Southern Mackay Ambient Marine Water Quality Monitoring Program - July 2018 to July 2019 report

Jordan Iles and Nathan Waltham

Report No. 19/48

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A Report for Healthy Rivers to Reef Partnership

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1 INTRODUCTION

1.1 Southern Mackay program

TropWATER (Centre for Tropical Water and Aquatic Ecosystem Research), James Cook University, has been commissioned to assist Healthy Rivers to Reef Partnership collect ambient marine water quality data for the southern Mackay region as part of the Mackay-Whitsunday – Isaac regional report card that is released each year. This report card provides an overview of the health and condition of regional catchments, rivers, creeks and nearshore habitats, and will be used in the future to set strategic, collaborative, management action plans to protect regional marine, freshwater and estuarine ecosystems. This update report has been prepared for the July 2018 to July 2019 monitoring period.

1.2 Rainfall and river flows

Total rainfall during the 2018/2019 wet season period was 1465 mm, placing it as a slightly above average wet season in comparison to wet season totals since 1910/1911 (Figure 1.1). Rainfall in recent years has also been highlighted indicating the high inter-annual variability of rainfall. This highlights the necessity for a long term commitment to ambient marine monitoring programs to capture and understand this variability.

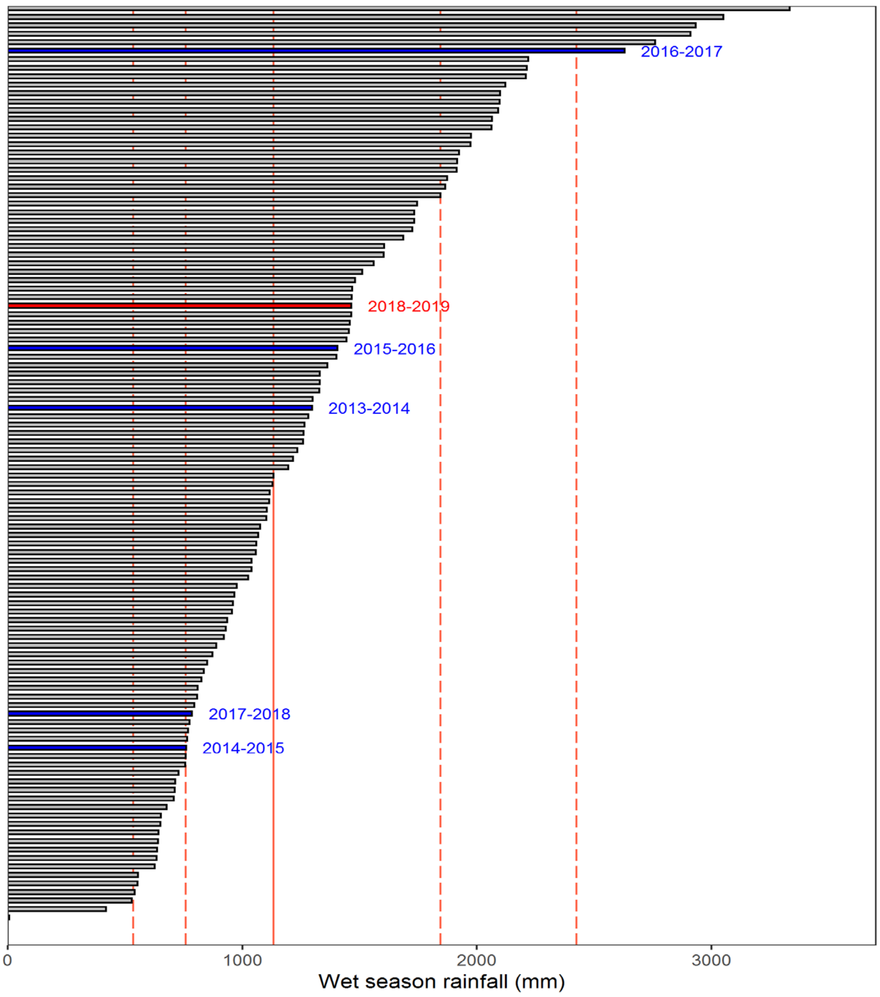

Figure 1.1 Wet season rainfall for the Mackay region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Bureau of Meteorology Plane Creek Sugar Mill weather station (Station number 033059). Totals were calculated for the wet season period 1st November to 31st March for each reporting year. Red bar represents the current 2018/19 ambient marine water quality monitoring period, blue bars show total rainfall over the previous five reporting years. Solid red line represents median wet season rainfall 1910/11 to 2018/19 and dashed red lines represent 5th, 20th, 80th, and 95th percentiles.

A hydrograph for the Pioneer River (as an example of river flow in the region) shows above average river discharge during the 2018/2019 reporting period in comparison to recent years prior (Figure 1.2). Heavy rainfall occurred in late January and early February 2019 due to the convergence of an active monsoon trough and slow-moving low-pressure system (Figure 1.3) causing increased river discharge.

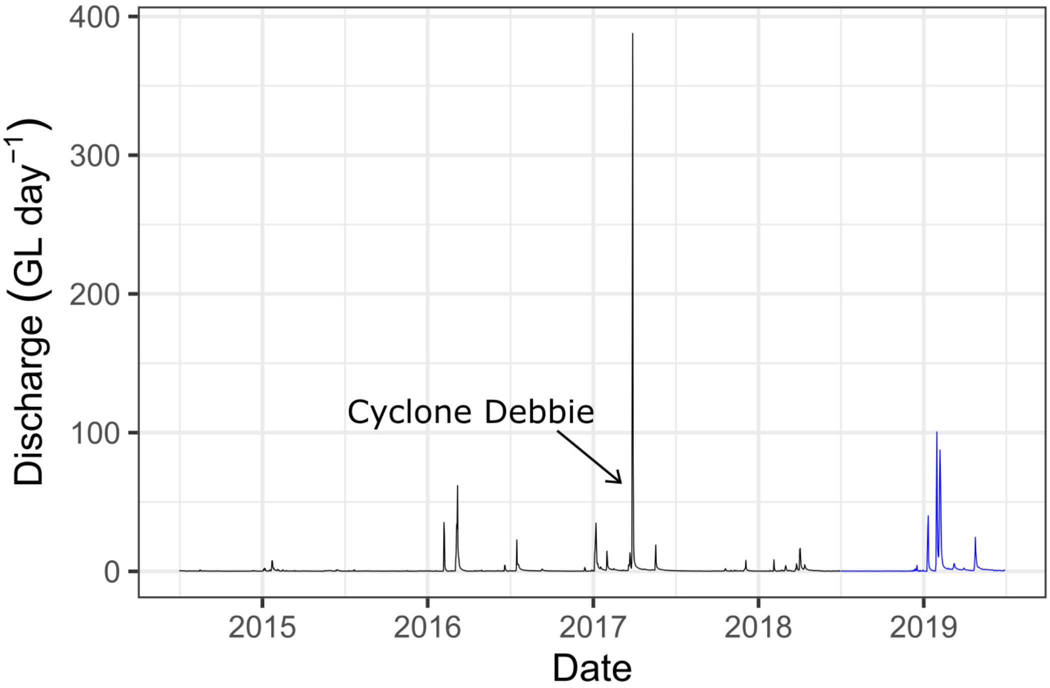

Figure 1.2 Discharge (GL day^{-1}) recorded downstream of Mirani Weir on the Pioneer River (station number: 125007A) since July 2014. The 2018-2019 monitoring period is highlighted in blue.

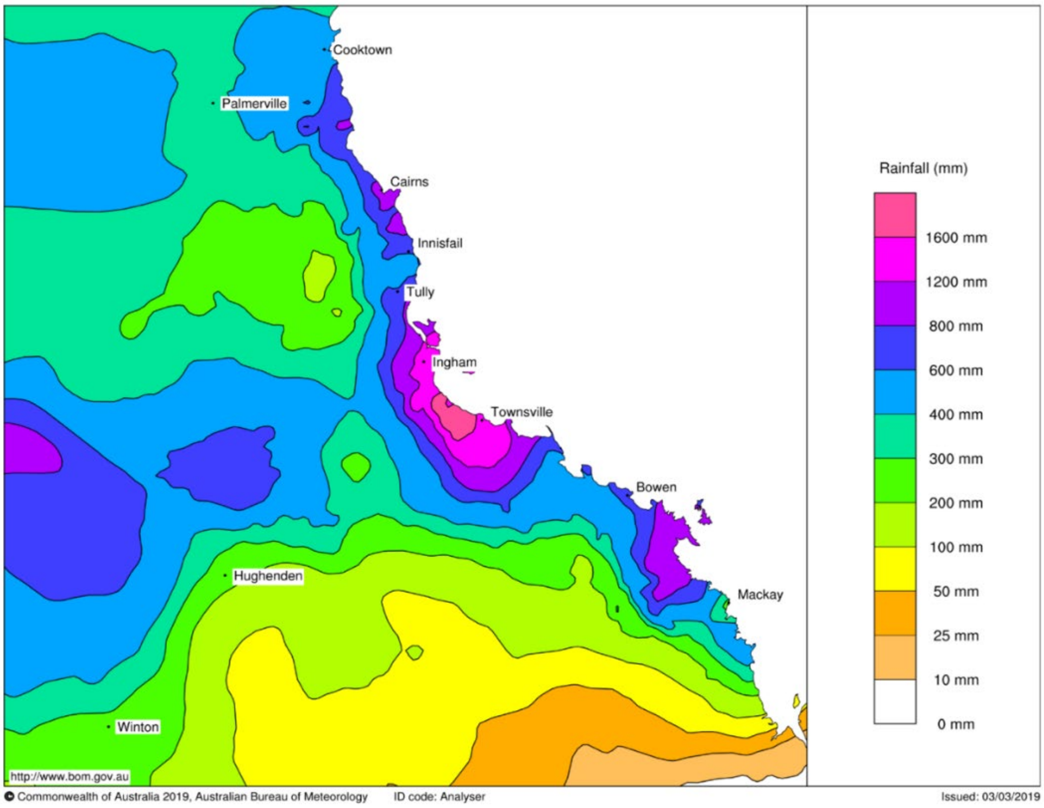

Figure 1.3 Heavy rainfall occurred in the region between 26 January to 9 February 2019 due to the convergence of an active monsoon trough and slow-moving low pressure system. Source: Commonwealth of Australia 2019, Special Climate Statement 69 – an extended period of heavy rainfall and flooding in tropical Queensland.

2 METHODOLOGY

2.1 Water quality monitoring sites

Three water quality monitoring sites were established in September 2017. Ambient water quality monitoring was conducted at all three sites approximately every 6 weeks, while a multiparameter instrument was deployed to collect high frequency data over consecutive years at a single site (Aquilla; MKY_CAM1). Regular maintenance visits occurred in parallel with water quality monitoring to perform sensor maintenance and download data from the instrument, as part of a broader regional program (see Waltham et al., 2018).

2.2 Ambient water quality

2.2.1 Physicochemical parameters

Spot water quality samples were collected from a research vessel at three sites approximately on a 6 week basis. Water temperature, electrical conductivity (EC), dissolved oxygen (DO), and pH were measured with a water quality multiprobe (Hydrolab Quanta) at each site (Figure 2.1). Parameters were recorded at three depth horizons: a) surface (0.25 m); b) mid-depth; and c) bottom. Secchi disk depth (Z_{sd}) and light (PAR) intensity were recorded as a measure of the optical clarity of the water column and to profile light attenuation. Light intensity was measured at the three depths with a PAR sensor (Li-Cor LI-192 Underwater Quantum Sensor).

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

- Particulate nitrogen and phosphorus;
- Nitrate/Nitrite (N_{ox});
- Total suspended solids; and
- Chlorophyll-*a*

Figure 2.1 TropWATER staff measuring and recording water quality parameters with a multiprobe (left) and collecting a water sample for laboratory analysis (right) during water quality sampling trips.

2.2.2 Nutrients and Chlorophyll *a*

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e., DERM 2009b; 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.

Water was passed through a 0.45 µm disposable membrane filter (Sartorius), fitted to a sterile 60 mL syringe (Livingstone), and placed into a 10 mL sample tubes for nutrient analysis in the laboratory. The use of these field sampling equipment and procedures have been previously shown to reduce the risk of contamination of samples, contributing to false positive results for reporting; TropWATER, 2015. Unfiltered sample for total nitrogen and total phosphorus analysis were frozen in a 60 mL tube. All samples are kept in the dark and cold until processing in the laboratory, except nutrients which are stored frozen until processing.

Water for chlorophyll-*a* determination was filtered through a Whatman 0.45 µm GF/F glass-fibre filter with the addition of approximately 0.2 mL of magnesium carbonate within (less than) 12 hours 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 defined analysis methods and detection limits (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'.

For all water quality plots the boxes delineate the 20^{th} and 80^{th} quantiles, while the centre line represents the median, and whiskers represent the 5^{th} and 95^{th} percentile.

Table 2.1 Water analyses performed during the ambient marine water quality monitoring program. The method used and limit of reporting (LOR) is provided for each parameter.

Group	Parameter	APHA method number	LOR
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}
	Turbidity	2130 B	0.1 NTU
Nutrients			
	Nitrogen and Phosphorus (TN, TP)	Simultaneous 4500-NO_3^- 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, N_{ox})	4500-NO_3^- F	1 µg N L^{-1}
	Ammonia	4500- NH_3 G	1 mg N L^{-1}
	Filterable Reactive Phosphorus (FRP)	4500-P F	1 µg P L^{-1}
	Chlorophyll-*a*	10200-H	0.1 µg L^{-1}

2.3 Multiparameter water quality logger

Sediment deposition, turbidity, Photosynthetically Available Radiation (PAR), water depth, Root Mean Squared (RMS) water depth and water temperature were measured at one site (MKY_CAM1) using a purpose built multiparameter water quality instrument manufactured at the Marine Geophysics Laboratory, School of Engineering and Physical Sciences, James Cook University (Figure 2.2). These instruments are programmed to measure these marine physical parameters using specifically designed sensors and store the data on a Campbell's Scientific 1000 data logger housed inside.

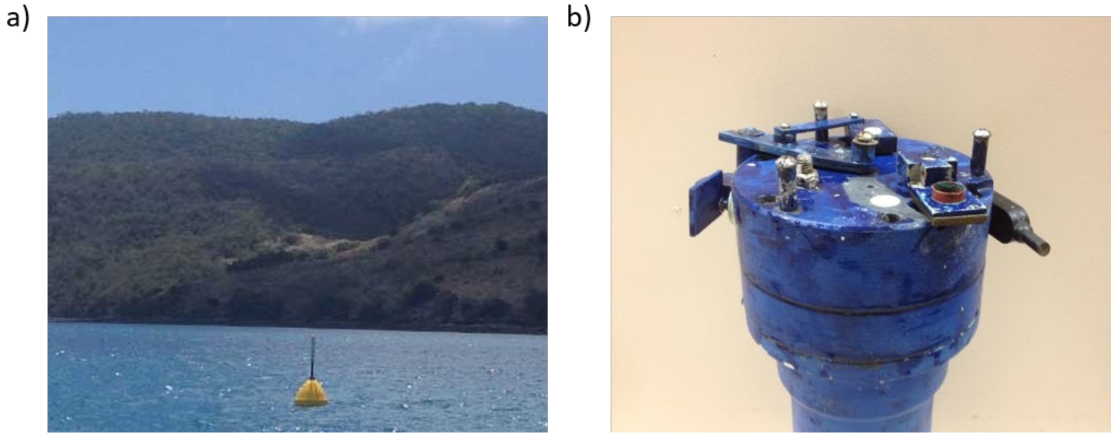

Figure 2.2 Example coastal multiparameter water quality instrument: a) site navigation beacon for safety and instrument retrieval; b) instrument showing sensors and wiping mechanisms

2.3.1 Turbidity

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

The international turbidity standard ISO7027 defines NTU only for 90 degree scatter, however, the Marine Geophysics Laboratory instruments used throughout this monitoring program 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. Suspended sediment concentrations (SSC) (mg L^{-1}) was calculated from turbidity measurements based on an established relationship between measured turbidity and suspended sediment concentration measured from discreet water samples.

2.3.2 Sediment deposition

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

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

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

2.3.3 Pressure

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

$$D_{rms} = \sqrt{\textstyle\sum_{n=1}^{10}(D_n - \overline{D})^2/n} \qquad \text{[Equation 1]}$$

*W*here:

D_n is the *n*th of the 10 readings,

$\overline{D}$ is the mean water depth (m) of the *n* readings.

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

2.3.4 Water temperature

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

2.3.5 Photosynthetically Active Radiation (PAR)

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

3 RESULTS

3.1 Field water quality measurements

3.1.1 Temperature

For the reporting period between July 2018 and July 2019 water temperature ranged between 20 and 28 °C (Figure 3.1). These patterns are consistent throughout the water column, indicating that the water column profile is vertically well mixed. There are no guidelines for water temperature in coastal areas, however, temperature is an essential interpretative aid for ecological assessment in environments. For example, species such as fish and other animals have thermal stress point which causes discomfort and could be misconstrued as being a toxicological impact.

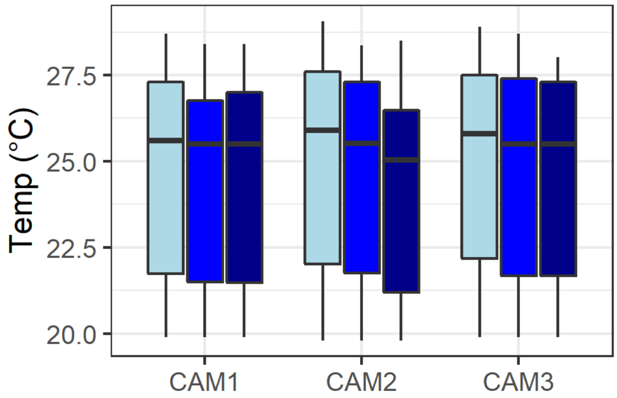

Figure 3.1 Water temperature (°C) measured at surface (light blue), mid (blue), and bottom (dark blue) depths pooled across all sampling events

3.1.2 Electrical Conductivity

Electrical conductivity ranged from 54 to 57 mS cm^{-1} and generally indicate oceanic conditions (Figure 3.2). Electrical conductivity was stable across all sites, with little evidence of changing conditions through the water column. Over time, this monitoring program could collect data that coincides with major rainfall events/periods that causes nearby creeks and rivers to deliver plumes of catchment freshwater flow to the nearshore area, including the vicinity of these monitoring sites.

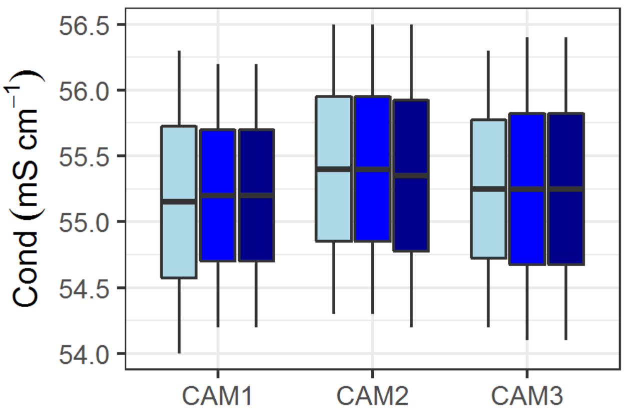

Figure 3.2 Electrical conductivity (mS cm^{-1}) measured at surface (light blue), mid (blue), and bottom (dark blue) depths pooled across all sampling events

3.1.3 pH

Field pH measurements were stable across sites and depths primarily ranging between 7.5 and 8.75 (Figure 3.3). These values are very similar to the nearshore coastal waters adjacent to Port of Hay Point and Port of Mackay.

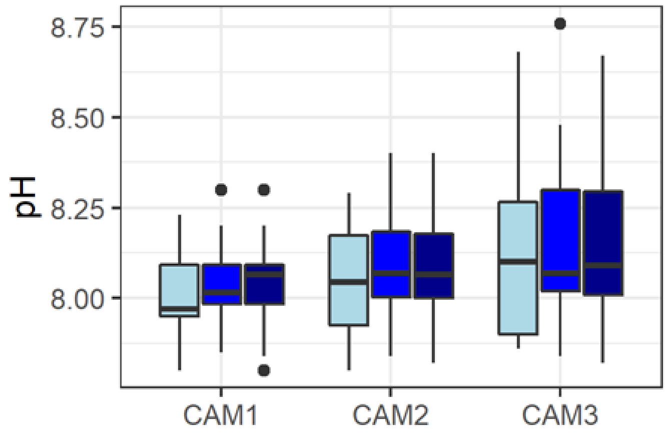

Figure 3.3 pH measured at surface (light blue), mid (blue), and bottom (dark blue) depths pooled across all sampling events

3.1.4 Dissolved oxygen

Dissolved oxygen saturation levels ranged between 80 to 120 % (Figure 3.4). There was no evidence of an oxycline in the waters at sites, with available oxygen generally the same at the surface and bottom waters. This highlights that the waters in the region are generally well mixed.

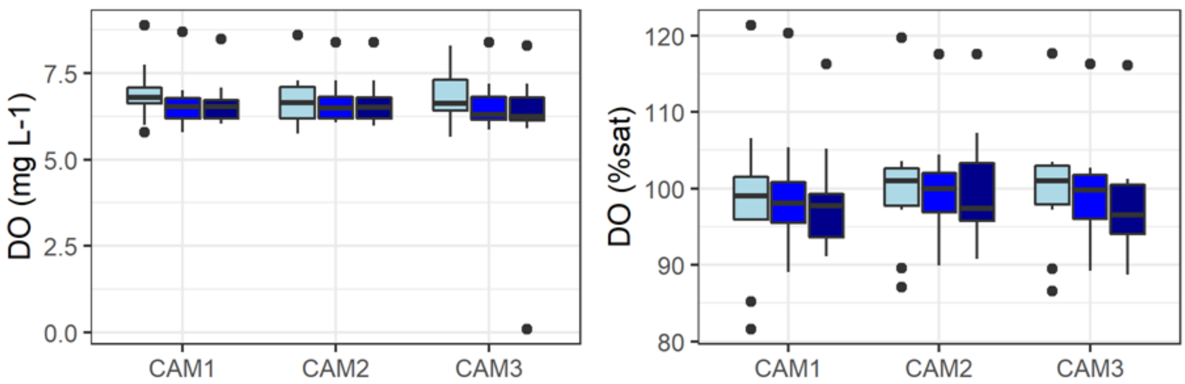

Figure 3.4 Dissolved oxygen concentrations (mg L^{-1}) (left) and percent saturation (right) measured at surface (light blue), mid (blue), and bottom (dark blue) depths pooled across all sampling events

3.1.5 Turbidity

Field turbidity measurements typically ranged between <1 to 70 NTU (Figure 3.5). Turbidity was similar among sites and relatively consistent throughout the water column during this reporting period, though CAM 3 might experience higher conditions. The range measured could be a response to localised variation in water quality, such as differences in tidal stage among sites during a survey – some sites may have been surveyed on an ebbing or flooding tide where water depth was lower or higher, short term localised changes in turbidity that is associated with tide or algal blooms that reduce vertical clarity.

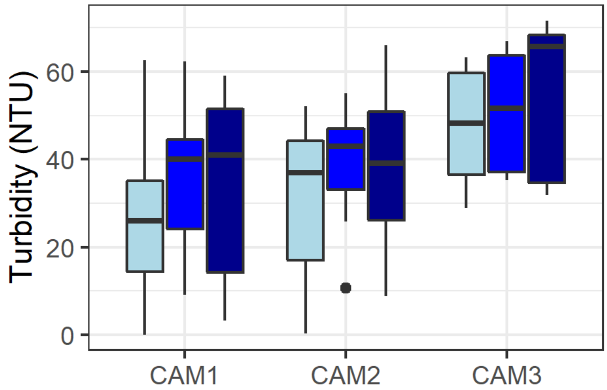

Figure 3.5 Turbidity (NTU) measured at surface (light blue), mid (blue), and bottom (dark blue) depths pooled across all sampling events

3.1.6 Secchi depth

Aquila (MKY_CAM1) generally had the shallowest Secchi disk depth (Figure 3.6). Secchi depth to depth ratio (Z_{sd}:Z) was approximately one quarter of the water column (all sites median = 0.23). The Z_{sd}:Z ratio was also lowest at Aquila (MKY_CAM1).

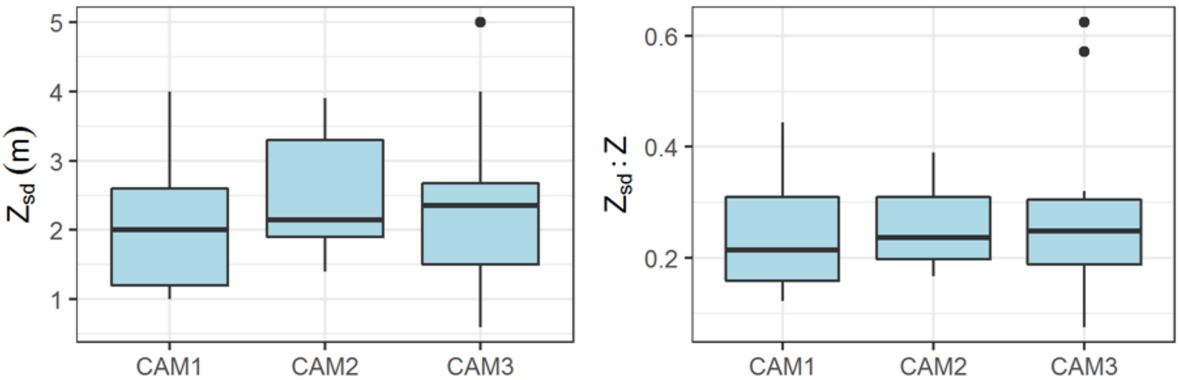

Figure 3.6 Secchi depth (Z_{sd}) (left) and Secchi depth to depth ration (Z_{sd}:Z) (right) at the three sites pooled across all sampling events

3.2 Water sample analysis

3.2.1 Chlorophyll-*a*

Chlorophyll-*a* concentrations were generally elevated above the guidelines (Figure 3.7). There would seem to be little variation among sites, despite several outlies in the data recorded at CAM2 and CAM3.

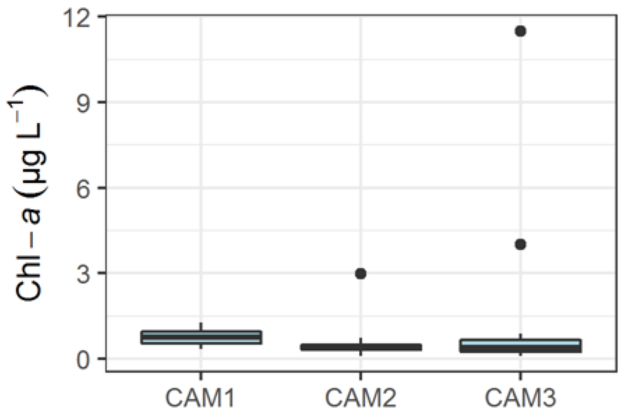

Figure 3.7 Chlorophyll-*a* measured at sites MKY_CAM1 (Aquila), MKY_CAM2, and MKY_CAM3.

3.2.2 Nutrients

Total nitrogen and total phosphorus, including the dissolved and particulate component of the data are presented below for completeness (Figure 3.8). For the purposes of this report, we only focus on particulate nitrogen (PN) and particulate phosphorus (PP) as these nutrient components are measured in the region more broadly (see Waltham et al., 2018).

High concentrations of PN and PP might be associated with the contribution from local land use activities, and with this year's rainfall extending into July 2019, there would be still some base flow from rivers potentially contributing nutrient loadings to this coastal region. In addition, other sources of the nutrients might be via remobilisation of coastal sediments, and release of available nutrients adsorbed to coastal sediments.

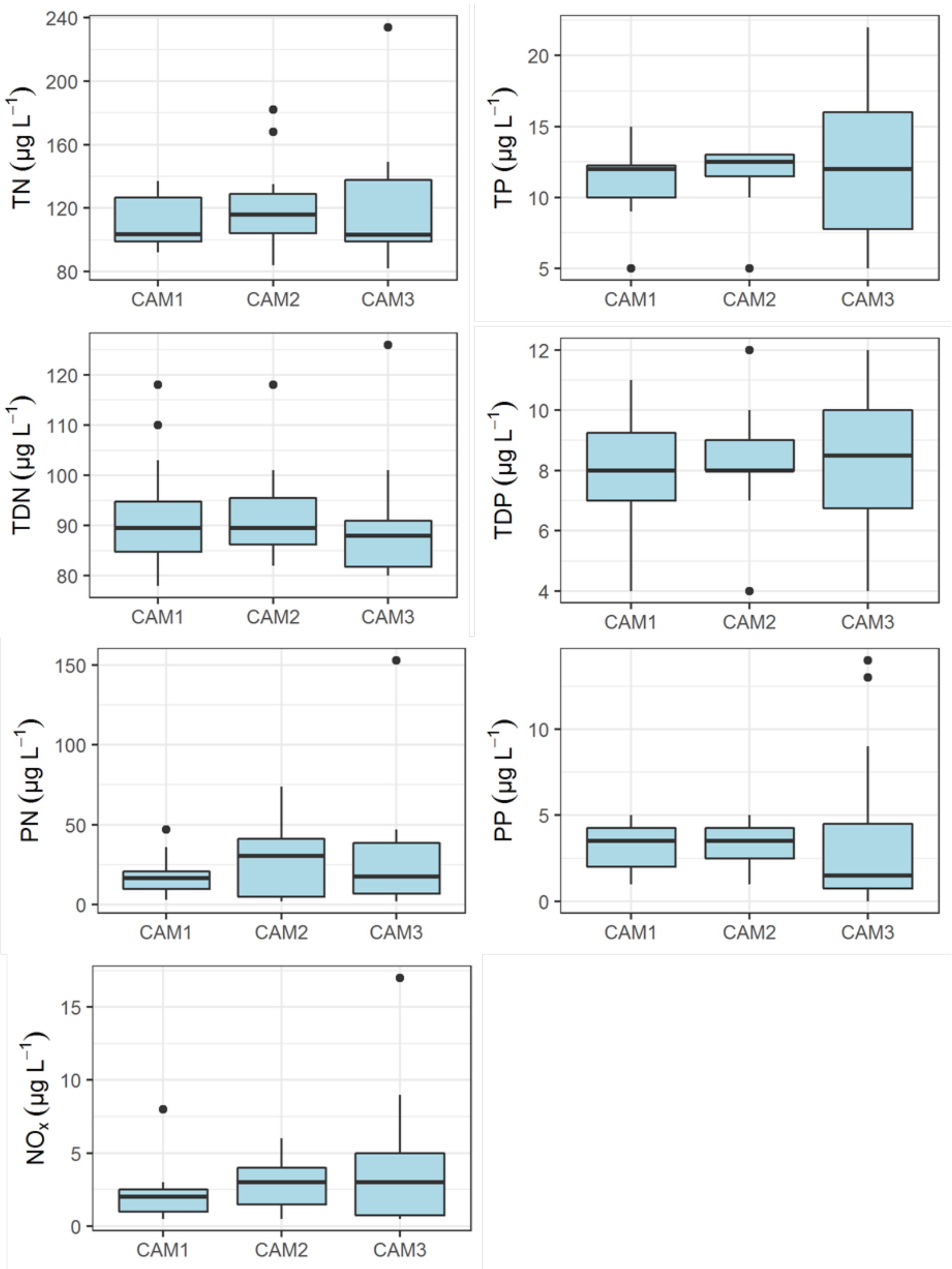

Figure 3.8 Total nitrogen (TN), total phosphorus (TP), total dissolved nitrogen (TDN), total dissolved phosphorus (TDP), particulate nitrogen (PN), particulate phosphorus (PP) and nitrate/nitrite (NO_x)

3.3 Multiparameter water quality

The multiparameter instrument deployed at the Aquila site (MKY_CAM1) measured water temperature, height, RMS water height, photosynthetically active radiation, turbidity, suspended sediment concentration, and depositional rate from September 2017 to August 2019. Data is missing around July 2018 due to technical problems with the logger.

3.3.1 Temperature

Water temperature ranged from 16.4 to 30.0 °C (median 25.7 °C) and primarily had a seasonal component, but also shorter term fluctuations most probably due to local oceanological conditions (i.e. upwelling, currents, weather) (Figure 3.9). The sharp spikes in temperature coincide with the 6-weekly logger maintenance trips where the instrument was briefly brought to the surface to download data and clean the instrument sensors.

Figure 3.9 Water temperature (°C) measurements at Aquila (MKY_CAM1) from September 2017 to August 2019.

3.3.2 Water depth and wave height

The water height above the instrument (sensu depth) ranged from 2.1 to 12.4 m (median 6.6 m) (Figure 3.10). Water height was primarily driven by tidal components, with the Mackay region experiencing macro-tidal conditions. Root mean square water height ranged from 0 to 0.35 m (median 0.01 m) (Figure 3.11)

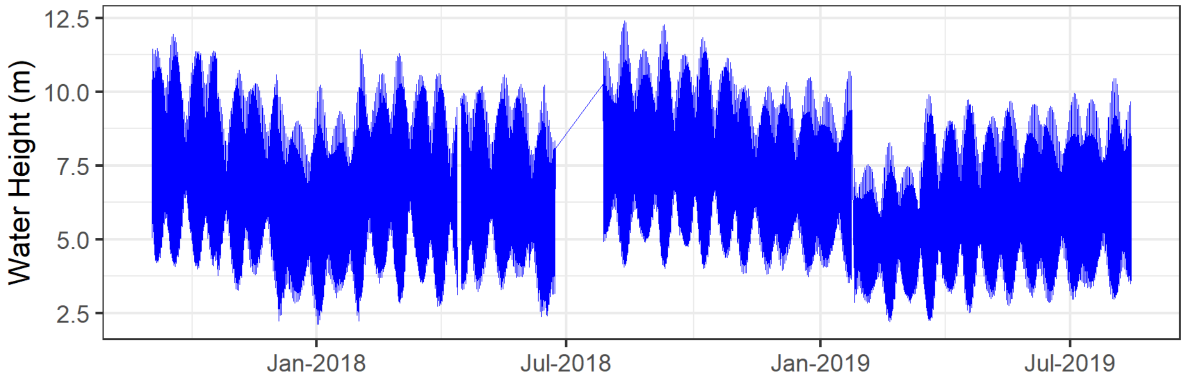

Figure 3.10 Water height (m) measurements at Aquila (MKY_CAM1) from September 2017 to August 2019.

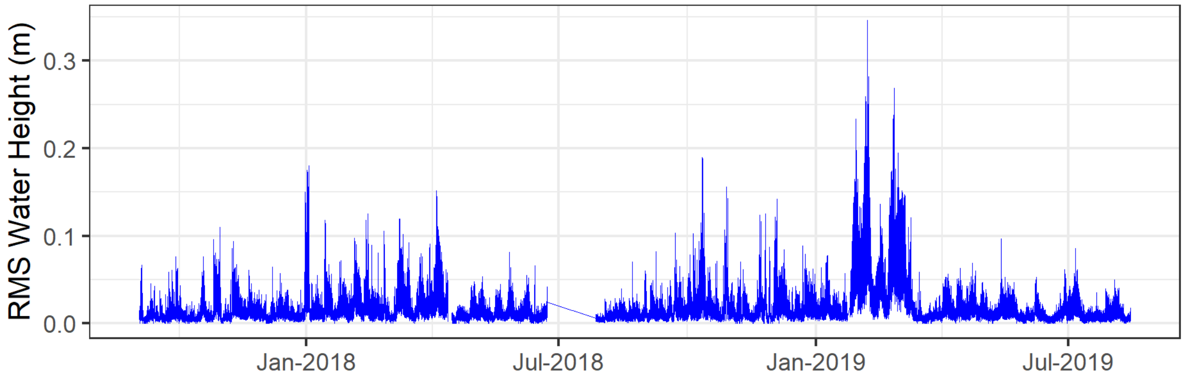

Figure 3.11 Root mean square water height (m) measurements at Aquila (MKY_CAM1) from September 2017 to August 2019.

3.3.3 Photosynthetically active radiation

Photosynthetically active radiation ranged from 0 (i.e. night-time) to 2050 µmol m^{-2} s^{-1} (Figure 3.12). The highest ambient light conditions in the benthic environment occurred during January and February 2019. The PAR measured in the benthic environment is influenced by time of day, weather conditions, and water attenuation which in turn is influenced by turbidity, suspended sediment concentration and the water depth at the time of measurement (which is heavily influenced by the stage in the tidal cycle).

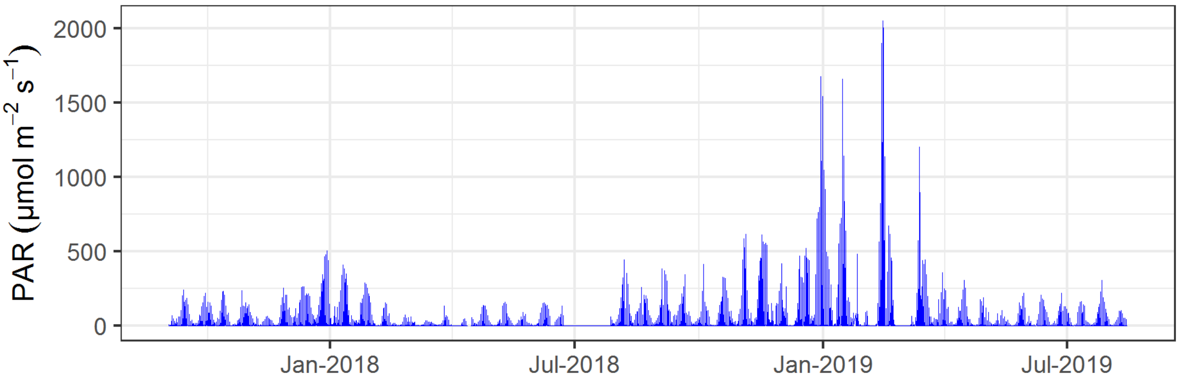

Figure 3.12 Photosyntically active radiation (µmol m^{-2} s^{-1}) measurements at Aquila (MKY_CAM1) September 2017 to August 2019.

3.3.4 Turbidity, suspended sediments, and sediment deposition

Turbidity levels measured in benthic habitat had a median value of 8.6 NTUe (Figure 3.13). Turbidity values commonly exceeded 50 NTUe. There was a certain amount of periodicity in turbidity values at the Aquila site (MKY_CAM1), which we attribute to primarily a physical response to tidal currents and water depth. Suspended sediment concentration at Aquilla (MKY_CAM1) derived from turbidity measurements is presented in Figure 3.14. The quantity of deposited sediment per 10 minute interval is presented in Figure 3.15. The maximum deposited sediment over a 10 minute period was 157.7 mg cm^{-2}. Deposition rates were elevated from April-September 2018, and from April 2019 onwards (Figure 3.15). These results indicate that there are seasonal drivers to sediment processes in the broader Mackay region (see Waltham et al., 2018). Turbidity and suspended sediment loads are highest during the wet season, likely due to increased catchment sediment loads entering the coastal ocean, biological production, and resuspension of sediments. Conversely, sediment deposition is generally highest throughout the dry season.

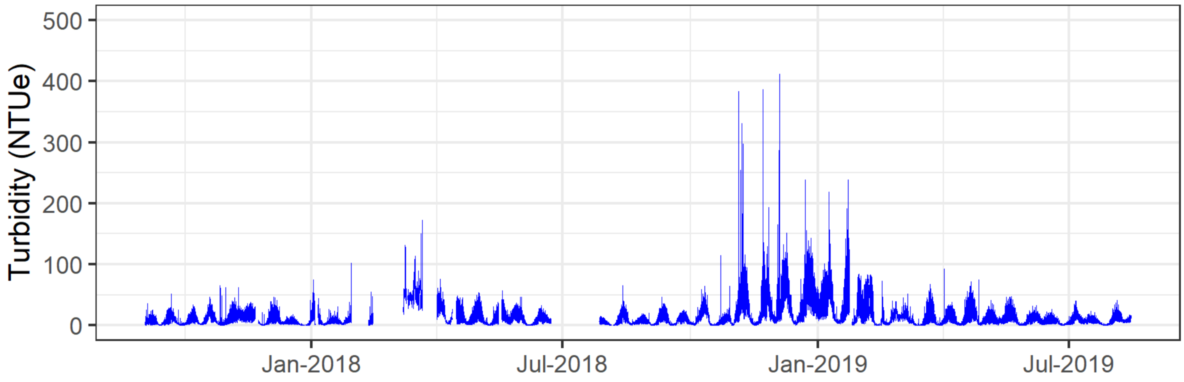

Figure 3.13. Turbidity (NTUe) measurements at Aquila (MKY_CAM1) from September 2017 to August 2019.

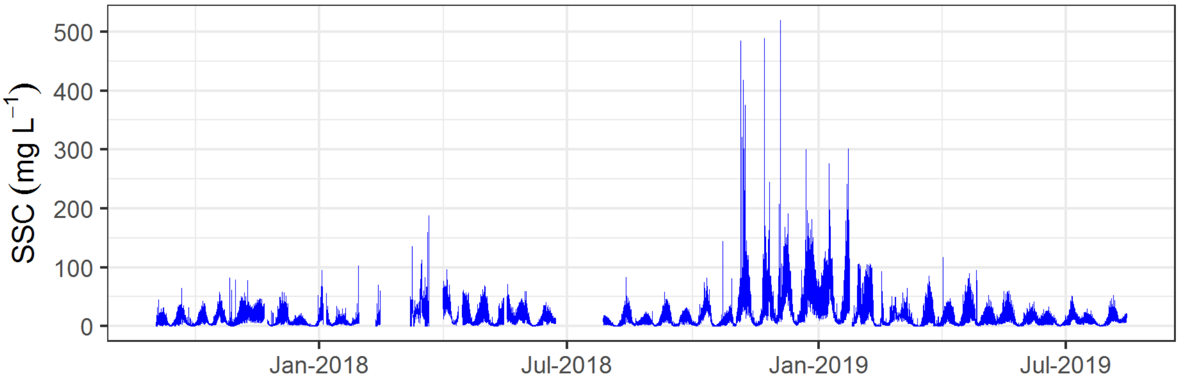

Figure 3.14 Suspended sediment concentration (mg L^{-1}) measurements at Aquila (MKY_CAM1) from September 2017 to August 2019.

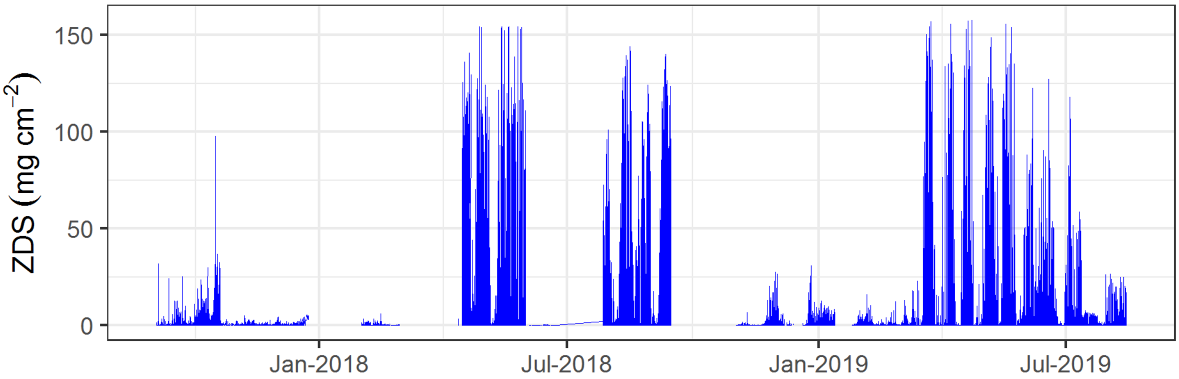

Figure 3.15 Sediment deposition (ZDS) (mg cm^{-2}) per 10 minute interval at Aquila (MKY_CAM1) from September 2017 to August 2019.

4 GENERAL CONCLUSIONS

4.1.1 Climatic conditions

- The 2018/19 survey period coincided with a slightly above average wet season for the region; future years could see lower or higher rainfall patterns which could contribute to very different results compared to these data here.

4.1.2 Ambient water quality

- The water column profile is well mixed for dissolved oxygen, temperature, electrical conductivity and pH. There also seems to be a strong seasonal pattern for water temperature, with highest temperatures recorded during the summer months, while winter months had much cooler conditions. There seems to be no similar seasonal pattern for dissolved oxygen, electrical conductivity and pH.
- Turbidity was generally higher at the bottom horizon, this pattern is probably related to the bottom horizon proximal to the sea floor and the effects of remobilised sediments. The elevated turbidity in the bottom horizon becomes an important consideration when examining sensitive receptor habitats. Corals and seagrass habitats are sensitive to water clarity changes, therefore measuring bottom horizon turbidity is a very relevant component of this program; surface measurements for turbidity, or indeed suspended solid concentrations, might not be an entirely relevant measure when the objective is to protect and enhance sensitive benthic habitats.
- Particulate nitrogen and phosphorus seem elevated above guideline values throughout this reporting period, and highlights the need for ongoing investigation to identify broader catchment landscape processes driving nutrient transport to the coastal ocean and enact effective management strategies.
- Chlorophyll-*a* concentrations continue to exceed regional guidelines, and are particularly high in summer months and when nutrient concentrations are also high.

4.1.3 Sediment deposition and turbidity

- Continuous sediment deposition and turbidity logging data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity along the coastline is driven by the re-suspension of sediment, 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.

4.1.4 Photosynthetically active radiation (PAR)

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

- Patterns of light were similar to coastal sites north around Mackay. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter. Therefore variation in depth at a location means benthic PAR is not directly comparable as a measure of water quality. Generally, however, from our experience shallow inshore sites reach higher levels of benthic PAR and are more variable compared to deeper water coastal sites.

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