Southern Mackay Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022

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A Report for Healthy Rivers to Reef Partnership

Report No. 23/4

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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 2021-2022 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).

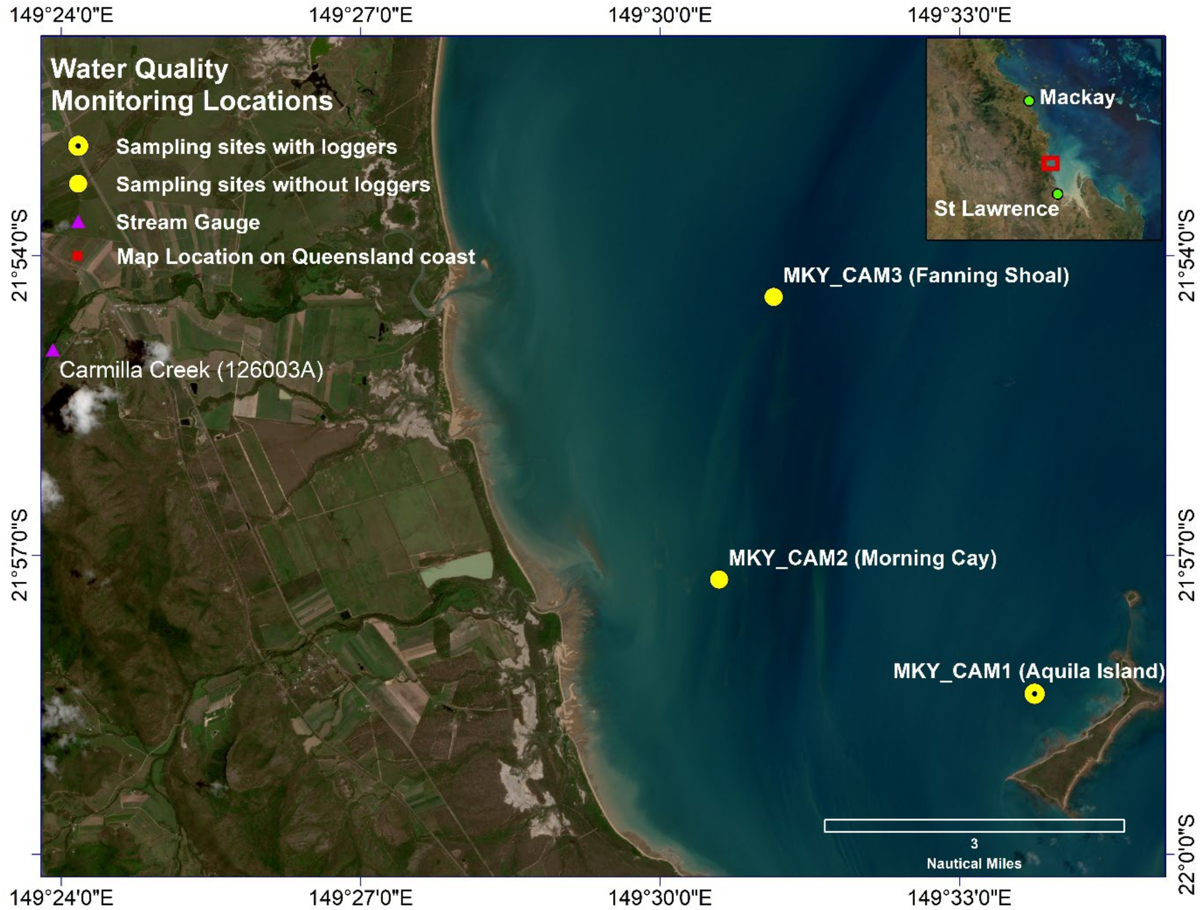

Figure 2-1. Map of the southern Mackay region where water quality monitoring locations (yellow circles), monitoring locations with loggers (yellow/black circle), and the stream gauge (purple triangle) referred to in this report, are located.

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 31st March. 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).

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-fibre 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 2-1. 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

Table 2-2. Field dates in the 2021-22 reporting period for water sampling, logger maintenance and pesticide sampling at the southern Mackay monitoring locations. Note that pesticide sampling and logger maintenance was only undertaken at Aquila Island.

Date	Water sampling	Logger maintenance	Pesticides
2021-09-13	Yes	Yes	No
2021-11-16	Yes	Yes	Yes
2021-12-16	Yes	Yes	Yes
2022-02-04	Yes	Yes	Yes
2022-03-31	Yes	Yes	Yes
2022-05-05	Yes	Yes	No
2022-06-16	Yes	Yes	No

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 sporadic cloud cover or boat shadow, though occasionally this was 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-NO3- F and 4500-P F analyses after alkaline persulphate digestion	25 µg N L-1
Total dissolved nitrogen (TDN)		
Total phosphorus (TP)		5 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 (NOx)	4500-NO3 - F	1 µg N L-1
Chlorophyll		
Chlorophyll-a	10200-H	0.1 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 2-6). Each set of passive samplers contained an Empore™ SPE disk (ED), and a passive flow monitor (PFM). Twenty-two pesticide and insecticides used to calculate pesticide risk metrics are reported (Table 2-7). A full list of chemicals analysed and detected is provided in Appendix 1.

Figure 2-2. Pesticide monitoring passive samplers such as these were retrieved from Aquila Island (MKY_CAM1) in December, February, March, and June of the reporting period (Table 2-5). Note: biological growth on the samplers.

Table 2-5. Pesticide passive samplers deployed at Aquila Island (MKY_CAM1) during the 2021-2022 wet season.

Site name	Site code	Start date	End date	Duration (days)
Aquila Island	MKY_CAM1	16/11/2021	16/12/2021	30
Aquila Island	MKY_CAM1	16/12/2021	04/02/2022	50
Aquila Island	MKY_CAM1	04/02/2022	31/03/2022	55
Aquila Island	MKY_CAM1	31/03/2022	05/05/2022	35

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). Note: A full list of pesticides monitored via passive samplers is included in Appendix 1

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 Insitu 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}

This is the first reporting year where the IMO loggers have been the foundation of the water quality program. They were deployed in September 2021 to replace the older generation loggers that had not been reliable and therefore logger data for this report begins in September 2021.

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 $\overline{D}$ is the mean water depth of the n readings.

PAR

Photosynthetically active radiation (PAR) 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 PAR 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:

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

Where:

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

i is each PAR reading during the day

PAR is the 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 description of rules for flagging data is in Appendix 3.

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 31st August 2021, with the rainfall onset occurring on 13th November 2021. The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. The 2021-2022 wet season rainfall total was 851 mm, while total rainfall for the water year was 1351.2 mm (Figure 3.2). This is lower than the annual median rainfall calculated since 1910.

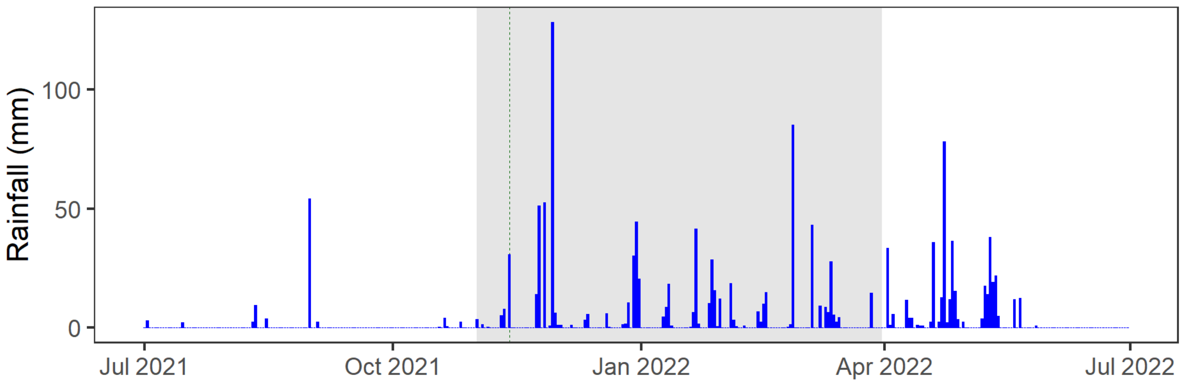

Figure 3-1. Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the 2021-2022 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

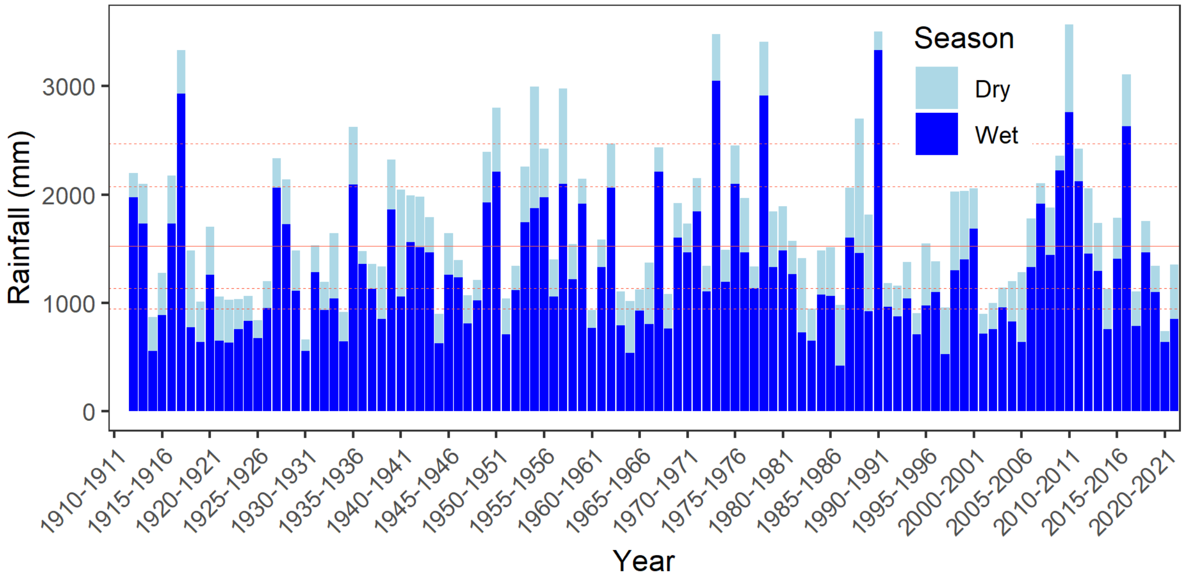

Figure 3-2: Annual rainfall by water year for the Mackay region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall 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/

Hydrographs for streams in the Pioneer Basin (Pioneer River) and Plane Basin (Sandy Creek) show onset of stream discharge on 28/12/2019 with a series of flow pulses through to March 2020 (Figure 3-3). Total discharge for the 2019-2020 reporting period was 206.7 GL (Pioneer River) and 30.12 GL (Sandy Creek).

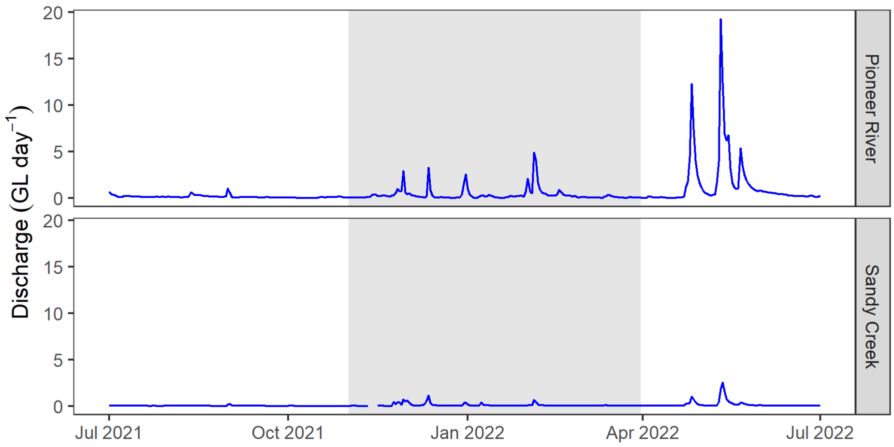

Figure 3-3: Stream discharge (GL d^{-1}) recorded for the Pioneer River (station 125007A) and Sandy Creek (station 126001A) during the 2021-2022 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/

3.2 Oceanographic conditions

Waves detected offshore from Mackay were predominantly 0.5 to 1.2 m in height and from a south-easterly direction (Figure 3-4). October 2021 showed the lowest wave activity of the year while February and April 2022 displayed the largest significant wave heights for the July 2021 – June 30, 2022, period (Figure 3-5).

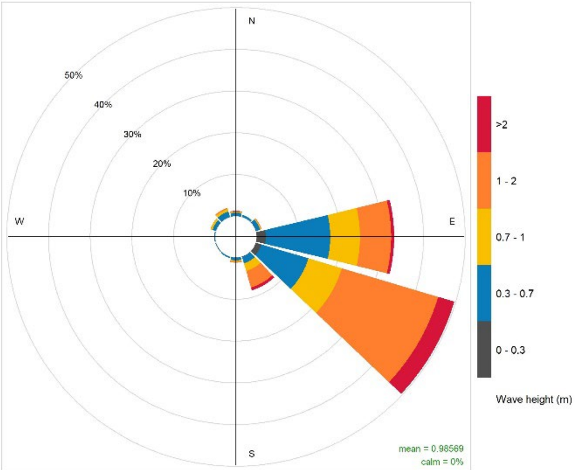

Figure 3-4. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

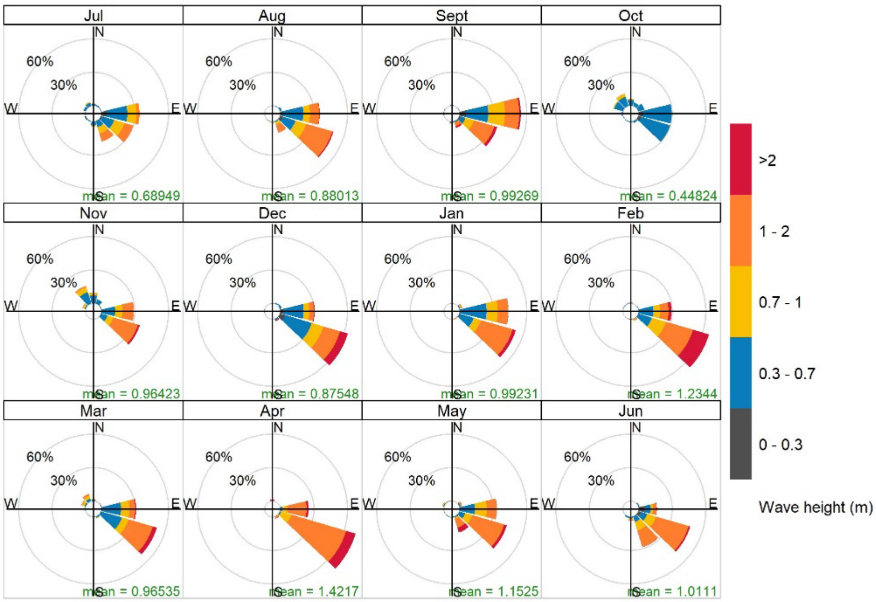

Figure 3-5. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

A marine heatwave was in effect during March 2022, with up to 8 degrees heating weeks (DHW) recorded in many parts of the Great Barrier Reef marine waters (https://coralreefwatch.noaa.gov/product/5km/index.php). This was the fourth such event since

2016 and the first to occur during a La Niña summer (when conditions are normally less conducive to marine heatwaves). Coral bleaching ranging from mild to severe was recorded at 32 of the 43 reefs surveyed during or immediately following this event (https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2020-2021).

3.3 Water quality

3.3.1 Physiochemical

The water column was mostly well mixed, with dissolved oxygen saturation consistent through the vertical profile apart from at Morning Cay in April 2022, and Fanning Shoal in November 2021 when dissolved oxygen was slightly more depleted in the middle and bottom waters. (Figure 3-6).

Electrical conductivity (EC) at the three locations ranged from 50.3 to 56.9 mS cm^{-1} and was in the range typical of seawater (Figure 3-7). The lowest period of conductivity occurred in the surface waters in mid-December, closely following the highest rainfall event of the year, when a halocline was present at Fanning Shoal. While this result may have been due to the heavy rainfall event, the other sites did not have this occurrence and its possible this datapoint was erroneous. Conductivity values overall followed seasonality with highest values occurring in June and lowest values in December, aligning with periods of high rainfall.

Water temperature ranged between 19.04 and 29.4°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.

pH values ranged between 8.16 and 8.33 across all sites throughout the year and was highest in December 2021 (Figure 3-9).

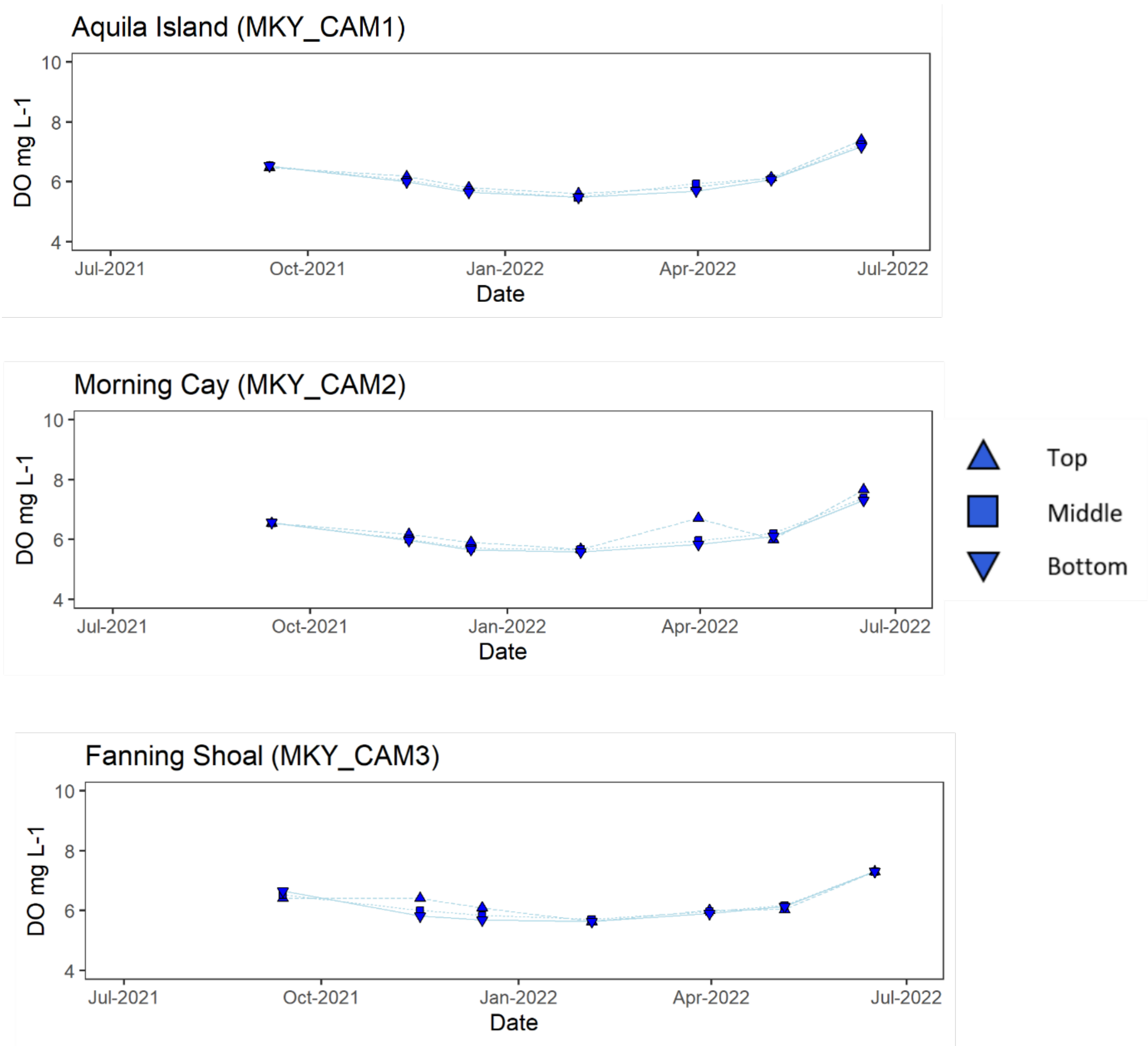

Figure 3-6. Dissolved oxygen concentration (mg/L) at three water quality monitoring sites in the southern Mackay region showing results for the top, middle, and bottom water.

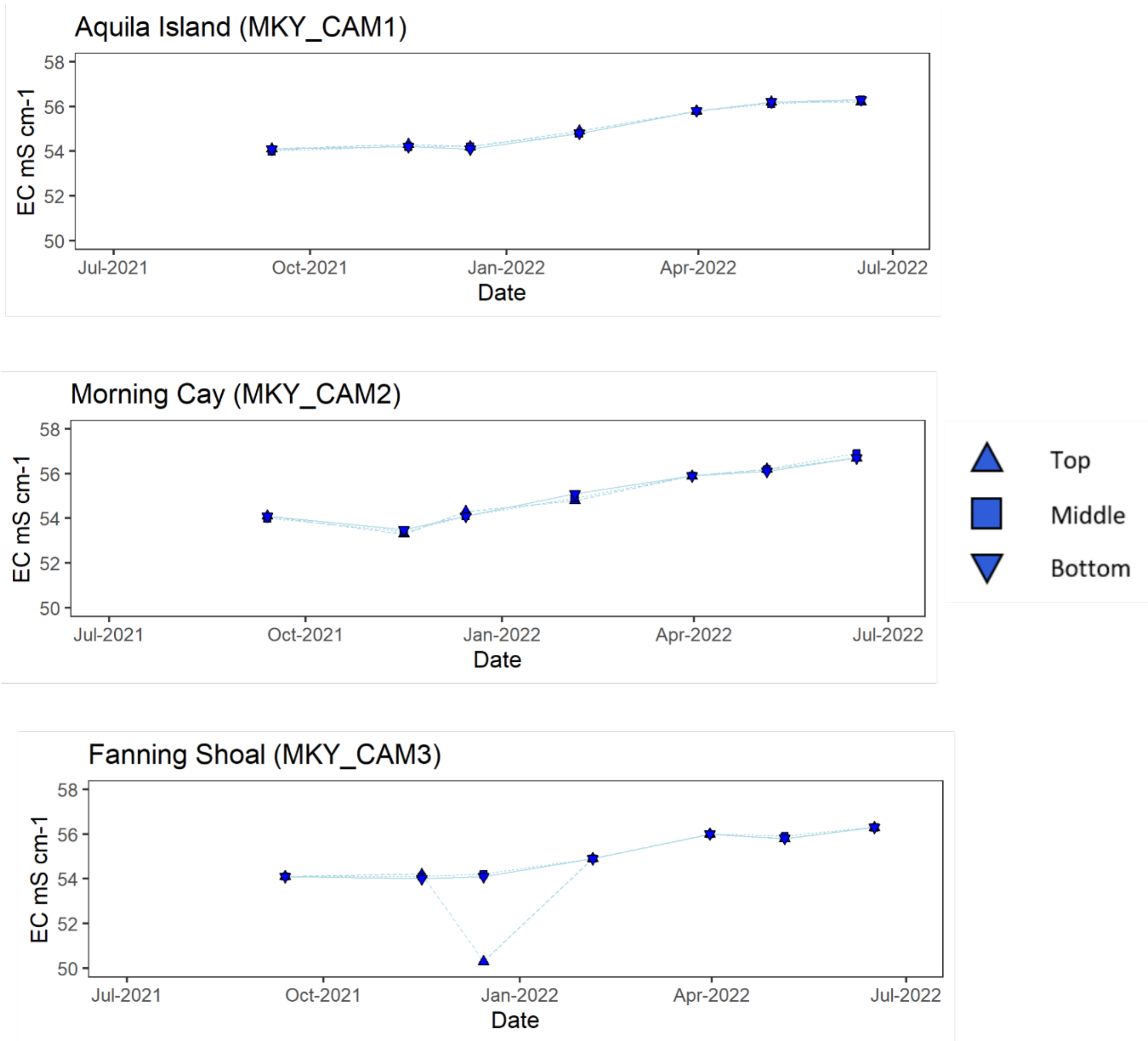

Figure 3-7. Electrical conductivity recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water. Note that the December surface water conductivity at Fanning Shoal may have been instrument error.

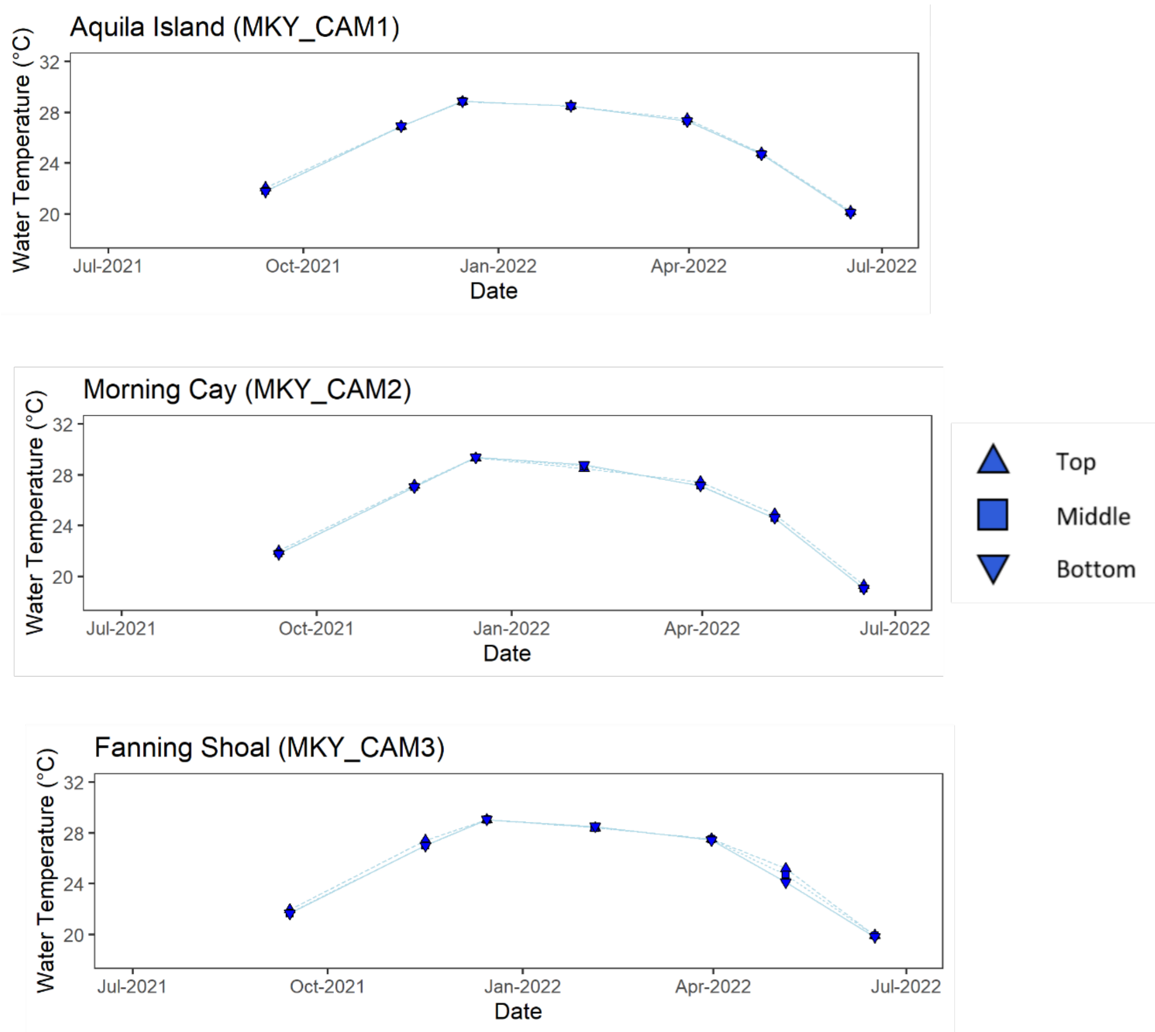

Figure 3-8. Water temperature recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water.

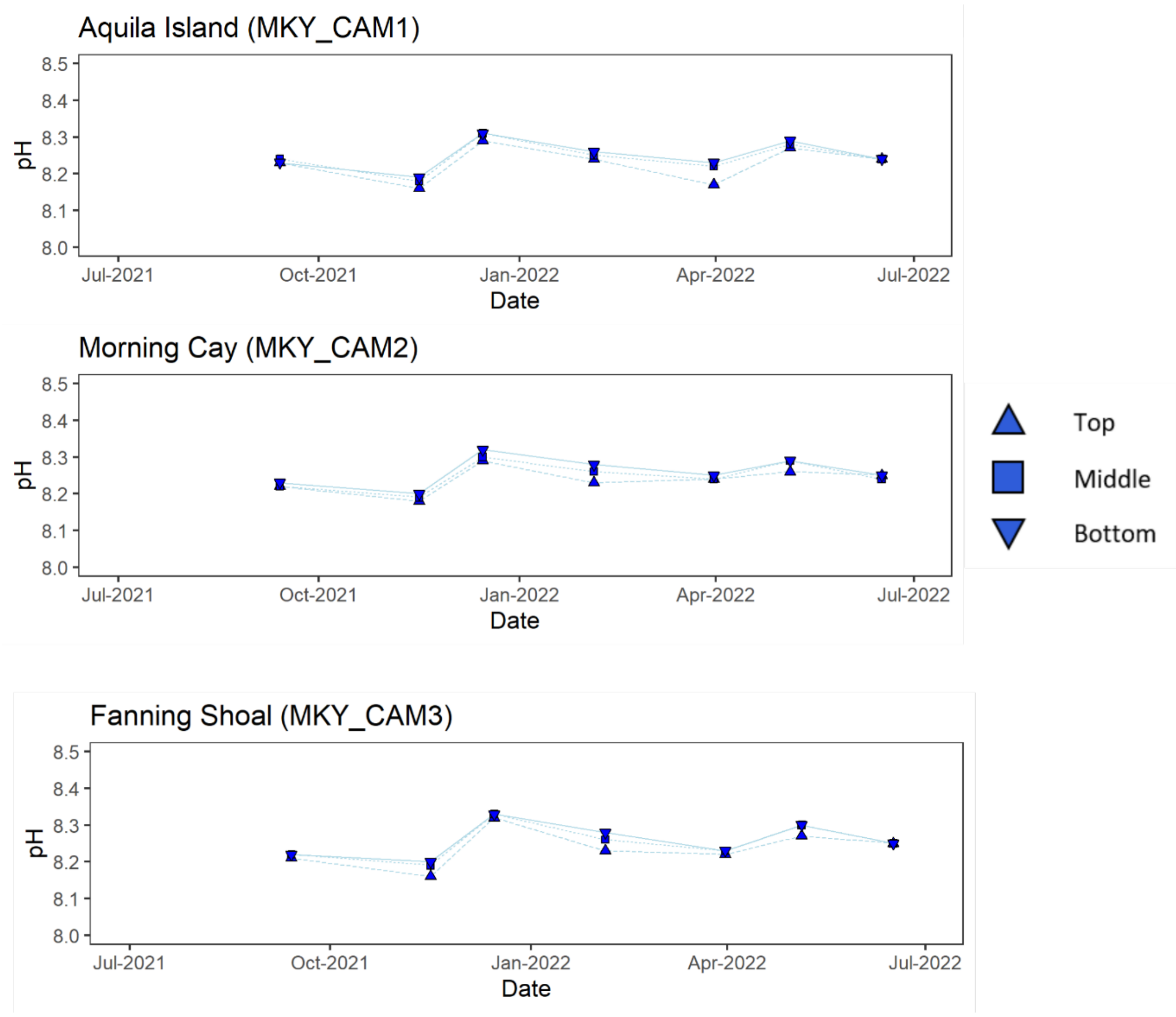

Figure 3-9. pH recorded at three water quality sites in the southern Mackay region showing results for the top, middle, and bottom water.

3.3.2 Nutrients

Particulate nitrogen (PN) concentrations ranged from 4 to 39 µg L^{-1} (Figure 3-10). Mean PN across the three sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} in March and June 2022.

Particulate phosphorus (PP) concentrations ranged from <1 to 8 µg L^{-1} (Figure 3-10). Mean PP was below the GBRMPA guideline trigger value of 2.8 µg L^{-1} for all sampling events except for February 2022.

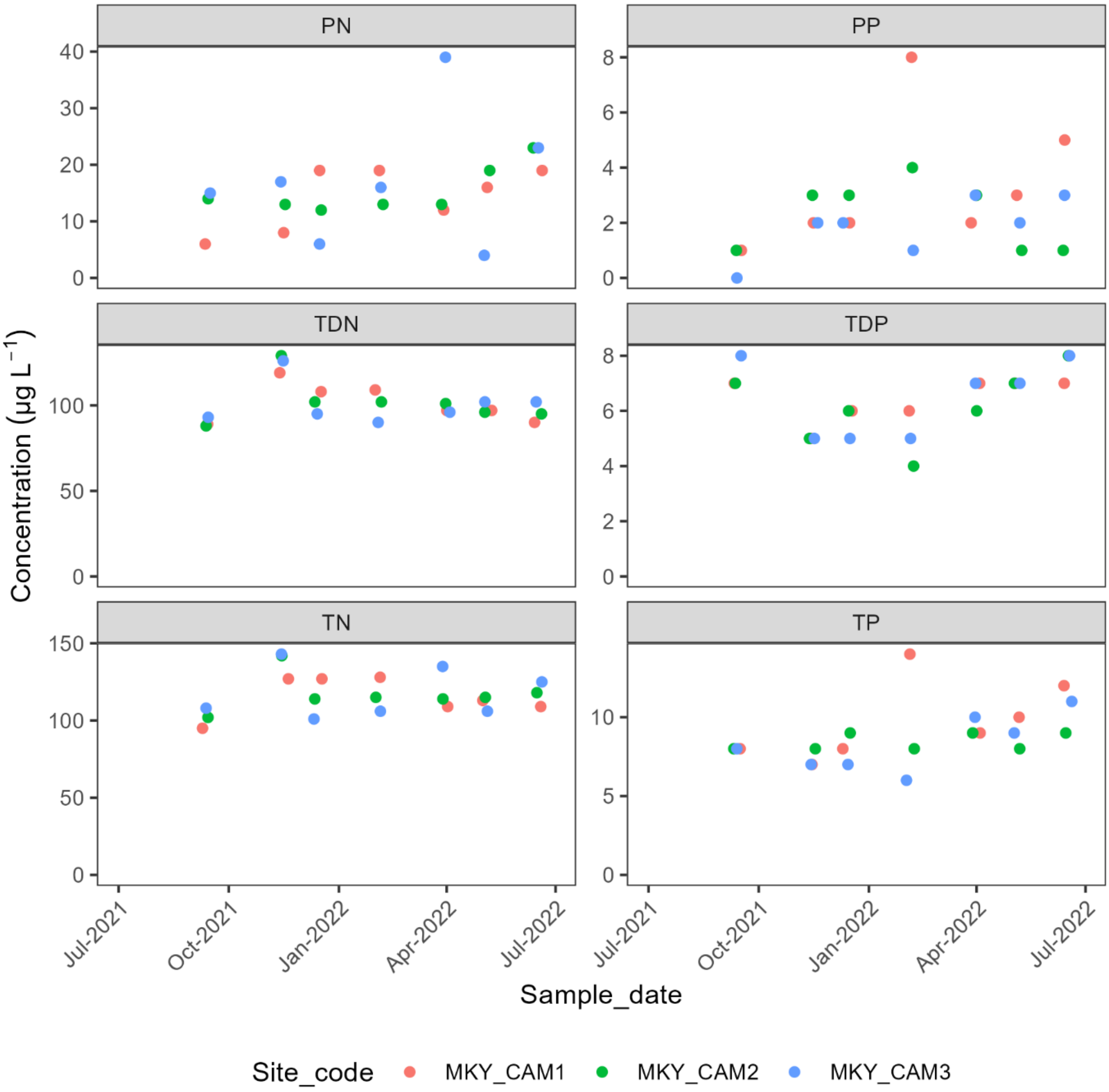

Figure 3-10. Particulate Nitrogen (PN), Total Dissolved Nitrogen (TDN), Total Nitrogen (TN), Particulate Phosphorous (PP), Total Dissolved Phosphorous (TDP) and Total Phosphorous (TP) concentrations measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), over the reporting period. Note unequal y-axis.

3.3.3 Water clarity

Secchi depth ranged from 1.5 m to 3.6 m over the reporting period (Figure 3-11).

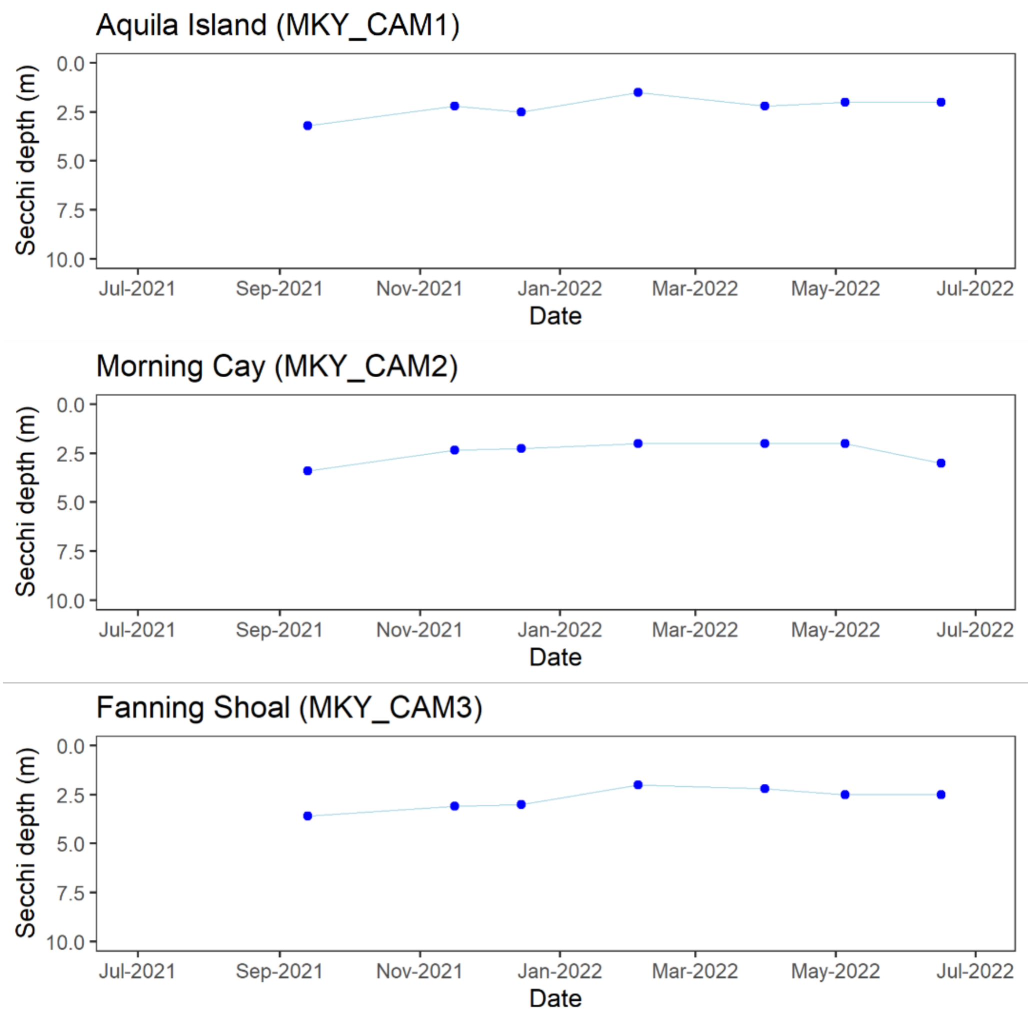

Figure 3-11. Secchi disk depth recorded at the three water quality sites throughout the reporting period.

3.3.4 Chlorophyll a

Chlorophyll-a showed high variability between both location and time of year across the three sampling sites (Figure 3-12). Average chlorophyll-a across the sites was highest over the wet season (December-March) with average levels exceeding guideline values for all sampling events except in September 2021.

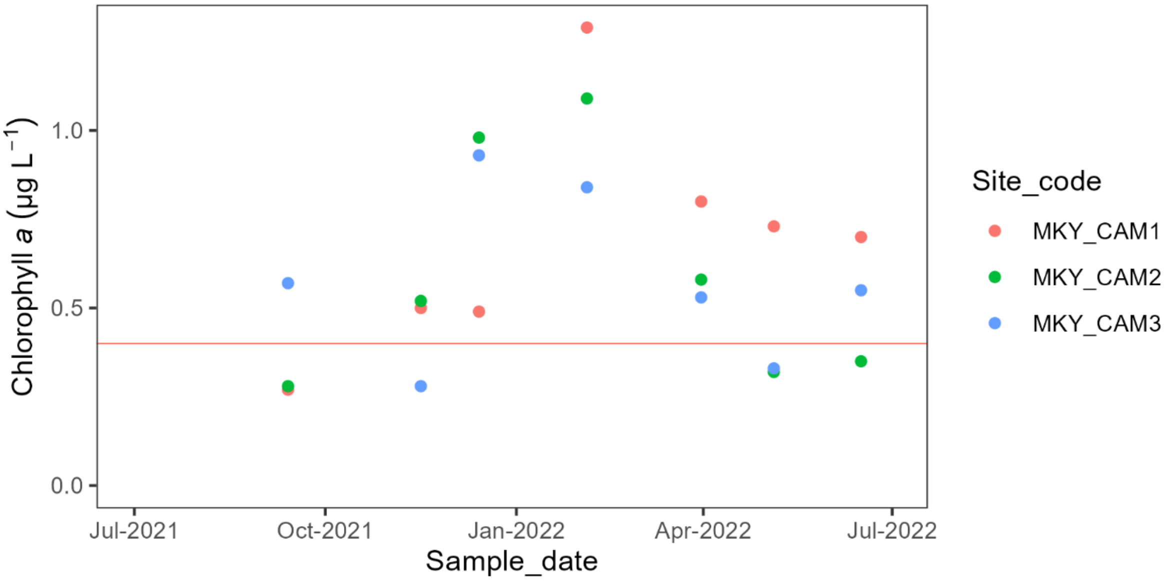

Figure 3-12. Chlorophyll-a concentrations measured in water samples collected from the three water quality sites, Aquila Island (MKY_CAM1), Morning Cay (MKY_CAM2), and Fanning Shoal (MKY_CAM3), throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

3.3.5 Pesticides

Pesticides detected at Aquila Island (MKY_CAM1) are presented in Table 3-2. Photosystem-two inhibiting herbicides (PSII) were present in all four sampling windows, with Atrazine detected in all samples, Diuron in the first two samples, and Tebuthiuron in the third and fourth samples (late wet season). The broad-spectrum herbicide Metalochlor was also present in the third sampling window.

Table 3-1. 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.

Site Name	**Aquila Island**			
Deployment Date	**16/11/2021**	**16/12/2021**	**4/02/2022**	**31/03/2022**
Retrieval Date	**16/12/2021**	**4/02/2022**	**31/03/2022**	**5/05/2022**
Days Deployed	**30**	**50**	**55**	**35**
Flow Rate (cm/s)	**33.7**	**19.9**	**18.4**	**28.8**
Pesticide Name				
2,4-D	*<0.900*	*<0.650*	*<0.620*	*<0.810*
Ametryn	*<1.62*	*<1.17*	*<1.11*	*<1.45*
Atrazine	**0.440**	**0.490**	**0.300**	**0.310**
Atrazine desethyl	*<0.260*	*<0.190*	*<0.180*	*<0.230*
Bromacil	*<0.150*	*<0.110*	*<0.100*	*<0.130*
Diuron	**0.310**	**0.190**	*<0.180*	*<0.230*

Fluometuron	*<0.150*	*<0.110*	*<0.110*	*<0.140*
Haloxyfop	*<0.110*	*<0.080*	*<0.080*	*<0.100*
Hexazinone	*<0.210*	*<0.150*	*<0.140*	*<0.190*
MCPA	*<0.650*	*<0.470*	*<0.450*	*<0.580*
Metolachlor (S+R)	*<0.210*	*<0.150*	**0.155**	*<0.190*
Prometryn	*<0.350*	*<0.260*	*<0.240*	*<0.320*
Simazine	*<0.150*	*<0.110*	*<0.100*	*<0.130*
Tebuthiuron	*<0.160*	*<0.120*	**0.595**	**0.420**
Terbuthylazine	*<0.200*	*<0.140*	*<0.140*	*<0.180*

Table 3-2. Pesticide mass per sampler recovered from passive samplers deployed at Aquila Island (MKY_CAM1).

Site Name		**Aquila Island**			
Deployment Date		**16/11/2021**	**16/12/2021**	**4/02/2022**	**31/03/2022**
Retrieval Date		**16/12/2021**	**4/02/2022**	**31/03/2022**	**5/05/2022**
Days Deployed		**30**	**50**	**55**	**35**
Flow Rate (cm/s)		**33.7**	**19.9**	**18.4**	**28.8**
Pesticide Name	**LOR**				
2,4-D	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Ametryn	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Atrazine	1.00	**2.06**	**3.14**	**2.02**	**1.63**
Atrazine desethyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Atrazine desisopropyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Bromacil	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Diuron	1.00	**1.20**	**1.02**	*<1.00*	*<1.00*
Fluazifop	0.10	*<0.100*	*<0.100*	*<0.100*	*<0.100*
Fluometuron	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Fluroxypyr	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Haloxyfop	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Hexazinone	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Imazapic	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Imidacloprid	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
MCPA	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*
Metolachlor (S+R)	1.00	*<1.00*	*<1.00*	**1.05**	*<1.00*

Metribuzin	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Metsulfuron methyl	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Prometryn	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Propazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Simazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Tebuconazole	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Tebuthiuron	1.00	*<1.00*	*<1.00*	**5.26**	**2.83**
Terbuthylazine	1.00	*<1.00*	*<1.00*	*<1.00*	*<1.00*
Terbutryn	5.00	*<5.00*	*<5.00*	*<5.00*	*<5.00*

3.4 In-situ loggers

Sections 3.4.1 – 3.4.5 will present the data collected by the In-situ Marine Optics (IMO) turbidity and multispectral PAR loggers which were rolled out across the region in September 2021. Section 3.4.6 will then present combined plots of the new IMO logger data with the old MGL logger data (July-September 2021) appended. These combined plots have also been Quality Controlled, with data that was classed as 'bad data' removed. For a description of the Quality Control data procedure see Appendix 3.

3.4.1 Water temperature

Water temperature recorded by the in-situ loggers is presented in *Figure 3-13.* Water temperature is primarily driven by season however, there was an anomalous period of increased water temperatures in the Austral summer of 2021-2022 with peak heat stress occurring in March 2022.

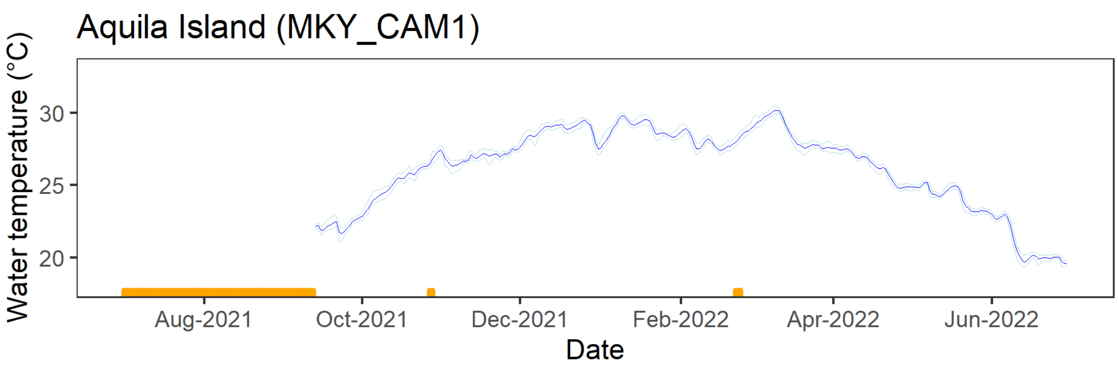

Figure 3-13. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the southern Mackay region. Periods of missing data are indicated by the orange bar.

3.4.2 Water depth

The daily mean tidal range for each site is presented in Figure 3.8. The southern Mackay region is mixed semidiurnal macrotidal, with daily tidal range measured to be from 1.79 to 8.25 m over the reporting period.

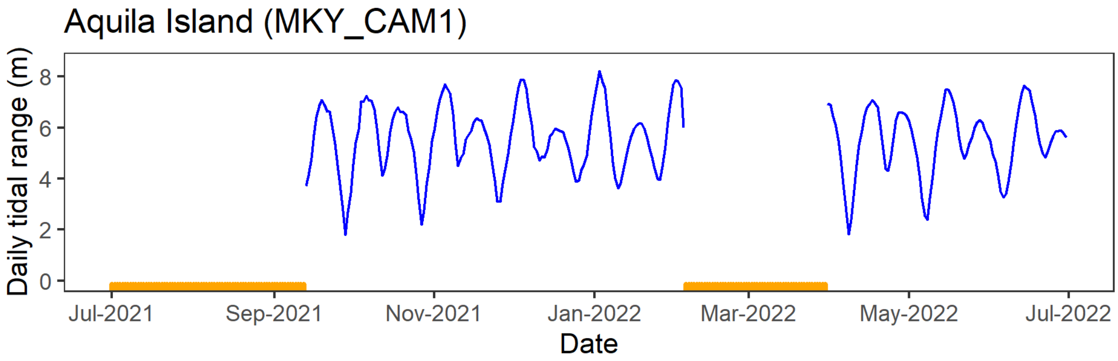

Figure 3-14. Daily tidal range measured by insitu loggers at Aquila Island (MKY_CAM1). Periods of missing data are indicated by the orange bar.

3.4.3 Wave activity

The Aquila Island logger site is located along the inshore coast and is exposed to varying levels of waves. Notable high energy periods were found in November 2021. (Figure 3-15).

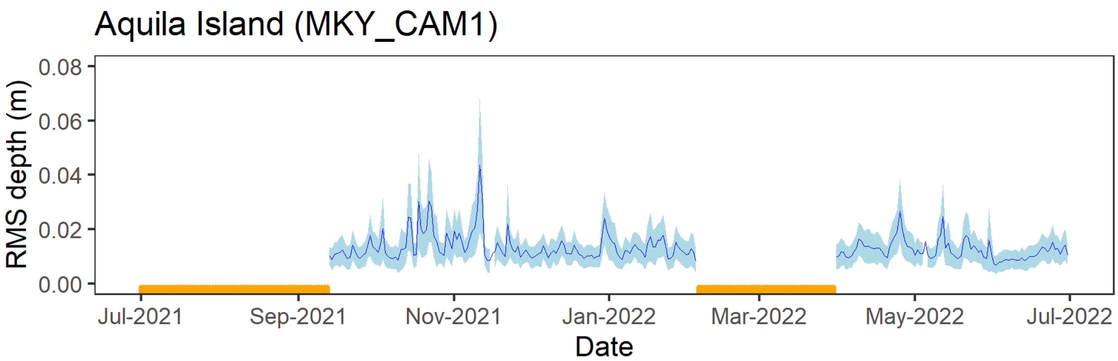

Figure 3-15. RMS depth measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue). Periods of missing data are indicated by the orange bar.

3.4.4 Turbidity

Turbidity measured at Aquila Island (MKY_CAM1) in the southern Mackay region is presented in Figure 3-16. Turbidity was highly variable at each site throughout the reporting period and showed a monthly pattern consistent with tidal patterns. Periods of high turbidity corresponded with spring tides and lower turbidity with neap tides. Turbidity at the inshore sites is also driven by tidal currents with periods of higher turbidity generally occurring during spring tides. Monthly mean and median turbidity were calculated for each of the monitoring sites (Table 3-4).

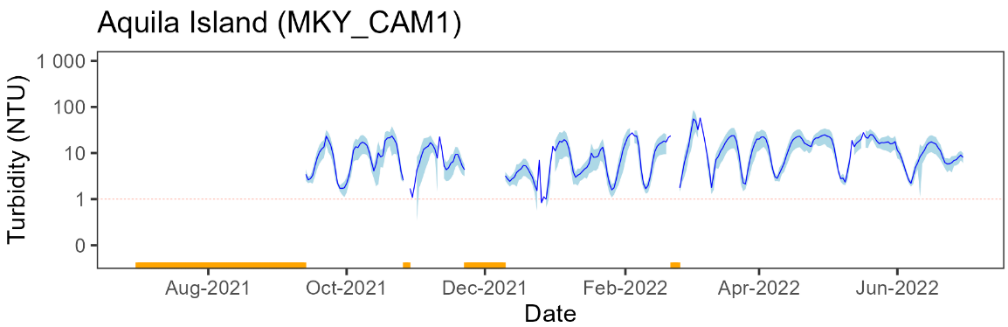

Figure 3-16. Turbidity measured at measured at Aquila Island (MKY_CAM1). Values presented are daily mean (blue line) +/- standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters. Periods of missing data are indicated by the orange bar.

Table 3-3. Monthly mean, median (Med), and standard deviation (SD) for turbidity (NTU) measured by in-situ loggers at Aquila Island in the southern Mackay region.

Aquila Island Monthly Mean Turbidity (NTU)			
Month	Mean	Med	SD
July 2021	NA	NA	NA
Aug 2021	NA	NA	NA
Sept 2021	7.85	4.25	7.57
Oct 2021	10.82	8.58	8.67
Nov 2021	9.36	6.81	14.26
Dec 2021	3.85	2.67	13.33
Jan 2022	8.23	5.19	7.49
Feb 2022	12.86	10.01	14.59
Mar 2022	17.54	11.61	24.07
Apr 2022	15.60	14.65	9.62
May 2022	15.84	15.98	15.78
June 2022	8.76	7.25	5.59

3.4.5 Photosynthetically active radiation (PAR)

PAR was highly variable at Aquila Island throughout the reporting period (Figure 3-17). Periods of increased light were evident during January when turbidity was also lowest. Note: some PAR data was removed during the Quality Control (QC) process due to instability of the logger frames on the benthic surface. Due the very strong currents in this location the logger frames required a specialised mooring technique. Prior to this being implemented, the loggers were recorded as being 'tilted' beyond a level where the data is considered 'good'. For example, if a light logger is pointing away from the light source (surface of water) the recorded PAR will be less than the actual PAR.

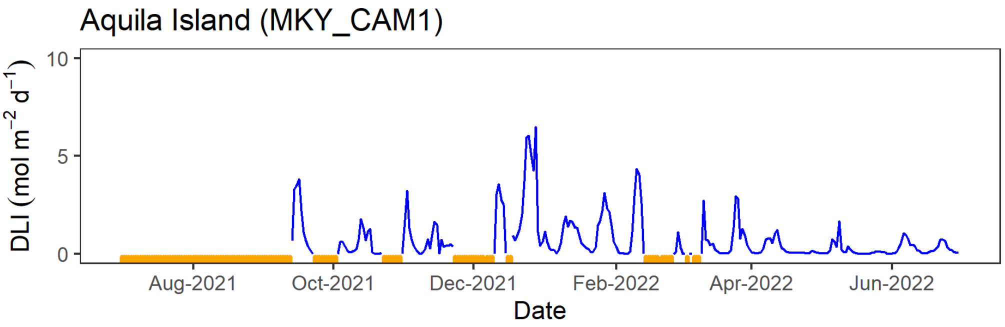

Figure 3-17. Daily light integral (mol photons m^{-2} d^{-1}) of photosynthetically active radiation measured at Aquila Island. Periods of missing or QC-removed data are indicated by the orange bar.

3.4.6 Combined IMO and MGL quality-controlled data

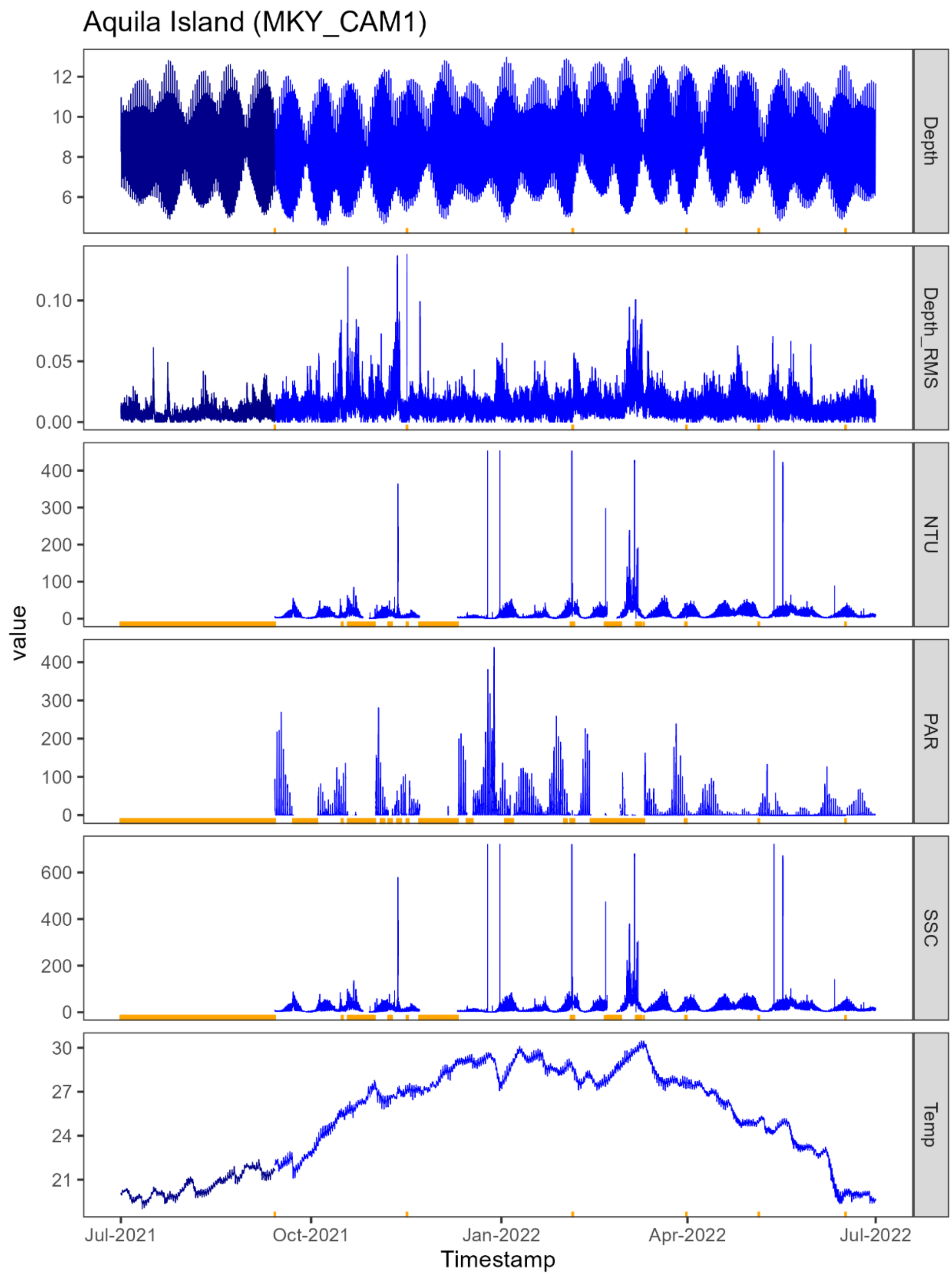

Figure 3-18. Data collected at Aquila Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes data 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). Data flagged as red (qc 4) was removed as bad data. A description of the QC flags is provided in Appendix 1.

There was some data loss throughout the reporting period due to teething problems with deployments of the new loggers. These have been addressed and future reporting periods are expected to have a higher data retrieval rate.

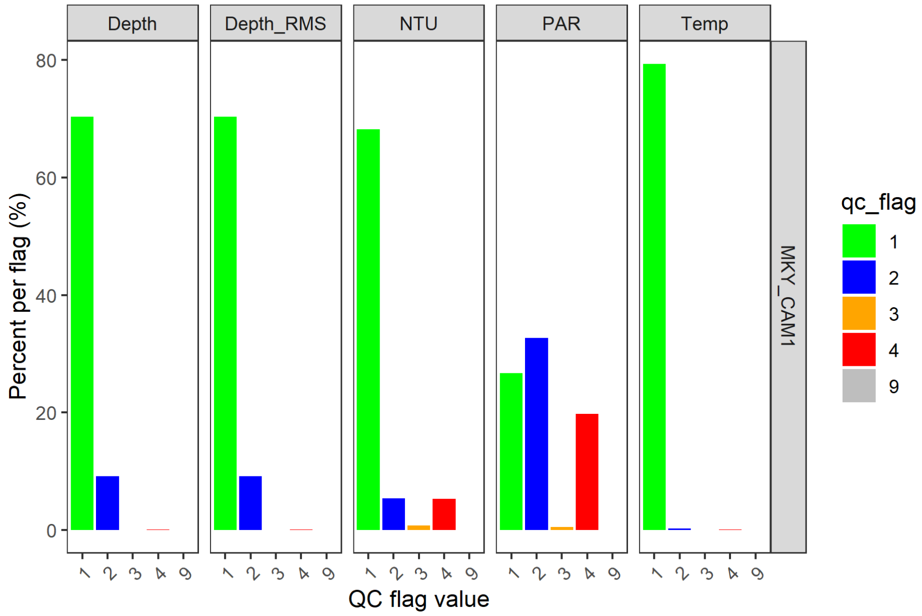

Figure 3-19. Data recovery and qc flags at the Aquila Island (MKY_CAM1) logger site over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2 (blue) indicates a 'probably good value'; flag 3 (yellow) indicates 'probably bad value', flag 4 (red) indicates a 'bad value' and flag 9 (grey) indicates data that is missing.

4 Conclusions and Recommendations

4.1 Conclusions

4.1.1 Climatic conditions

1. The 2021-2022 wet season received more rainfall when compared to the previous year's monitoring (2020-2021) however annual rainfall was below the median rainfall since 1910. The wet season rainfall total was 851 mm, while total rainfall for the water year was 1351.2 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 seasonal pattern for water temperature, with highest water temperatures experienced during summer months, and cooler conditions in the winter months. Marine heatwaves are increasingly a feature of this region with March 2022 recording the first 'La-Nina year' heatwave.
2. The water column is usually well mixed, as would be expected from high energy coastal sites; occasionally some stratification is observed, particularly for dissolved oxygen and electrical conductivity (salinity), though temperature and pH are usually consistent throughout the water depth. Mixing is particularly important when considering dissolved oxygen concentrations, which is known to reach critical levels for fish in coastal waters in Queensland.
3. Particulate nitrogen (PN), particulate phosphorus (PP), and Chlorophyll-*a* concentrations exceeded guideline values during many surveys at all sites. This pattern continues and requires further discussion with relevant authorities to address the source of nutrient supply.

4.1.3 Turbidity

1. Continuous 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 by either wind/waves or strong currents. This has been most notable here given the corresponding tidal and turbidity patterns.
2. Guideline values for turbidity in the southern Mackay region should take into consideration the natural variability of suspended sediment that is due to the strong tidal currents that are a feature of the region. This natural variability in turbidity supports many turbid reefs, both insipid and fringing, that are adapted to these conditions.
3. As the data set here continues to increase, assessment of the rainfall patterns (frequency and duration), and metocean conditions can be examined, providing more detailed insight into the long-term water quality relationships across this region.

4.1.4 Photosynthetically active radiation (PAR)

1. Fine-scale patterns of PAR are primarily driven by tidal cycles with fortnightly increases in PAR coinciding with neap tides and 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).
2. 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 PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae, and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality. This may be especially relevant in the southern Mackay region due to the naturally variable turbidity to which habitats are adapted.

4.2 Recommendations

This monitoring program has been underway for five 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 below 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.

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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 A5.

Table A 1. Quality Control rules applied to the logger data in the automated process.

QC rule 1: Syntax test	QC rule 7: Spike test
QC rule 2: Impossible date test	QC rule 8: Rate of change test
QC rule 3: In/out-water test	QC rule 9: Stationary test
QC rule 4: Global range test	QC rule 10: Standard deviation test
QC rule 5: Regional range tests	QC rule 11: Burst count test
QC rule 6: Impossible depth test	QC rule 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’ (yellow) 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 will be published in early 2023.

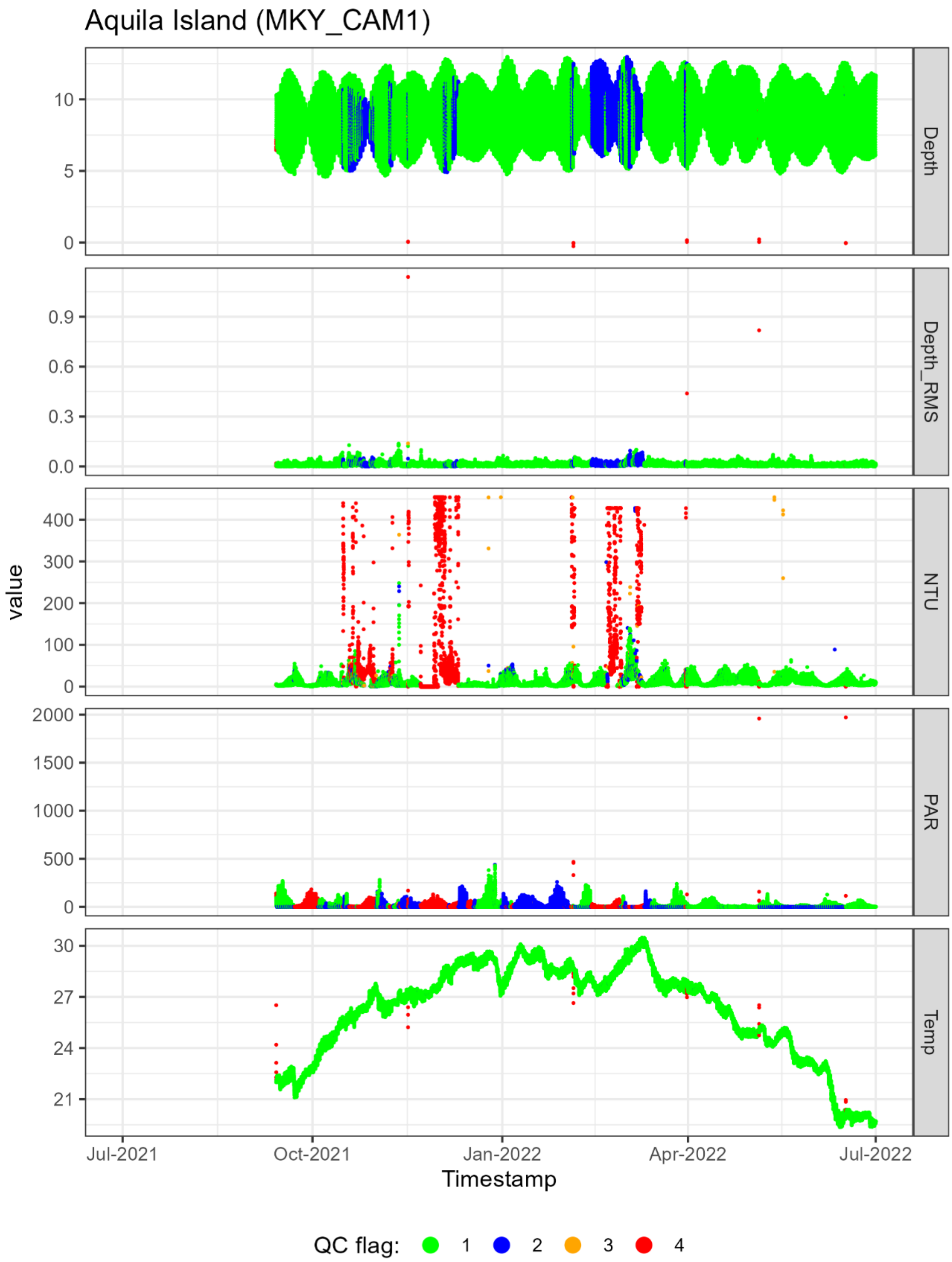

Figure A 1. Raw data collected at Aquila Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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