Southern Mackay Ambient Marine Water Quality Monitoring Program: Annual Report 2022-2023

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Southern Mackay Ambient Marine Water Quality Monitoring Program: Annual Report 2022-2023

A Report for Healthy Rivers to Reef Partnership

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1 Introduction

1.1 Program outline

The Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University (JCU) has been commissioned to assist the Healthy Rivers to Reef Partnership to collect marine water quality data for the southern Mackay region as part of the Mackay-Whitsunday-Isaac regional report card. The report card is released each year, providing an overview of the health and condition of regional catchments, rivers, creeks, and nearshore habitats along this section of the Great Barrier Reef coastline. The information will be used to set strategic and collaborative management action plans to protect the regions marine, freshwater, and estuarine ecosystems. This report has been prepared for the 2022-2023 water quality monitoring period.

Figure 1.1: James Cook University research vessel 'Kasmira' enroute to Aquila Island ready to conduct water quality monitoring in the Southern Mackay region.

1.2 Background

Declining water quality in coastal and marine ecosystems is a major concern for the future of the Great Barrier Reef (GBR) (Brodie et al., 2019). While major impact events such as cyclones and marine heatwaves cause the most destruction to the reef, water quality is the primary determinant for both resilience and recovery of reef ecosystems in the face of these events (Lam et al., 2018; McNeil et al., 2019). Water quality risks to the GBR include an increased load of fine sediments, nutrients (nitrogen and phosphorous), and pesticides/herbicides that originate from diffuse agricultural and industrial sources throughout the catchments, and are discharged into the GBR lagoon (Waterhouse et al., 2017). Policies introduced to reduce discharge of land-based pollutants (e.g., Reef Water Quality Protection Plan Secretariat, 2013b) have to date shown little progress towards reversing the declining water quality trend and are unlikely to protect the GBR ecosystems within the aspired timeframes (Kroon et al., 2016). The poor water quality, exacerbated by extreme weather events, continues to be a major pressure on the GBR and will potentially worsen under climate change (Great Barrier Reef Marine Park Authority, 2014). The Reef 2050 plan (Queensland Government, 2018) contains a water quality theme with actions, targets and objectives to address these threats and enable timely and suitable responses to emerging issues and risks.

1.3 Program objectives

As the southern Mackay and Isaac coasts lie within the Great Barrier Reef region, the primary objective of the program is to characterise variability in water quality by monitoring a suite of key parameters to better define potential impacts to water quality. Along with regular monitoring of water quality parameters, an understanding of the meteorological and oceanographic (metocean) conditions that affect the regions coastal ecosystems is important in understanding seasonal and interannual variability in water quality. The extensive marine monitoring program implemented by TropWATER is designed to characterise the ambient water quality so that potential impacts to habitats can be identified. The partnership’s objective also moves beyond basic environmental stewardship and incorporates robust scientific research initiatives undertaken by leading researchers and specialists in marine water quality, coastal habitat, seagrass, coral ecology, and natural resource management. The long-term acquisition of data under the partnership presents an invaluable resource for understanding the interannual variability and climatic influences that drive water quality and ecological processes along coastal Queensland.

2 Methods

2.1 Regional Description

The southern Mackay and Isaac region is situated on the central Queensland Coast between Mackay and St Lawrence (Figure 2.1). There is an extensive agricultural presence along the coastal plain, interspersed by several creek systems that link to the marine environment. This section of the Queensland coastline is characterised by large tidal ranges (up to 8 metres) with the adjacent (to the south) Broad Sound and Shoalwater Bay marine areas being the largest shallow macro-tidal bays on Australia's east coast. Strong tidal currents are therefore a feature across this inshore region, often resulting in highly turbid water due to tidal resuspension of bottom sediments (Kleypas 1996). Despite the sediment load, the Northumberland Islands group within this region support a high cover of coral in both incipient (lacking a reef flat) and fringing reef systems (Cheal et al., 2001).

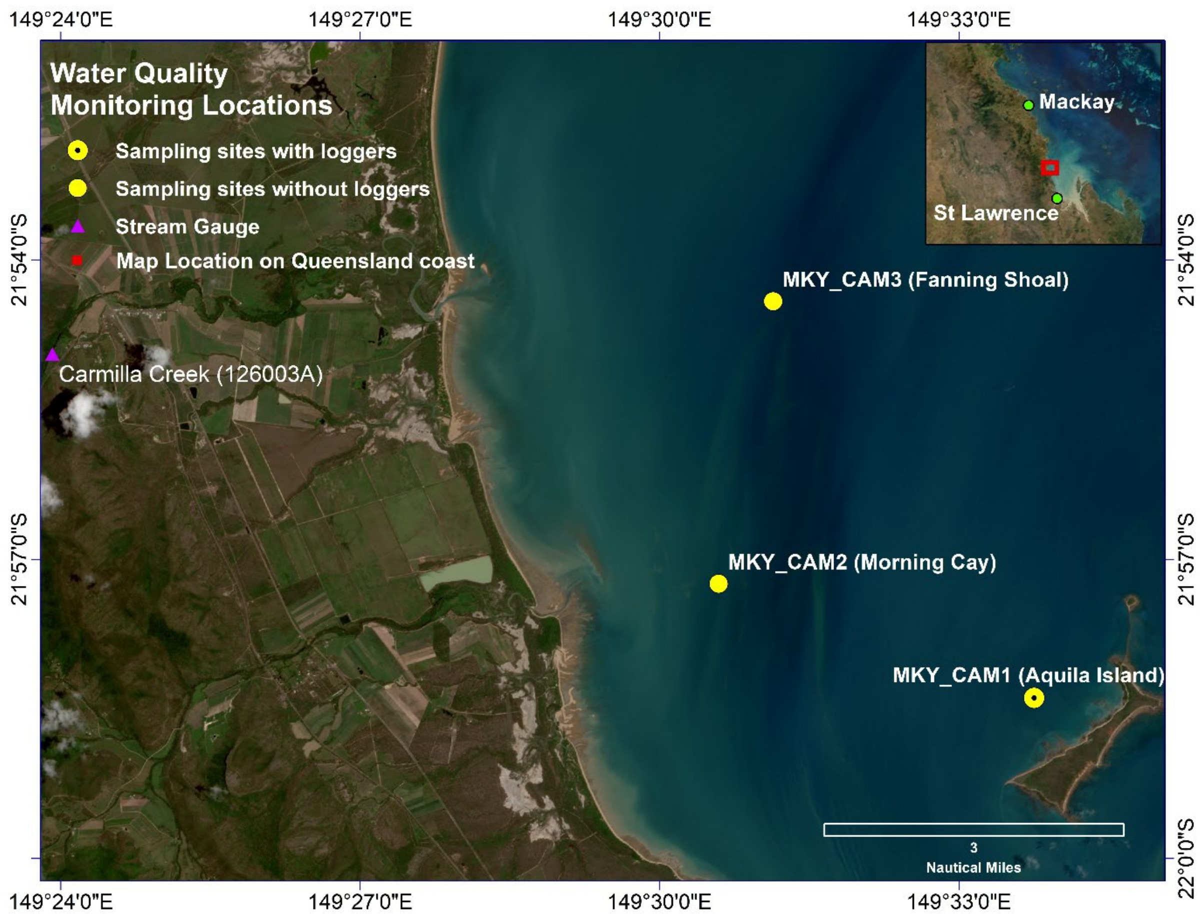

Figure 2.1. Map of the southern Mackay region where water quality monitoring locations (yellow circles), monitoring locations with loggers (yellow/black circle), and the stream gauge (purple triangle) referred to in this report, are located.

2.2 Characterisation of weather, hydrological status, and oceanographic conditions

Climate data for the region was extracted from the Australian Bureau of Meteorology climate data online tool (http://www.bom.gov.au/climate/data/). Total rainfall, rainfall onset date, along with wet season rainfall totals were calculated. The nominal wet season is defined as 1st November to 30th April. The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. Stream discharge data for streams discharging into the coastal waters of the region was extracted from the Queensland Government water monitoring information portal (https://water-monitoring.information.qld.gov.au/). Total discharge and date of first significant discharge event were calculated. The water year reported throughout is defined as 1st July to 30th June. Wave data for the region was extracted from Queensland Government open data portal (https://www.data.qld.gov.au/) comprising of the significant wave height (Hs), calculated as the average of the highest third of the waves in a recorded period (26.6 minutes), and the Peak Direction (which the waves are coming from), as recorded by the wave buoy located at Bailey Reef, 19 nautical miles offshore from Mackay Harbour. Note that this wave buoy is approximately 50 nautical miles north of the southern Mackay monitoring sites and may not be representative of the wave energy experienced at these sites, particularly when the wave direction is from a south-easterly direction, as the southern Mackay region is somewhat protected from this aspect by Cape Townshend and Stanage Point.

2.3 Monitoring and sampling design

The southern Mackay region has three active ambient marine water quality monitoring sites (Figure 2.1, Table 2.1) that were established in September 2017 as part of a broader regional program (see Waltham, Iles and Cartwright, 2022). Ambient water quality monitoring consisting of water samples that are laboratory analysed and spot measurements with a multiparameter instrument were conducted at all three sites approximately every 6-8 weeks (Table 2.2). One site (Aquila Island) also has a pair of data loggers deployed on the seafloor to continuously record environmental data. Regular change-out of loggers to perform sensor maintenance and download data from the instruments occurred in parallel with the water sampling. The sites were chosen to align with key sensitive receptor habitats (e.g., corals or seagrass), and key features in the study region (e.g. river flow points). Coral and seagrass receptor habitat assessments are available in companion reports on the TropWATER website (www.tropwater.com).

Table 2.1. Location of water quality monitoring sites in the Southern Mackay region.

Site name	Site code	Latitude	Longitude	Depth (m)	Loggers deployed
Aquila Island	MKY_CAM1	-21.97	149.55	9	Yes
Morning Cay	MKY_CAM2	-21.95	149.50	10	No
Fanning Shoal	MKY_CAM3	-21.90	149.52	11	No

Water samples were collected from 0.2 m below water surface by hand. Samples were collected for analytical determination of total nitrogen, total phosphorus, total dissolved nitrogen, total dissolved phosphorus, pH, salinity, electrical conductivity, total suspended solids, chlorophyll-*a* and phaeophytin-*a* (Table 2.3). Dissolved nutrient samples were filtered onsite with a 0.45 µm syringe filter (Sartorius minisart PES 0.45). TSS samples were collected in a 1 L bottle, Chlorophyll-*a* was collected in a dark 1 L bottle, pH and salinity were collected in a 60 mL vial. Water samples were stored on ice immediately and transported to the laboratory for analysis.

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

Table 2.2. Field dates in the 2022-23 reporting period for water sampling and water quality logger maintenance at the southern Mackay monitoring locations. Note that water quality logger is only at the Aquila Island (MKY_CAM1) site, while water sampling was conducted at all three sites.

Date	Water sampling	Logger maintenance
2022-06-16	Yes	Yes
2022-08-18	Yes	Yes
2022-10-11	Yes	Yes
2022-12-07	Yes	Yes
2023-02-01	Yes	Yes
2023-03-28	Yes	Yes
2023-05-26	Yes	Yes

Physiochemical parameters were measured at three depths in the water column with a multiparameter water quality meter (Hydrolab Quanta, Hydrolab CO, USA). The water quality meter records water temperature, electrical conductivity, pH, % saturation oxygen, and dissolved oxygen (Table 2.4). The three measurement depths were surface (0.25 m below surface), mid-water, and bottom (1 m above seafloor). Photosynthetically active radiation (PAR) was measured at the three depths, and above water with an underwater quantum sensor (LI-192) and light meter (LI-250A) (Licor Biosciences, Nebraska USA). Care was taken to measure PAR without interference of boat shadow or sporadic cloud cover, though the latter was occasionally unavoidable.

Water clarity as measured with a Secchi disk was recorded at each site at the time of water sampling. A Secchi disk was lowered to a depth where it is no longer visible then raised back to depth where it becomes visible again. The mean depth between those two points was then recorded as Secchi disk depth.

Table 2.3. Water quality parameters that were analysed using water samples collected at three locations, Aquila Island, Morning Cay and Fanning Shoal, and the methods and reporting limits of the laboratory analysis.

Parameter	APHA method number	Reporting limit
Routine water quality analysis		
pH	4500-H+ B	-
Salinity	2520 B	0.1 PSU
Electrical conductivity (EC)	2510 B	5 µS cm^{-1}
Total Suspended Solids (TSS)	2540 D @ 103 - 105°C	0.2 mg L^{-1}
Nutrients		
Total nitrogen (TN)	Simultaneous 4500-NO_3- F and 4500-P F analyses after alkaline persulphate digestion	10 µg N L^{-1}
Total dissolved nitrogen (TDN)		
Total phosphorus (TP)		1 µg P L^{-1}
Total Dissolved phosphorus (TDP)		
Particulate nitrogen (PN)	Calculated as PN = TN - TDN	-
Particulate phosphorus (PP)	Calculated as PP = TP - TDP	-
Nitrogen oxides (NO_x)	4500-NO_3 - F	1 µg N L^{-1}
Chlorophyll		
Chlorophyll-a	10200-H	0.2 µg L^{-1}
Phaeophytin-a		

Table 2.4. Physiochemical measurements that were collected at three locations, Aquila Island, Morning Cay, and Fanning Shoal.

Parameter	Units
Multiparameter water quality meter	
Water temperature	Degrees Celsius (°C)
Electrical conductivity (SpC)	mS cm^{-1}
pH	
Dissolved Oxygen	%sat
Dissolved Oxygen	mg L^{-1}
Light meter	
Photosynthetically active radiation (PAR)	µmol m^{-2} s^{-1}
Water clarity	
Secchi disk depth	Meters (m)

2.4 Pesticide monitoring

Passive samplers were deployed at Aquila Island (MKY_CAM1) for pesticide monitoring over the wet season (Figure 2.2, Table 2.5). Each set of passive samplers contained an Empore™ SPE disk (ED), and a passive flow monitor (PFM). Passive samplers were supplied and analysed by Queensland Alliance for Environmental Health Sciences (QAEHS) at The University of Queensland. Samplers were extracted and the extract then analysed by liquid chromatography mass spectrometry (LCMS) for polar pesticides. An additional 10% samplers were deployed, extracted, and analysed for QA/QC purposes, which also included lab and field blanks, duplicates, and matrix recovery spikes. Water concentration estimates (either time weighted average or point in time) were calculated where possible, otherwise mass loads per sampler are given. Water concentration estimates are derived by applying sampling rates from calibration studies to the amount of analyte accumulated by the sampler. The twenty-two herbicides and insecticides used to calculate pesticide risk metrics (ms-PAF) are listed in Table 2.6.

Figure 2.2. Pesticide monitoring passive samplers were deployed at Aquila Island (MKY_CAM1) throughout the wet season. Empore disk (ED) samplers and passive flow monitors (PFM) pictured being prepared for deployment.

Table 2.5. Pesticide passive samplers deployed at Aquila Island (MKY_CAM1) during the 2021-2022 wet season.

Deployment	Site name	Site code	Start date	End date	Duration (days)
1	Aquila Island	MKY_CAM1	2022-10-26	2022-12-07	42
2	Aquila Island	MKY_CAM1	2022-12-07	2023-02-01	56
3	Aquila Island	MKY_CAM1		Lost sampler	
4	Aquila Island	MKY_CAM1	2023-03-28	2023-05-26	59

Table 2.6. Pesticide analytes used for ms-PAF calculations to determine the pesticide risk baseline. Column two shows the type of pesticide - photosystem-two inhibiting herbicide (PSII), other herbicide (OH), and insecticide (I).

Analyte	Type	Detection method	Limit of reporting (LOR)
2,4-D	OH	ED	5 ng sampler^{-1}
Ametryn	PSII	ED	5 ng sampler^{-1}
Atrazine	PSII	ED	1 ng sampler^{-1}
Diuron	PSII	ED	1 ng sampler^{-1}
Fipronil	I	ED	5 ng sampler^{-1}
Fluroxypyr	OH	ED	1 ng sampler^{-1}
Haloxyfop	OH	ED	1 ng sampler^{-1}
Hexazinone	PSII	ED	1 ng sampler^{-1}
Imidacloprid	I	ED	1 ng sampler^{-1}
MCPA	OH	ED	5 ng sampler^{-1}
Metolachlor	OH	ED	1 ng sampler^{-1}
Metribuzin	PSII	ED	1 ng sampler^{-1}
Metsulfuron-methyl	OH	ED	1 ng sampler^{-1}
Pendimethalin	OH	ED	5 ng sampler^{-1}
Prometryn	PSII	ED	1 ng sampler^{-1}
Simazine	PSII	ED	1 ng sampler^{-1}
Tebuthiuron	PSII	ED	1 ng sampler^{-1}
Terbuthylazine	PSII	ED	1 ng sampler^{-1}

2.5 Seafloor mounted continuous dataloggers

A pair of water quality loggers were deployed at Aquila Island (MKY_CAM1) to measure water temperature, water depth, turbidity, and light. The loggers were attached to stainless steel frame to be placed on the seafloor (Figure 2.3). The loggers used are NTU-LPT and MS9-LPT loggers manufactured by In-situ Marine Optics, Perth WA (https://insitumarineoptics.com). The loggers record a burst of 50 measurements of water temperature (°C), water depth (m), turbidity (NTU), and light (PAR, µmol m^{-2} s^{-1}) at a frequency of 5 Hz every 10-minutes.

Figure 2.3. Water quality loggers attached to instrument frames ready for deployment to the seabed. The horizontally orientated logger is an NTU-LPT turbidity logger, and the vertically orientated logger is a MS9-LPT multispectral light logger manufactured by In-situ Marine Optics.

Table 2.7. Specifications of NTU-LPT turbidity logger and MS9-LPT multispectral light loggers.

Parameter	Units	Sensor range	Accuracy / Resolution
Water temperature	Degrees Celsius (°C)	-55 to 125 °C	+/- 1.0 °C
Water depth	Meters (m)	0 – 90 m	+/- 1.0 %
Turbidity	Nephelometric turbidity units (NTU)	0 – 400 NTU	0.05 NTU
Irradiance	µW cm^{-2} nm^{-1}	0 – 400 µW cm^{-2} nm^{-1}	2.5 x 10^{-3} W cm^{-2} nm^{-1}

Logger data processing

After each deployment, dataloggers are returned to the laboratory and their logfiles downloaded. The mean values for water temperature, water depth, turbidity and irradiance were calculated for each 10-minute burst interval.

RMS Depth

A pressure sensor is located on the MS9-LPT 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. The average water depth and Root Mean Square (RMS) water depth can be used to analyse the influence that tide and water depth may have on turbidity, deposition, and light levels at an instrument location. The RMS water height is a measure of short-term variation in pressure at the sensor. Changes in pressure over a 10 second time-period at the sensor are caused by wave energy. RMS water height can be used to analyse the link between wave re-suspension and SSC. It is important to clearly establish that RMS water height is not a measurement of wave height at the sea surface. What it does provide is a relative indication of wave shear stress at the sea floor that is directly comparable between sites of different depths. For example, where two sites both have the same surface wave height, if site one is 10 m deep and has a measurement of 0.01 RMS water height and site two is 1m deep and has a measurement of 0.08 RMS water height. Even though the surface wave height is the same at both sites, the RMS water height is greater at the shallower site, and we would expect more re-suspension due to wave shear stress at this site.

Each time a pressure measurement is made the pressure sensor takes 50 measurements over a period of 10 seconds. From these 50 measurements, average water depth (m) and Root Mean Square (RMS) water height are calculated. RMS water height, D_{rms}, is calculated as follows:

$$RMS_{depth} = \sqrt{\frac{\sum_{n=1}^{N}(D_n - \bar{D})^2}{N}} \qquad \text{[Equation 1]}$$

Where D_n is the n_{th} of the 50 readings and $\bar{D}$ is the mean water depth of the n readings.

bPAR

Benthic photosynthetically active radiation (bPAR) was calculated from the response of the nine individual irradiance channels on the MS9 logger. Light data between 400 and 700 nm was interpolated and integrated internally. The mean value for bPAR was calculated for each 10-minute burst interval. Daily light integral (DLI) describes the number of photosynthetically active photons that are delivered to a specific area over a 24-hour period. Daily light integral (DLI) was calculated as follows:

$$DLI = \sum_i bPAR_i * \frac{600}{1000000} \qquad \text{[Equation 2]}$$

Where:

DLI is the daily light integral in mol photons m^{-2} d^{-1}

i is each bPAR reading during the day

bPAR is the benthic photosynthetically active radiation in µmol photons m^{-2} s^{-1}

600 is the time interval between readings

1,000,000 is the unit conversion

Suspended Sediment Concentration

Suspended sediment concentration was calculated from turbidity data after establishing a relationship with each site. Full methods are provided in (Cartwright, Iles, Mattone, O'Callaghan, & Waltham, 2022). The following equation may be used to calculate suspended sediment concentration from logger data acquired from IMO-NTU turbidity loggers at each site:

$$SSC = Turb * Cf \pm e \qquad \text{[Equation 3]}$$

Where:

SSC is the calculated suspended sediment concentration in mg L^{-1}

Turb is the measured turbidity value in NTU

C_f is the conversion factor (unique for each site)

e is the root mean square error value

Note that error values are not presented in the converted data values.

Quality control

During logger processing the data is passed through automatic and manual quality control steps to flag data. The automated QC steps are rule-based tests. Manual QC follows the automated steps to catch anything missed or which is difficult for machine to detect. A concise description of rules for flagging data is in Appendix 1. More detail of the data processing workflow and quality control procedures is contained in a separate document (Iles, Cartwright, Johns, & Waltham, 2023).

Statistical summaries for each water quality parameter measured are provided in the results section. Annual values (mean, median, minimum, maximum) are calculated over the twelve-month period corresponding to both the water year and reporting period (July 2022 to June 2023). Data collected over the monitoring period has been compared to the Pioneer River and Plane Creek Basins Environmental Values and Water quality objectives (EPP, 2019). The three Southern Mackay sites are in water area/type SD2383 open coastal waters (including macrotidal) landward of the plume line, shown in WQ1222 (s3, s4).

3 Results and Discussion

3.1 Rainfall and river flows

Daily rainfall for the Mackay region is shown on Figure 3.1. The first rainfall greater than 5 mm for the water year occurred on 3rd September 2021, with the rainfall onset occurring on 4th October 2022. The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. The 2022-2023 wet season rainfall total was 1394 mm, while total rainfall for the water year was 1673 mm (Figure 3.2). This is slightly higher than the annual median rainfall calculated since 1910.

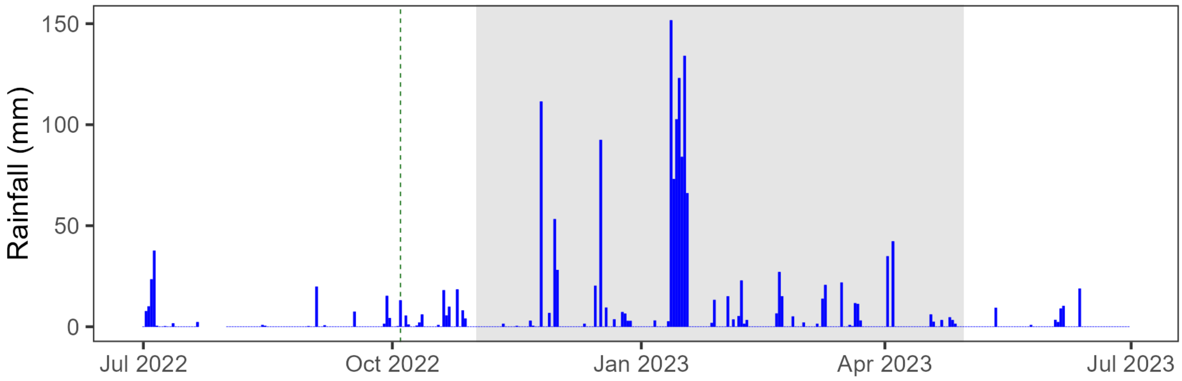

Figure 3.1. Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the 2021-2022 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

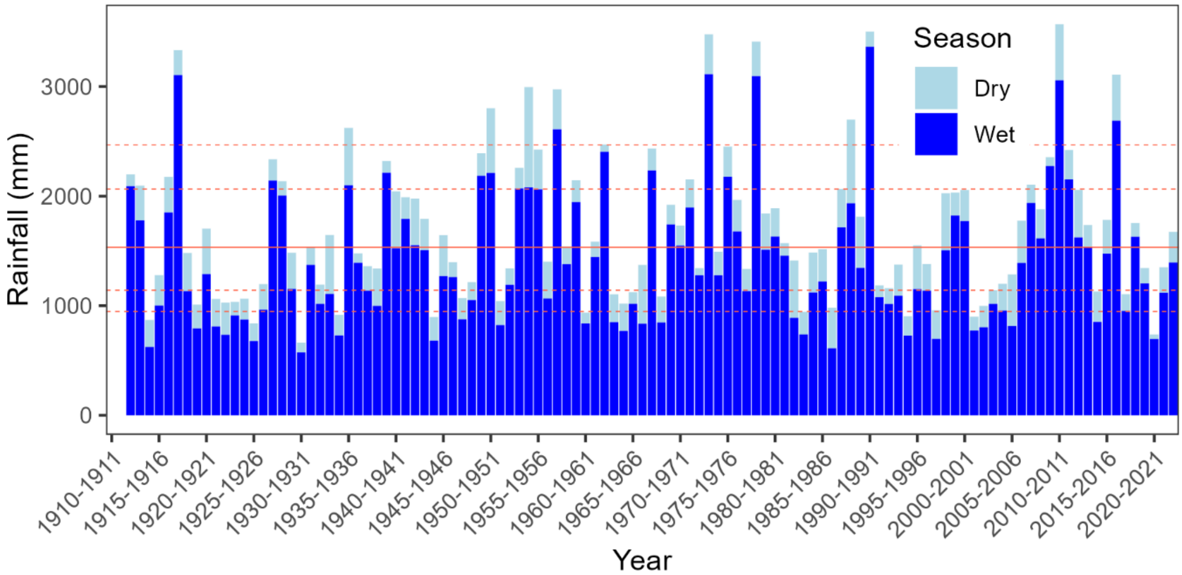

Figure 3.2. Annual rainfall by water year for the Mackay region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 30th April for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Daily rainfall data was obtained from the Plane Creek Sugar Mill (station 033059). Data source: http://www.bom.gov.au/climate/data/

The Hydrograph for Carmila Creek shows a small discharge event mid-January 2023 (Figure 3.3). Carmila Creek is a small catchment compared to the Pioneer River and Sandy Creek further north up the coast. Hydrographs for streams in the Pioneer Basin (Pioneer River) and Plane Basin (Sandy Creek) show the largest stream discharge event of the reporting period starting on 12th January 2023 with a series of flow pulses through to March 2020. There were smaller but notable discharge events on 5th July 2022 and 21st March 2023. Total discharge for the 2022-2023 reporting period was 47.8 GL (Carmila Creek), 711.1 GL (Pioneer River) and 181.7 GL (Sandy Creek).

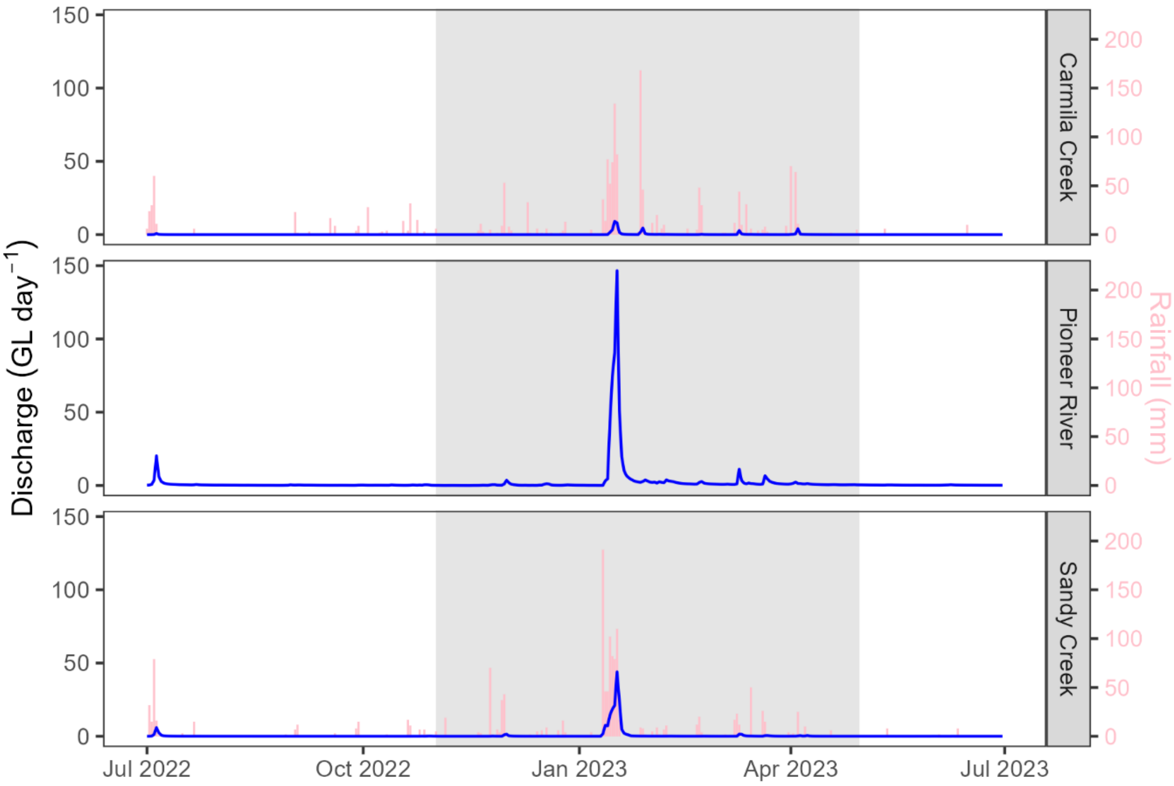

Figure 3.3. Stream discharge (GL d^{-1}) recorded for Carmila Creek (station 126003A) along with the Pioneer River (station 125007A) and Sandy Creek (station 126001A) to the North during the 2022-2023 reporting period. The nominal wet season period is shaded grey. Rainfall data from the Carmila and Sandy Creek gauging stations are also shown in pink. Data source: https://water-monitoring.information.qld.gov.au/

3.2 Oceanographic conditions

Waves detected offshore from Mackay were predominantly 0.7 to 2 m in height and from a south-easterly direction (Figure 3.4). September 2022 showed the lowest wave activity of the year while February and April 2023 displayed the largest significant wave heights during the 1st July 2022 to 30th June 2023 period (Figure 3.5). Note: this wave buoy is approximately 50 nautical miles north of the southern Mackay monitoring sites and may not be representative of the wave energy experienced at these sites, particularly when the wave direction is from a south-easterly direction, as the southern Mackay region is somewhat protected from this aspect by Cape Townshend and Stanage Point.

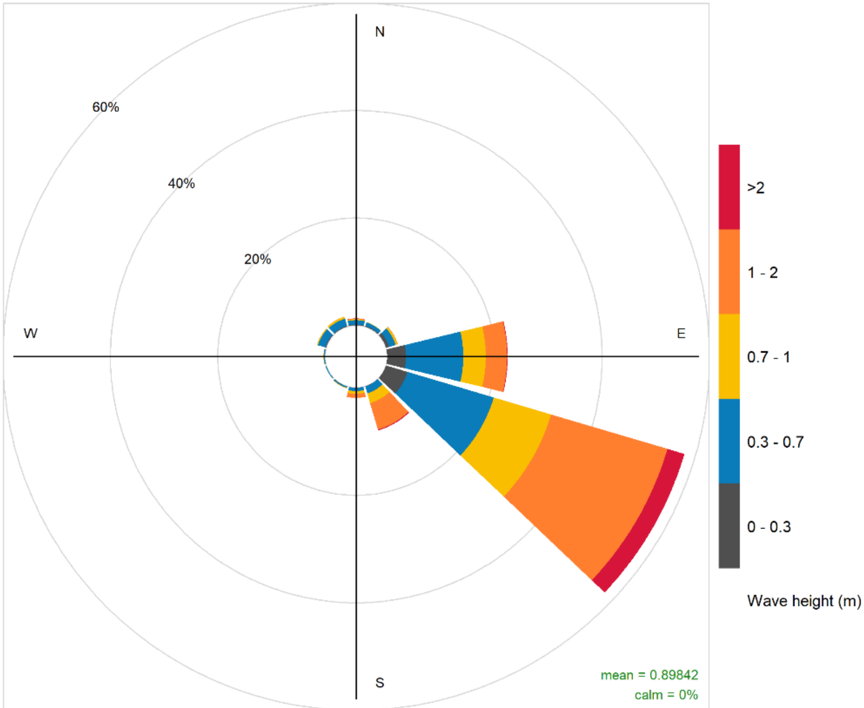

Figure 3.4. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between 1st July 2022 and 30th June 2023. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

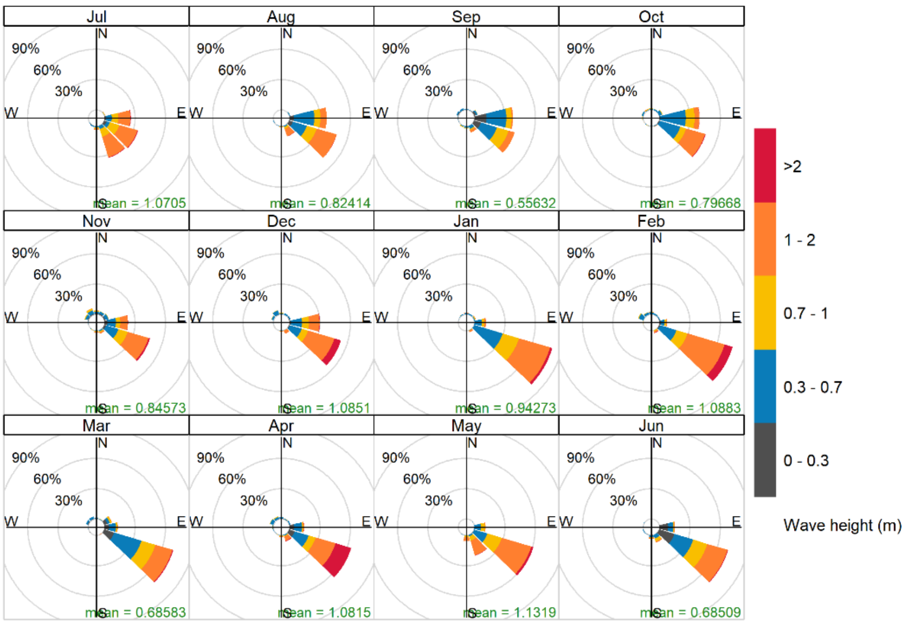

Figure 3.5. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between 1st July 2022 and 30th June 2023. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

Sea Surface Temperatures (SST) were warmer than average during 2023, with the Mackay region also experiencing a record annual mean daily maximum air temperature of 27.7 °C (http://www.bom.gov.au/climate/).

3.3 Water quality

3.3.1 Physiochemical

Physiochemical profiling was conducted at each water quality site numerous times throughout the year coinciding with logger changeovers. Results has been compared to EPP water quality objectives (WQO) for SD2383.

Dissolved oxygen (DO) concentrations at the water quality monitoring sites ranged from 5.64 to 9.25 mg L^{-1} with a mean value of 6.48 mg L^{-1} over the reporting period. DO concentrations were similar between sites and across the three depths on each sampling occasion, with a slight trend of higher DO in the winter months and lower DO in the summer evident (Figure 3.6). There were some higher DO concentrations in surface waters compared to mid- and bottom- waters in October 2022. The conditions reported on the field datasheet at the time of measurement were choppy and 15 knot winds. Hence, higher surface DO at this time was most likely due to diffusion of atmospheric oxygen via wind and wave mixing. DO was generally within acceptable WQO range (95 - 105 %sat) throughout the year, except event measurements in early-February 2023 and late-May 2023 where DO (%sat) was below the WQO lower limit. The annual mean DO across all sites was 94.5 %sat which is marginally below the WQO lower limit of 95 % sat.

Electrical conductivity (EC) at the three locations ranged from 51.3 to 56.1 mS cm^{-1} with an annual mean of 54.3 mS cm^{-1} and was in the range typical of seawater (Figure 3.7). There was little difference in EC values throughout the water column, indicating the waters were well mixed. The slightly lower EC values measured in February 2023 are most likely due to dilution effect from the rainfall and river discharge events which occurred mid-January.

Water temperature ranged between 19.4 and 28.6 °C with an annual mean of 24.5 °C (Figure 3.8). 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 cooler water temperatures observed during the winter months. Water temperature was generally similar throughout the vertical water column profiles at all sites, indicating that the water column is well mixed throughout the region. There was a weak thermal gradient present in March 2023 with surface waters slightly warmer than bottom waters at this time.

pH values ranged between 8.15 and 8.28 with an annual mean of 8.21 across all sites throughout the year (Figure 3.9). Unfortunately, pH values measured in the field during several sampling events over the reporting year were deemed unreliable due to sensor malfunction and suspected poor calibration while conducting quality control and removed from the dataset, however, pH is also measured on surface water samples collected for lab analysis so we have presented these alongside the field measurements on Figure 3.9.

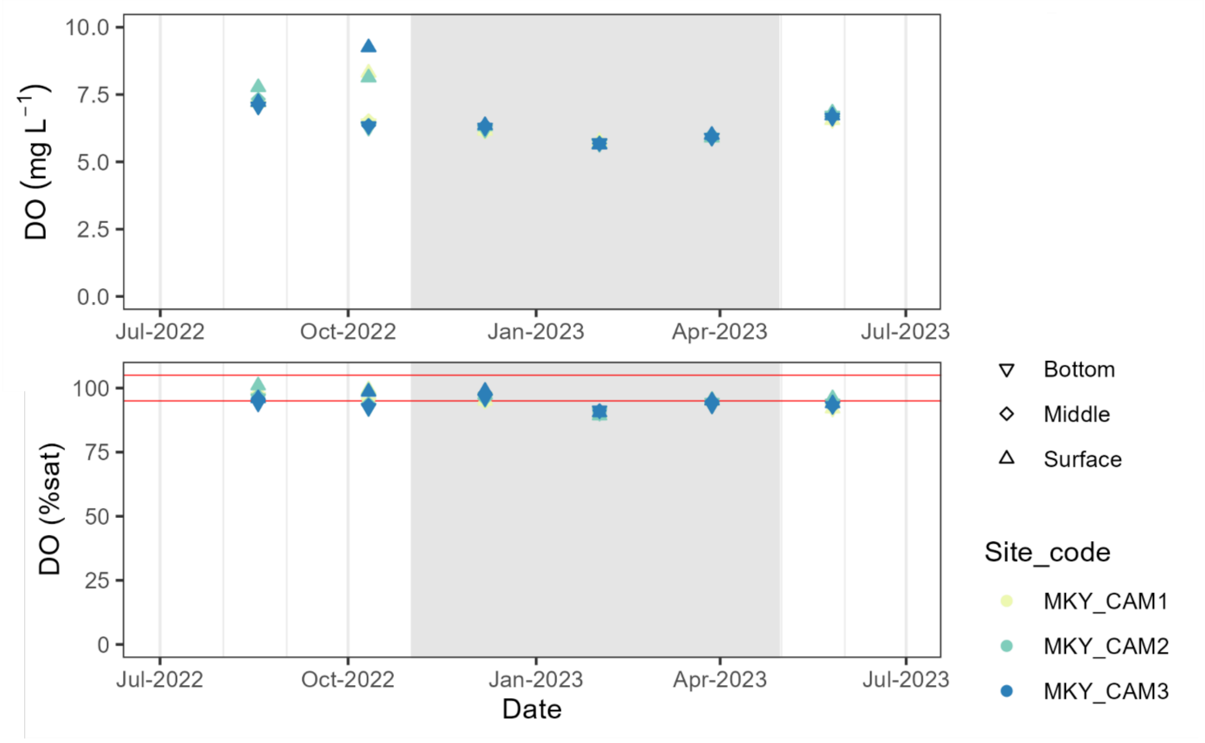

Figure 3.6. Dissolved oxygen concentration (mg L^{-1}) and percent saturation (%sat) at three water quality monitoring sites in the southern Mackay region showing results for the surface, middle, and bottom water. Horizontal red lines represent EPP 2019 WQO lower and upper limits.

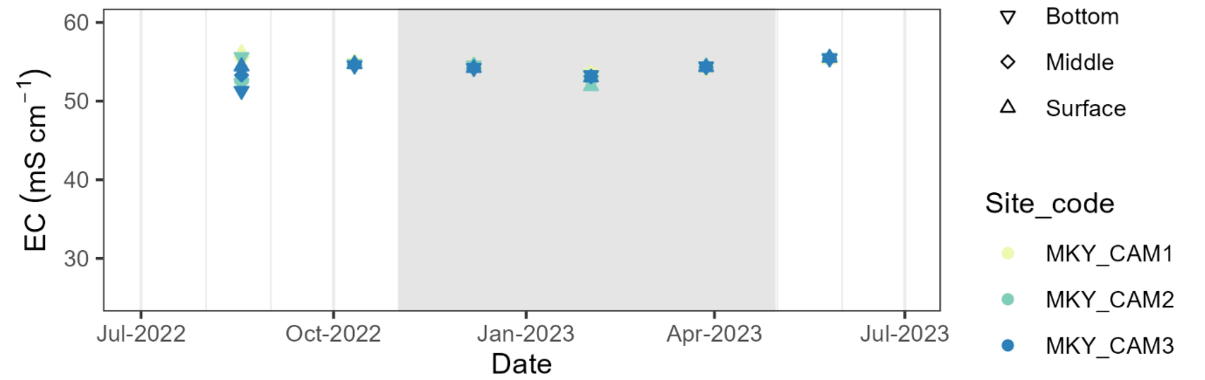

Figure 3.7. Electrical conductivity recorded at three water quality sites in the southern Mackay region showing results for the surface, middle, and bottom water.

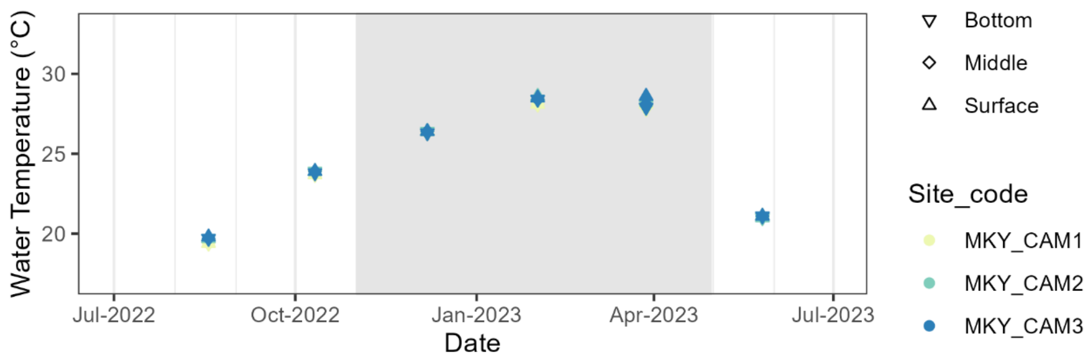

Figure 3.8. Water temperature recorded at three water quality sites in the southern Mackay region showing results for the surface, middle, and bottom water.

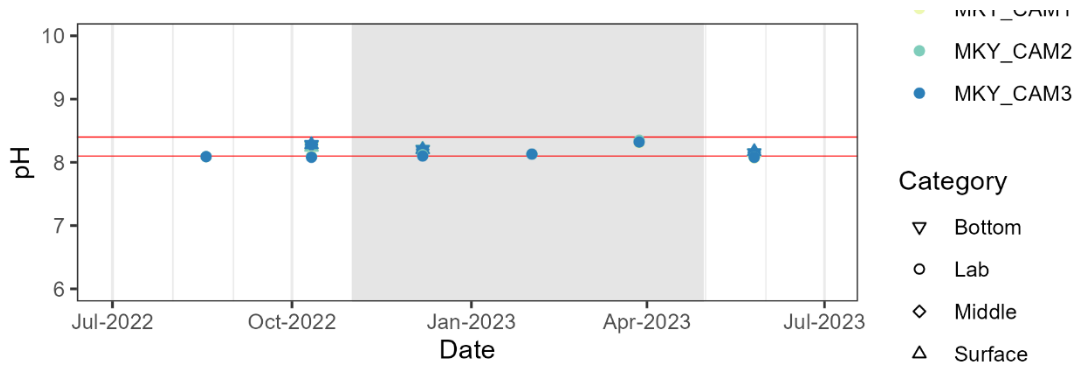

Figure 3.9. pH recorded at three water quality sites in the southern Mackay region showing results for the surface, middle, and bottom water (field measurements) and from water samples (lab measurements). Horizontal red lines represent EPP 2019 WQO lower and upper limits.

3.3.2 Nutrients

Nitrogen concentrations measured in water samples collected from the three Southern Mackay water quality sites are shown in Figure 3.10. Total nitrogen (TN) concentrations ranged from 107 to 169 µg L^{-1}. Median TN was 147 µg L^{-1} and exceeded the WQO 80th percentile of 115 µg L^{-1}. Total dissolved nitrogen (TDN) concentrations ranged from 90 to 134 µg L^{-1}. Median TDN was 110 µg L^{-1} and exceeded the WQO 80th percentile of 95 µg L^{-1}. Particulate nitrogen (PN) concentrations ranged from 12 to 52 µg L^{-1}. Mean PN across the three sites was 29.7 µg L^{-1}. The mean PN exceeded the aquatic ecosystem water quality objective of ≤ 20 µg L^{-1} (ann. mean). PN exceeded the WQO's in both the dry and wet seasons. The mean dry season PN = 30.1 µg L^{-1} and WQO dry season mean = 16 µg L^{-1}. The mean wet season PN = 29.3 µg L^{-1} and WQO wet season mean = 24 µg L^{-1}. Oxidised nitrogen (NO_x) concentrations ranged from <1 to 4 µg L^{-1}. Median NO_x was 1.5 µg L^{-1} and exceeded the WQO 80th percentile of 0.88 µg L^{-1}.

Phosphorus concentrations measured in water samples collected from the three Southern Mackay water quality sites are shown in Figure 3.11. Total phosphorus (TP) concentrations ranged from 5 to 17 µg L^{-1}. Median TP was 11 µg L^{-1} and exceeded the WQO 20th percentile of 6 µg L^{-1} but was below the 50th and 80th WQO percentiles. Total dissolved phosphorus (TDP) concentrations ranged from 3 to 11 µg L^{-1}. Median TDP was 7 µg L^{-1} and exceeded the WQO 20th percentile of 4 µg L^{-1} but was below the 50th and 80th WQO percentiles. Particulate phosphorus (PP) concentrations ranged from 1 to 10 µg L^{-1}. Mean PP across the three sites was 4.1 µg L^{-1}. The mean PP exceeded the aquatic ecosystem water quality objective of 2.8 µg L^{-1} (ann. mean). PP exceeded the WQO's in both the dry and wet seasons. The mean dry season PP = 3.9 µg L^{-1} and WQO dry season mean = 2.3 µg L^{-1}. The mean wet season PP = 4.3 µg L^{-1} and WQO wet season mean = 3.3 µg L^{-1}.

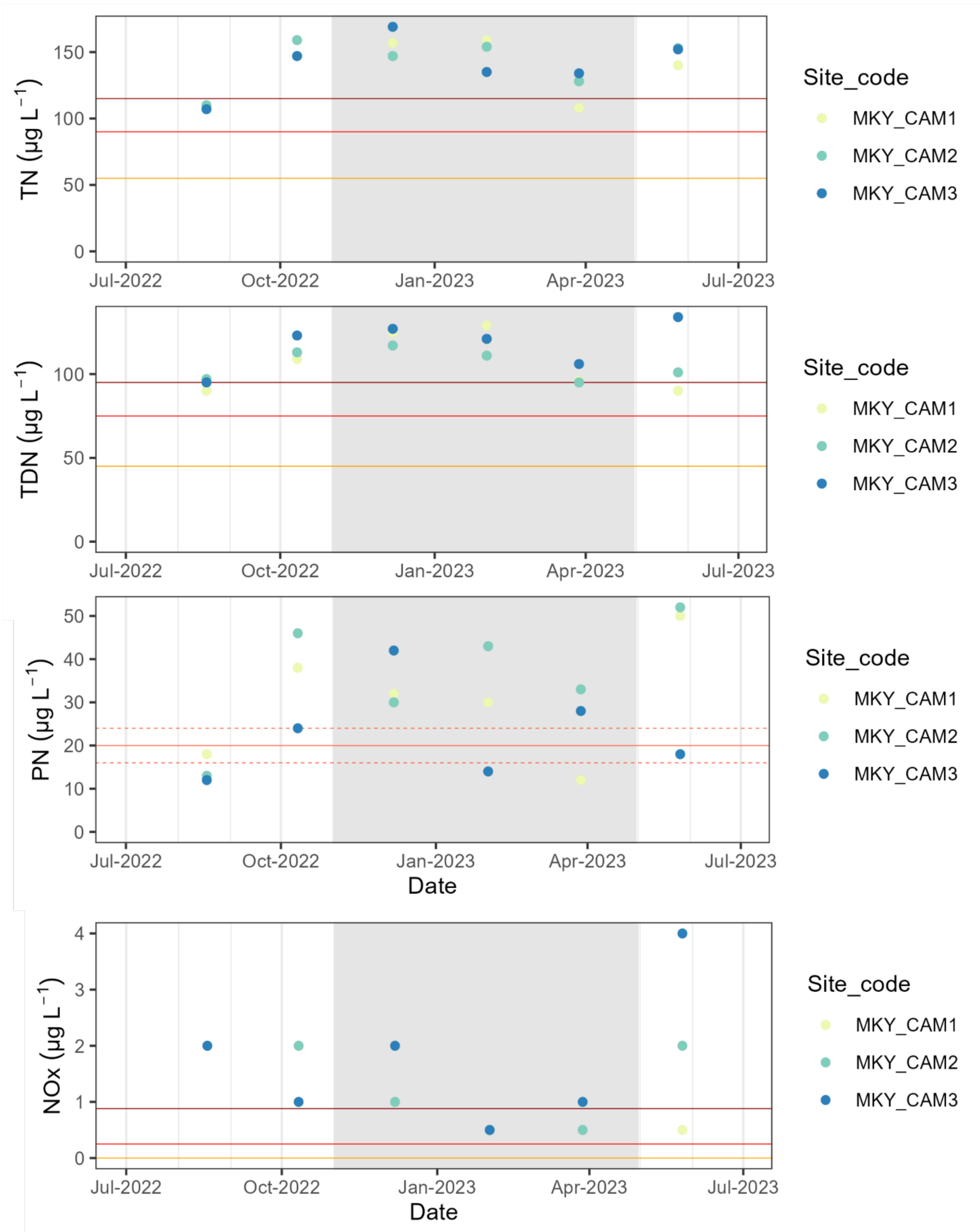

Figure 3.10. Total Nitrogen (TN), Total Dissolved Nitrogen (TDN), Particulate Nitrogen (PN), and Oxidised nitrogen (NO_x) concentrations measured in water samples collected from the three Southern Mackay water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Horizontal lines represent EPP 2019 WQO 20th (orange), 50th (red) and 80th (dark red) percentiles. Horizontal red line on PN panel represents EPP 2019 WQO annual (solid red line), dry season and wet season (dashed red line) means. Note unequal y-axis.

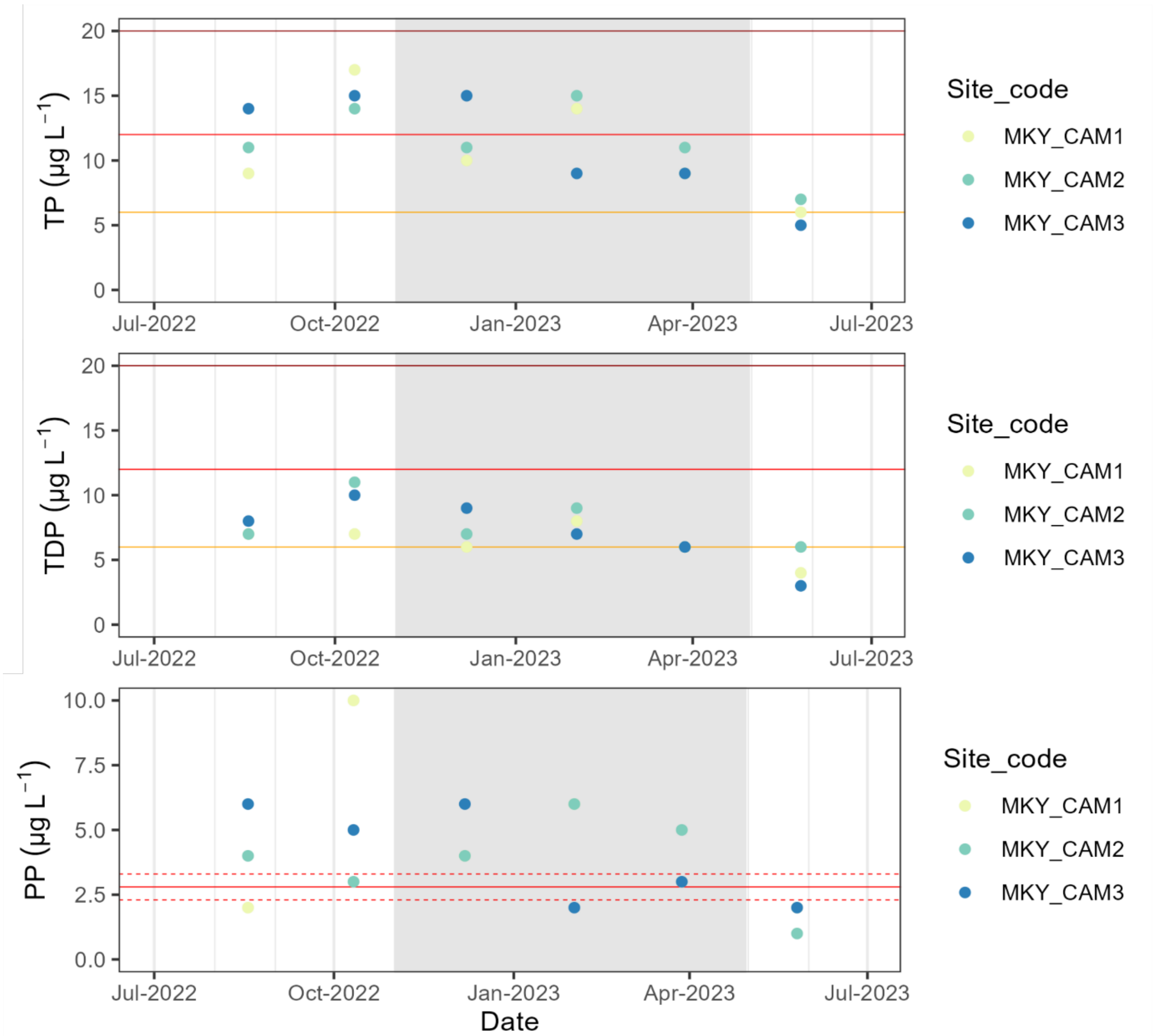

Figure 3.11. Total Phosphorus (TP), Total Dissolved Phosphorus (TDP), and Particulate Phosphorus (PP) concentrations measured in water samples collected from the three Southern Mackay water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Horizontal lines represent EPP 2019 WQO 20th (orange), 50th (red) and 80th (dark red) percentiles. Horizontal red line on PP panel represents EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means. Note unequal y-axis.

3.3.3 Water clarity

Secchi depth ranged from 1.0 m to 4.0 m with a mean of 2.3 m over the reporting period (Figure 3.12). Water clarity as measured by Secchi disk depth was poorest in October 2022. Water clarity at the three sites is generally well below (exceeds) the water quality objectives (Secchi depth ≥ 8m (ann. mean). Water clarity is generally poor at the Southern Mackay sites due to the regions predominantly sand-mud substrate, strong tidal currents, and shallow water depth leading to sediment resuspension. Water clarity is typically best during neap tides and poorest during spring tides when tidal currents are strongest.

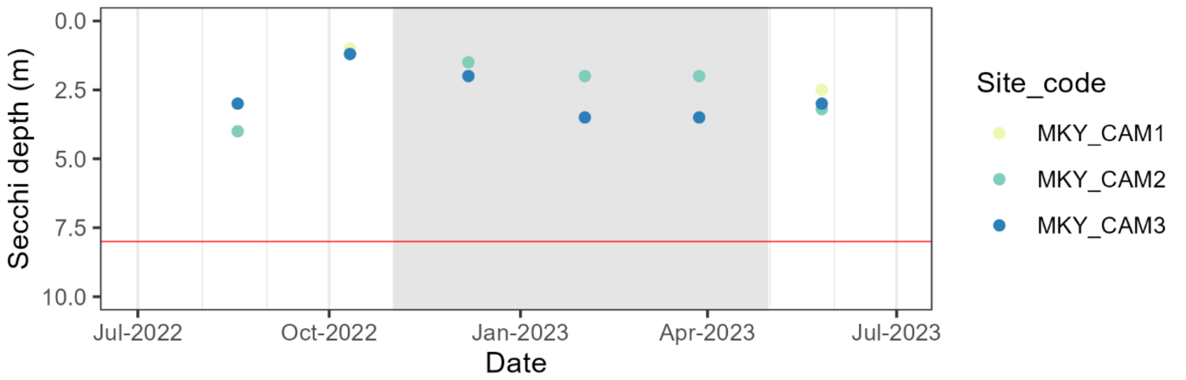

Figure 3.12. Secchi disk depth recorded at the three water quality sites throughout the reporting period. Horizontal red line represents EPP 2019 WQO annual mean.

Total suspended solids ranged from 0.78 to 26 mg L^{-1} with a mean of 5.04 mg L^{-1} over the reporting period (Figure 3.13). TSS exceeded the WQO annual mean and seasonally adjusted means.

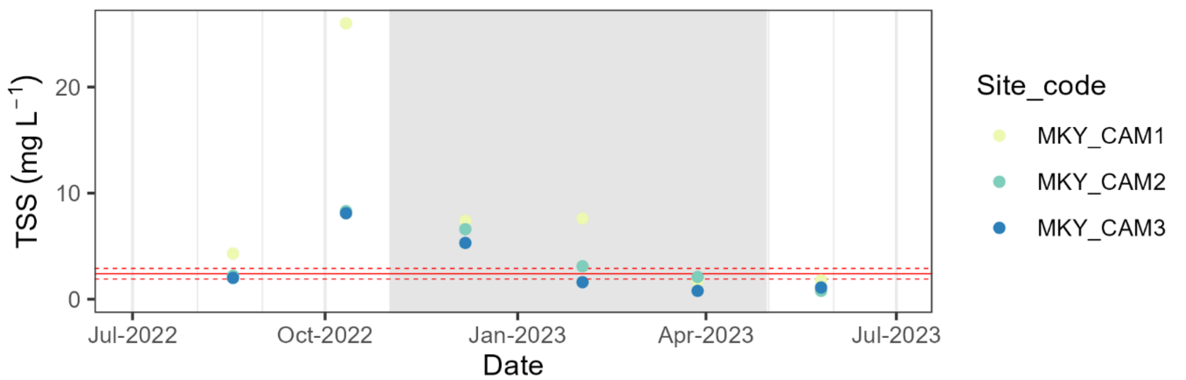

Figure 3.13. Total suspended solids (TSS) measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Horizontal red lines represent EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means.

3.3.4 Chlorophyll a

Chlorophyll-*a* concentrations ranged from <0.2 to 3.15 µg L^{-1} with an annual mean of 0.83 µg L^{-1} (Figure 3.14). Chlorophyll-*a* concentrations measured over the reporting period exceeded the WQO value (annual mean 0.45 µg L^{-1}). Chlorophyll-*a* concentrations also exceeded seasonally adjusted means.

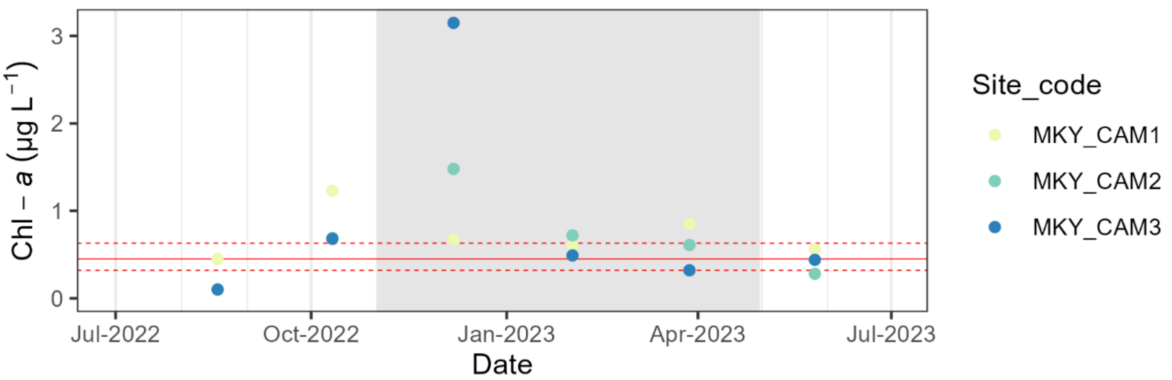

Figure 3.14. Chlorophyll-a concentrations measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), throughout the reporting period. Horizontal red lines represent EPP 2019 WQO annual (solid red line), dry and wet season (dashed red line) means.

3.3.5 Pesticides

The results of pesticide passive sampler monitoring at Aquila Island (MKY_CAM1) are presented in Table 3.1 (mass per sampler) and Table 3.2 (water concentration). Seven photosystem II herbicides (PSII), one 'other' herbicide, and one insecticide were detected at Aquila Island over the 2022-2023 wet season. PSII herbicides included atrazine and its metabolite atrazine desethyl, diuron, hexazinone, simazine, tebuthiuron, and terbuthylazine. Atrazine, diuron, and tebuthiuron were detected during all deployments throughout the wet season. Atrazine desethyl, simazine, and terbuthylazine were detected during the first deployment period (26/10/2022 to 7/12/2022). Hexazinone was detected during deployment periods 1 and 2, but not 4 (26/10/2022 to 01/02/2023). The broad-spectrum herbicide Metolachlor (S+R) was detected during the first deployment period (26/10/2022 to 07/12/2022). The insecticide Imidacloprid was detected during the second deployment period (07/12/2022 to 01/02/2023). Atrazine concentrations were below GBRMPA 2010 default guideline values (GBRMPA, 2010). Diuron, Hexazinone, Imidacloprid, Simazine, and Tebuthiuron (King, Smith, Mann, & Warne, 2017), along with Terbuthylazine (King, Smith, Warne, Frangos, & Mann, 2017) were also below proposed aquatic ecosystem protection guideline values. Of note: there was no significant local stream discharge during the first deployment period when most pesticides were detected at their highest concentrations (Figure 3.15). It is likely that pesticide runoff occurred from the small rainfall events towards the end of the first deployment (end of November 2022). These rainfall events were not large enough to be seen as stream discharge at the local creek but likely mobilised pesticides, an occurrence that should be noted.

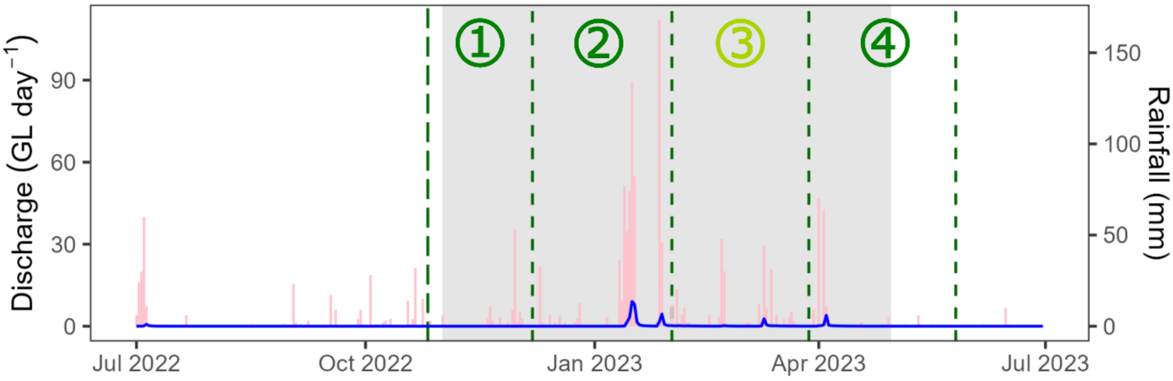

Figure 3.15. Passive sampler deployment periods (numbered green circle and dashed lines) overlayed on the stream discharge plot (GL d-1) recorded for Carmila Creek (station 126 003A) during the 2022-2023 reporting period. The nominal wet season period is shaded grey. Rainfall data from the Carmila gauging station is also shown in pink. Data source: https://water-monitoring.information.qld.gov.au/

Table 3.1. Pesticide mass per sampler recovered from passive samplers deployed at Aquila Island (MKY_CAM1).

Deployment #		**1**		**2**	**4**	
Deployment Date		26/10/2022		7/12/2022	28/03/2023	
Retrieval Date		07/12/2022		01/02/2023	26/05/2023	
Days Deployed		42		56	59	
Flow Rate (cm/s)		24.2		17.2	16.5	
Sample Name		AQ1122_ED_AQA		AQ1222_ED_AQA	AQ0123_ED_AQA	
		Primary	Duplicate	Primary	Primary	Duplicate
Pesticide Name	LOQ					
2,4-D	5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Ametryn	5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Atrazine	1.00	10.2	13.0	1.51	2.86	2.65
Atrazine desethyl	1.00	1.14	1.19	<1.00	<1.00	<1.00
Atrazine desisopropyl	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Bromacil	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Diuron	0.500	2.22	1.97	0.950	0.897	0.879
Fluazifop	0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Fluometuron	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Fluroxypyr	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Haloxyfop	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Hexazinone	1.00	2.07	1.89	1.37	<1.00	<1.00
Imazapic	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Imidacloprid	1.00	<1.00	<1.00	3.74	<1.00	<1.00
MCPA	5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Metolachlor (S+R)	1.00	7.38	7.08	<1.00	<1.00	<1.00
Metribuzin	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Metsulfuron methyl	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Prometryn	1.00	<1.00	<1.00	<1.00	<1.99^	<1.99^
Propazine	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Simazine	1.00	1.65	2.40	<1.00	<1.00	<1.00
Tebuconazole	1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Tebuthiuron	1.00	19.2	18.3	6.27	8.50	14.9
Terbuthylazine	1.00	2.05	2.15	<1.00	<1.00	<1.00
Terbutryn	5.00	<5.00	<5.00	<5.00	<5.00	<5.00

^ - Limit of Reporting (LOR) raised by blank level: Where an analyte is detected in field or lab blanks above the Limit of Quantification (LOQ), the effective LOR is raised to the average blank value plus three times the standard deviation.
Data reported as <LOR where applicable.

Table 3.2. Pesticide water concentration recovered from passive samplers deployed at Aquila Island (MKY_CAM1). Due to analytical constraints water concentration is only calculated for select analytes.

Deployment #	**1**		**2**	**4**	
Deployment Date	26/10/2022		7/12/2022	28/03/2023	
Retrieval Date	07/12/2022		01/02/2023	26/05/2023	
Days Deployed	42		56	59	
Flow Rate (cm/s)	24.2		17.2	16.5	
Sample Name	AQ1122_ED_AQA		AQ1222_ED_AQA	AQ0123_ED_AQA	
	Primary	Duplicate	Primary	Primary	Duplicate
Pesticide Name					
2,4-D	<0.716	<0.716	<0.625	<0.606	<0.606
Ametryn	<1.29	<1.29	<1.12	<1.09	<1.09
Atrazine	1.74	2.21	0.224	0.412	0.382
Atrazine desethyl	0.233	0.243	<0.178	<0.173	<0.173
Atrazine desisopropyl	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Bromacil	<0.116	<0.116	<0.101	<0.098	<0.098
Diuron	0.455	0.404	0.170	0.156	0.153
Fluazifop	*<0.017	*<0.017	*<0.015	*<0.014	*<0.014
Fluometuron	<0.124	<0.124	<0.108	<0.105	<0.105
Fluroxypyr	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Haloxyfop	<0.088	<0.088	<0.077	<0.075	<0.075
Hexazinone	0.346	0.316	0.200	<0.142	<0.142
Imazapic	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Imidacloprid	*<0.170	*<0.170	*0.556	*<0.144	*<0.144
MCPA	<0.518	<0.518	<0.453	<0.439	<0.439
Metolachlor (S+R)	1.23	1.18	<0.146	<0.142	<0.142
Metribuzin	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Metsulfuron methyl	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Prometryn	<0.282	<0.282	<0.246	<0.475^	<0.475^
Propazine	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Simazine	0.191	0.277	<0.101	<0.098	<0.098
Tebuconazole	*<0.170	*<0.170	*<0.149	*<0.144	*<0.144
Tebuthiuron	2.51	2.39	0.716	0.941	1.65
Terbuthylazine	0.322	0.338	<0.137	<0.133	<0.133
Terbutryn	<1.10	<1.10	<0.960	<0.932	<0.932

^ - Limit of Reporting (LOR) raised by blank level: Where an analyte is detected in field or lab blanks above the Limit of Quantification (LOQ), the effective LOR is raised to the average blank value plus three times the standard deviation.
Data reported as <LOR where applicable and expressed as a water concentration estimate.
* - Sampling rate for analyte not available: Water concentration estimate provided using the atrazine as the surrogate sampling rate for comparison purposes only.

3.4 In-situ loggers

3.4.1 Water temperature

Water temperature recorded close to the seafloor by the in-situ loggers is presented in Figure 3.16. Water temperature ranged from 16.91 to 29.81 °C (Table 3.3). La-Niña conditions persisted throughout the 2022/2023 summer with the ensuing monsoon keeping water temperatures much milder than the marine heatwave conditions of the 2021/2022 summer.

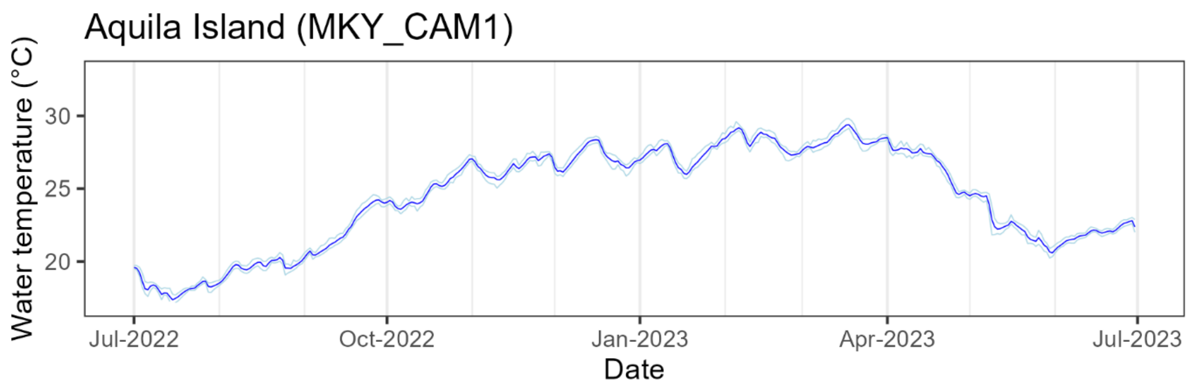

Figure 3.16. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the southern Mackay region.

Table 3.3. Monthly summary statistics for water temperature (°C) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2022	18.23	18.2	0.54	16.91	19.73	17.85	18.47	4464
Aug-2022	19.65	19.69	0.43	18.36	20.61	19.45	19.95	4456
Sep-2022	22.17	21.8	1.4	20.06	24.59	20.82	23.66	4320
Oct-2022	24.89	24.76	1.02	23.27	27.34	23.99	25.59	4460
Nov-2022	26.54	26.59	0.59	25.04	27.57	26.04	27.06	4320
Dec-2022	27.11	26.95	0.71	25.84	28.62	26.56	27.63	4460
Jan-2023	27.3	27.44	0.69	25.7	28.84	26.76	27.86	4464
Feb-2023	28.3	28.45	0.61	26.91	29.6	27.78	28.78	4026
Mar-2023	28.39	28.28	0.51	27.43	29.81	28.01	28.71	4460
Apr-2023	26.8	27.36	1.19	24.35	28.63	25.95	27.65	4320
May-2023	22.57	22.35	1.28	20.24	24.94	21.59	23.71	4458
Jun-2023	21.93	21.99	0.52	20.59	23.02	21.6	22.22	4320
Dry season	21.57	21.63	2.35	16.91	27.34	19.68	23.57	26478
Wet season	27.4	27.48	1.03	24.35	29.81	26.72	28.15	26050
Overall	24.46	25.48	3.44	16.91	29.81	21.61	27.48	52528

3.4.2 Water depth

The water quality logger at Aquila Island was positioned at a mean water depth of 8.2 m (Table 3.4). The daily mean tidal range for the water quality monitoring site at Aquila Island is presented in Figure 3.17. The southern Mackay region is mixed semidiurnal macrotidal, with daily tidal range measured to be from 2.28 to 8.12 m over the reporting period.

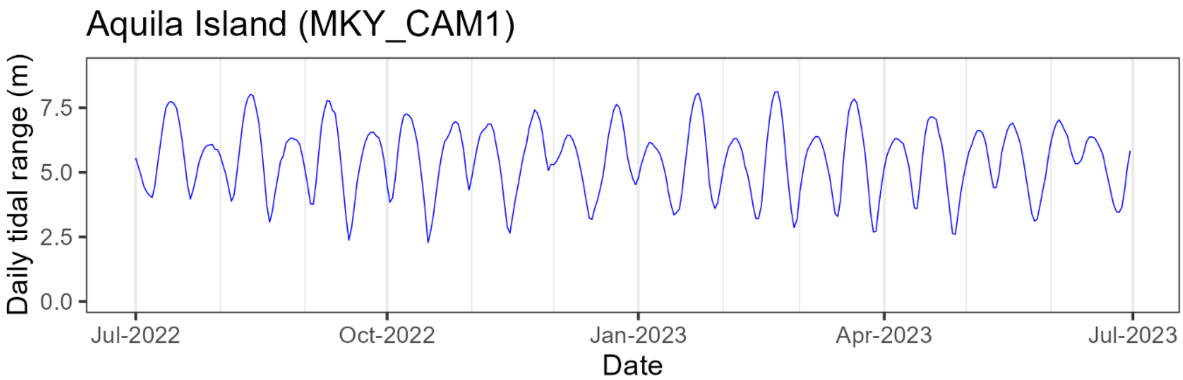

Figure 3.17. Daily tidal range measured by In-situ loggers at Aquila Island (MKY_CAM1). Periods of missing data are indicated by the orange bar.

Table 3.4. Monthly summary statistics for water depth (m) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2022	8.48	8.47	1.78	4.9	12.7	6.95	9.96	4464
Aug-2022	8.49	8.48	1.82	4.67	12.72	6.97	9.97	4456
Sep-2022	8.6	8.55	1.82	4.83	12.68	7.13	10.05	4320
Oct-2022	8.69	8.66	1.8	4.98	12.47	7.26	10.13	4460
Nov-2022	8.72	8.66	1.81	5.13	12.55	7.23	10.18	4320
Dec-2022	8.37	8.32	1.78	4.65	12.28	6.87	9.84	4460
Jan-2023	8.18	8.17	1.75	4.4	12.49	6.72	9.58	4464
Feb-2023	7.35	7.32	1.81	3.57	11.74	5.89	8.79	4026
Mar-2023	7.33	7.32	1.8	3.65	11.49	5.88	8.77	4460
Apr-2023	7.82	7.83	1.77	4.27	11.48	6.38	9.3	4320
May-2023	7.98	7.99	1.76	4.39	11.35	6.52	9.47	4458
Jun-2023	8.49	8.47	1.74	5.21	12.25	6.93	9.96	4320
Dry season	8.45	8.44	1.8	4.39	12.72	6.97	9.93	26478
Wet season	7.97	7.93	1.86	3.57	12.55	6.49	9.42	26050
Overall	8.21	8.17	1.85	3.57	12.72	6.74	9.69	52528

3.4.3 Wave activity

The Aquila Island logger site is located along the inshore coast and is exposed to varying levels of waves. The area generally protected from predominant south-easterly swells by Cape Townshend and Stanage Point. Notable wave activity occurred during October-November 2022 corresponding with periods of high wind activity, and February 2023 when Severe Tropical Cyclone Gabrielle tracked south-east close to the Reef and generated large swells (Figure 3.18).

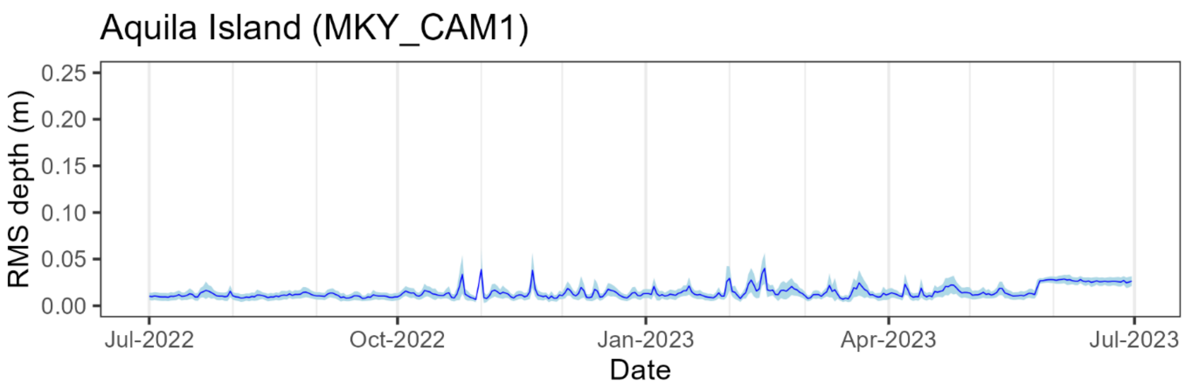

Figure 3.18. RMS depth measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue).

Table 3.5. Monthly summary statistics for wave activity (Depth RMS) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2022	0.011	0.011	0.005	0	0.066	0.008	0.014	4464
Aug-2022	0.011	0.011	0.005	0	0.034	0.008	0.013	4456
Sep-2022	0.01	0.01	0.004	0	0.037	0.007	0.013	4320
Oct-2022	0.013	0.012	0.009	0	0.131	0.009	0.015	4460
Nov-2022	0.013	0.011	0.01	0	0.122	0.008	0.015	4320
Dec-2022	0.013	0.012	0.007	0	0.054	0.009	0.015	4460
Jan-2023	0.013	0.012	0.007	0	0.076	0.009	0.015	4464
Feb-2023	0.018	0.015	0.011	0	0.091	0.011	0.022	4026
Mar-2023	0.013	0.012	0.008	0	0.08	0.009	0.015	4460
Apr-2023	0.015	0.013	0.008	0	0.071	0.01	0.018	4320
May-2023	0.015	0.013	0.007	0	0.052	0.01	0.02	4458
Jun-2023	0.026	0.027	0.005	0.011	0.047	0.023	0.03	4320
Dry season	0.014	0.012	0.008	0	0.131	0.009	0.019	26478
Wet season	0.014	0.012	0.009	0	0.122	0.009	0.016	26050
Overall	0.014	0.012	0.009	0	0.131	0.009	0.017	52528

3.4.4 Turbidity

Turbidity measured by optical sensors at Aquila Island (MKY_CAM1) in the southern Mackay region is presented in Figure 3.19. The annual mean turbidity at Aquila Island was 8.54 NTU for the reporting period (Table 3.6). Turbidity levels showed a recurring 28-day pattern consistent with tidal cycles. Periods of high turbidity corresponded with spring tides and lower turbidity with neap tides. This is evident when comparing daily tidal range (Figure 3.17) with turbidity (Figure 3.19). Turbidity generally lowered to low values during the neap tide period unless the period also corresponded with wave activity (i.e., RMS depth: Figure 3.18), in which case turbidity would remain high throughout the neap period. Water clarity is generally naturally poor at the Southern Mackay sites due to the regions predominantly sand-mud substrate, strong tidal currents, and shallow water depth leading to sediment resuspension. Water clarity is typically best during neap tides and poorest during spring tides when tidal currents are strongest.

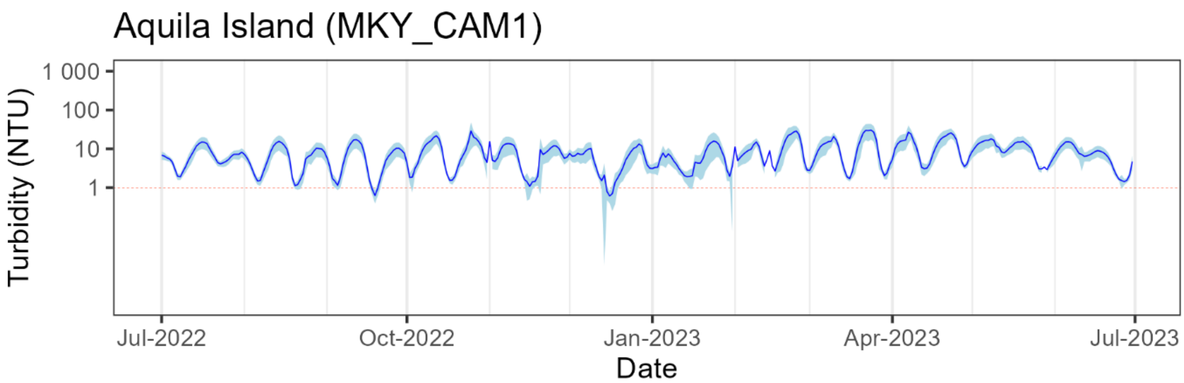

Figure 3.19. Turbidity measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters.

While turbidity is a primary indicator of water quality (Erftemeijer et al., 2012), the relationship between turbidity and benthic light is not always strong (Sofonia and Unsworth, 2010; Kirk, 1985). As benthic photosynthetically active radiation (bPAR) 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 bPAR in the suite of water quality variables when capturing local baseline conditions of ambient water quality. This may be especially relevant in the southern Mackay region due to the naturally variable turbidity to which habitats are adapted.

Table 3.6. Monthly summary statistics for turbidity (NTU) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n
Jul-2022	6.91	5.8	4.29	1.1	29.19	4.02	8.48	4463
Aug-2022	6.58	4.81	5.36	0.59	32.1	2.15	9.69	4456
Sep-2022	6.66	4.41	6.13	0.03	34.51	1.72	10.27	4320
Oct-2022	9.68	6.24	9.12	0.77	116.91	2.86	14.92	4460
Nov-2022	7.61	5.73	6.86	0.4	84.57	2.7	10.79	4320
Dec-2022	5.71	4.28	4.82	0.14	45.86	1.95	8.46	4460
Jan-2023	6.03	3.76	5.96	0.49	51.72	2.39	7.34	4464
Feb-2023	11.13	7.56	10.08	1.2	71.5	3.78	14.34	4026
Mar-2023	11.69	7.62	11.21	1.18	80.25	3.11	17.06	4460
Apr-2023	12.73	9.94	9.42	1.58	104.65	4.63	19.7	4320
May-2023	10.68	9.62	6.29	1.9	71.32	5.51	15.08	4458
Jun-2023	7.33	6.62	4.95	0.96	56.34	3.31	10.05	4320
Dry season	7.98	6.22	6.43	0.03	116.91	3.12	11.26	26477
Wet season	9.1	5.84	8.81	0.14	104.65	2.98	12.48	26050
Overall	8.54	6.04	7.73	0.03	116.91	3.04	11.76	52527

3.4.5 Benthic photosynthetically active radiation (bPAR)

Benthic photosynthetically active radiation (bPAR) was highly variable at Aquila Island throughout the reporting period. Fine-scale patterns of bPAR are primarily driven by tidal cycles with fortnightly increases in bPAR coinciding with neap tides and weaker tidal flows. Larger episodic events, such as low-pressure systems and storms, can lead to extended periods of low light conditions due to a combination of strong winds, increases in wave height and resuspension of particles, as well as rainfall leading to increased catchment flows and an input of suspended solids (Fabricius et al., 2013).

Raw bPAR values (recorded at 10-minute intervals) are presented in Figure 3.21. Missing bPAR data from 14th July to 18th August 2022 were due to the sensor failing the tilt test due to the logger frame tipping over. Missing data from 11th May to 30th June 2023 were due to a logger not initialising correctly.

The daily light interval (DLI), which is the sum of all bPAR per day, is presented in Figure 3.20. DLI at Aquila Island was tightly driven by the tidal cycle (i.e., higher turbidity occurred during spring tides leading to lower DLI and vice versa for neap tides). Annual mean DLI was 1.31 mol m^{-2} d^{-1}. The WQO for shallow water areas (<10 m) is 6 mol m^{-2} day^{-1} over a rolling 14-day average.

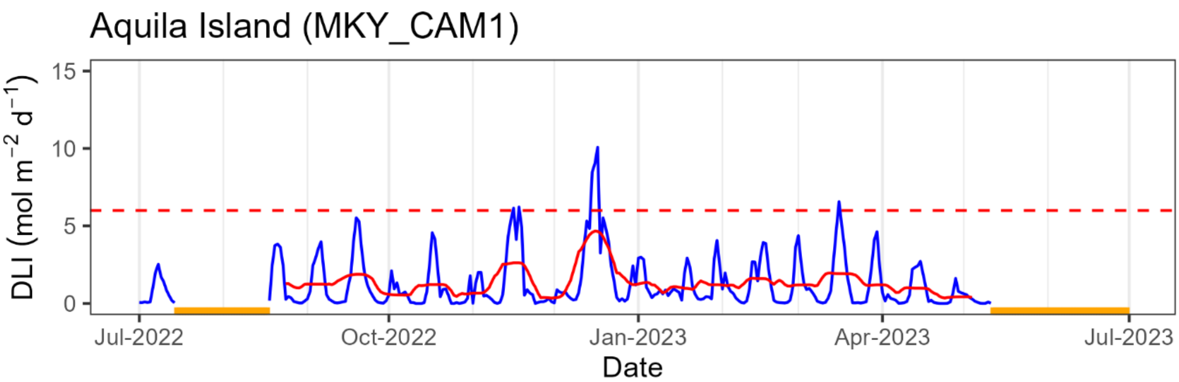

Figure 3.20. Daily light integral (mol photons m^{-2} d^{-1}) of benthic photosynthetically active radiation measured at Aquila Island. Rolling 14-day average (red line) and light requirements from the water quality objective for shallow inshore areas (red dash) shown. Periods of missing or QC-removed data are indicated by the orange bar.

Table 3.7. Monthly summary statistics for Daily Light Integral (DLI: mol photons m^{-2} d^{-1}) measured by continuous dataloggers at the Aquila Island (MKY_CAM1) ambient water quality monitoring site. SD = standard deviation, Min = minimum, Max = maximum, Q1 = 1st quartile (25th percentile), Q3 = 3rd quartile (75th percentile), n = sample size (number of measurements). Wet season 1st November to 30th April.

Period	Mean	Median	SD	Min	Max	Q1	Q3	n (days)
Jul-2022	0.76	0.35	0.85	0.04	2.52	0.07	1.3	14
Aug-2022	1.27	0.31	1.57	0.03	3.83	0.13	2.47	14
Sep-2022	1.46	0.69	1.69	0.02	5.52	0.14	2.38	30
Oct-2022	0.86	0.51	1.17	0	4.56	0.05	0.94	31
Nov-2022	1.49	0.52	2.01	0	6.22	0.11	2.01	30
Dec-2022	2.45	1.17	2.82	0.03	10.08	0.36	3.87	31
Jan-2023	1.25	0.74	1.09	0.21	4.06	0.47	2.14	31
Feb-2023	1.2	0.86	1.29	0.03	3.93	0.15	2.04	28
Mar-2023	1.72	0.89	1.89	0.02	6.57	0.08	2.73	31
Apr-2023	0.66	0.24	0.84	0	2.72	0.05	0.76	30
May-2023	0.2	0.09	0.23	0	0.63	0.01	0.34	11
Jun-2023	-	-	-	-	-	-	-	0
Dry season	1.01	0.41	1.35	0	5.52	0.06	1.47	100
Wet season	1.47	0.7	1.85	0	10.08	0.19	2.33	181
Overall	1.31	0.57	1.7	0	10.08	0.12	2.01	281

3.4.6 Water quality logger data

Logger data collected at 10-minute intervals which has passed through the quality control process is presented in Figure 3.21.

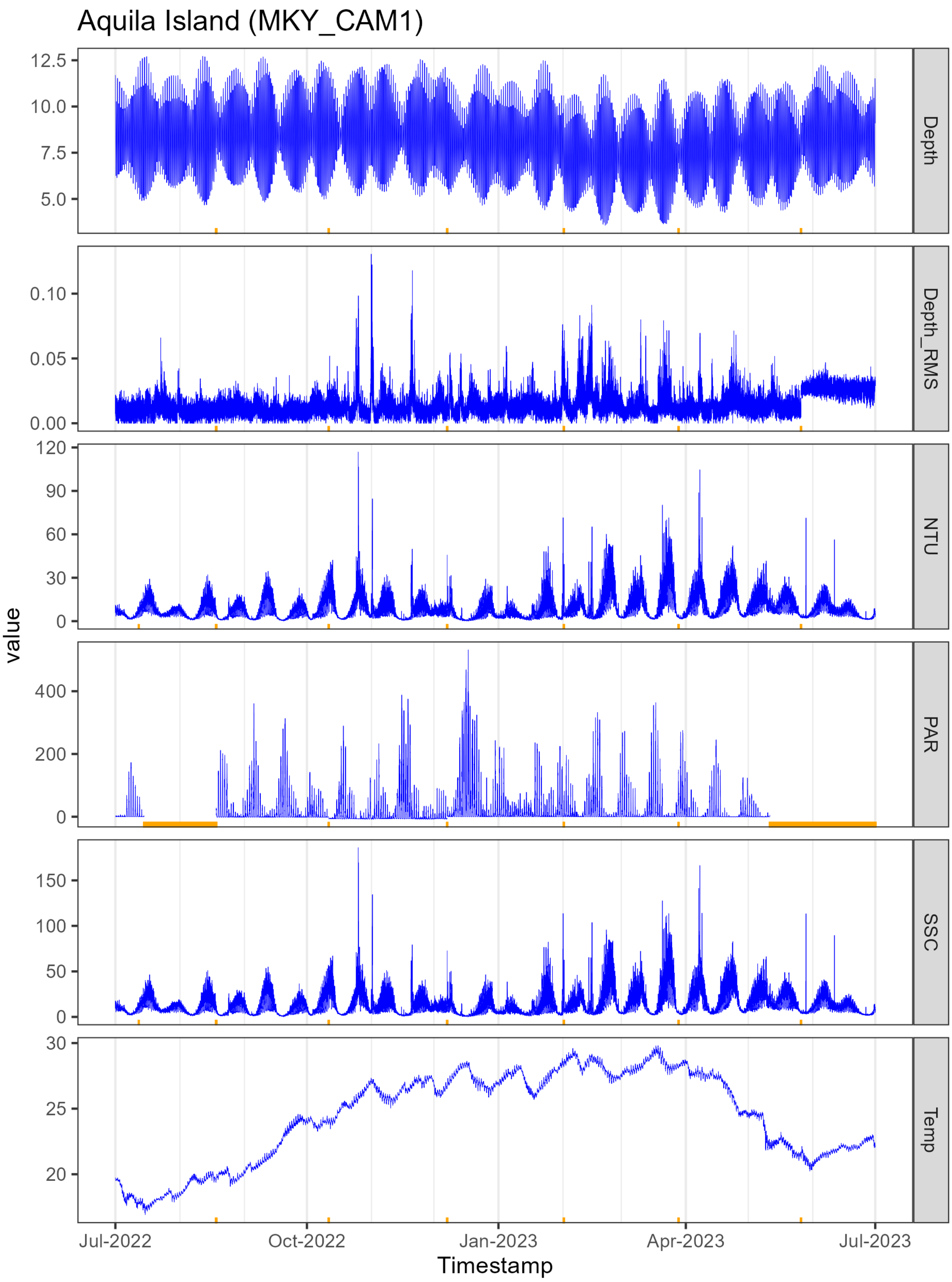

Figure 3.21. Data collected at Aquila Island with In-situ Marine Optics (IMO) dataloggers. Data presented excludes data flagged as flag 4 (Bad data). Periods of missing data are indicated by the orange bar. For more information on Quality Control Procedures see Appendix 1.

3.4.7 Data Recovery

Data recovery and quality control flagging for in situ loggers varied across the sites (Figure 3.22). Overall, data recovery for the reporting period was near 100 % with the exception of some flagged and missing data for the PAR sensor. Data flagged as bad data (QC flag 4 – red) was removed prior to preparing figures and tables for this report. A brief description of the quality control process and QC flags is provided in Appendix 1 while more substantive outline of the quality control process undertaken on the logger data is outlined in Iles et al. (2023).

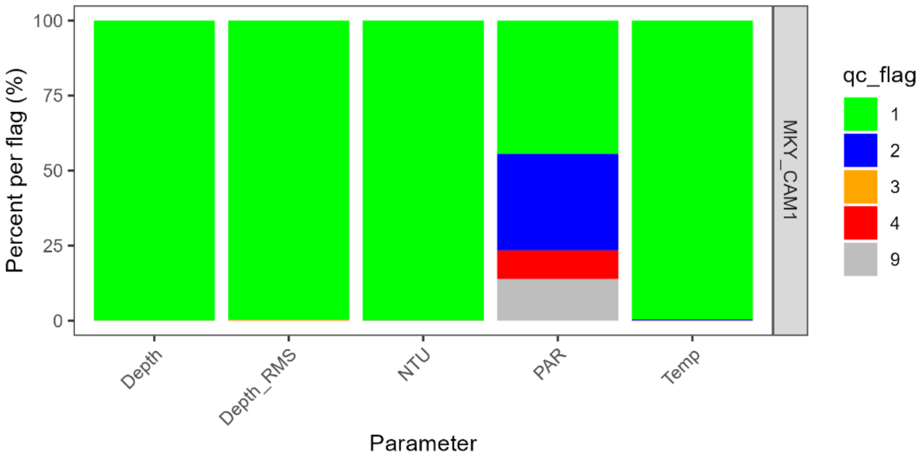

Figure 3.22. Data recovery and qc flags at the Aquila Island (MKY_CAM1) logger site over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2 (blue) indicates a 'probably good value'; flag 3 (orange) indicates 'probably bad value', flag 4 (red) indicates a 'bad value' and flag 9 (grey) indicates data that is missing.

4 Conclusions and Recommendations

4.1 Conclusions

4.1.1 Climatic conditions

1. The 2022-2023 wet season received more rainfall when compared to the previous three years, with annual rainfall also above the median rainfall since 1910. The wet season rainfall total was 1394.1 mm, while total rainfall for the water year was 1673.2 mm. This is an important factor to consider when interpreting data during this monitoring period. Comparison of these data with future (and past) years is needed to characterise ambient water quality conditions and to determine metocean drivers of water quality variability. 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 variable pattern of water temperature, with highest temperatures experienced during summer months, quickly cooling during April/May, then quickly warming again during September/October. Slightly above average water temperatures were recorded in the region during 2022/2023.
2. Nitrogen continues to be present in the coastal waters at elevated concentrations compared to water quality objectives (WQO). Total nitrogen (TN), total dissolved nitrogen (TDN) and oxidised nitrogen (NOx) exceeded the water quality objective (WQO) 80^{th} percentile. Particulate nitrogen (PN) exceeded the WQO annual mean and seasonally adjusted means.
3. Phosphorus continues to be present in the coastal waters at moderately elevated concentrations. Total phosphorus (TP) and total dissolved phosphorus (TDP) exceeded the water quality objective 20^{th} percentile but were below the 50^{th} and 80^{th} percentiles. Particulate phosphorus (PP) exceeded the WQO annual mean and seasonally adjusted means.
4. Chlorophyll-*a* exceeded the WQO annual mean and seasonally adjusted means.

4.1.3 Water clarity

1. Water clarity is generally naturally poor at the Southern Mackay sites due to the regions predominantly sand-mud substrate, strong tidal currents, and shallow water depth leading to sediment resuspension.
2. Turbidity levels showed a recurring 28-day pattern consistent with tidal cycles. Periods of high turbidity corresponded with spring tides and lower turbidity with neap tides unless the period also corresponded with wave activity.
3. Future water quality objectives for turbidity in the southern Mackay region should take into consideration the naturally high levels of suspended sediment that is due to resuspension of sand-mud from the strong tidal currents that are a feature of the region. This natural variability in turbidity supports many turbid reefs, both insipient and fringing, that are adapted to these conditions.
4. Secchi depth was less than (exceeded) the WQO annual mean.
5. Total suspended solids (TSS) exceeded the WQO annual mean and seasonally adjusted means.

4.1.4 Benthic photosynthetically active radiation (bPAR)

1. Annual mean daily light integral was less than requirements under the water quality objectives for shallow water areas.
2. Daily Light Integral (DLI) at Aquila Island is tightly driven by the tidal cycle (i.e., higher turbidity during spring tides leads to lower DLI and vice versa for neap tides).

4.2 Recommendations

This monitoring program has been underway for seven 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 the southern Mackay and Isaac region. This understanding will continue to assist managers with future strategic planning. For example, while the total rainfall during this reporting year was above the long-term median, the distribution of rainfall during the season becomes important and future assessment of these patterns should be made within sufficient data and confidence. With an emerging long-term dataset, there is potential for answering important research questions around coastal processes and water quality guidelines in this important region of the Great Barrier Reef coastline. Continued monitoring may help to assess if any sediment, nutrient and pesticide reduction programs in the region are making any impact in terms of coastal marine water quality improvement. For example, are these catchment programs reaching their objectives and value for money?

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Appendix 1. Quality control procedures

To complement the new loggers that were introduced into the program in the 2021-22 reporting year, a new quality control (QC) process for water quality data has been implemented. The QC process is science-based, sourced from public documentation, and based on the quality assurance of Real Time Oceanographic (QARTOD) program (NOAA, 2020), which is adopted by CSIRO, IMOS, and AIMS. Data goes through both automated and manual quality control steps. The 12 automated control tests are outlined in Table A1.

Table A 1. Quality control tests applied to the logger data in the automated process.

QC test 1: Syntax test	QC test 7: Spike tests
QC test 2: Impossible date test	QC test 8: Rate of change test
QC test 3: In/out water test	QC test 9: Stationary test
QC test 4: Global range test	QC test 10: Standard deviation test
QC test 5: Regional range test	QC test 11: Burst count test
QC test 6: Impossible depth test	QC test 12: Orientation test

Dependent on the outcome of these QA tests, data may be flagged 'good data' (green), 'probably good data' (blue), 'probably bad data' (orange) and 'bad data' (red). There are four sensors on each logger: Temperature, Depth, Tilt, and either turbidity (NTU) or photosynthetically active radiation (PAR). For each sensor on the logger the 'worst' flag from QC rules 1 to 12 is reported for each 10-minute time interval (Figure A-1). End user decides what level of data 'quality' they wish to use for their application. For example, for most applications 'good data' and 'probably good data' is considered acceptable, 'probably bad data' could be used with caveats, and 'bad data' should be discarded. Unwanted data can easily be masked in excel or other data management programs by filtering by 'QC flag'. A full technical report with detailed descriptions of the quality control procedures and tests as applied to the data in this project is available on the TropWATER website (Iles et al., 2023).

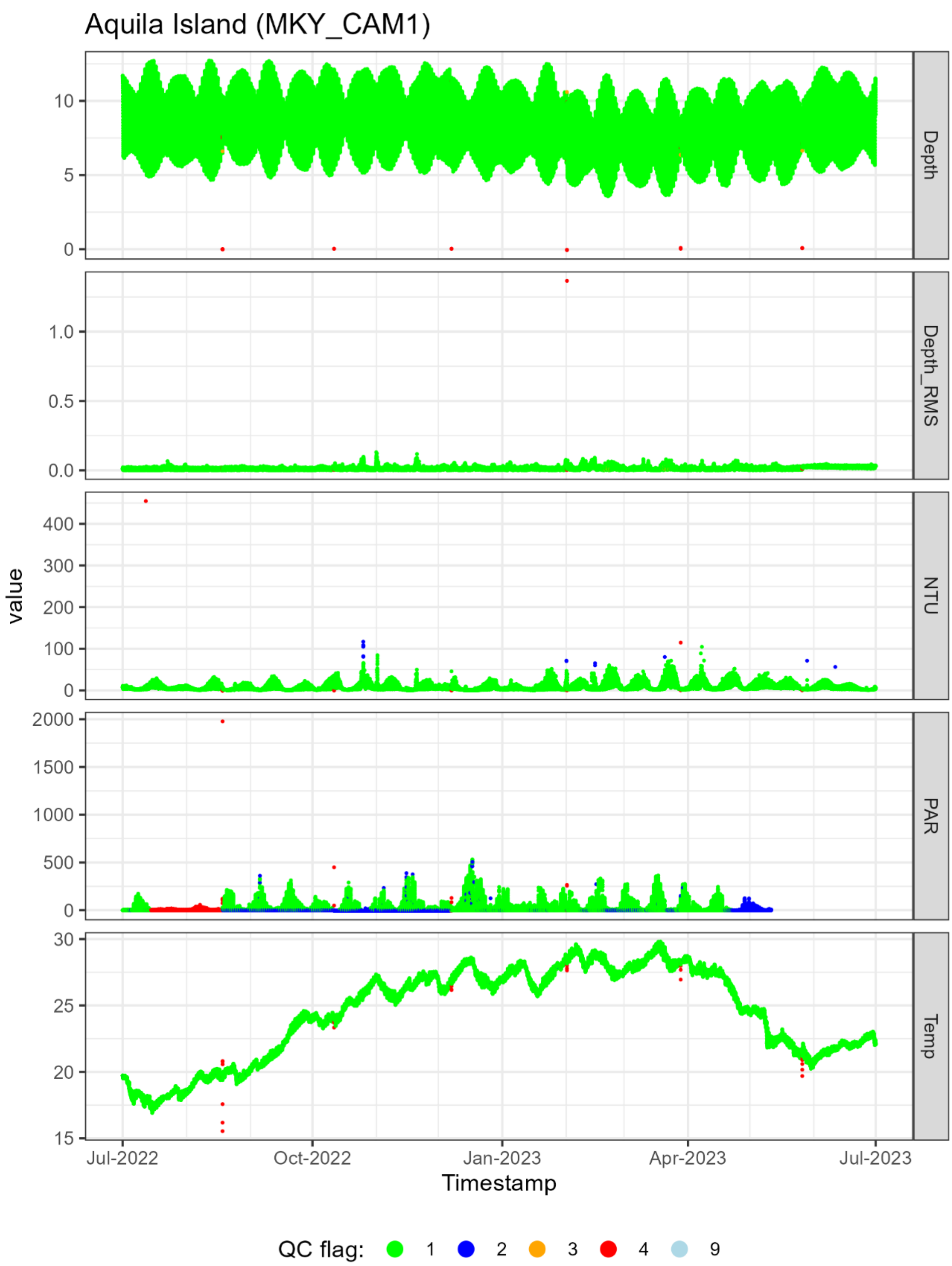

Figure A 1. Raw data collected at Aquila Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.