4316	4461	4320	4461	4464	4028	4464	4315	4462	4320	52189
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.922	1.000	0.999	0.999	1.000	0.999	1.000	0.999	1.000	0.999	1.000	1.000	0.993
St. Dev	0.0095	0.0095	0.0062	0.0084	0.0081	0.0292	0.0686	0.0658	0.0573	0.0084	0.0049	0.0096	0.0433
St. Error	0.0001	0.0001	0.0001	0.0001	0.0001	0.0004	0.0010	0.0010	0.0009	0.0001	0.0001	0.0001	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	25.42	26.33	26.75	28.28	29.99	30.53	30.27	29.65	29.70	29.51	27.91	26.58	28.42
median	25.42	26.47	26.45	28.19	29.99	30.63	30.53	29.67	29.77	29.58	28.17	26.48	28.93
min	24.73	24.65	22.86	25.98	29.11	29.16	28.73	28.21	28.08	28.51	26.32	25.77	22.86
lower	25.19	25.67	26.25	27.27	29.73	30.12	29.63	29.39	29.35	29.11	27.22	26.27	26.66
upper	25.61	26.90	27.32	29.27	30.29	30.90	30.79	29.91	30.10	29.85	28.51	26.85	29.92
max	26.41	28.11	28.54	30.92	30.87	32.12	31.49	30.43	31.23	30.42	29.18	27.85	32.12
90th percentile	25.80	27.25	28.00	29.96	30.48	31.19	31.00	30.07	30.61	30.11	28.77	27.24	30.58
10th percentile	25.06	25.17	26.07	26.67	29.46	29.67	29.19	29.22	28.67	28.78	26.73	26.08	25.83
n(recordings obtained)	4114	4464	4317	4461	4320	4450	4464	4028	4464	4309	4462	4320	52173
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.922	1.000	0.999	0.999	1.000	0.997	1.000	0.999	1.000	0.997	1.000	1.000	0.993
St. Dev	0.29	0.78	0.73	1.20	0.37	0.55	0.70	0.33	0.69	0.47	0.75	0.43	1.81
St. Error	0.00	0.01	0.01	0.02	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	3.09	1.65	5.39	4.01	2.47	0.71	1.08	1.01	2.77	3.70			2.57
median	2.91	1.26	4.95	3.48	2.30	0.49	0.98	0.67	2.77	3.79			2.22
min	0.86	0.16	0.81	1.76	0.73	0.00	0.00	0.03	0.04	1.67			0.00
lower	2.54	0.59	2.63	3.11	1.41	0.03	0.11	0.28	1.92	2.88			0.95
upper	3.99	2.50	7.87	4.79	3.50	1.14	1.65	1.50	3.81	4.55			3.65
max	5.66	4.22	11.22	10.16	4.75	2.09	3.86	3.91	6.52	5.71			11.22
90th percentile	4.76	3.37	8.80	6.16	4.18	2.03	2.30	2.36	4.50	5.05			5.02
10th percentile	1.26	0.40	2.13	2.22	0.82	0.00	0.02	0.04	0.26	2.54			0.23
n(recordings obtained)	29	31	30	31	30	31	31	28	31	24	0	0	296
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.935	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.800	0.000	0.000	0.811
St. Dev	1.32	1.19	2.89	1.78	1.23	0.72	1.03	1.02	1.62	1.10			2.07
St. Error	0.24	0.21	0.53	0.32	0.22	0.13	0.19	0.19	0.29	0.23			0.12


SSC (mg L-1)
250
200
150
100
50
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)
700
600
500
400
300
200
100
0
RMS Water Height (m)
0.20
0.15
0.10
0.05
0.00
Water Temperature (°C)
32
30
28
26
24
PAR (mol m-2 day-1)
10
8
6
4
2
0

WQ4

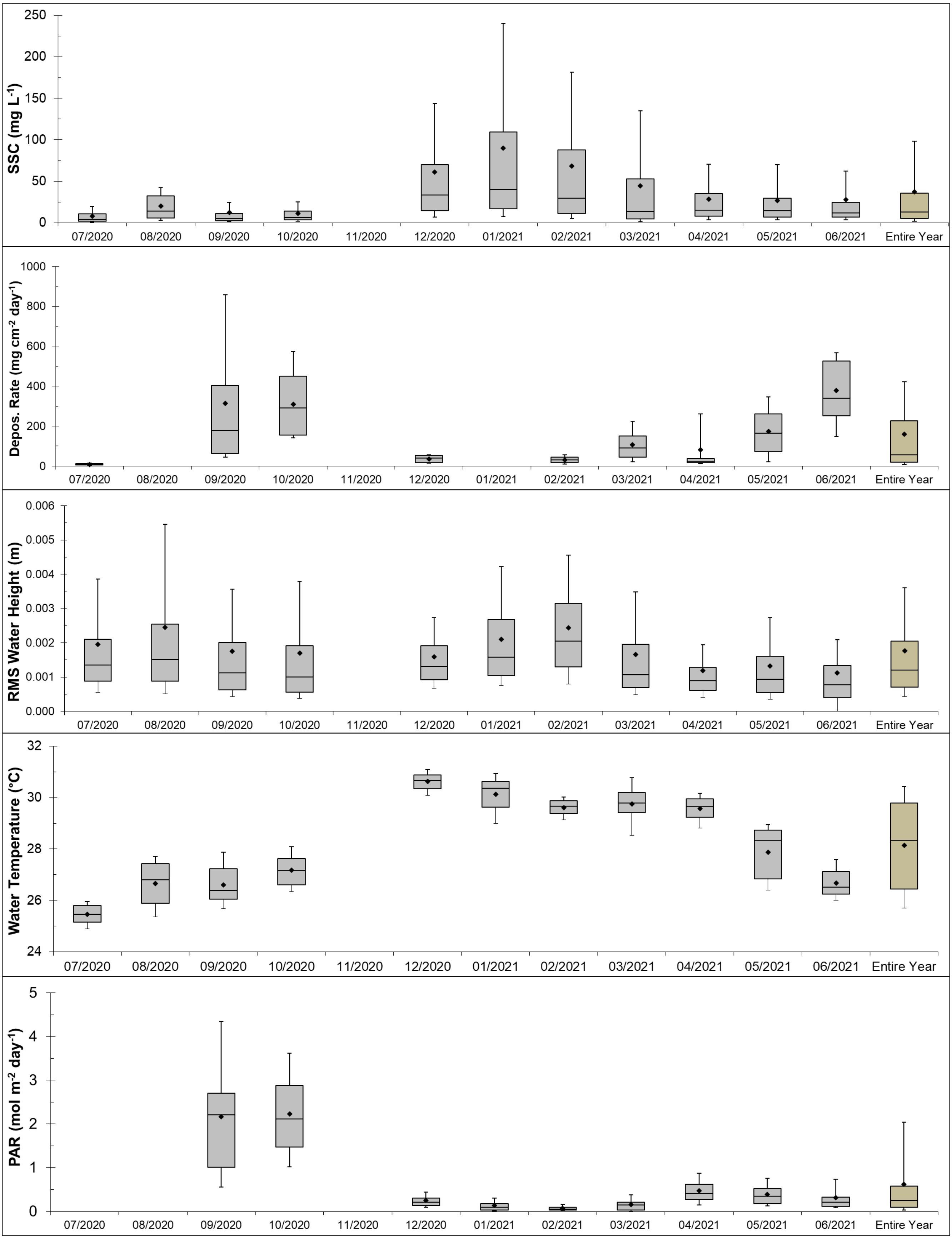
Turbidity (SSC)	SSC 07/2020	SSC 08/2020	SSC 09/2020	SSC 10/2020	SSC 11/2020	SSC 12/2020	SSC 01/2021	SSC 02/2021	SSC 03/2021	SSC 04/2021	SSC 05/2021	SSC 06/2021	SSC Entire Year
Mean	7.95	20.21	12.55	11.16		60.95	89.87	68.66	44.60	28.70	26.84	27.89	37.41
median	4.35	14.03	5.06	6.22		33.49	40.05	29.42	13.39	15.22	14.49	11.79	13.15
min	0.00	0.00	0.00	3.24		29.27	0.00	0.00	0.00	0.00	0.00	0.00	7.00
lower	1.92	5.80	2.48	3.36		14.49	16.81	11.53	4.41	8.00	6.76	6.68	5.12
upper	11.02	32.16	11.50	13.96		70.01	109.26	88.02	52.68	35.15	29.62	24.38	35.84
max	144.82	150.18	294.35	191.92		595.76	817.05	720.26	653.57	434.66	328.99	348.32	817.05
90th percentile	19.87	42.46	24.82	25.08		143.54	240.24	181.68	134.77	70.42	70.03	62.06	98.22
10th percentile	1.06	2.81	1.28	2.09		6.62	7.31	5.48	1.51	3.83	3.48	3.45	2.14
n(recordings obtained)	4088	803	4119	2202	0	2317	3793	3846	4306	4123	4328	2991	36916
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.916	0.180	0.953	0.493	0.000	0.519	0.850	0.954	0.965	0.954	0.970	0.692	0.702
St. Dev	9.34	18.10	28.22	13.84		79.00	122.71	94.75	72.20	35.41	34.76	49.22	68.87
St. Error	0.15	0.64	0.44	0.29		1.64	1.99	1.53	1.10	0.55	0.53	0.90	0.36

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	8.65		314.09	308.97		35.71		30.89	106.32	82.16	173.10	378.36	160.47
median	8.11		178.66	290.77		40.66		30.03	89.55	22.62	164.04	340.00	56.22
min	1.12		23.95	124.75		7.27		2.73	0.00	7.61	6.12	45.95	0.00
lower	4.33		62.50	155.93		15.98		16.75	43.66	16.43	72.61	251.92	18.74
upper	11.80		404.86	449.59		53.04		44.08	150.00	36.50	259.92	526.38	226.86
max	23.13		1487.71	651.43		63.61		61.10	310.13	635.37	419.76	859.34	1487.71
90th percentile	15.03		857.48	574.26		56.92		55.81	224.98	261.88	346.46	567.44	422.31
10th percentile	2.38		43.50	141.87		13.52		9.89	20.79	11.21	21.97	148.11	8.57
n(recordings obtained)	23	0	30	15	0	11	0	20	22	22	21	15	179
T(recordings possible)	31	31	30	31	30	31	31	28	31	30	31	30	365
f(period obtained; n/T)	0.742	0.000	1.000	0.484	0.000	0.355	0.000	0.714	0.710	0.733	0.677	0.500	0.490
St. Dev	5.63		357.67	184.34		20.27		17.11	84.00	160.71	129.07	206.40	222.44
St. Error	1.17		65.30	47.60		6.11		3.83	17.91	34.26	28.17	53.29	16.63

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	0.0020	0.0025	0.0017	0.0017		0.0016	0.0021	0.0024	0.0017	0.0012	0.0013	0.0011	0.0018
median	0.0013	0.0015	0.0011	0.0010		0.0013	0.0016	0.0020	0.0011	0.0009	0.0009	0.0008	0.0012
min	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
lower	0.0009	0.0009	0.0006	0.0006		0.0009	0.0010	0.0013	0.0007	0.0006	0.0006	0.0004	0.0007
upper	0.0021	0.0025	0.0020	0.0019		0.0019	0.0027	0.0032	0.0020	0.0013	0.0016	0.0013	0.0020
max	0.0323	0.0352	0.0250	0.0184		0.0175	0.0167	0.0195	0.0294	0.0245	0.0133	0.0220	0.0352
90th percentile	0.0039	0.0055	0.0036	0.0038		0.0027	0.0042	0.0046	0.0035	0.0019	0.0027	0.0021	0.0036
10th percentile	0.0006	0.0005	0.0004	0.0004		0.0007	0.0008	0.0008	0.0005	0.0004	0.0003	0.0000	0.0004
n(recordings obtained)	4118	4464	4311	2220	0	2355	4464	4030	4464	4317	4459	4320	43522
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.922	1.000	0.998	0.497	0.000	0.528	1.000	1.000	1.000	0.999	0.999	1.000	0.828
St. Dev	0.0022	0.0030	0.0021	0.0021		0.0012	0.0016	0.0017	0.0018	0.0014	0.0013	0.0015	0.0019
St. Error	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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	25.45	26.66	26.61	27.17		30.62	30.12	29.61	29.75	29.57	27.88	26.67	28.14
median	25.45	26.80	26.39	27.16		30.66	30.36	29.66	29.79	29.64	28.34	26.51	28.34
min	24.49	24.74	24.39	25.50		29.27	28.30	28.59	27.31	28.30	25.27	25.13	24.39
lower	25.15	25.88	26.04	26.61		30.35	29.62	29.38	29.41	29.23	26.84	26.25	26.45
upper	25.79	27.42	27.23	27.62		30.88	30.62	29.87	30.20	29.95	28.74	27.12	29.79
max	26.36	28.32	29.09	28.95		31.77	31.45	30.41	31.52	30.69	29.64	28.25	31.77
90th percentile	25.95	27.72	27.88	28.08		31.09	30.93	30.02	30.77	30.16	28.95	27.59	30.44
10th percentile	24.89	25.35	25.68	26.34		30.08	29.00	29.13	28.52	28.82	26.40	26.00	25.69
n(recordings obtained)	4108	4464	4307	2220	0	2355	4464	4027	4464	4308	4455	4320	43492
T(recordings possible)	4464	4464	4320	4464	4320	4464	4464	4032	4464	4320	4464	4320	52560
f(period obtained; n/T)	0.920	1.000	0.997	0.497	0.000	0.528	1.000	0.999	1.000	0.997	0.998	1.000	0.827
St. Dev	0.40	0.89	0.83	0.68		0.37	0.70	0.34	0.78	0.49	1.03	0.60	1.82
St. Error	0.01	0.01	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			2.17	2.23		0.25	0.14	0.08	0.16	0.48	0.39	0.31	0.62
median			2.21	2.11		0.21	0.10	0.05	0.15	0.41	0.35	0.21	0.25
min			0.25	0.00		0.07	0.00	0.01	0.00	0.06	0.08	0.05	0.00
lower			1.01	1.48		0.13	0.03	0.03	0.03	0.27	0.18	0.12	0.10
upper			2.71	2.88		0.30	0.18	0.10	0.21	0.62	0.52	0.32	0.58
max			5.33	4.47		0.54	0.75	0.31	0.49	1.33	0.86	1.19	5.33
90th percentile			4.35	3.62		0.45	0.31	0.16	0.38	0.87	0.76	0.74	2.04
10th percentile			0.55	1.03		0.10	0.01	0.02	0.00	0.15	0.13	0.08	0.03
n(recordings obtained)	0	0	30	16	0	17	31	28	31	30	31	29	243
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	1.000	0.516	0.000	0.548	1.000	1.000	1.000	1.000	1.000	0.967	0.666
St. Dev			1.47	1.15		0.14	0.15	0.07	0.14	0.30	0.23	0.30	0.98
St. Error			0.27	0.29		0.03	0.03	0.01	0.03	0.06	0.04	0.06	0.06


SSC (mg L⁻¹)
250
200
150
100
50
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)
1000
800
600
400
200
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)
0.006
0.005
0.004
0.003
0.002
0.001
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
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)
5
4
3
2
1
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

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