Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022

Port of Mackay and Hay Point Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022

A Report for North Queensland Bulk Ports Corporation

Report No. 22/60

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Executive Summary

Background

1. In July 2014, North Queensland Bulk Ports (NQBP) in partnership with The Centre for Tropical Water and Aquatic Ecosystems (TropWATER) at James Cook University implemented an ambient marine water quality monitoring program in the region surrounding the Ports of Mackay and Hay Point. By incorporating a combination of approaches including spot measurements, acquisition of data via deployment of high frequency continuous loggers, water sample collection, and laboratory analysis of samples for a range of nutrients, pesticides, herbicides, and heavy metals, the objective of the program is to collect a long-term water quality dataset that characterises the ambient water quality conditions within the Mackay region.
2. Sites extend approximately 60km along the Mackay coastline, from Slade Island to Freshwater Point, aligning 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)
3. In September 2021, a major investment by NQBP saw the roll out of new state-of-the-art water quality loggers that will allow more reliable data logging and a broader range of data acquisition across the region, and an increased capacity to answer important scientific questions. This report covers the period from July 2021 to June 2022, during which time these new loggers were deployed to replace the old loggers, and therefore the data is a mix of these old and new formats.

Climatic conditions

1. This reporting year saw 1351.2 mm of rainfall in the Mackay region, which is below the median annual rainfall measured over the past 100 years. Wet season rainfall, at 851 mm, was slightly higher than in the 2020-21 year.
2. There was a large rainfall event in late November 2021, while stream discharge was highest in the Pioneer River in May and June 2022.

Water chemistry

1. Water quality conditions were measured at all sites on a ~8 weekly basis. Parameters collected were water temperature, electrical conductivity, pH, dissolved oxygen, and photosynthetically active radiation at three depths (surface, mid-water, and bottom), along with Secchi disk depth.
2. The water column is mostly well mixed, with depth profiles for temperature and pH, showing only minor gradients of change. Dissolved oxygen however, reduced with depth on several sampling occasions in Mackay Harbour and a halocline, where surface waters showed lower conductivity (reduced salinity), occurred at Round Top Island in December 2021.
3. Particulate nitrogen (PN) and particulate phosphorus (PP) concentrations exceeded guideline values on many sampling occasions across almost all sites, with only Slade Island mostly below guideline values.

4. Chlorophyll-*a* concentrations exceeded guideline values during most surveys at most sites.

5. Trace metals were generally well below guideline values throughout the reporting year. The only exception was copper, which was above trigger values at all sites in September 2021. As with previous years, this suggests a low risk of contamination in the region but does require some caution given the limited spatial and temporal monitoring of this program.
6. There were several pesticides/herbicides detected in the early wet season at Slade Island. Several PFAS substances were also detected in the early wet season.

Turbidity

1. Turbidity logger data supports the pattern found more broadly in north Queensland coastal marine environments, that during dry periods with minimal rainfall, elevated turbidity experienced is likely in relation to re-suspension of sediment. Large peaks in NTU/SSC and RMS water depth were recorded over periods longer than a week, giving rise to the notion that the re-suspension events can occur over extended periods.

Photosynthetically active radiation (PAR)

1. PAR was lowest at Freshwater Point compared to the other three sites.
2. Patterns of light were similar among all the coastal sites, with lower light associated with periods of higher rainfall and significant climate events.

Recommendations

This monitoring program has been underway for eight years (2014 to present) and should remain in place to continue to characterise, and build, a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities but will also assist with future strategic planning and management. With an emerging long-term dataset, there is potential for answering important research questions around coastal processes affecting the Great Barrier Reef lagoon water quality in this region.

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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) have partnered with North Queensland Bulk Ports (NQBP) to undertake long-term environmental monitoring and research initiatives surrounding the Ports of Mackay and Hay Point (Figure 1-1). As part of the agreement, an ambient water quality monitoring program has been implemented that incorporates discreet field measurements, acquisition of data via deployment of continuous dataloggers, and water sample collection for laboratory analysis of a range of nutrients, pesticides, PFAS, and heavy metals. The program aims to characterise variability in water quality by monitoring a suite of key parameters to better define the potential impacts associated with port operations adjacent to sensitive habitats in the Great Barrier Reef (GBR) lagoon. Along with regular monitoring of water quality parameters, an understanding of the meteorological and oceanographic (metocean) conditions that affect Queensland coastal ecosystems is important in understanding seasonal and interannual variability in water quality.

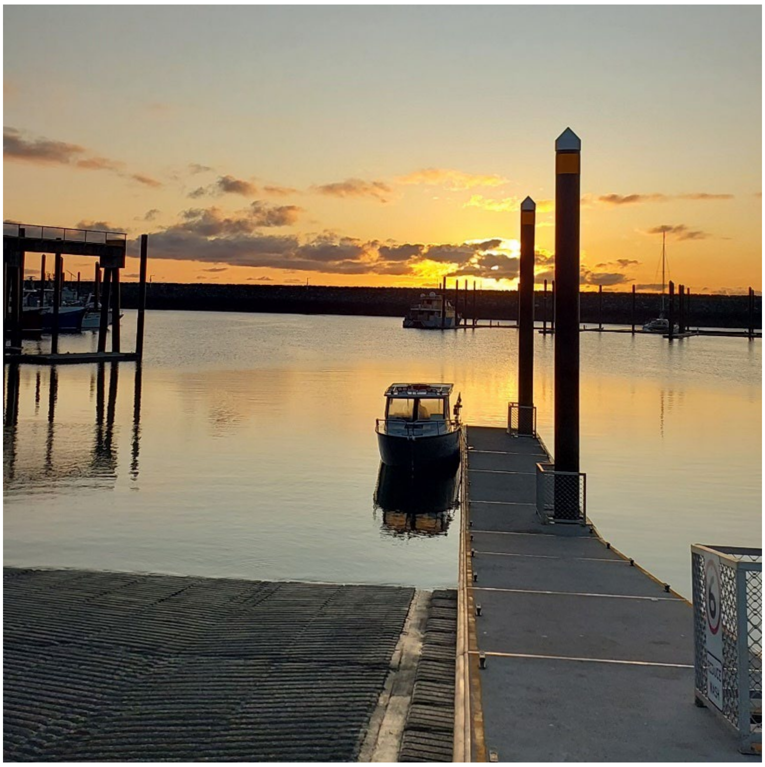

Figure 1-1: James Cook University research vessel 'Kasmira' at Mackay Harbour ready to depart for water quality monitoring across the region.

Declining water quality in coastal and marine ecosystems is a major concern for the future of the 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 corals 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 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.

1.2 Program objectives

As the Ports of Mackay and Hay Point lies within the Great Barrier Reef region, the primary objective of the program is to assist NQBP to manage risks to the environment. The extensive marine monitoring program implemented by TropWATER is designed to characterise the ambient water quality surrounding the port so that any impacts to habitats can be minimised. The partnership objective also moves beyond basic environmental stewardship and incorporates robust science 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 Port Description

The Port of Mackay and the Port of Hay Point are situated on the central Queensland Coast (Figure 2-1). The Port of Mackay is located approximately four kilometres north of the Pioneer River and is enclosed by large break walls that protect the port and marina property, while also allowing exchange of oceanic waters. The port has a series of operational and associated loading/unloading facilities, and an extensive marina operation and commercial fishing fleet. The port is operated by North Queensland Bulk Ports Corporation (NQBP).

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

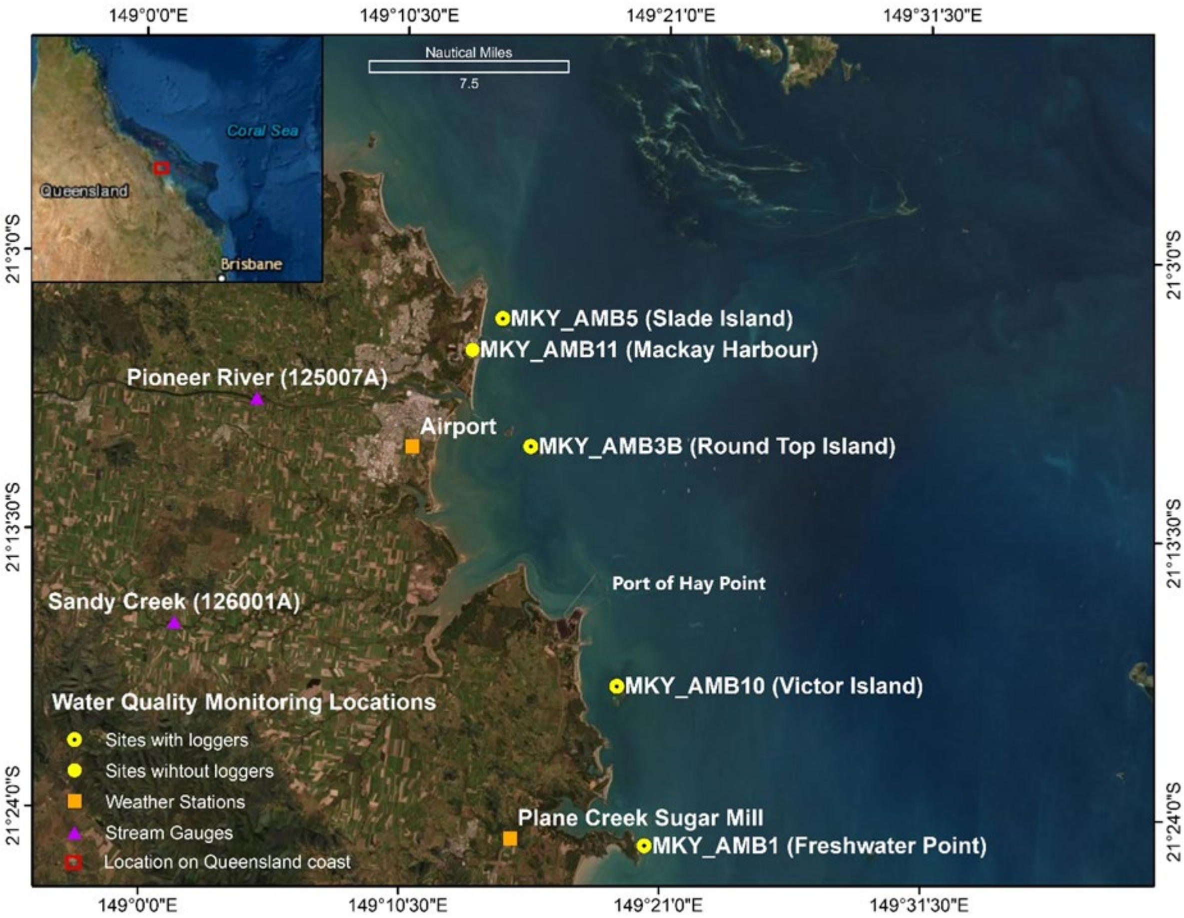

Figure 2-1. Map of Mackay and Hay Point showing the water quality monitoring locations (yellow circles), meteorological stations (orange squares), and stream gauges referred to in this report.

In both ports, routine maintenance dredging is necessary to maintain declared navigational depths within the swing basin and berth areas, departure paths, aprons, and harbours. For the Port of Mackay, the most recent dredging campaign was completed in 2013, while the last maintenance dredging campaign undertaken by NQBP at the Port of Hay Point was completed in 2010. Any dredging activity necessary in the operating ports in the region are undertaken in accordance with

Commonwealth and State approvals with management objectives guided by the Port of Mackay Long Term Dredge Management Plan and the Port of Hay Point Dredge Management Plan.

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.

2.3 Monitoring and sampling design

The Mackay region has five active ambient marine water quality monitoring sites (Figure 2-1, Table 2.1). Sites extend approximately 60km along the Mackay coastline, from Slade Island to Freshwater Point, aligning 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. Site locations and main features

Site name	Site code	Latitude	Longitude	Depth (m)	Site features
Freshwater Point	MKY_AMB1	-21.42	149.34	9	Coral/seagrass/other invertebrates
Round Top Island	MKY_AMB3B	-21.17	149.26	11	Coral/seagrass/other invertebrates
Slade Island	MKY_AMB5	-21.09	149.24	10	Coral
Victor Island	MKY_AMB10	-21.32	149.32	8	Coral/seagrass/other invertebrates
Mackay Harbour	MKY_AMB11	-21.11	149.22	6	Sediment

2.4 Water quality sampling

Four of the sites have a pair of data loggers deployed on the seafloor to continuously record environmental data (Mackay Harbour does not have loggers). The sites are revisited on an 8 weekly schedule to conduct water sampling, record physiochemical measurements, and exchange dataloggers (*Table 2-2*).

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

Date	Water sampling	Logger maintenance	Metals sampling	Pesticides
2021-09-12	Yes	Yes	Yes	No
2021-11-15	Yes	Yes	No	Yes
2021-12-14	Yes	Yes	No	No
2022-02-03	Yes	Yes	No	No
2022-03-31	Yes	Yes	Yes	Yes (PFAS only)
2022-05-06	Yes	Yes	No	No
2022-06-17	Yes	Yes	No	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 and immediately transported to 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'.

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.

Water samples were collected for dissolved metals analysis on two occasions (September 2021 and March 2022). Dissolved metals samples were immediately filtered onsite with an 0.45 µm syringe filter (Sartorius minisart PES 0.45) and stored on ice (Table 2.5).

Table 2-3. Water quality parameters that were analysed using water samples collected at five locations, Freshwater Point, Slade Island, Round Top Island, Victor Island, and Mackay Harbour, 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	-
Chlorophyll		
Chlorophyll-*a*	10200-H	0.1 µg L^{-1}
Phaeophytin-*a*		

Table 2-4. Physiochemical measurements that were collected at five locations, Freshwater Point, Slade Island, Round Top Island, Victor Island, and Mackay Harbour.

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)

Table 2-5. Dissolved metals that were tested for from water samples collected at five locations, Freshwater Point, Slade Island, Round Top Island, Victor Island, and Mackay Harbour

Parameter	APHA method number	Reporting limit
Dissolved metals		
Arsenic (As)	3125B ORC/ICP/MS	-
Cadmium (Ca)		0.2 µg L^{-1}
Copper (Cu)		1 µg L^{-1}
Zinc (Zn)		5 µg L^{-1}
Lead (Pb)		0.2 µg L^{-1}
Nickel (Ni)		0.5 µg L^{-1}
Silver (Ag)		0.1 µg L^{-1}
Mercury (Hg)		0.1 µg L^{-1}

2.5 Pesticide monitoring

Passive samplers were deployed at Slade Island (MKY_AMB5) for pesticide monitoring (Figure 2.2; Table 2-6). Each set of passive samplers contained an Empore™ SPE disk (ED), a microporous polyethylene tube (MPT), 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 were retrieved from Slade Island (MKY_AMB5) in November 2021 and March 2022. Note: biological growth on the samplers.

Table 2-6. Pesticide and PFAS passive samplers deployed at Slade Island (MKY_AMB5) during the 2021-2022 wet season.

Site name	Site code	Start date	End date	Duration (days)
Slade Island	MKY_AMB5	15/11/2021	14/12/2021	29
Slade Island	MKY_AMB5	01/04/2022	06/05/2022	35

Table 2-7. Pesticide analytes used for ms-PAF calculations to determine the pesticide risk baseline. 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}
Isoxaflutole (as diketonitrile)	OH	ED	0.1 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}
Triclopyr	OH	ED	5 ng sampler^{-1}

	Early wet season	Late wet season

	Analyte		Mass per sampler (ng)	Water concentration (ng L^{-1})	Mass per sampler (ng)	Water concentration (ng L^{-1})
Perfluoroalkyl Carboxylic Acids (PFCAs)						
	Perfluorobutanoic acid	PFBA	<0.760	<5.34	<0.760	<3.97
	Perfluoropentanoic acid	PFPeA	<0.100	<0.870	<0.100	<0.646
	Perfluoroheptanoic acid	PFHpA	<0.430	<0.740	<0.430	<0.549
	Perfluorooctanoic acid	PFOA	<0.400	<0.861	<0.400	<0.640
	Perfluorononanoic acid	PFNA	<0.170	<0.283	<0.170	<0.210
Perfluoroalkane Sulfonates						
	Perfluorohexane sulfonate	PFHxS	<0.200	<0.339	<0.200	<0.252
	Perfluorooctane sulfonate	PFOS	<0.290	<0.477	<0.290	<0.355

2.6 Seafloor mounted continuous dataloggers

A pair of water quality loggers were deployed at each site 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 2-8. 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. Because they were deployed in September 2021, there is a period of approximately two months where the previous loggers (MGL) are the only source of continually logged data. Full descriptions of these older MGL loggers are available in previous annual reports (e.g., Port of Mackay and Hay Point Ambient marine Water Quality Monitoring 2018-2019).

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.

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.

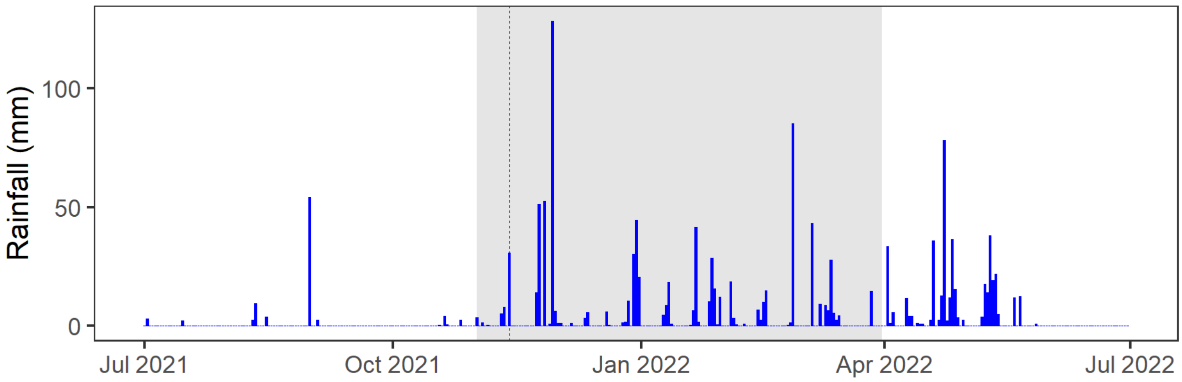

Figure 3-1. Rainfall recorded at Plane Creek Sugar Mill (station 033059) for the 2021-2022 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

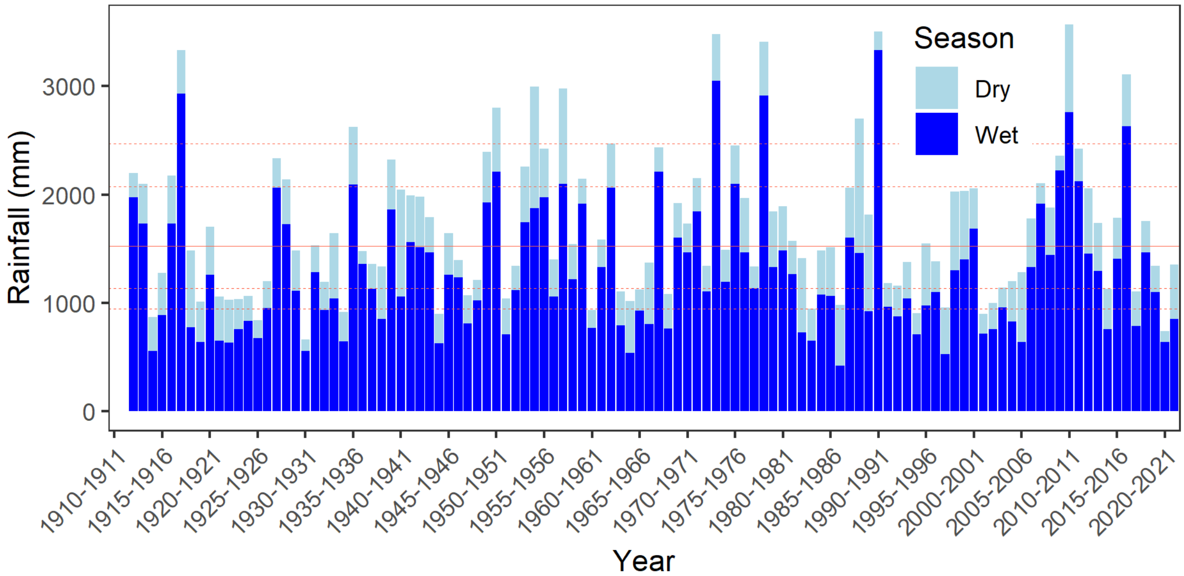

Figure 3-2: Annual rainfall by water year for the Mackay region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall 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 24/11/2022 with a series of flow pulses through to May 2022 (Figure 3-3). Total discharge for the 2021-2022 reporting period was 277.1 GL (Pioneer River) and 49.75 GL (Sandy Creek).

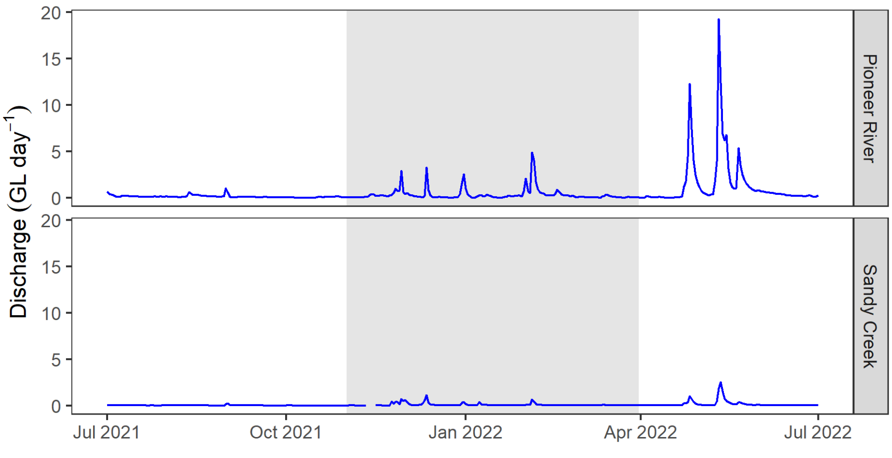

Figure 3-3: Stream discharge (GL d^{-1}) recorded for the Pioneer River (station 125016A) and Sandy Creek (station 126001A) during the 2021-2022 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/

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).

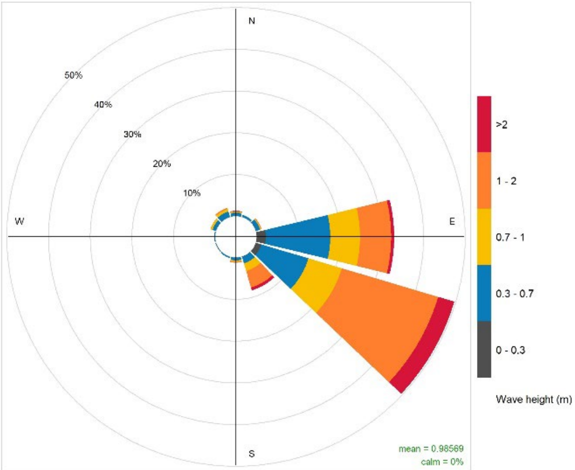

Figure 3-4. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

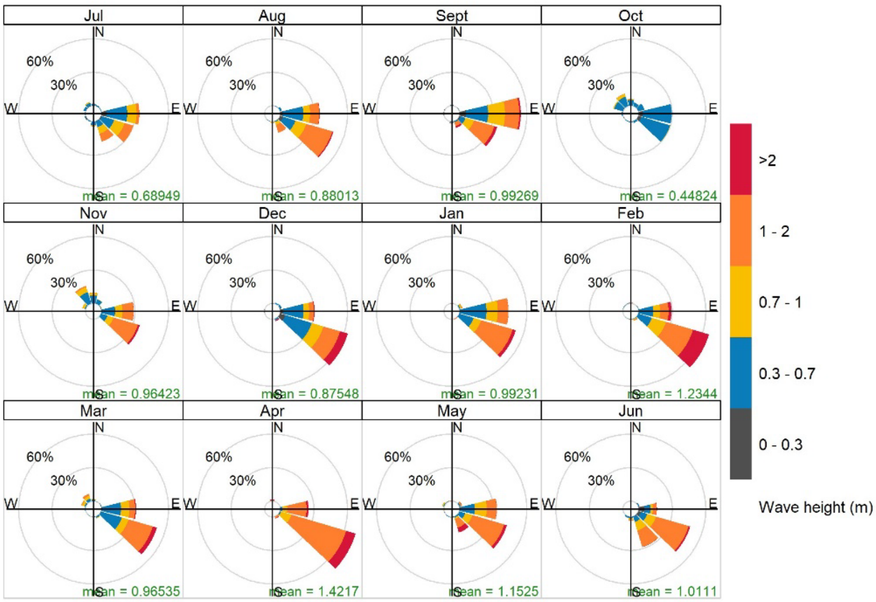

Figure 3-5. Frequency of counts by wave direction (%), and significant wave height (m) at the Mackay wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

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 well mixed, with dissolved oxygen saturation consistent through the vertical profile apart from in Mackay Harbour which often saw dissolved oxygen more depleted in the middle and bottom waters. (Figure 3-6).

Electrical conductivity (EC) at the five locations ranged from 51.5 to 56.9 mS cm^{-1} and was in the range typical of seawater (Figure 3-7). Conductivity values followed seasonality with highest values occurring in June and lowest values in December, aligning with periods of high rainfall.

Water temperature ranged between 21.2 and 29.8°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 cool water temperatures observed during the winter months. Water temperature was generally similar through the water column for all sites, indicating that the water column profile is vertically well mixed throughout the region.

pH values ranged between 8.12 and 8.29 across all sites throughout the year (Figure 3-9).

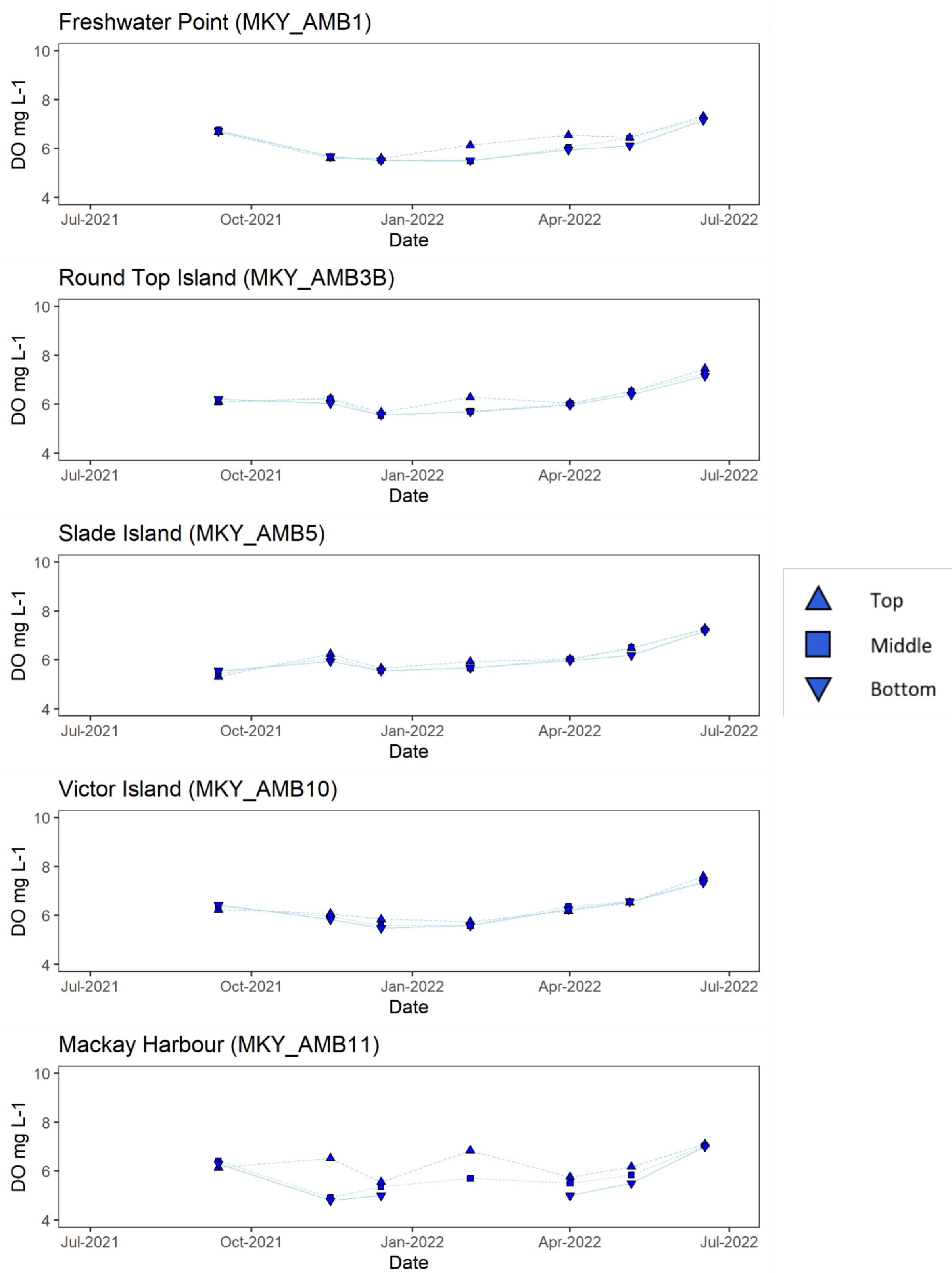

Figure 3-6. Dissolved oxygen concentration (mg/L) at five water quality monitoring sites in the Mackay region showing results for the top, middle, and bottom water.

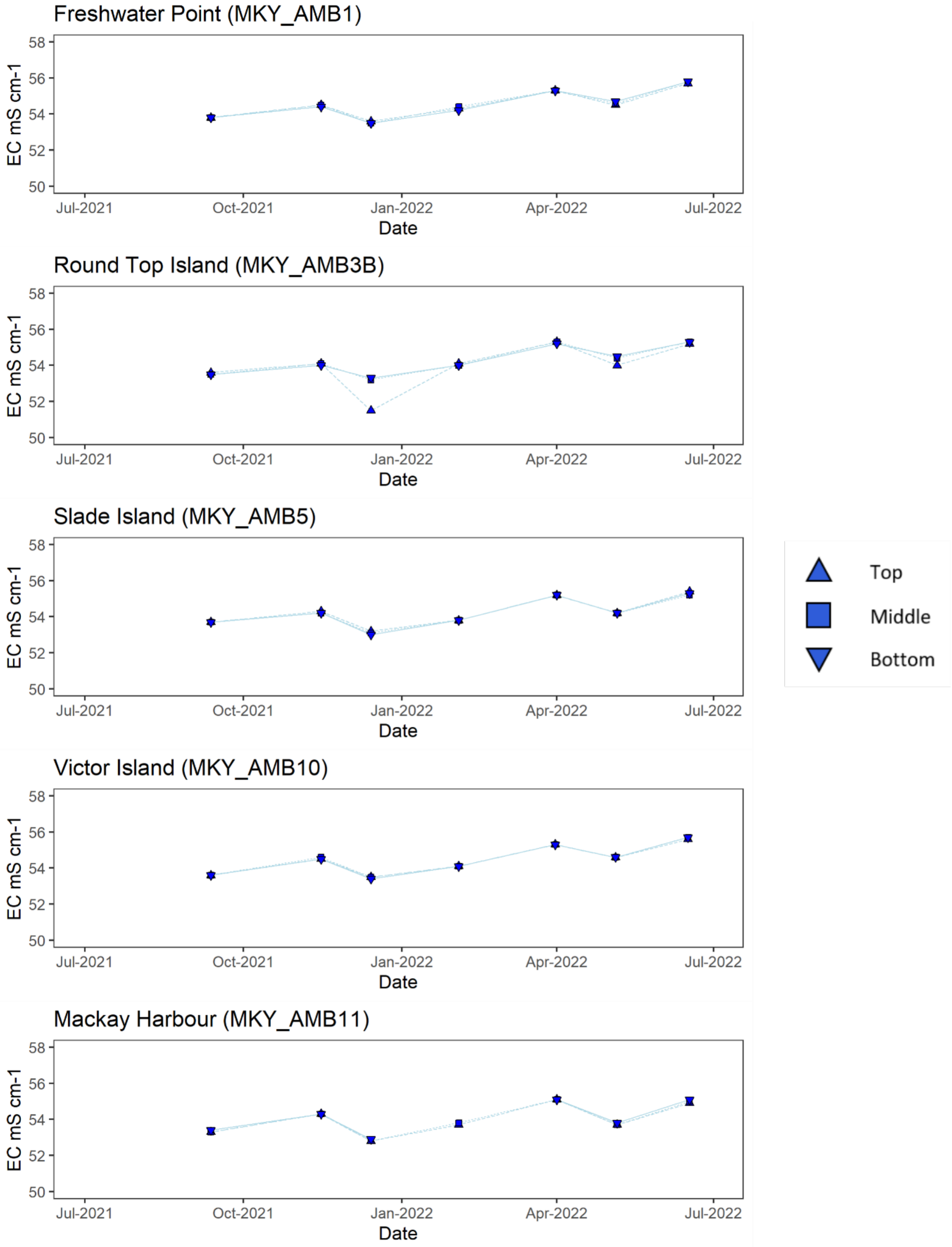

Figure 3-7. Electrical conductivity recorded at five water quality sites in the Mackay region showing results for the top, middle, and bottom water.

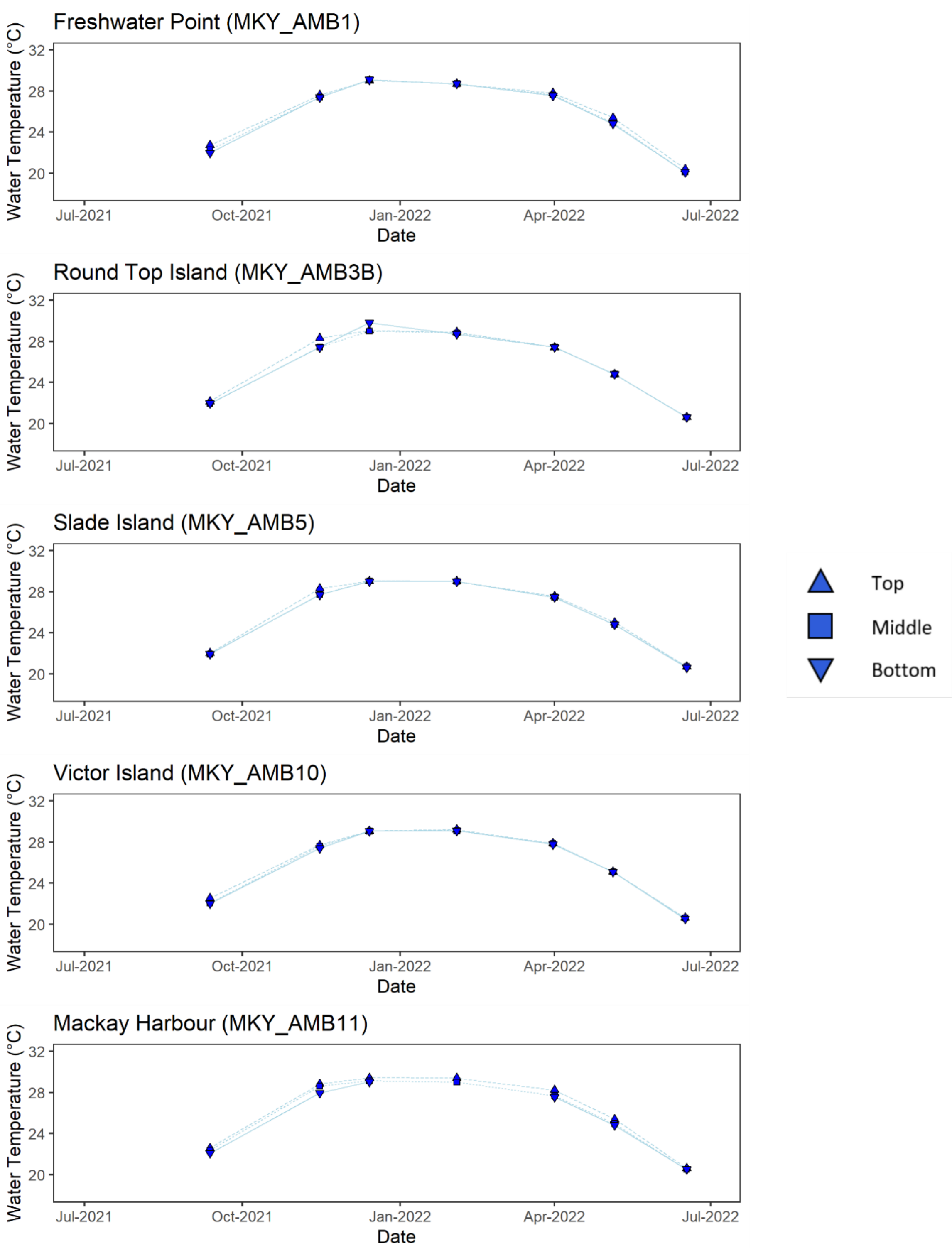

Figure 3-8. Water temperature recorded at three depths at the five water quality sites in the Mackay region throughout the reporting period.

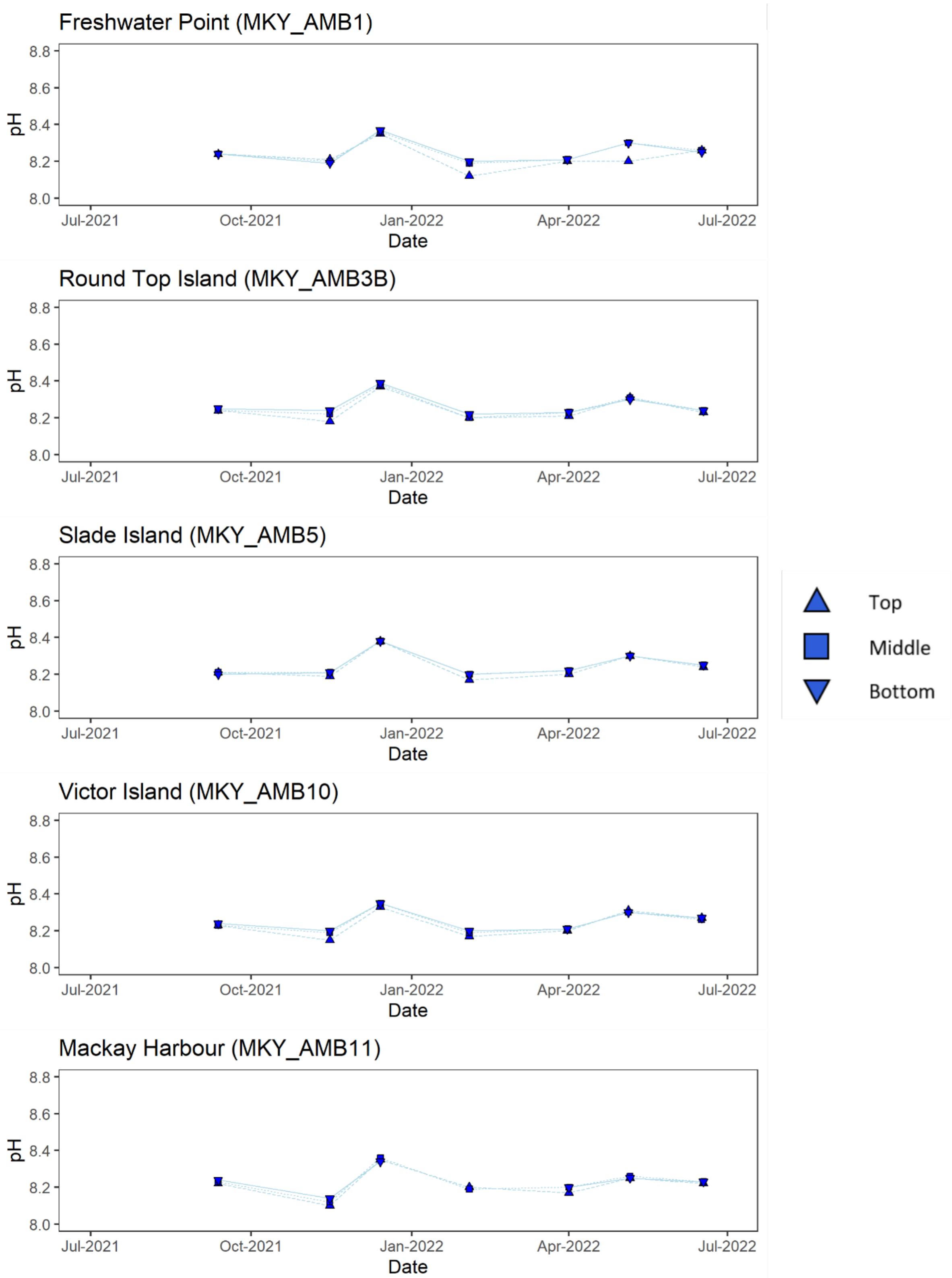

Figure 3-9. pH recorded at three depths at the five water quality sites in the Mackay throughout the reporting period.

3.3.2 Nutrients

Particulate nitrogen (PN) concentrations ranged from 5 to 105 µg L^{-1} (Figure 3-10). Mean PN across the three sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} in September and November 2021

Particulate phosphorus (PP) concentrations ranged from <1 to 4 µg L^{-1} (Figure 3-10). Mean PP was generally below the GBRMPA guideline trigger value of 2.8 µg L^{-1} for all sampling events except for September 2021.

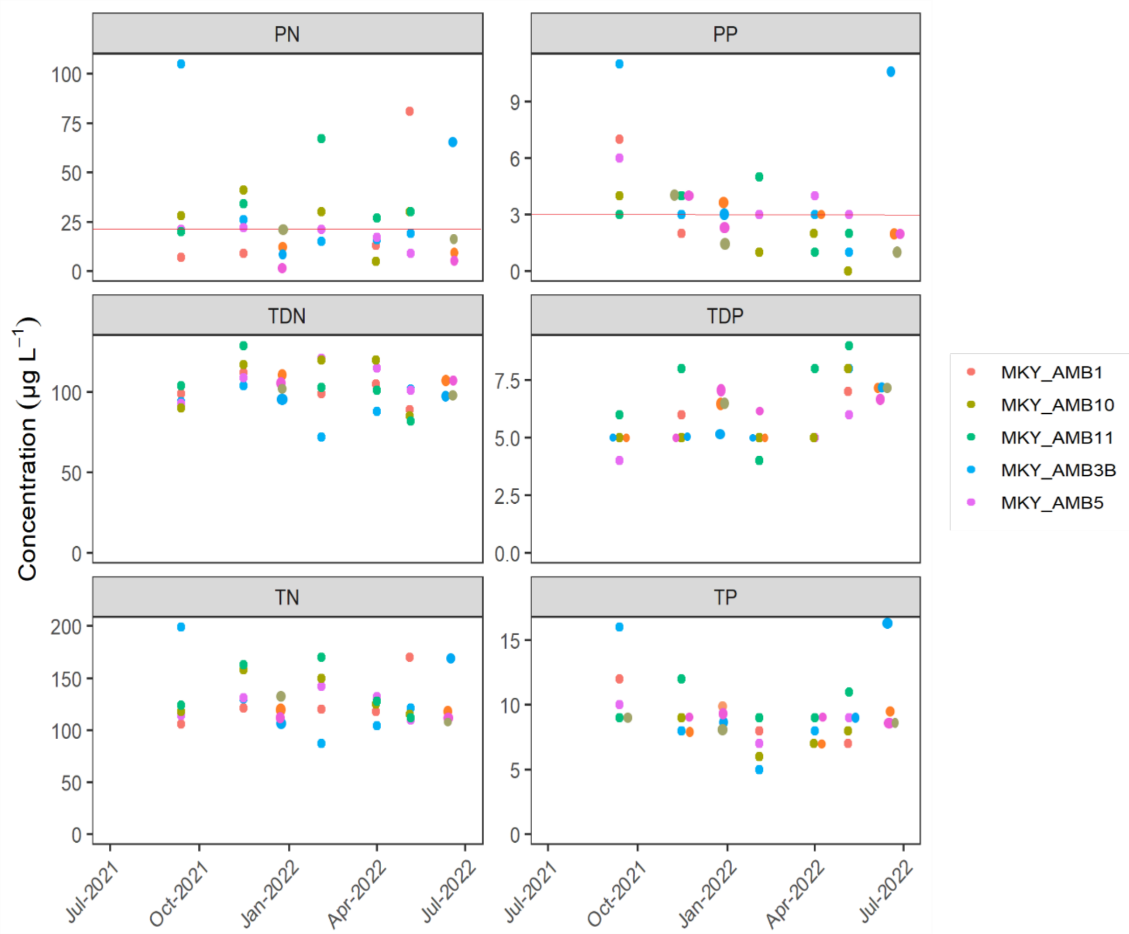

Figure 3-10. Particulate Nitrogen (PN), Total Dissolved Nitrogen (TDN), Total Nitrogen (TN), Particulate Phosphorous (PP), Total Dissolved Phosphorous (TDP) and Total Phosphorous (TP) concentrations measured in water samples collected from the five water quality sites, Freshwater Point (MKY_AMB1), Round Top Island (MKY_AMB3B), Slade Island (MKY_AMB5), Victor Island (MKY_AMB10) and Mackay Harbour (MKY_AMB11), over the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value for Particulate Nitrogen and Particulate Phosphorous. Erroneous results from Mackay Harbour in June 2022 were removed.

3.3.3 Water clarity

Secchi depth ranged from 4.5 m to 20.0 m over the reporting period (Figure 3-11).

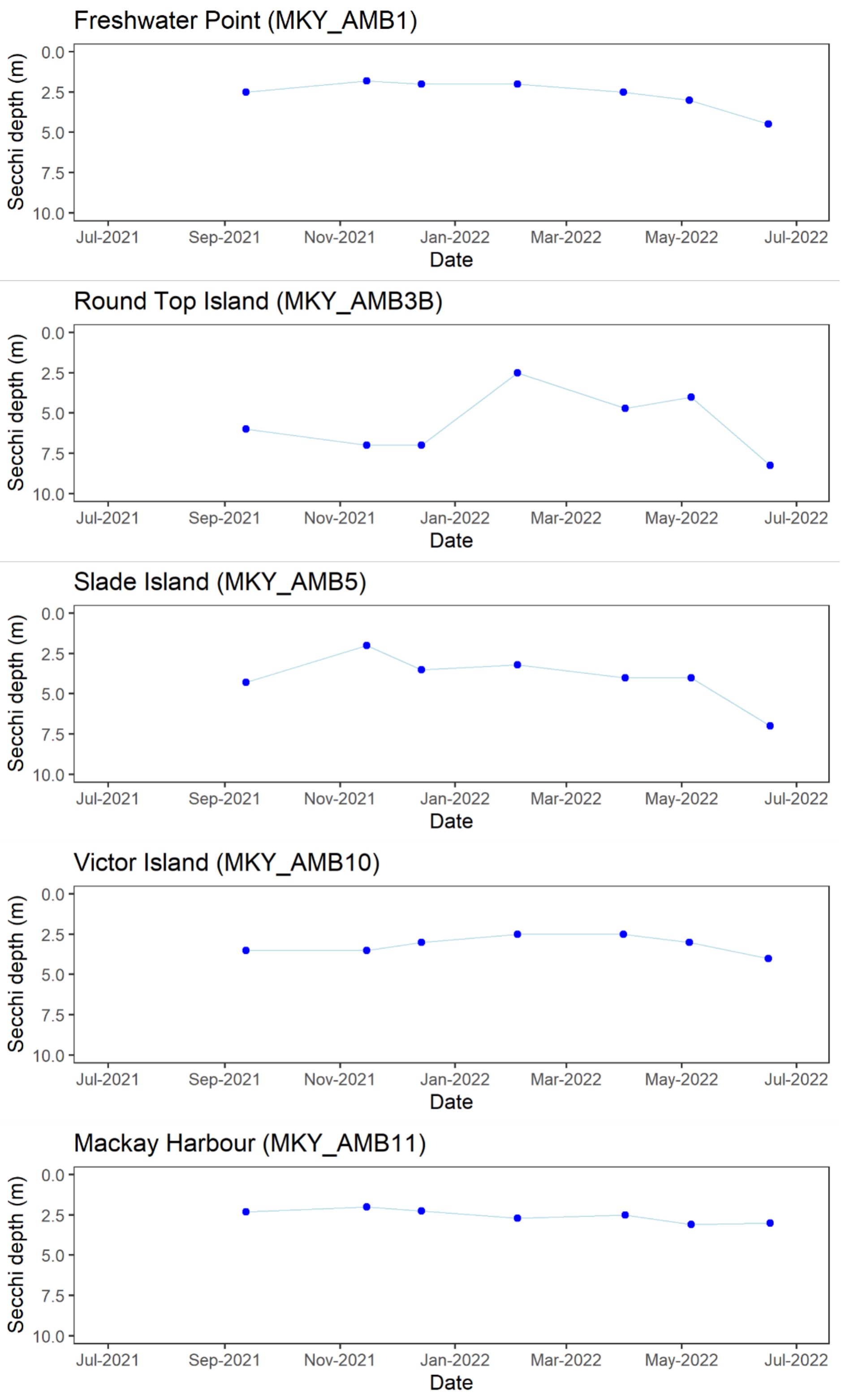

Figure 3-11. Secchi disk depth recorded at the five water quality sites throughout the reporting period.

3.3.4 Chlorophyll a

Chlorophyll-a showed high variability between both location and time of year across the five sampling sites (Figure 3-12). Roundtop and Slade Islands both displayed large spikes in chlorophyll in September 2021. Chlorophyll-a levels were above guideline values for all sampling occasions except May 2022 at Roundtop Island and June 2022 at Freshwater Point, Slade Island and Victor Island.

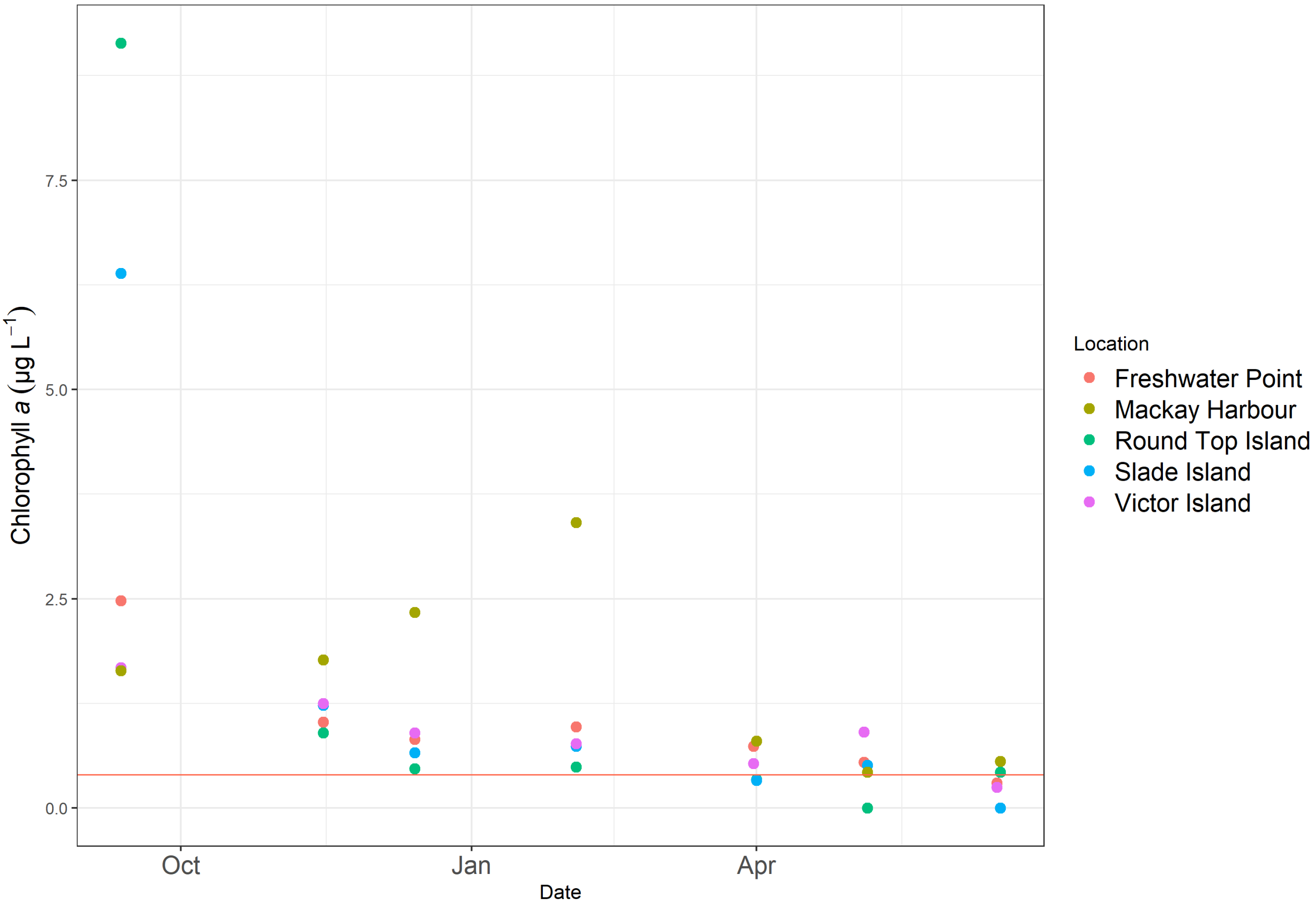

Figure 3-12. Chlorophyll-a concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value.

3.3.5 Dissolved metals

Heavy metal concentrations are presented in Table 3-1. Concentrations were compared to the ANZECC water quality guidelines (ANZECC, 2000). Most of the metals targeted for analysis were not detected above the 95% level of protection trigger values for marine waters. Silver, Cadmium, Lead, Nickel, Zinc, and Mercury were not detected (< LOD). Copper exceeded the ANZECC 95% level of protection trigger values for marine waters at all sites in September 2021, and arsenic was detected in low concentrations at both times of year. Note that ANZECC guidelines do not have a trigger value for arsenic. A low reliability marine guideline trigger value of 4.5 µg L^{-1} for As (V) and 2.3 µg L^{-1} for As (III) has been derived (ANZECC, 2000), however, these trigger guidelines are only an indicative interim working level. Arsenic concentrations were below these values at all locations on both sampling occasions.

Table 3-1. Heavy metal concentrations measured in water samples collected from five water quality sites in the Mackay region in September 2021 and March 2022. ANZECC water quality guideline 95% level of protection trigger values for marine waters are shown for comparison (ANZECC, 2000).

Location	Month	Silver	Cadmium	Copper	Lead	Nickel	Arsenic	Zinc	Mercury
	Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L
	Reporting limits (LOD)	0.1	0.2	1	0.2	0.5	-	5	0.0001
	ANZECC 95% level	1.4	5.5	1.3	4.4	70	-	15	0.4
Freshwater Point	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.4	<5	<0.0001
Mackay Harbour	Sep-2021	<0.1	<0.2	3	<0.2	<0.5	1.5	<5	<0.0001
Round Top Island	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.4	<5	<0.0001
Slade Island	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.3	<5	<0.0001
Victor Island	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.3	<5	<0.0001
Freshwater Point	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.3	<5	<0.0001
Mackay Harbour	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.4	<5	<0.0001
Round Top Island	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.5	<5	<0.0001
Slade Island	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.4	<5	<0.0001
Victor Island	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.4	<5	<0.0001

3.3.6 Pesticides

Pesticides used for ms-PAF calculations from Slade Island (MKY_AMB5) are presented in Table 3-2. During the early wet season five pesticide compounds were detected. The photosystem-two inhibiting herbicides (PSII) Atrazine, Diuron, Hexazinone, and Tebuthiuron were detected along with the 'other' herbicide Diketonitrile and the insecticide Imidacloprid. No pesticides were sampled in the late wet season due to loss of the ED sampler in rough conditions. A full list of pesticide results is included in Appendix A1.1 (mass per sample) and A1.2 (concentration).

Table 3-2. Pesticide mass per sampler and water concentration recovered from passive samplers deployed at Slade Island (MKY_AMB5). Due to analytical constraints water concentration is only calculated for select analytes. A hyphen (-) denotes where concentration was not calculated.

Early wet season		
Analyte	Mass per sampler (ng)	Water concentration (ng L^{-1})
2-4 D	<1.00	<0.910
Ametryn	<5.00	<1.64
Atrazine	10.99	2.36
Diketonitrile	2.635	-
Diuron	37.75	9.74
Fipronil	<0.500	<0.090
Fluroxypyr	<1.00	-
Haloxyfop	<1.00	<0.110
Hexazinone	13.75	2.93
Imidacloprid	1.55	-
MCPA	<5.00	<0.660
Metolachlor	4.56	0.97
Metribuzin	<1.00	-
Metsulfuron-methyl	<1.00	-
Pendimethalin	<5.00	-
Prometryn	<1.00	<0.360
Simazine	<1.00	<0.150
Tebuthiuron	<1.00	<0.170
Terbuthylazine	<1.00	<0.200
Triclopyr	<5.00	<0.550

3.3.7 Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

Several Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) were detected at Slade Island (MKY_AMB5) during the early wet season (Table 3-3). A full list of PFAS results is included in Appendix A1.3.

Table 3-3. Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) mass per sampler and water concentration recovered from passive samplers deployed at Slade Island (MKY_AMB5).

			Early wet season		**Late wet season**	
	Analyte		Mass per sampler (ng)	Water concentration (ng L^{-1})	Mass per sampler (ng)	Water concentration (ng L^{-1})
Perfluoroalkyl Carboxylic Acids (PFCAs)						
	Perfluorobutanoic acid	PFBA	NR	NR	<0.760	<3.97
	Perfluoropentanoic acid	PFPeA	<0.100	<0.780	<0.100	<0.646
	Perfluoroheptanoic acid	PFHpA	0.455	0.740	<0.430	<0.549
	Perfluorooctanoic acid	PFOA	0.425	0.869	<0.400	<0.640
	Perfluorononanoic acid	PFNA	0.205	0.305	<0.170	<0.210
Perfluoroalkane Sulfonates						
	Perfluorohexane sulfonate	PFHxS	<0.200	<0.304	<0.200	<0.252
	Perfluorooctane sulfonate	PFOS	0.360	0.531	<0.290	<0.355

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.

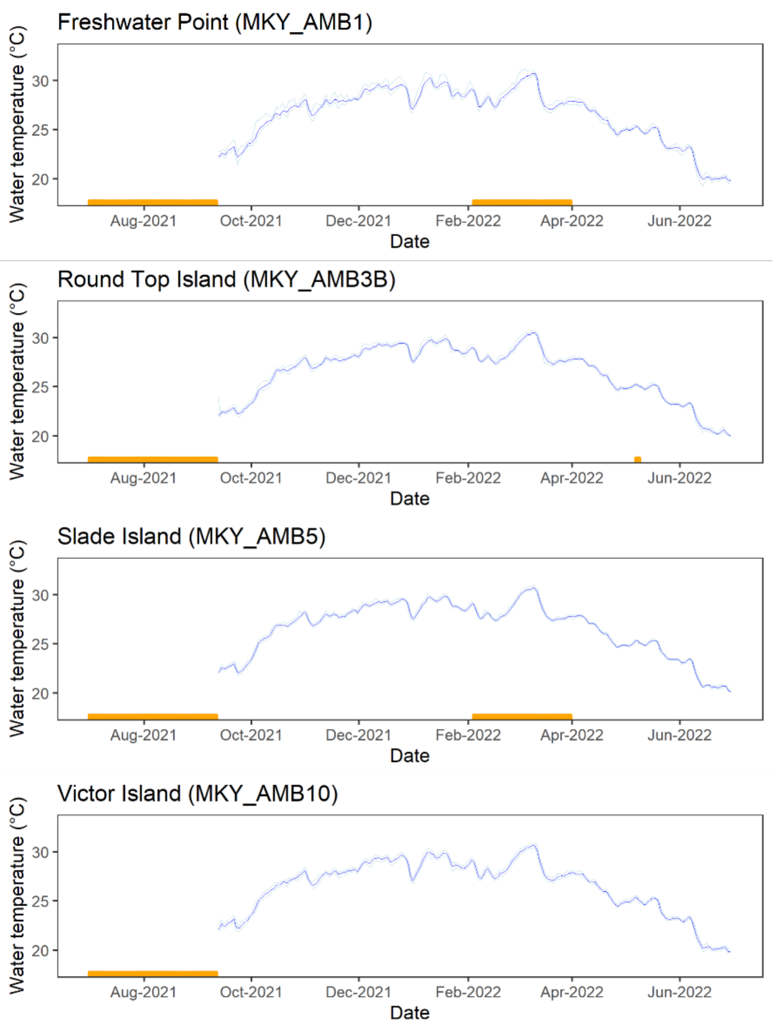

Figure 3-13. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the Bowen region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figure 3-18– Figure 3.21.

3.4.2 Water depth

The daily mean tidal range for each site is presented in Figure 3.8. The Mackay region is mixed semidiurnal mesotidal to macrotidal, with daily tidal range measured to be from 1.48 to 6.92 m during the reporting period.

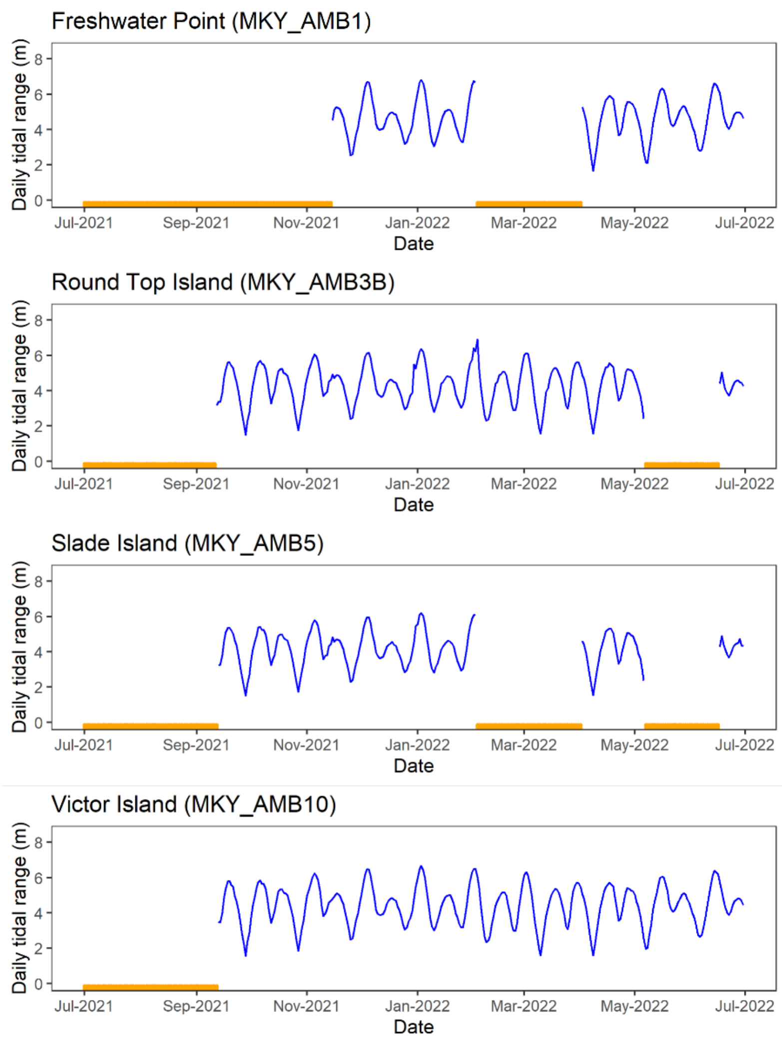

Figure 3-14. Daily tidal range measured by insitu loggers at the Mackay monitoring sites. Periods of missing data are indicated by the orange bar.

3.4.3 Wave activity

Wave activity RMS depth

All four logger sites are located along the inshore coast and are exposed to varying levels of waves, winds, and currents. Notable high energy periods were found in early January and late April 2022 (Figure 3-15).

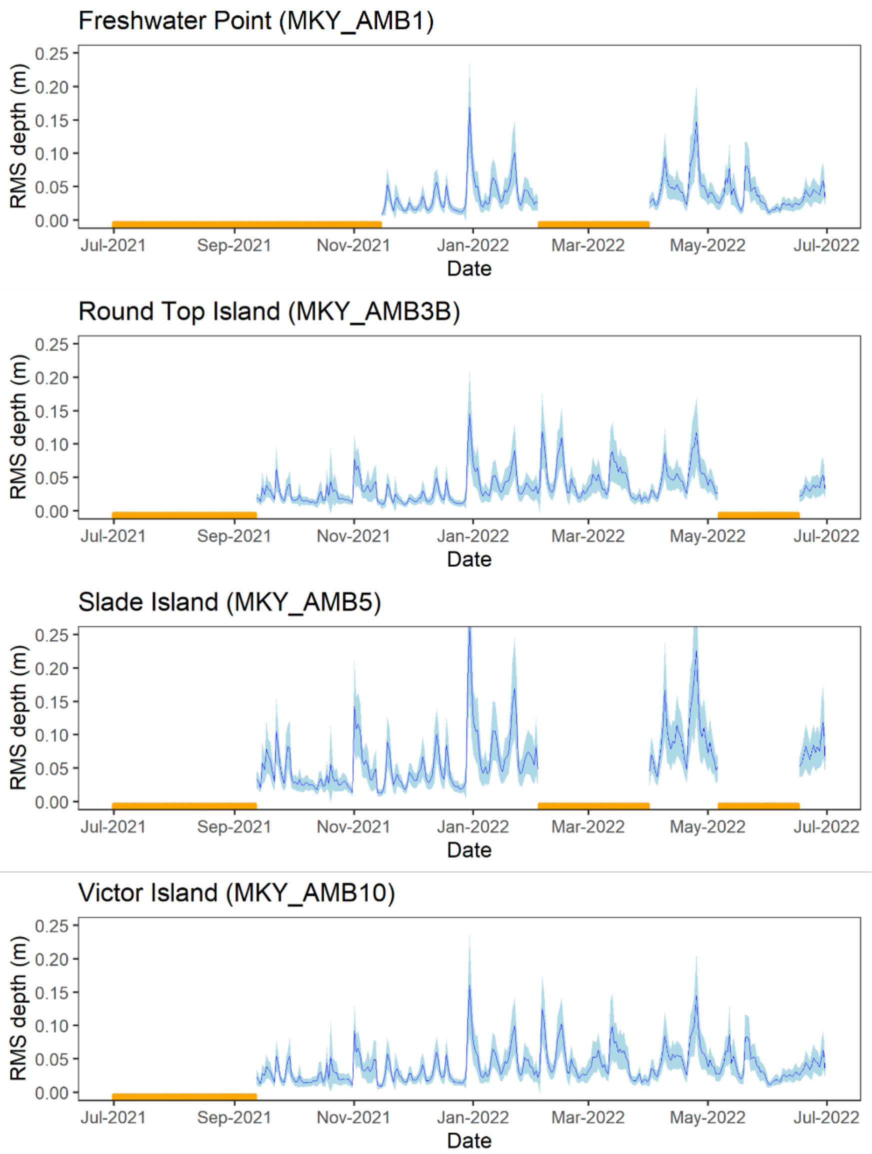

Figure 3-15. RMS depth measured at the Mackay and Hay Point monitoring sites. Values presented are daily mean (blue line) +/- standard deviation (light blue). Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3-18– 3.21.

3.4.4 Turbidity

Turbidity measured at water quality monitoring sites in the Mackay region is presented in Figure 3-17. Turbidity was highly variable at each site throughout the reporting period. Periods of high turbidity often corresponded with periods of high wave activity as is evident in the heightened RMS depth values for those periods, e.g., January and April 2022. 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).

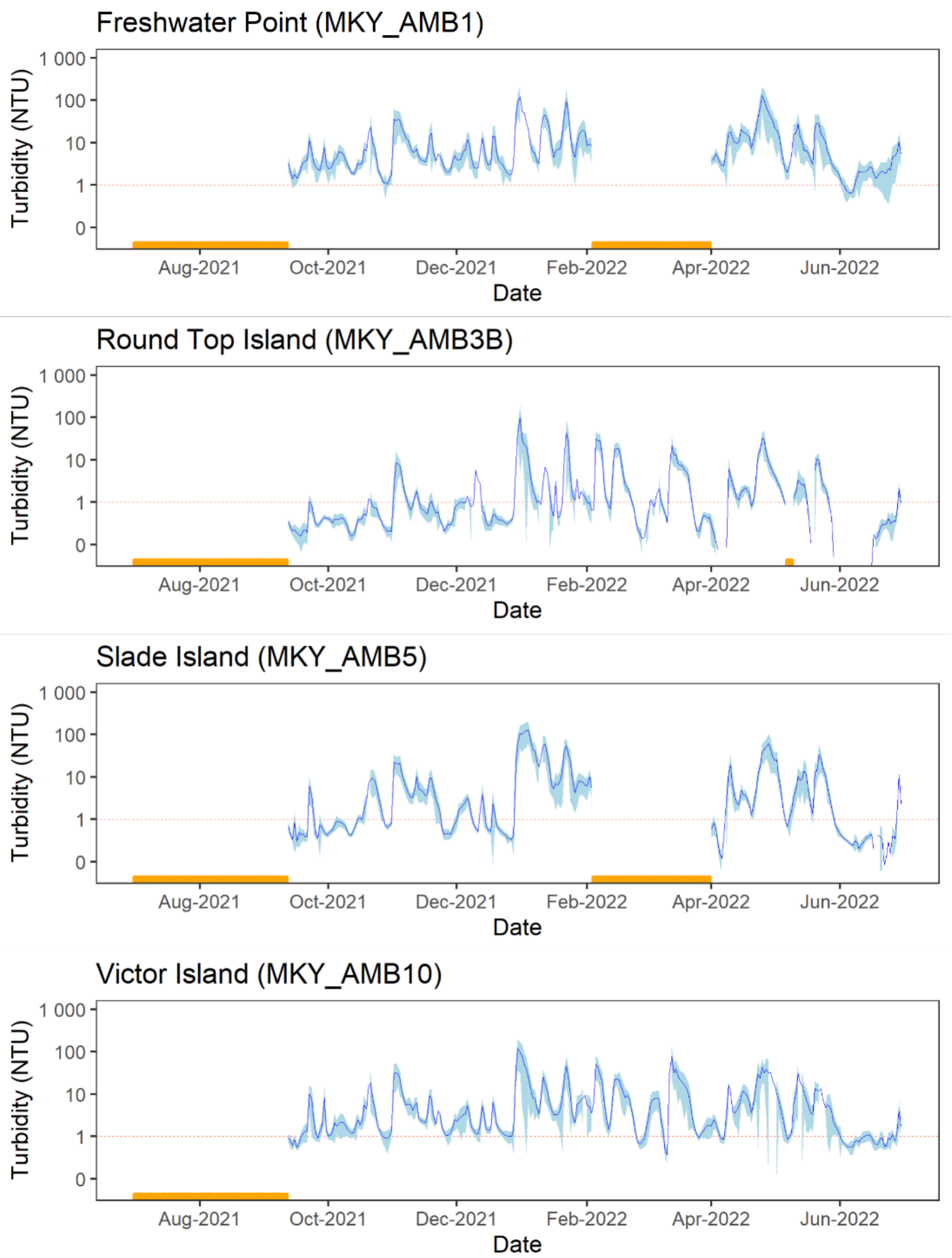

Figure 3-16. Turbidity measured at water quality monitoring sites in the Mackay region. Results presented are daily mean (blue line) and standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18 – 3.21.

Table 3-4. Monthly mean, median, and standard deviation for turbidity (NTU) measured at four water quality monitoring sites where insitu loggers are deployed in the Mackay region. Note the high standard deviations, particularly in December 2021 and January 2022, that are indicative of shorter periods of very high turbidity during those times. Unlike Figure 3-16, the values in this table have undergone quality control and the mean values do not include any anomalous spikes that may occur in the raw data.

	Freshwater Pt			Round Top Is.			Slade Is.			Victor Is.		
Month	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD
July 2021	1.14	0.90	0.93	0.18	0.14	0.24	5.78	3.18	6.12	0.83	0.00	4.60
Aug 2021	2.72	1.99	2.95	0.60	0.12	1.51	NA	NA	NA	3.21	0.33	8.27
Sept 2021	3.61	2.56	3.43	1.40	0.36	3.91	1.01	0.45	1.78	6.30	1.46	13.35
Oct 2021	4.69	2.89	7.31	0.43	0.36	0.42	2.10	0.83	3.45	3.09	1.53	6.13
Nov 2021	10.72	5.40	14.25	1.64	0.68	2.82	6.44	3.79	8.07	7.19	3.16	11.01
Dec 2021	12.93	3.82	32.84	5.65	0.48	27.25	7.20	0.81	25.06	10.12	1.76	33.04
Jan 2022	22.66	11.69	34.69	7.06	1.37	17.51	36.23	15.52	47.60	15.49	6.92	26.35
Feb 2022	8.86	8.27	3.85	6.90	1.44	11.10	7.57	6.70	4.37	11.23	4.86	15.98
Mar 2022	NA	NA	NA	3.44	0.76	5.86	NA	NA	NA	11.44	3.51	21.70
Apr 2022	26.22	12.39	41.49	5.35	1.78	9.46	12.81	3.30	22.00	12.77	6.38	19.85
May 2022	10.82	5.63	13.39	2.47	1.66	3.14	8.68	4.67	11.39	7.80	4.30	11.67
June 2022	2.45	1.54	2.83	-0.01	-0.32	0.63	0.77	0.31	3.46	0.97	0.77	0.84

3.4.5 Photosynthetically active radiation (PAR)

PAR was highly variable at all sites throughout the reporting period (Figure 3-17). Periods of low light in January and May 2022 correspond with periods of high turbidity across all sites.

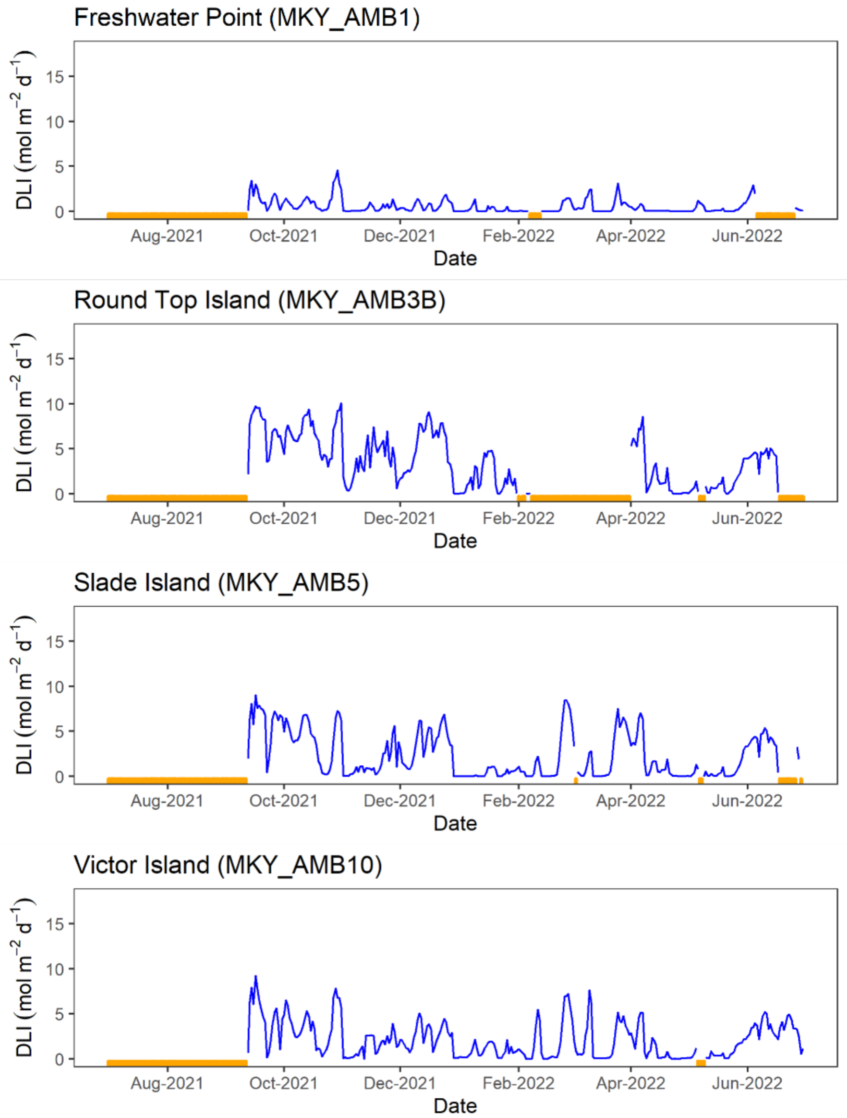

Figure 3-17. Daily light integral (mol photons m^{-2} d^{-1}) of photosynthetically active radiation measured at water quality monitoring sites in the Bowen region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021 and have not undergone the newly implemented, rigorous quality control procedure. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18-3.21.

3.4.6 Combined IMO and MGL quality-controlled data

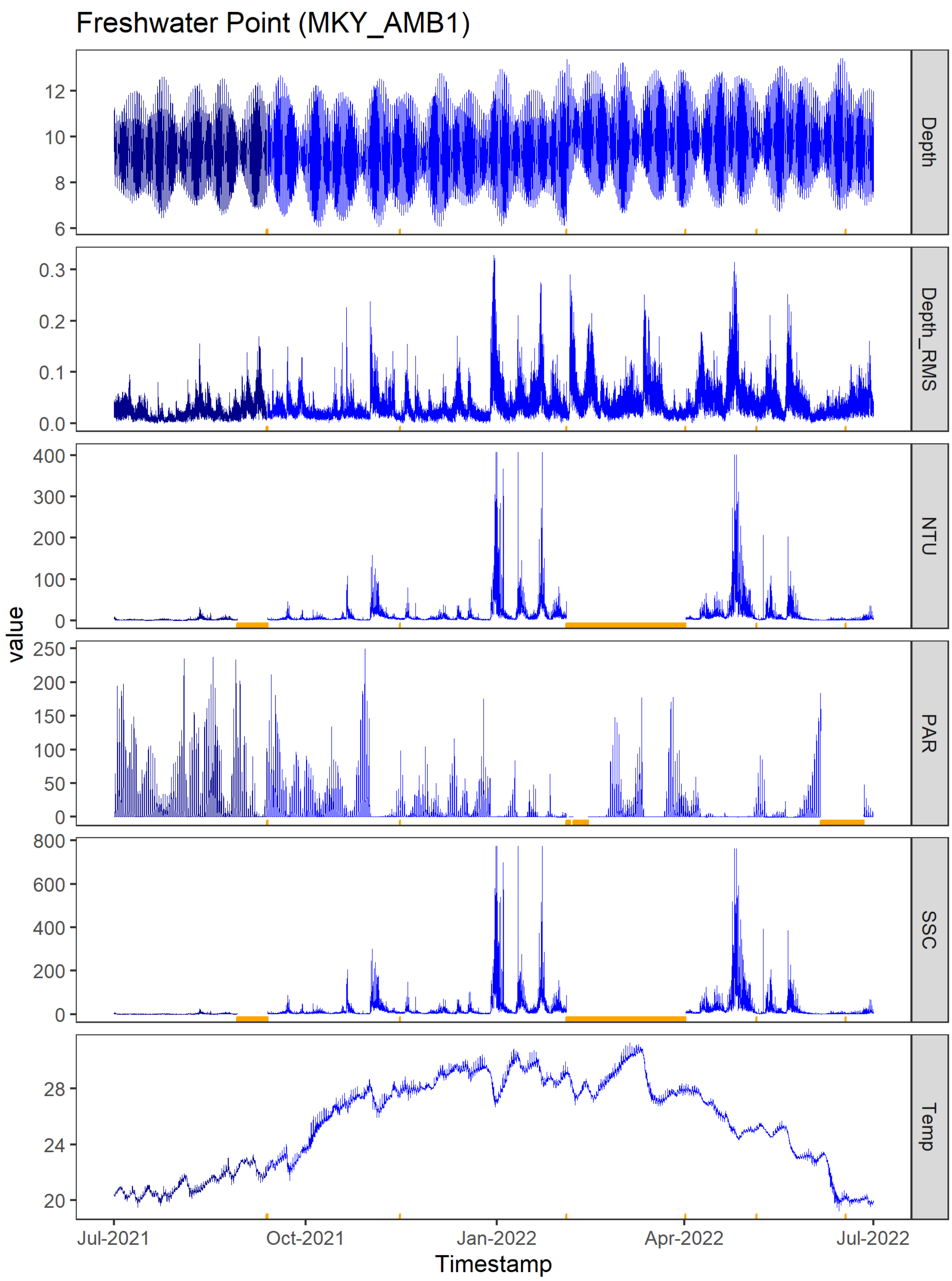

Figure 3-18. Data collected at Freshwater Point with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes 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 2.

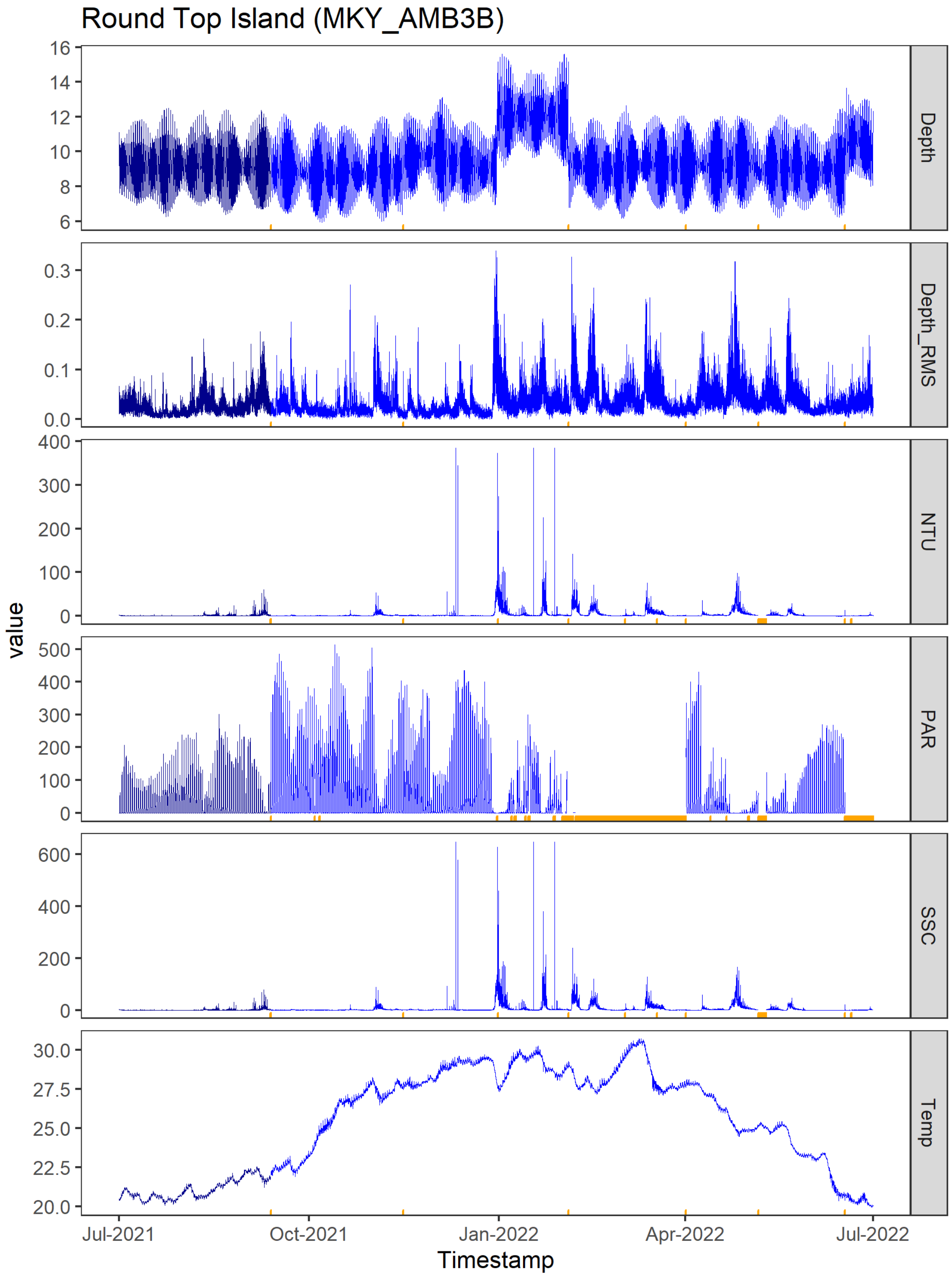

Figure 3-19. Data collected at Round Top Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes 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 2.

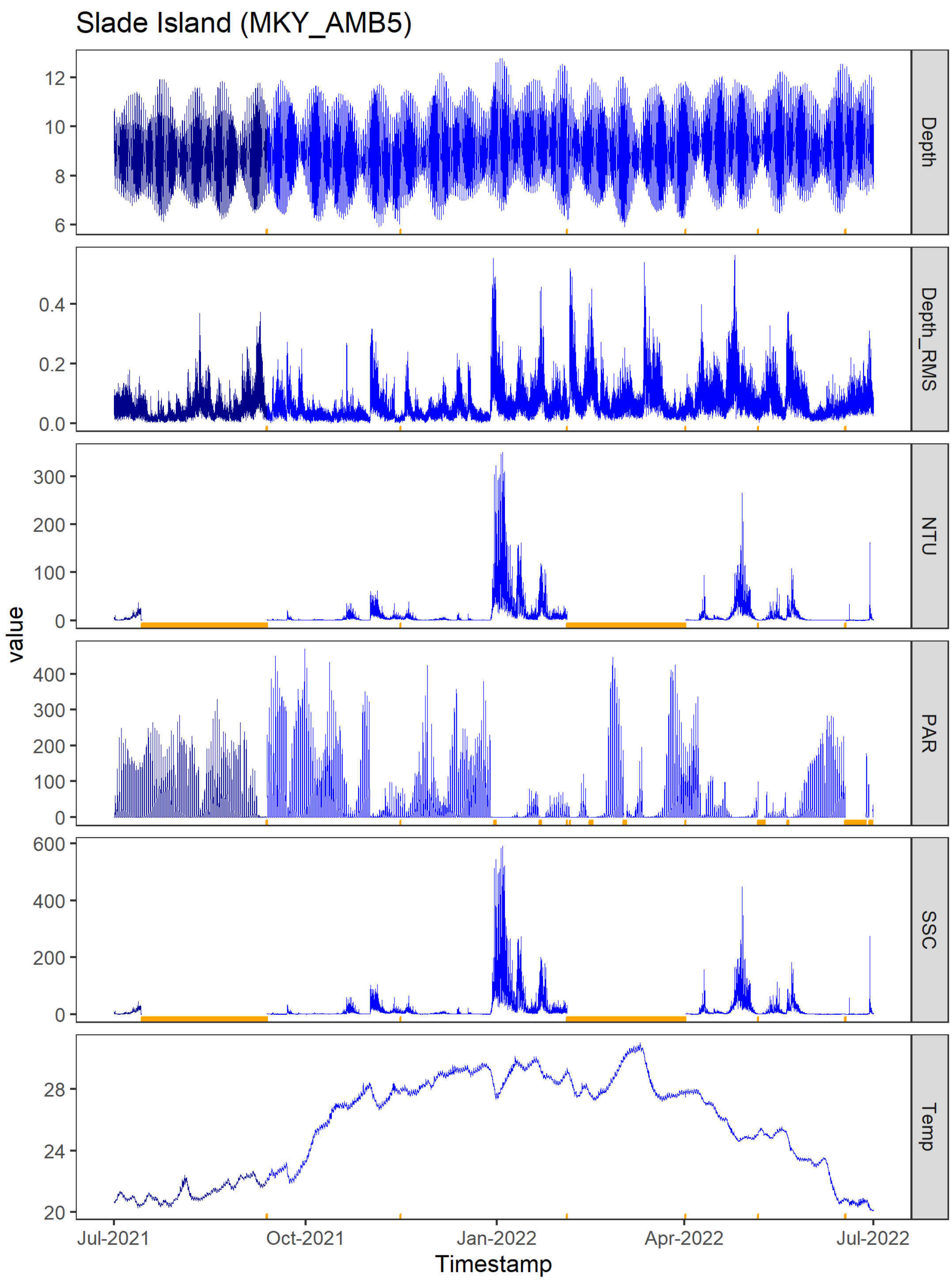

Figure 3-20. Data collected at Slade Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes data flagged as flag 4 (Bad data). Periods of missing data are indicated by the orange bar. For more information on Quality Control Procedures and plots of flagged data see Appendix 2.

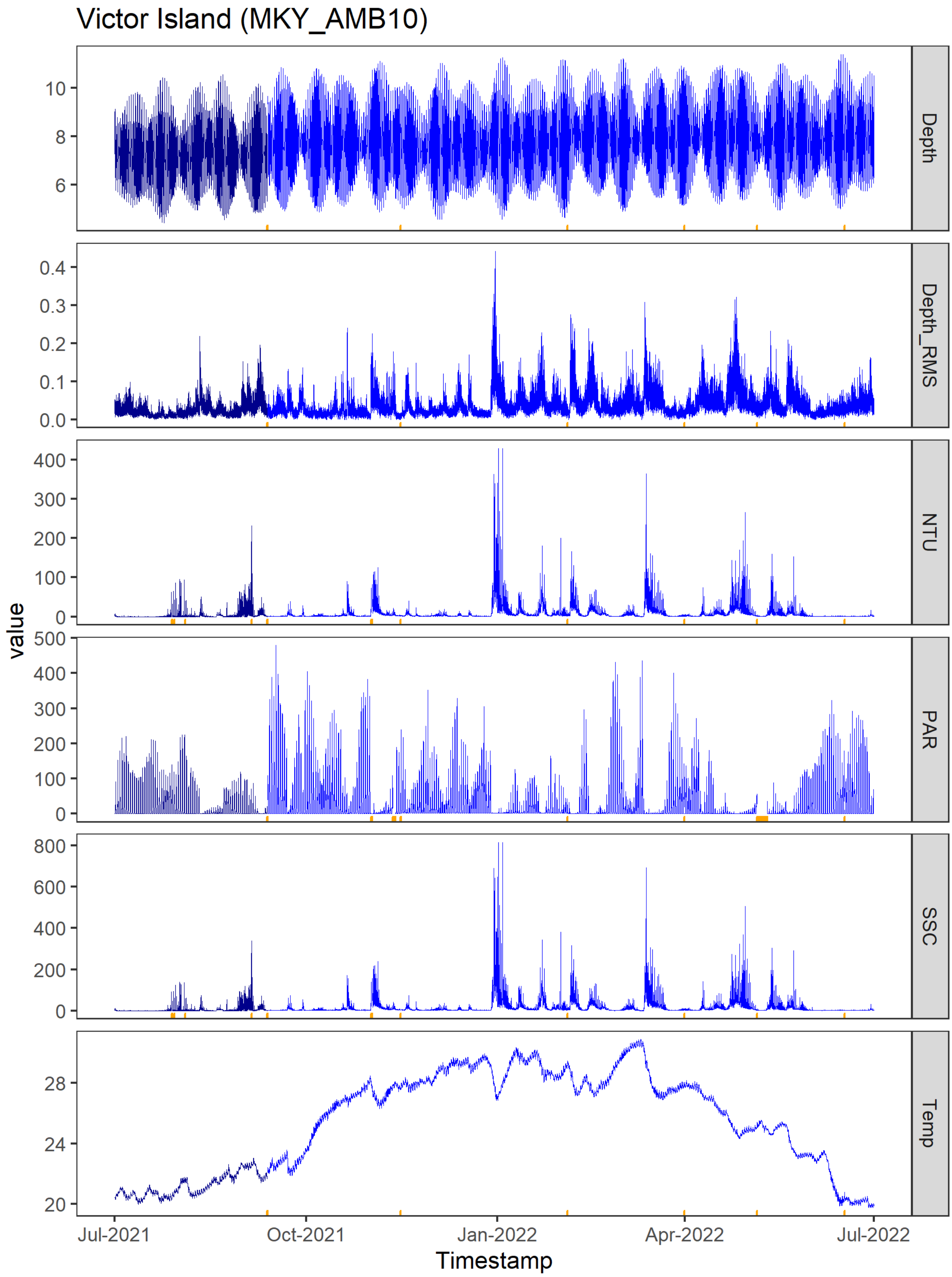

Figure 3-21. Data collected at Victor Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes data flagged as flag 4 (Bad data). Periods of missing data are indicated by the orange bar. For more information on Quality Control Procedures and plots of flagged data see Appendix 2.

3.4.7 Data Recovery

Data recovery and quality control flagging for insitu 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 are provided in Appendix 3.

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.

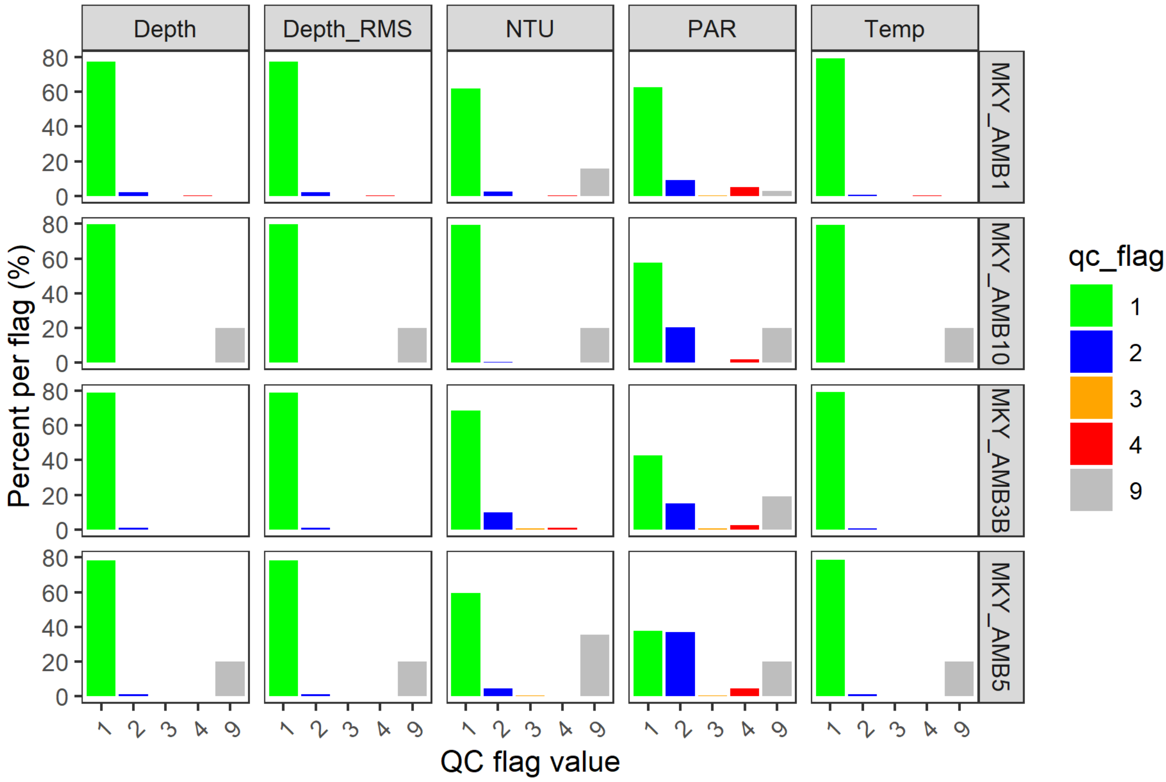

Figure 3-22. Data recovery and qc flags at each of the four Mackay/ Hay Point logger sites, Freshwater Point (MKY_AMB1), Roundtop Island (MKY_AMB3B), Slade Island (MKY_AMB5), and Victor Island (MKY_AMB10), over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2 (blue) indicates a 'probably 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 the rainfall was still in the lowest 10th percentile 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.
2. December through to April saw many high-energy wave events across the region, primarily coming from a south-easterly direction, which contributed to high variability in ambient water quality throughout this period.

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.
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) and phosphorus (PP) concentrations exceed guideline values during most surveys and at all sites. This pattern continues and requires further discussion with relevant authorities to address the source of nutrient supply
4. Chlorophyll-*a* concentrations exceed guideline values during all surveys at most sites.
5. Trace metals were generally well below guideline values throughout the reporting year, like previous years, which suggests that their likely a low risk of contamination in the region, which does require some caution given the limited spatial and temporal monitoring as part of this program. Only copper was present above guideline values.

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 and this has been most notable here given the links drawn between RMS water depth and NTU/SSC. Large peaks in NTU/SSC and RMS water depth were recorded over periods longer than a week.

2. As the data set here continues to increase, assessment of the rainfall patterns (frequency and duration), and oceanographic conditions can be examined, providing more detailed insight into the long-term rainfall and 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 lower 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. Patterns of light were similar among all the sites however there were differences in the levels of PAR at each, with light levels reducing at the most exposed sites. Light penetration in water is affected in an exponential relationship with depth as photons are absorbed and scattered by particulate matter (Kirk 1985). Therefore, variation in depth at each location means benthic PAR is not directly comparable among sites as a measure of water quality.
3. While turbidity is the main indicator of water quality used in monitoring of dredge activity and benthic light is significantly correlated with suspended solid concentrations (Erftemeijer et al., 2012), the relationship between these two parameters is not always strong (Sofonia and Unsworth 2010). As PAR is more biologically relevant to the health of photosynthetic benthic habitats such as seagrass, algae, and corals it is becoming more useful as a management response tool when used in conjunction with known thresholds for healthy growth for these habitats (e.g., Chartrand et al., 2012). For this reason, it is important to include photosynthetically active radiation (PAR) in the suite of water quality variables when capturing local baseline conditions of ambient water quality.

4.2 Recommendations

This monitoring program has been underway for eight years (2014 to present) and should remain in place to continue to characterise and build a detailed understanding of the water quality dynamics in and around this port facility. This understanding will continue to assist NQBP to manage current activities but will also assist with future strategic planning and management. For example, while the total wet season rainfall during this reporting year was in the bottom 10th percentile of long-term records, the distribution of rainfall during the season becomes important and future assessment of these patterns should be made within sufficient data and confidence. With an emerging long-term dataset, there is potential for answering important research questions around coastal processes in this important region of the Great Barrier Reef coastline.

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Appendix 1. Passive sampler results

A1.1 ED-PPCP mass per sampler

Table A 1. Results (mass per sampler) from ED-PPCP sampler deployed at Slade Island in the early wet season of 2021.

ED PPCP Mass per Sampler (ng)			
Site Name		MKY-AMB5 Slade Island	
Deployment Date		15/11/2021	
Retrieval Date		14/12/2021	
Days Deployed		29	
Flow Rate (cm/s)		36.2	
Sample Name	LOR	TRP1121_ED_1	TRP1121_ED_1_DUP
2,4,5-T	1.00	<1.00	<1.00
2,4-D	5.00	<5.00	<5.00
3,4 Dichloroaniline	1.00	<1.00	<1.00
Acesulfame	1.00	<1.00	<1.00
Ametryn	5.00	<5.00	<5.00
Ametryn hydroxy	1.00	<1.00	**1.09**
Atenolol	1.00	<1.00	<1.00
Atorvastatin	1.00	<1.00	<1.00
Atrazine	1.00	**14.2**	**7.78**
Atrazine desethyl	1.00	<1.00	<1.00
Atrazine desisopropyl	1.00	<1.00	<1.00
Bendiocarb	0.500	<0.500	<0.500
Bromacil	1.00	<1.00	<1.00
Bromoxynil	1.00	<1.00	<1.00
Caffeine	*33.9	<33.9	<33.9
Carbamazepine	1.00	<1.00	<1.00
Carbaryl	0.500	<0.500	<0.500
Carbendazim	1.00	<1.00	<1.00
Codeine	1.00	<1.00	<1.00
Cyproconazole	1.00	<1.00	<1.00
DCPMU	0.100	**1.36**	**1.35**
DCPU	0.500	<0.500	<0.500
DEET	*52.3	<52.3	<52.3
Diazinon	0.100	<0.100	<0.100
Diclofenac	0.100	<0.100	<0.100
Difenoconazole	5.00	<5.00	<5.00
Diketonitrile	0.100	**2.65**	**2.62**
Diuron	1.00	**34.0**	**40.7**
Fipronil	0.500	<0.500	<0.500
Fluazifop	0.100	<0.100	<0.100
Fluazinam	50.0	<50.0	<50.0
Fluometuron	1.00	<1.00	<1.00
Fluroxypyr	1.00	<1.00	<1.00
Gabapentin	1.00	<1.00	<1.00
Haloxyfop	1.00	<1.00	<1.00
Hexazinone	1.00	**13.3**	**14.2**
Hydrochlorthiazide	1.00	<1.00	<1.00
Imazapic	1.00	<1.00	<1.00
Imazapyr	1.50	<1.50	<1.50
Imazethapyr	1.00	<1.00	<1.00

Imidacloprid	1.00	**1.64**	**1.46**
Iopromide	0.500	*<0.500*	*<0.500*
Malathion	1.00	*<1.00*	*<1.00*
MCPA	5.00	*<5.00*	*<5.00*
Metalaxyl	0.100	*<0.100*	*<0.100*
Methidathion	5.00	*<5.00*	*<5.00*
Methomyl	1.00	*<1.00*	*<1.00*
Metolachlor (S+R)	1.00	**4.93**	**4.19**
Metribuzin	1.00	*<1.00*	*<1.00*
Metsulfuron methyl	1.00	*<1.00*	*<1.00*
Naproxen	1.00	*<1.00*	*<1.00*
Oryzalin	0.700	**1.98**	**1.38**
Oxazepam	0.500	*<0.500*	*<0.500*
Paracetamol	1.00	*<1.00*	*<1.00*
Paraxanthine	*3.68	*<3.68*	*<3.68*
Pencycuron	10.0	*<10.0*	*<10.0*
Pendimethalin	5.00	*<5.00*	*<5.00*
Picloram	5.00	*<5.00*	*<5.00*
Prometryn	1.00	*<1.00*	*<1.00*
Propachlor	0.800	*<0.800*	*<0.800*
Propazine	1.00	*<1.00*	*<1.00*
Propiconazole	1.00	*<1.00*	*<1.00*
Propoxur	1.00	*<1.00*	*<1.00*
Pyrimethanil	0.500	*<0.500*	*<0.500*
Salicyclic acid	35.0	*<35.0*	*<35.0*
Simazine	1.00	*<1.00*	*<1.00*
Simazine hydroxy	1.00	*<1.00*	*<1.00*
Sulfadiazine	0.500	*<0.500*	*<0.500*
Sulfamethoxazole	0.100	*<0.100*	*<0.100*
Sulfoxaflor	0.500	*<0.500*	*<0.500*
Tadalafil	0.100	*<0.100*	*<0.100*
Tebuconazole	1.00	*<1.00*	*<1.00*
Tebuthiuron	1.00	*<1.00*	*<1.00*
Temazepam	1.00	*<1.00*	*<1.00*
Terbuthylazine	1.00	*<1.00*	*<1.00*
Terbuthylazine desethyl	1.00	*<1.00*	*<1.00*
Thiamethoxam	0.700	*<0.700*	*<0.700*
Triclopyr	5.00	*<5.00*	*<5.00*
Trimethoprim	0.100	*<0.100*	*<0.100*
Venlafaxine	1.00	*<1.00*	*<1.00*
Verapamil	0.100	*<0.100*	*<0.100*

* Limit of Reporting (LOR) raised by blank level

where a compound is detected in field or lab blanks, the effective LOR is raised to a value equal to the aver

A1.2 ED-PPCP water concentration

Table A 2. Results (water concentration) from ED-PPCP sampler deployed at Slade Island in the early wet season of 2021

Atrazine Relative Rs		
ED PPCP Water Concentration (ng/L)		
Site Name	**MKY-AMB5 Slade Island**	
Deployment Date	**15/11/2021**	
Retrieval Date	**14/12/2021**	
Days Deployed	**29**	
Flow Rate (cm/s)	**36.2**	
Sample Name	**TRP1121_ED_1**	**TRP1121_ED_1_DUP**
2,4-D	*<0.910*	*<0.910*
Ametryn	*<1.64*	*<1.64*
Atrazine	**3.08**	**1.69**
Atrazine desethyl	*<0.260*	*<0.260*
Bromacil	*<0.150*	*<0.150*
Caffeine	*<4.33*	*<4.33*
Carbamazepine	*<0.140*	*<0.140*
Carbendazim	*<0.260*	*<0.260*
Codeine	*<0.270*	*<0.270*
DEET	*<8.35*	*<8.35*
Diazinon	*<0.040*	*<0.040*
Diclofenac	*<0.030*	*<0.030*
Diuron	**8.87**	**10.6**
Fipronil	*<0.090*	*<0.090*
Fluometuron	*<0.160*	*<0.160*
Haloxyfop	*<0.110*	*<0.110*
Hexazinone	**2.83**	**3.02**
Hydrochlorthiazide	*<0.210*	*<0.210*
MCPA	*<0.660*	*<0.660*
Metolachlor (S+R)	**1.05**	**0.890**
Prometryn	*<0.360*	*<0.360*
Propoxur	*<0.180*	*<0.180*
Simazine	*<0.150*	*<0.150*
Sulfamethoxazole	*<0.030*	*<0.030*
Tebuthiuron	*<0.170*	*<0.170*
Terbuthylazine	*<0.200*	*<0.200*
Triclopyr	*<0.550*	*<0.550*
Trimethoprim	*<0.090*	*<0.090*

A1.3 PE-PFAS mass per sampler

Table A 3. Results (mass per sampler) of the PE-PFAS sampler deployed at Slade Island in the early (November/December) and late (April/May) wet season during the reporting period.

		Site Name		Slade Island			
		Deployed Date		########		########	
		Retrieved Date		14/12/2021		06/05/2022	
		Days Deployed		29		35	
		Site Code		MKY-AMB5		MKY-AMB5	
		Sample Name		TRP1121_PE_	1121_PE_1_	RP0322_PE_	0322_PE_1_DUP
PFAS Category	**Analyte**	**QAEHS Acronym**	**LOR**				
Perfluoroalkyl Carboxylic Acids (PFCAs)	Perfluorobutanoic acid	PFBA	*0.760	NR	NR	<0.760	<0.760
	Perfluoropentanoic acid	PFPeA	0.100	NR	<0.100	<0.100	<0.100
	Perfluorohexanoic acid	PFHxA	*0.160	<0.160	<0.160	<0.160	<0.160
	Perfluoroheptanoic acid	PFHpA	*0.430	0.480	<0.430	<0.430	<0.430
	Perfluorooctanoic acid	PFOA	*0.400	0.450	<0.400	<0.400	<0.400
	Perfluorononanoic acid	PFNA	*0.170	0.180	0.230	<0.170	<0.170
	Perfluorodecanoic acid	PFDA	*3.69	<3.69	<3.69	<3.69	<3.69
	Perfluoroundecanoic acid	PFUnDA	0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorododecanoic acid	PFDoDA	0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorotridecanoic acid	PFTriDA	0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorotetradecanoic acid	PFTeDA	1.00	<1.00	<1.00	<1.00	<1.00
	Perfluorohexadecanoic acid	PFHxDA	1.00	<1.00	<1.00	<1.00	<1.00
	Perfluorooctadecanoic acid	PFODA	1.00	<1.00	<1.00	<1.00	<1.00
Perfluoroalkane Sulfonates	Perfluorobutane sulfonate	PFBS	0.100	<0.100	<0.100	<0.100	<0.100
	Perfluoropentane sulfonate	PFPeS	0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorohexane sulfonate	PFHxS	*0.200	<0.200	<0.200	<0.200	<0.200
	Perfluoroheptane sulfonate	PFHpS	0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorooctane sulfonate	PFOS	*0.290	0.390	0.330	<0.290	<0.290
	Perfluorononane sulfonate	PFNS	0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorodecane sulfonate	PFDS	0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorododecane sulfonate	PFDoDS	1.00	<1.00	<1.00	<1.00	<1.00
Cyclic Perfluoro Sulfonates	Perfluoroethylcyclohexane sulfonate	PFECHS	0.100	<0.100	<0.100	<0.100	<0.100
Perfluoroalkane Sulfonamides	Perfluorooctane sulfonamide	FOSA	0.400	<0.400	<0.400	<0.400	<0.400
	N-methyl perfluorooctane sulfonamide	N-MeFOSA	0.400	<0.400	<0.400	<0.400	<0.400
	N-ethyl perfluorooctane sulfonamide	N-EtFOSA	0.400	<0.400	<0.400	<0.400	<0.400
Alcohol Perfluoroalkane Sulfonamides	N-methyl perfluorooctane sulfonamide ethanol	N-MeFOSE	0.400	<0.400	<0.400	<0.400	<0.400
	N-ethyl perfluorooctane sulfonamide ethanol	N-EtFOSE	0.400	<0.400	<0.400	<0.400	<0.400
Perfluoroalkane Sulfonamido Acetic Acid	Perfluorooctane sulfonamidoacetic acid	FOSAA	0.400	<0.400	<0.400	<0.400	<0.400
	N-ethyl-fluorooctane sulfonamidoacetic acid	N-EtFOSAA	0.400	<0.400	<0.400	<0.400	<0.400
	N-methyl-fluorooctane sulfonamidoacetic acid	N-MeFOSAA	0.400	<0.400	<0.400	<0.400	<0.400
Fluorotelomer Sulfonates	4:2-Fluorotelomer sulfonate	4:2 FTS	0.100	<0.100	<0.100	<0.100	<0.100
	6:2-Fluorotelomer sulfonate	6:2 FTS	0.100	<0.100	<0.100	<0.100	<0.100
	8:2-Fluorotelomer sulfonate	8:2 FTS	0.400	<0.400	<0.400	<0.400	<0.400
	10:2-Fluorotelomer sulfonate	10:2 FTS	0.400	<0.400	<0.400	<0.400	<0.400

NR = Not reportable

A1.4 PE-PFAS water concentration

Table A 4. . Results (water concentration) of the PE-PFAS sampler deployed at Slade Island in the early (November/December) and late (April/May) wet season during the reporting period.

		Site Name	**Slade Island**			
		Deployed Date	**########**		**########**	
		Retrieved Date	**14/12/2021**		**06/05/2022**	
		Days Deployed	**29**		**35**	
		Site Code	**MKY-AMB5**		**MKY-AMB5**	
		Sample Name	**RP1121_PE_**	**121_PE_1_**	**RP0322_PE_**	**322_PE_1_DUP**
PFAS Category	**Analyte**	**QAEHS Acronym**				
Perfluoroalkyl Carboxylic Acids (PFCAs)	**Perfluorobutanoic acid**	**PFBA**	*NR*	*NR*	*<3.97*	*<3.97*
	Perfluoropentanoic acid	**PFPeA**	*NR*	*<0.780*	*<0.646*	*<0.646*
	Perfluorohexanoic acid	**PFHxA**	*<0.060*	*<0.060*	*<0.050*	*<0.050*
	Perfluoroheptanoic acid	**PFHpA**	**0.740**	*<0.663*	*<0.549*	*<0.549*
	Perfluorooctanoic acid	**PFOA**	**0.869**	*<0.772*	*<0.640*	*<0.640*
	Perfluorononanoic acid	**PFNA**	**0.268**	**0.343**	*<0.210*	*<0.210*
	Perfluorodecanoic acid	**PFDA**	*<4.14*	*<4.14*	*<3.43*	*<3.43*
Perfluoroalkane Sulfonates	**Perfluorobutane sulfonate**	**PFBS**	*<0.116*	*<0.116*	*<0.096*	*<0.096*
	Perfluorohexane sulfonate	**PFHxS**	*<0.304*	*<0.304*	*<0.252*	*<0.252*
	Perfluorooctane sulfonate	**PFOS**	**0.575**	**0.487**	*<0.355*	*<0.355*

NR = Not reportable

Appendix 2. 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 5. 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 (Figures A-1 – A-4).

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.

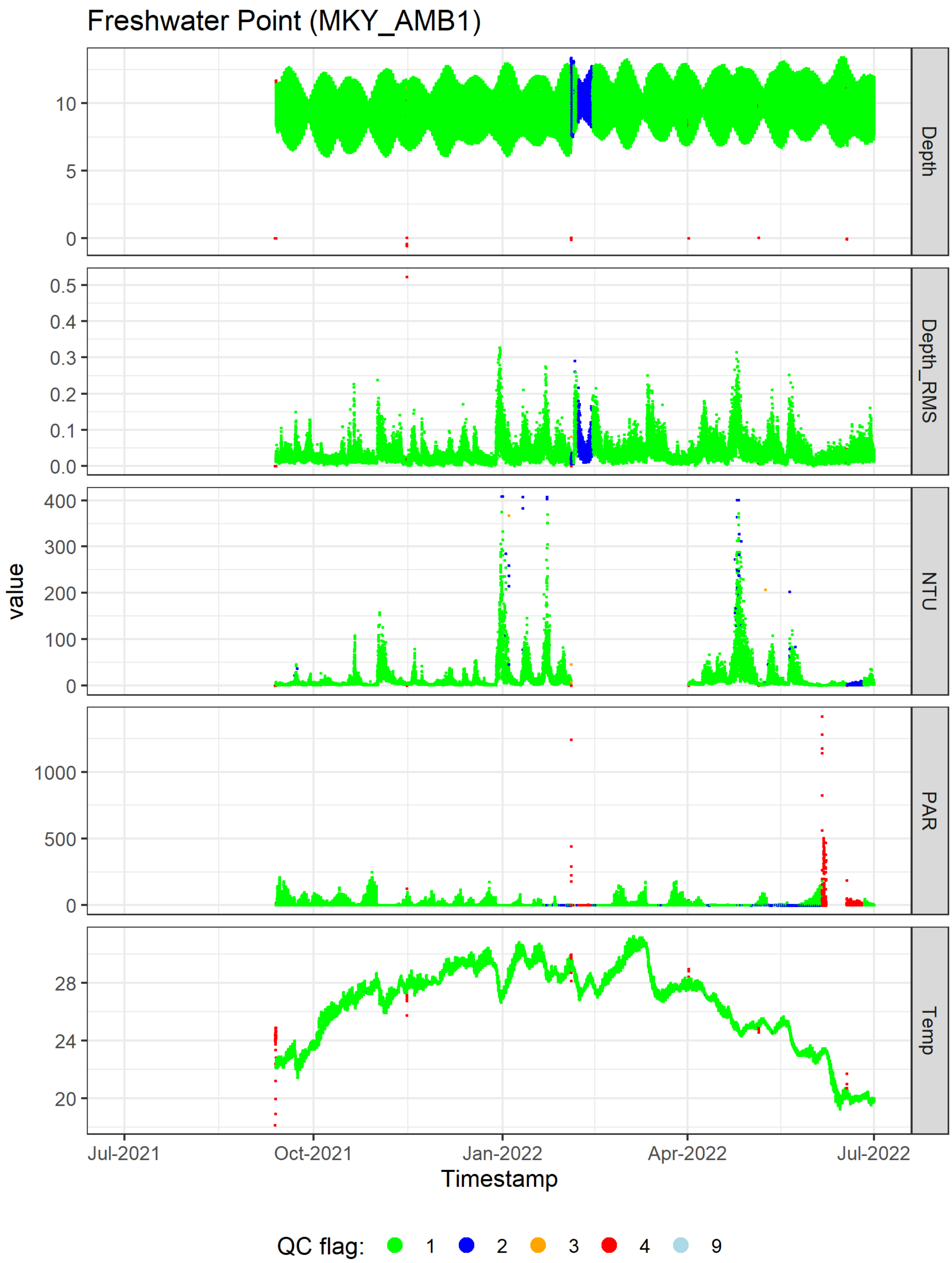

Figure A 1. Raw data collected at Freshwater Point with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) =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

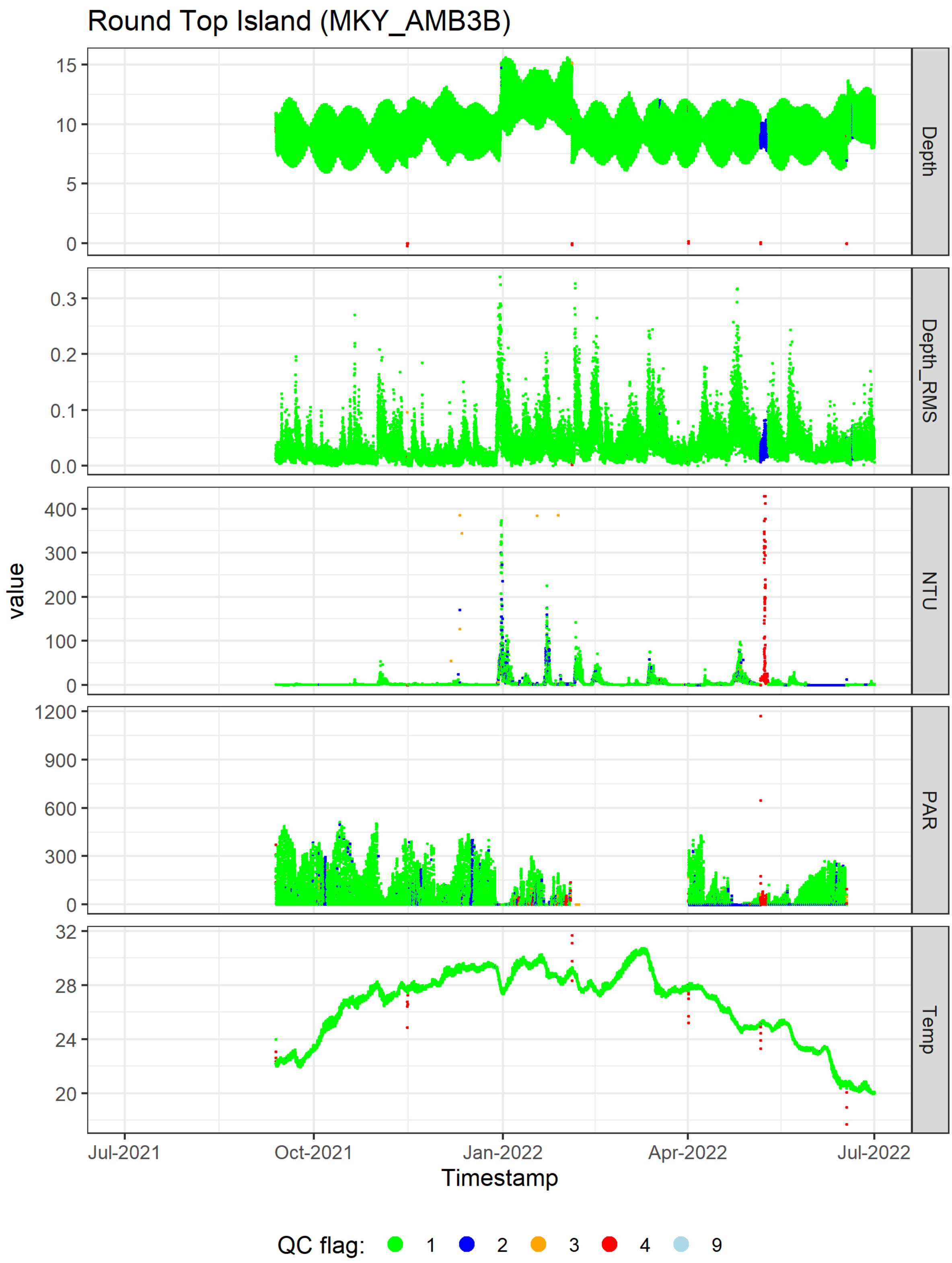

Figure A 2. Raw data collected at Round Top Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) =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

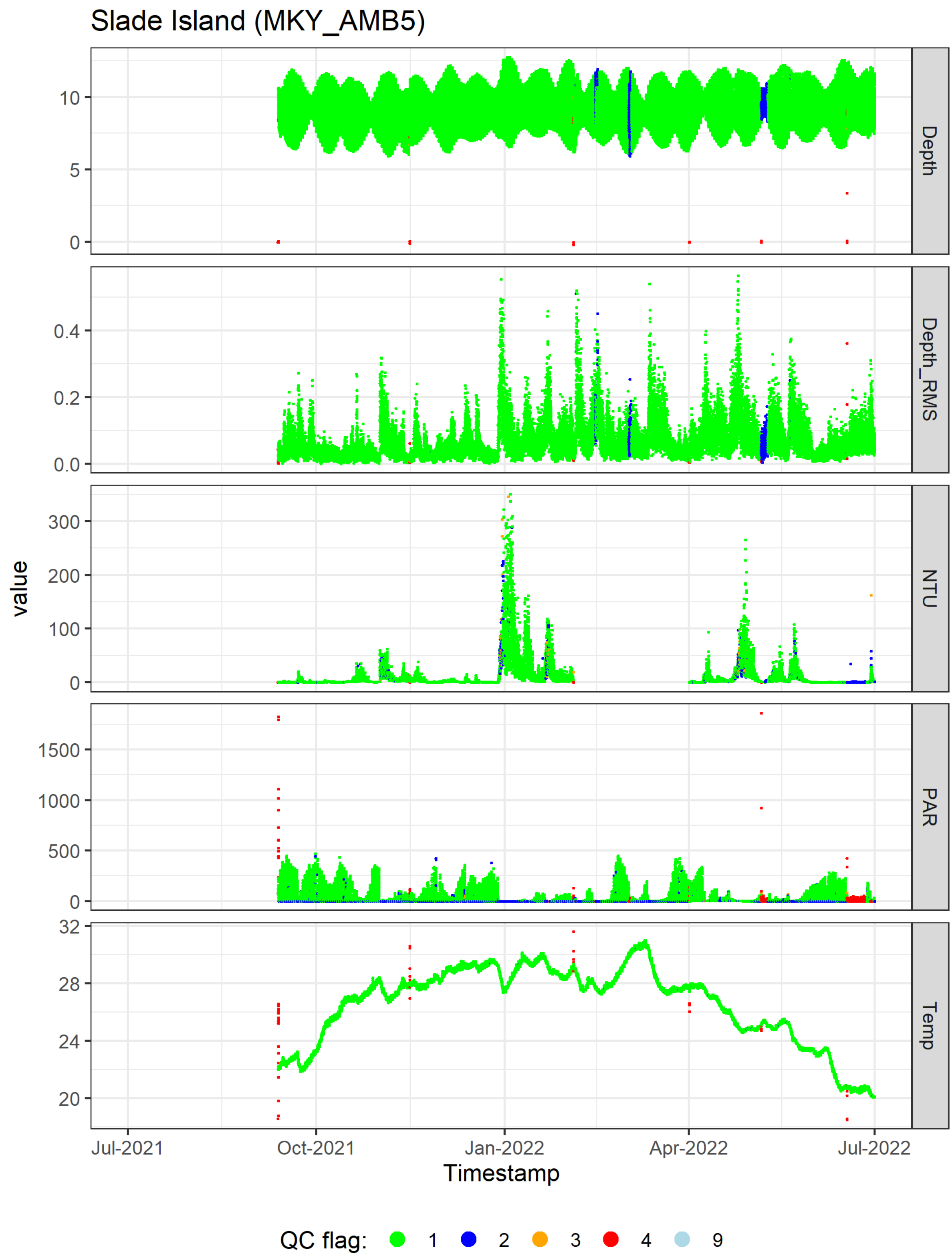

Figure A 3. Raw data collected at Slade Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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

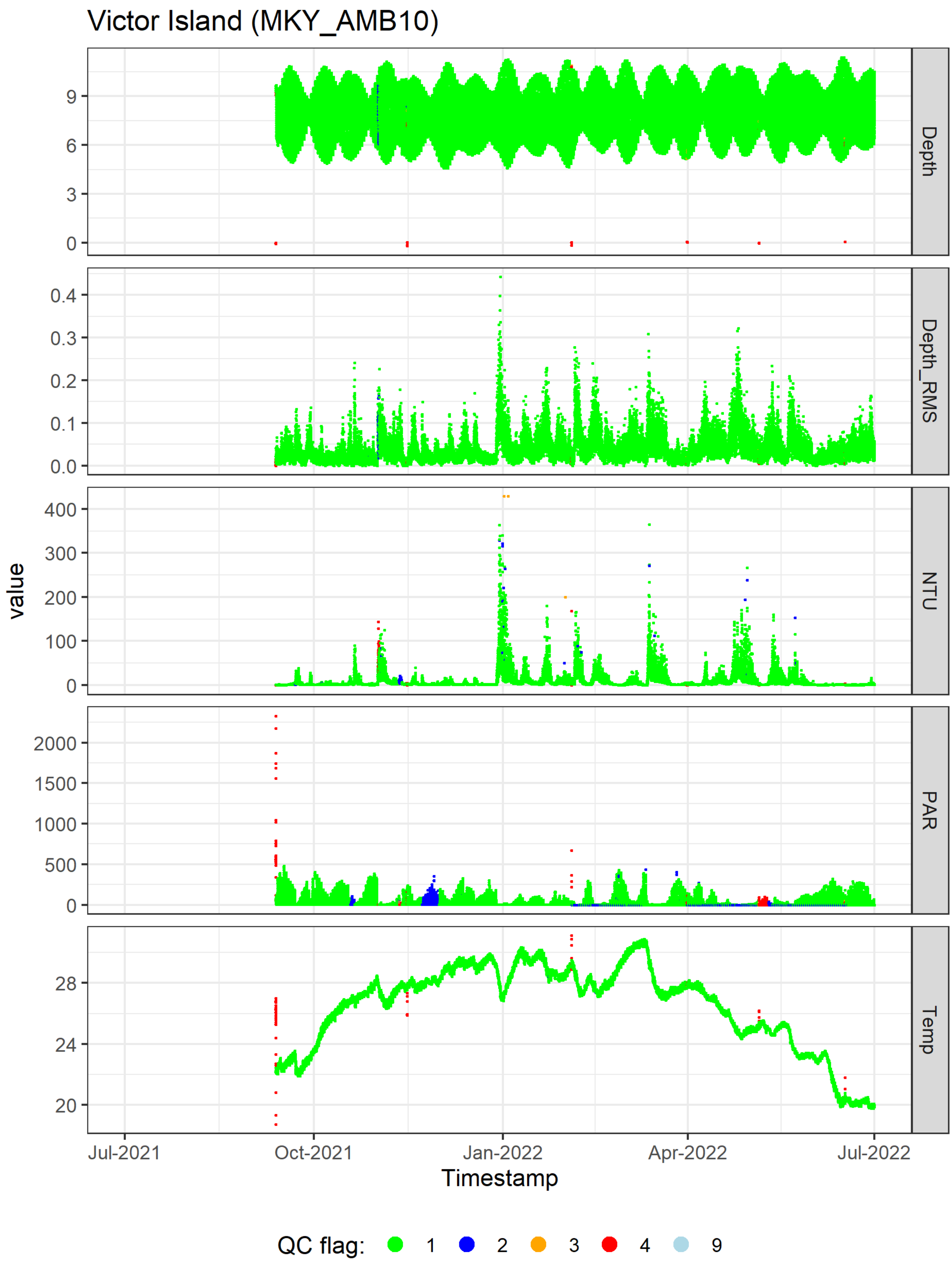

Figure A 4. Raw data collected at Victor Island with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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