Port of Abbot Point Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022

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A Report for North Queensland Bulk Ports Corporation

Report No. 22/59

Prepared by Nathan Waltham, Jordan Iles, Paula Cartwright

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University, Townsville, Queensland, Australia
Phone : (07) 4781 4262
Email: TropWATER@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

The report may be cited as:
Waltham NJ, Iles, JA, Cartwright, P. 2022, 'Port of Abbot Point Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 22/59, James Cook University, Townsville, 44 pp.

Contacts

For more information contact: Nathan Waltham, nathan.waltham@jcu.edu.au

Executive Summary

Background

1. In November 2017, 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 Port of Abbot 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 Abbot Point region.
2. The Port of Abbot Point, 25 km north of Bowen, has three established sites for ambient water quality monitoring. Sites include two inshore coastal sites (Camp Island and Euri Creek) and one offshore Island site (Holbourne Island) whose locations align with key sensitive receptor habitats (e.g., corals or seagrass), and key features of 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 a total 810.8 mm of rainfall in the Bowen region, which is higher than the median annual rainfall measured since 1961. Wet season rainfall however, at 543.2 mm, was lower than the previous reporting year (2020-21).
2. There was a large rainfall event in late January 2022, with an associated stream discharge event from the Don River.
3. April saw the highest wave activity of the year, with more waves over 1.2 m than any other months.

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 at Camp Island (March and June 2022) and increased with depth at Holbourne Island (April 2022).
3. All three sites showed elevated particulate nitrogen (PN) and particulate phosphorus (PP) concentrations that exceeded guideline values on several sampling occasions.

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

5. Trace metals were generally well below guideline values throughout the reporting year. Arsenic (low concentrations) and copper were detected at all sites, with copper exceeding trigger values 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 late wet season at Euri Creek. No PFAS substances were detected in the early or late 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 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 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 water quality in this region of the Great Barrier Reef lagoon.

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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 Port of Abbot Point. 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.

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 to, 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 Port of Abbot 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.

Figure 1-1. James Cook University research vessel 'Kasmira' underway to conduct water quality monitoring at Holbourne Island

2 Methods

2.1 Port Description

The Port of Abbot Point is situated in naturally deep waters off the central Queensland Coast approximately 25 km north of Bowen (Figure 2.1). Operated by North Queensland Bulk Ports (NQBP) as a coal port, the terminal has a current export capacity of 50 million tonnes per annum with potential for expansion, making it one of Australia's key strategic trading ports.

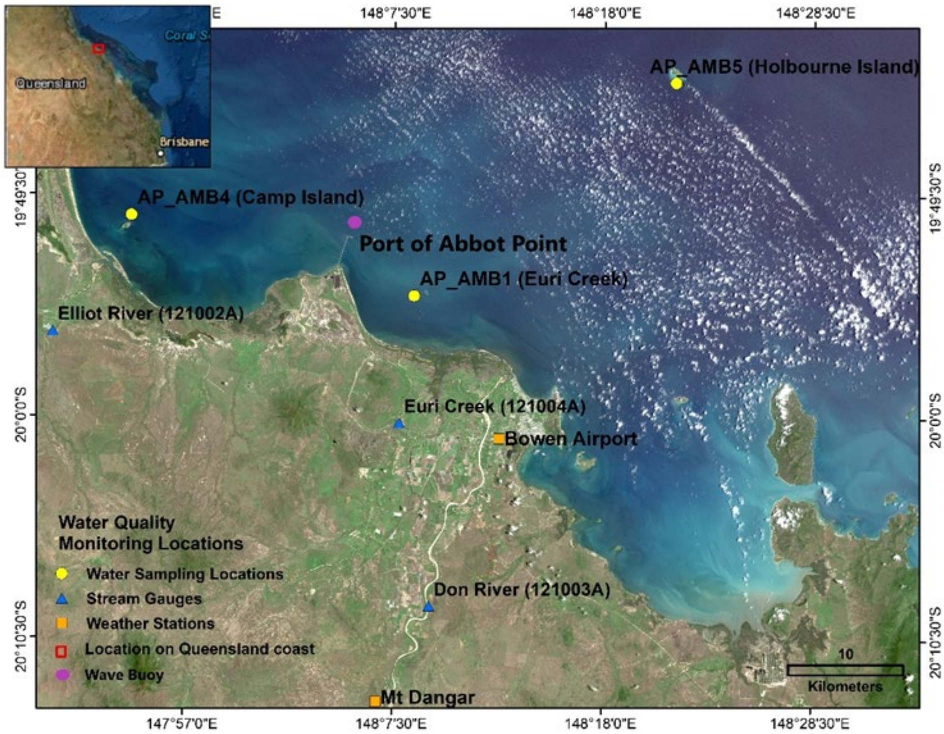

Figure 2-1. Map of water quality monitoring site locations adjacent to the Port of Abbot Point in the Bowen region. Yellow markers are sites where loggers were deployed, and discreet water samples were taken.

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 offshore from Abbot Point (Figure 2.1).

2.3 Monitoring and sampling design

The Bowen region has three active ambient marine water quality monitoring sites (Figure 2.1, Table 2.1). Two inshore sites are located adjacent to Euri Creek and Camp Island. An offshore site is located adjacent to Holbourne Island. Each site has a pair of dataloggers deployed on the seafloor to continuously record environmental data. The sites are revisited on an 8 weekly schedule to conduct water sampling, record physiochemical measurements, and exchange dataloggers (Table 2.2).

Table 2.2-1. Site locations and main features

Site name	Site code	Latitude	Longitude	Depth (m)	Site features
Euri Creek	AP_AMB1	-19.908817	148.138047	10	Seagrass
Camp Island	AP_AMB4	-19.842807	147.904126	9	Coral/ macroalgae/ seagrass
Holbourne Island	AP_AMB5	-19.724934	148.354198	15	Coral

2.4 Water quality sampling

Each monitoring site was visited by our research vessel for sampling on an ~8-week basis (Table 2.2).

Table 2.3-1. Field dates for water sampling, logger maintenance, metal detection and pesticide sampling at the three monitoring locations. Note that pesticide sampling was only undertaken at Euri Creek.

Date	**Water sampling**	**Logger maintenance**	**Metals sampling**	**Pesticides**
2021-07-20	Yes	Yes	No	No
2021-09-14	Yes	Yes	Yes	No
2021-11-17	Yes	Yes	No	Yes
2021-12-14	Yes	Yes	No	No
2022-02-02	Yes	Yes	No	No
2022-03-30	Yes	Yes	Yes	Yes
2022-05-04	Yes	Yes	No	No
2022-06-15	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 2.3-2. Water quality parameters that were analysed using water samples collected at three locations, Euri Creek, Camp Island and Holbourne Island, 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 2.3-3. Physiochemical measurements

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 2.3-4. Dissolved metals

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 Euri Creek (AP_AMB1) 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 retrieved from Euri Creek (AP_AMB1) in December 2020. Note: biological growth on the samplers.

Table 2.4-1. Pesticide and PFAS passive samplers deployed at Euri Creek (AP_AMB1) during the 2021-2022 wet season.

Site name	Site code	Start date	End date	Duration (days)
Euri Creek	AP_AMB1	17/11/2021	13/12/2021	26
Euri Creek	AP_AMB1	30/03/2022	4/05/2022	35

Table 2.4-2. 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 $sampler^{-1}$

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. At each site a pair of 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 2.5-1. 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 Abbot 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:

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

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 Bowen region is shown in 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 25th 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 543.2 mm, while total rainfall for the water year was 810.8 mm (Figure 3.2). This is slightly above the median annual rainfall calculated since 1961-1962.

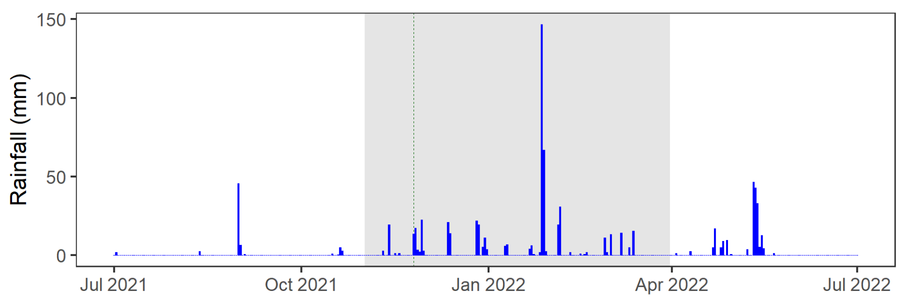

Figure 3-1. Rainfall recorded at Mount Danger (station 033096) for the 2021-2022 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

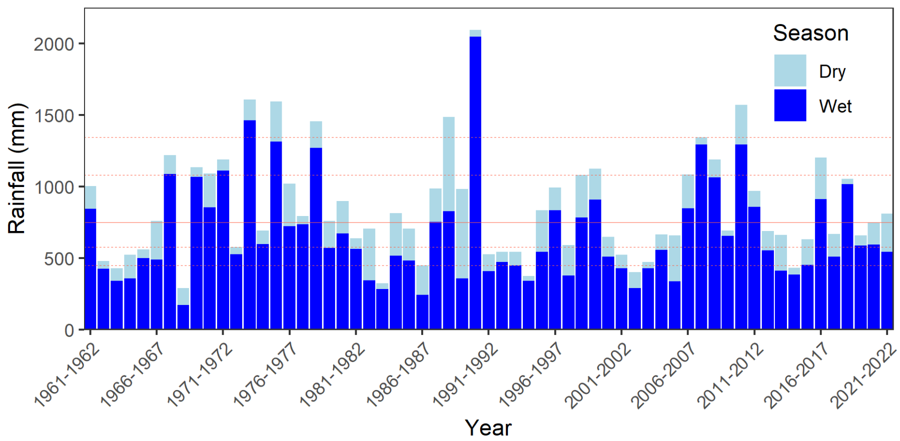

Figure 3-2. Annual rainfall by water year for the Bowen region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Daily rainfall data was obtained from the Mount Danger weather station (station 033096). Data source: http://www.bom.gov.au/climate/data/

Hydrographs for streams from the Don River catchment show onset of stream discharge on 25/11/2021 with a small flow pulse followed by a second pulse on 26/12/2021. There was a notable discharge event in late January 2022 and a smaller one in May 2022 (Figure 3.3). Total discharge for the 2021-2022 water year was 48.2 GL (Don River), 7.73 GL (Elliot River), and 27.6 GL (Euri Creek).

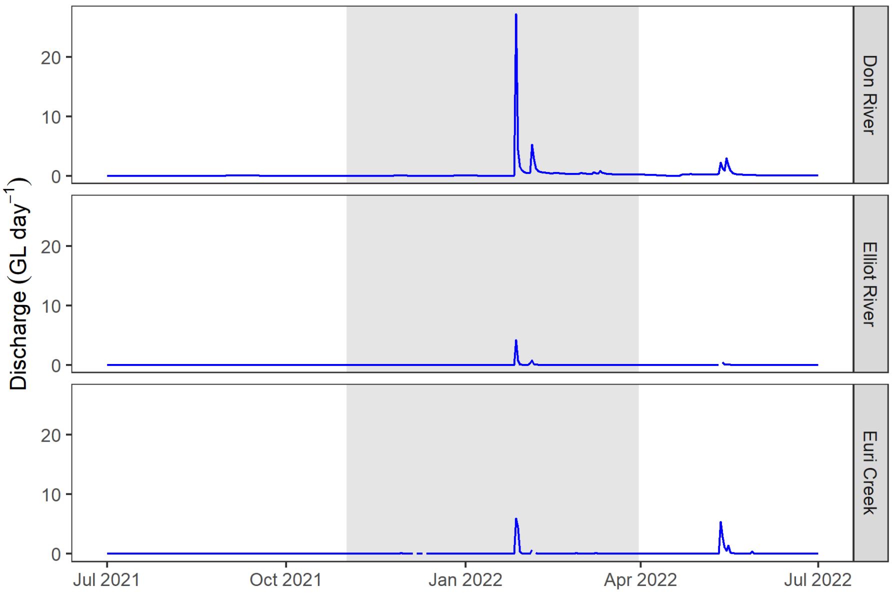

Figure 3-3. Stream discharge (GL d^{-1}) from the Don River (station 121003A), Elliot River (station 121002A), and Euri Creek (station 121004A) during the 2021-2022 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/

3.2 Oceanographic conditions

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

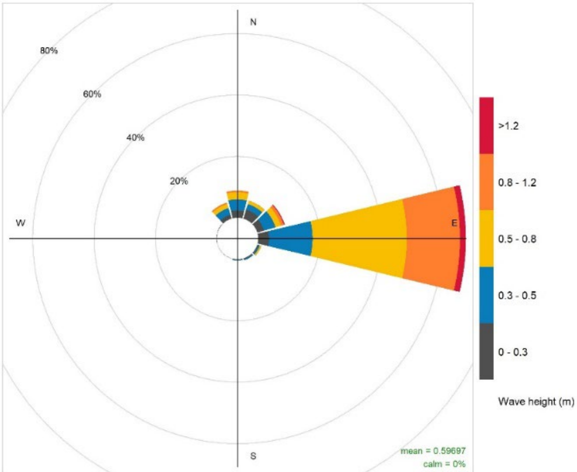

Figure 3-4. Frequency of counts by wave direction (%), and significant wave height (m) at the Abbot Point wave buoy station between July 1, 2021 and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

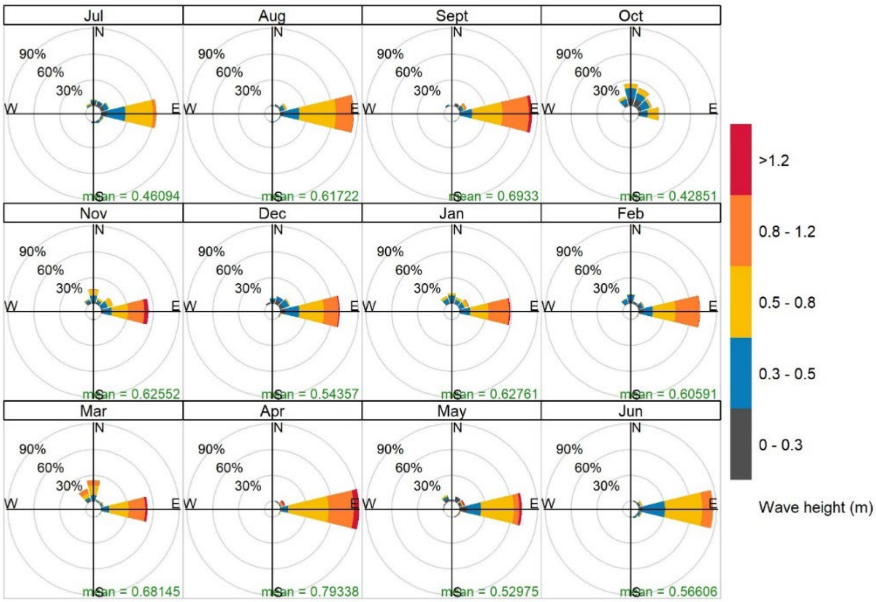

Figure 3-5. Frequency of counts by wave direction (%), and significant wave height (m) at the Abbot Point wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

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 at Camp Island and Euri Creek in April and June 2022 when the top waters were more oxygenated, and at Holbourne Island in April 2022 when the bottom waters were more oxygenated (Figure 3-6). Electrical conductivity (EC) at the three locations ranged from 51.9 to 54.8 mS cm^{-1} and was in the range typical of seawater (Figure 3-7). Conductivity values followed seasonality with higher values occurring during summer months and lower values during winter months, though lower values were present after periods of high rainfall. Water temperature ranged between 21.6 and 30.4 °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 cool water temperatures observed during the winter months. The annual temperature range at the offshore site AP_AMB5 (Holbourne Island) was less than inshore sites. 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 8.16 and 8.38 across all sites throughout the year (Figure 3-9).

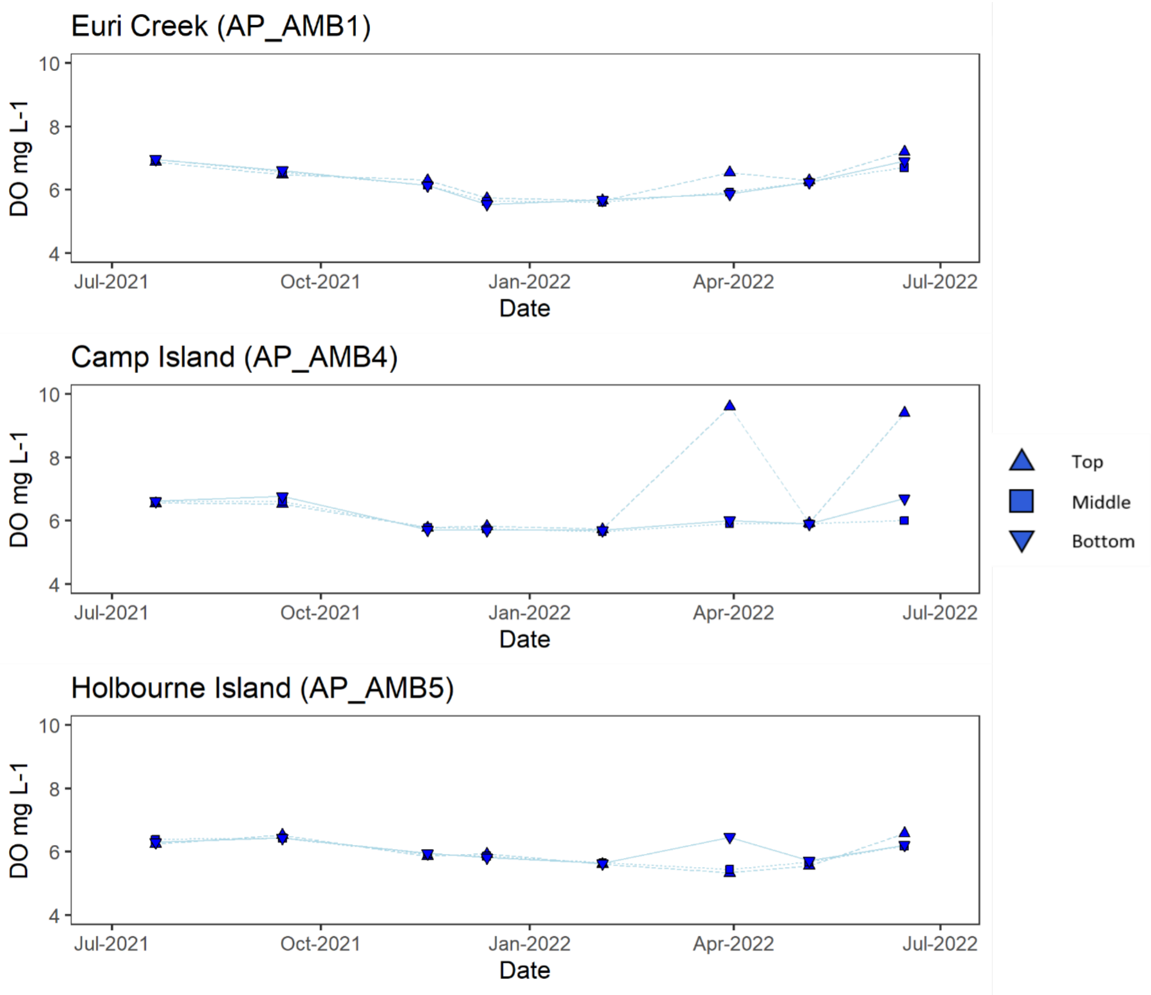

Figure 3-6. Dissolved oxygen concentration (mg/L) at three water quality monitoring sites showing results for the top, middle, and bottom water.

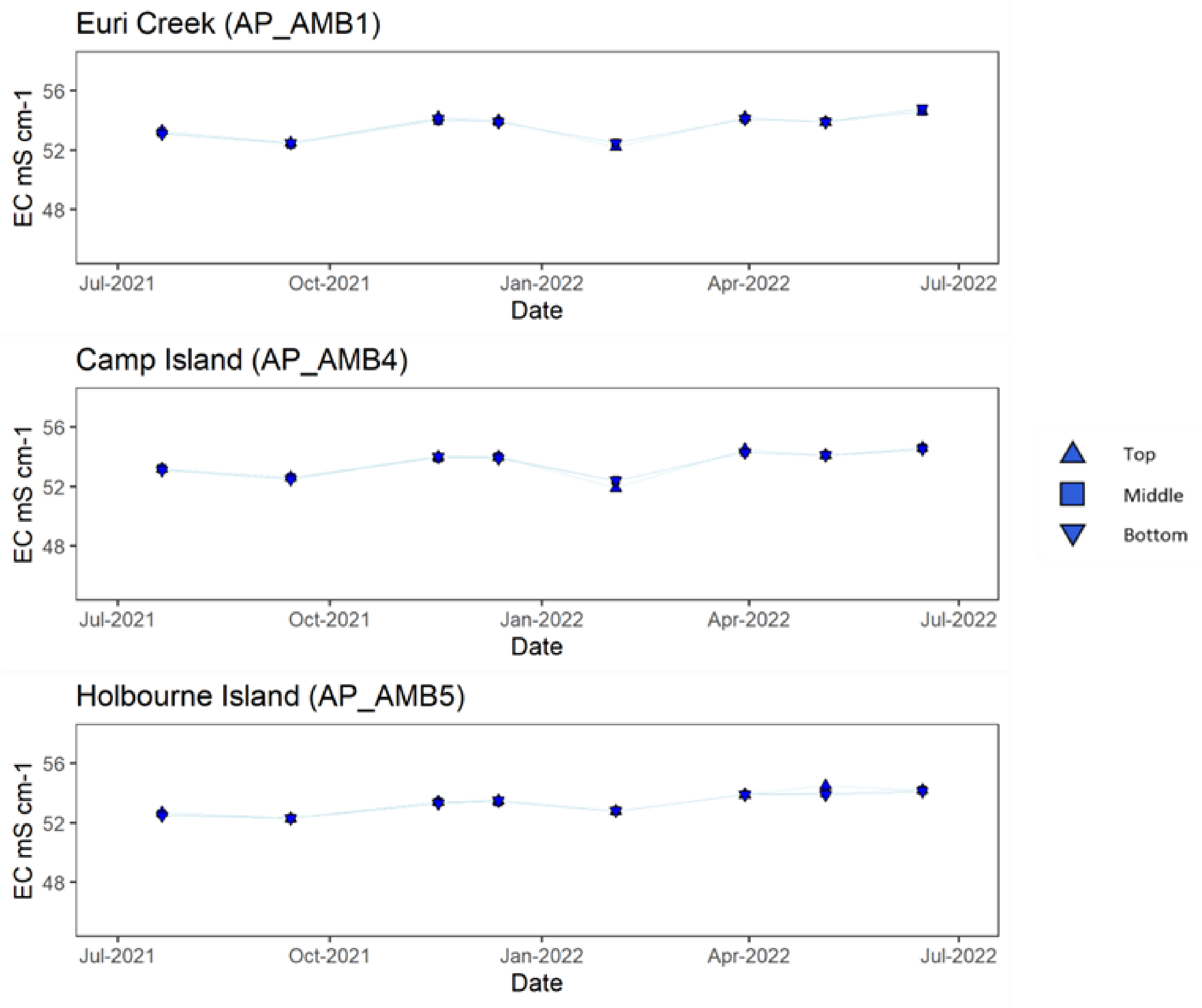

Figure 3-7. Electrical conductivity recorded at three depths at the three water quality sites throughout the reporting period.

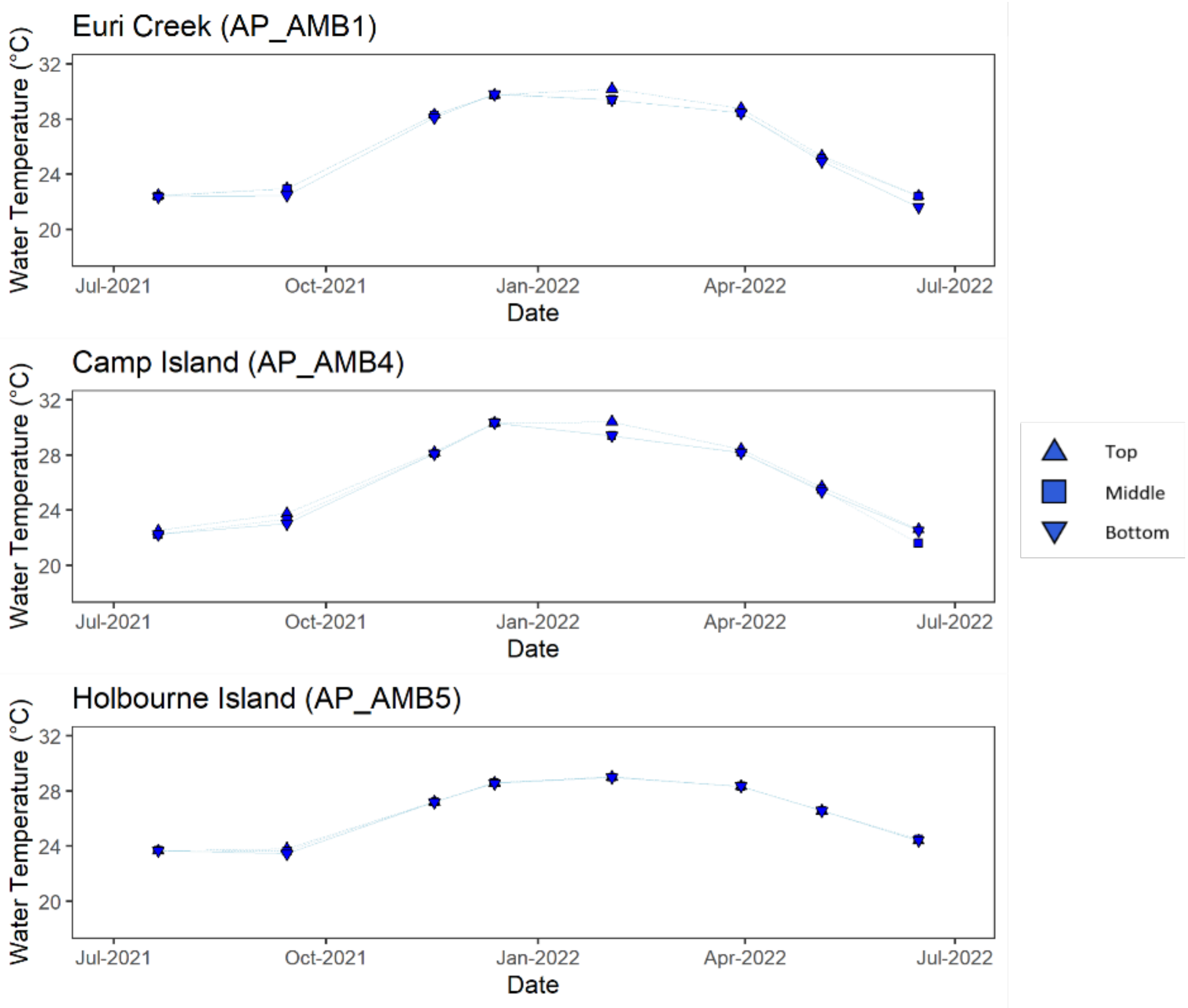

Figure 3-8. Water temperature recorded at three depths at the five water quality sites throughout the reporting period.

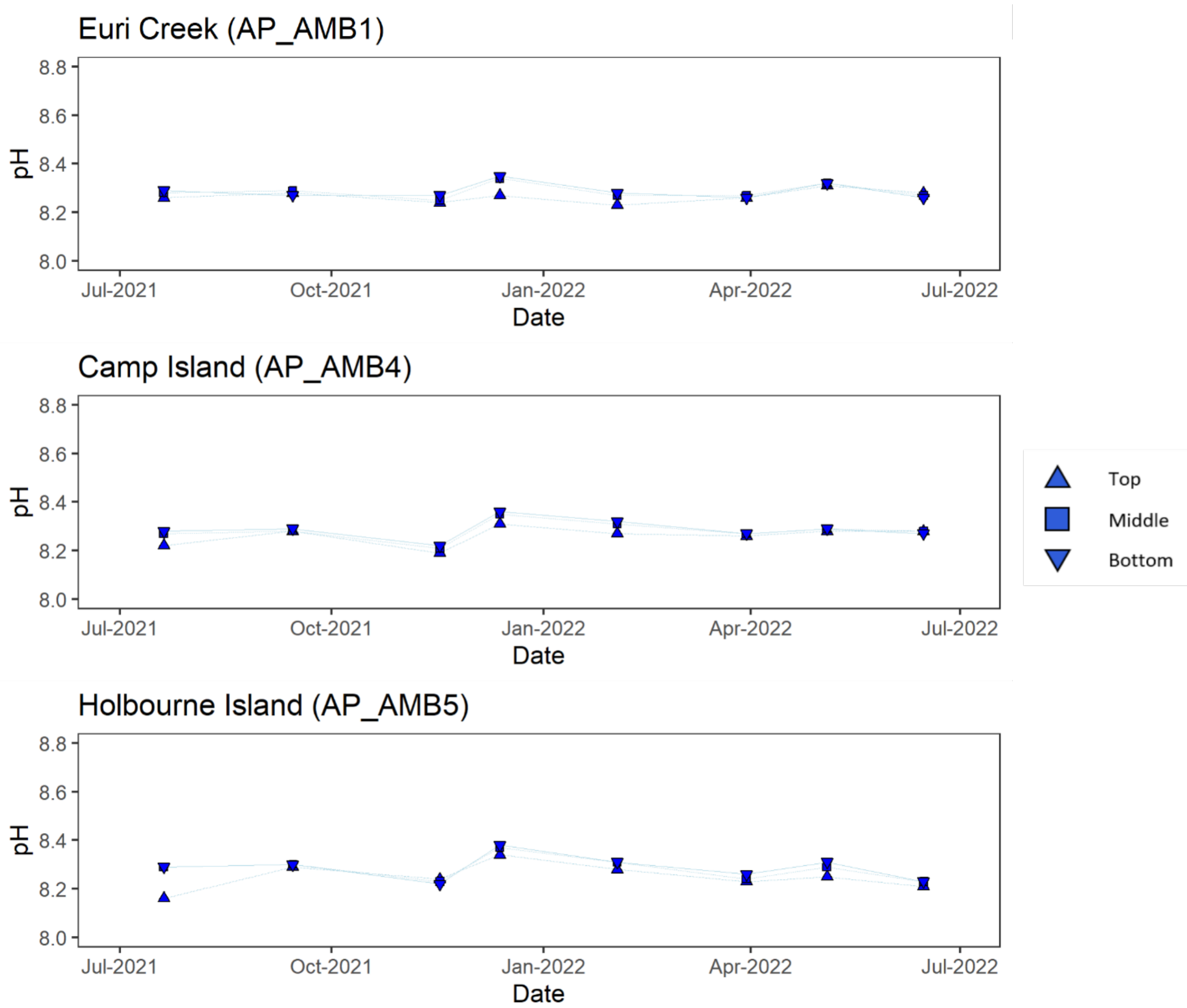

Figure 3-9. pH recorded at three depths at the three water quality sites throughout the reporting period.

3.3.2 Nutrients

Particulate nitrogen (PN) concentrations ranged from 5 to 100 µg L^{-1} (Figure 3-10). Mean PN across the three sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} in July and September 2021

Particulate phosphorus (PP) concentrations ranged from <1 to 7 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 July 2021.

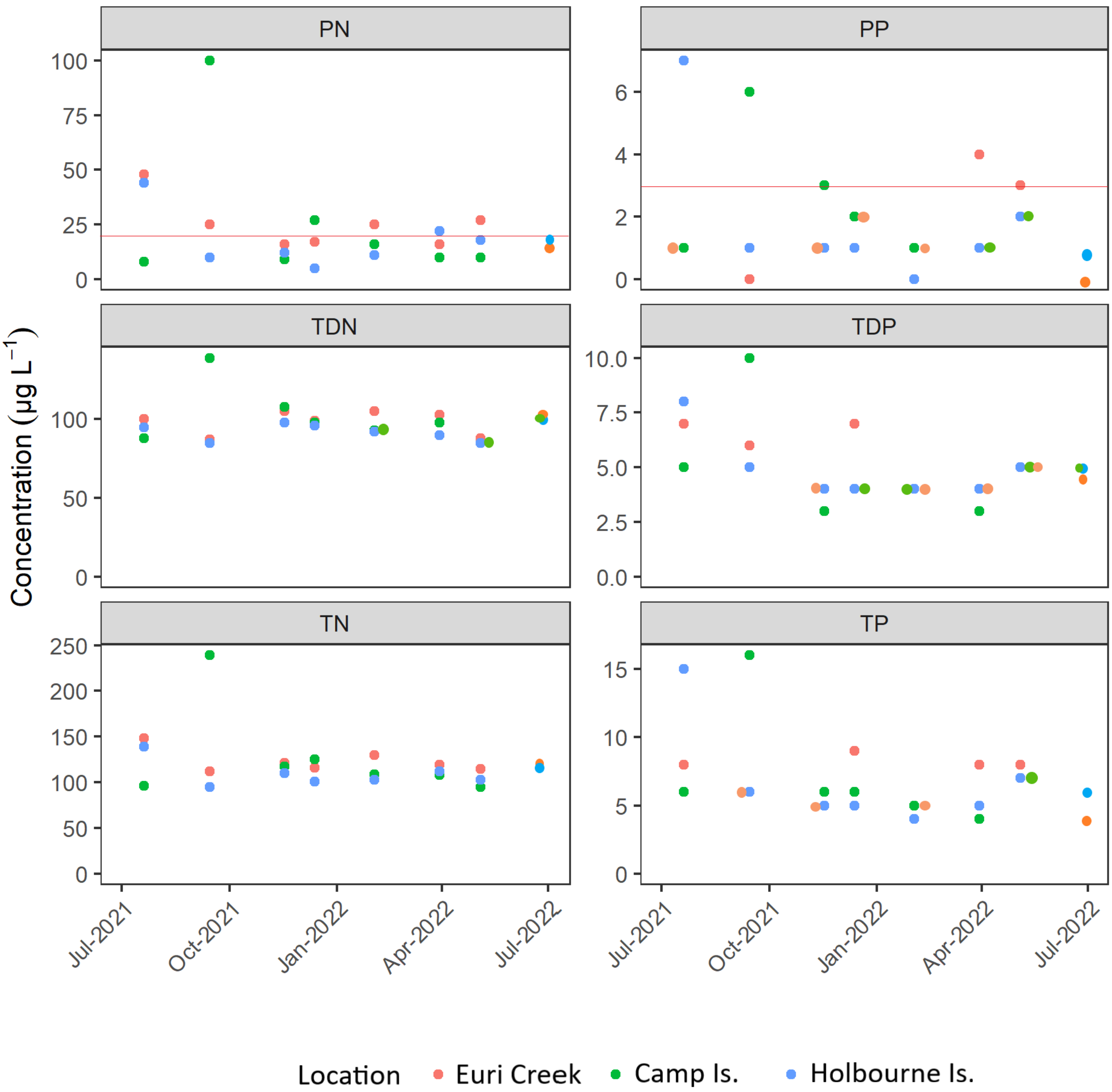

Figure 3-10. Particulate Nitrogen (PN), Total Dissolved Nitrogen (TDN), Total Nitrogen (TN), Particulate Phosphorous (PP), Total Dissolved Phosphorous (TDP) and Total Phosphorous (TP) concentrations measured in water samples collected from the three water quality sites over the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value for Particulate Nitrogen and Particulate Phosphorous.

3.3.3 Water clarity

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

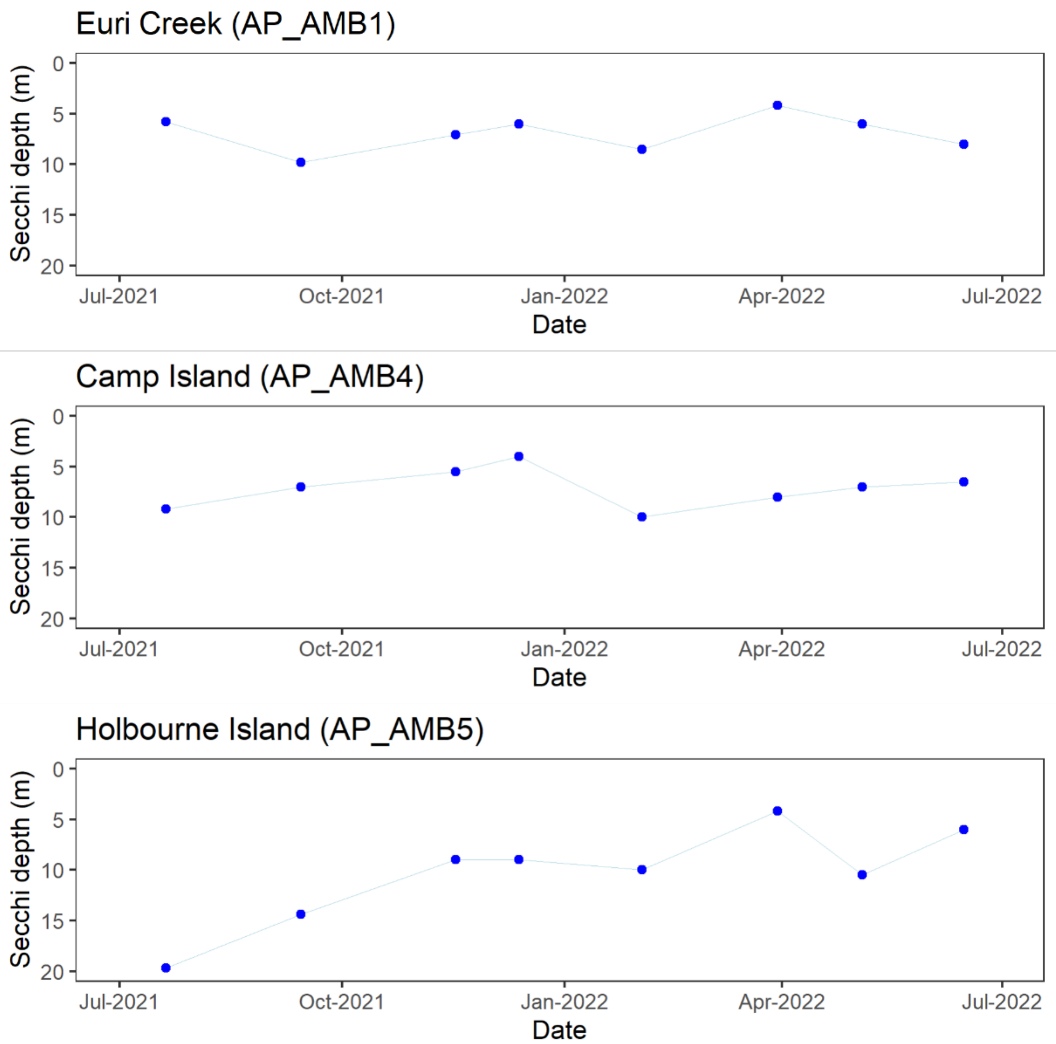

Figure 3-11. Secchi disk depth recorded at the three water quality sites throughout the reporting period.

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). Near coastal sites Euri Creek and Camp Island displayed large spikes in chlorophyll-a that were above guideline values in October and December 2021, while the offshore site Holbourne Island displayed the highest chlorophyll-a of the three sites in April 2022. Outside of this April spike at Holbourne Island, all sites displayed lowest chlorophyll in Austral winter and highest in Austral Spring.

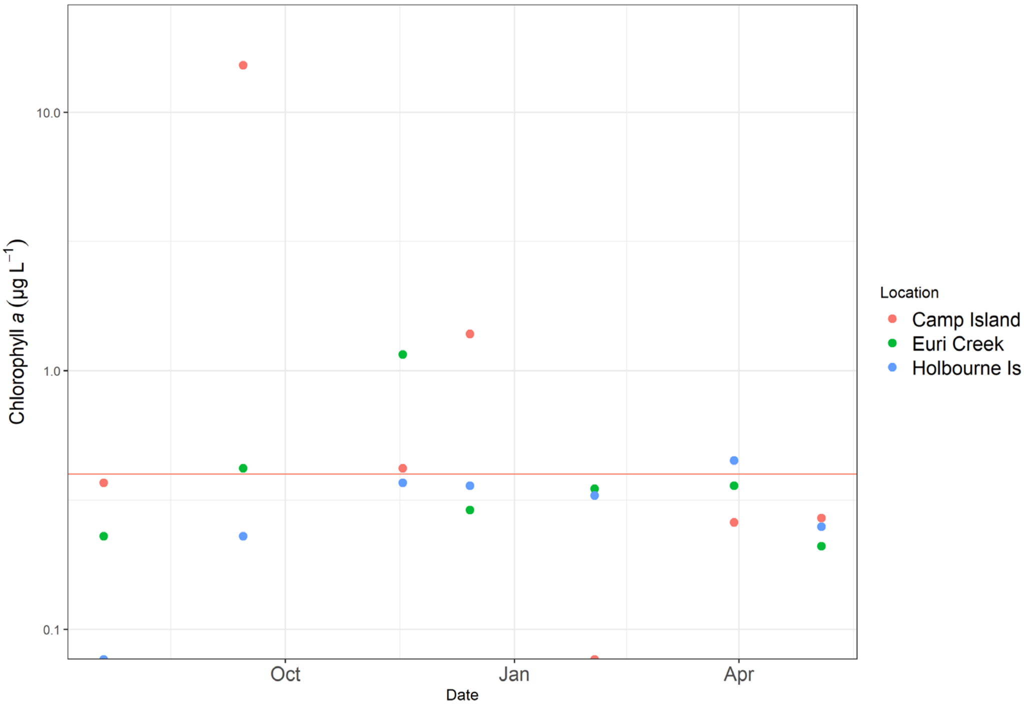

Figure 3-12. Chlorophyll-a concentrations measured in water samples collected from the five water quality sites throughout the reporting period. Y-axis is on log scale. The large spike at Camp Island in September 2021 was likely due to a Trichodesmium bloom that was present at the time of sampling. Horizontal 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 Euri Creek 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 measured at Camp Island in September 2021 were above the trigger value for As(III) at 2.8 µg/L, a higher concentration than found here in previous years.

Table 3.3-1. Heavy metal concentrations measured in water samples collected from three water quality sites in the Bowen region throughout the reporting period. 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
Euri Creek	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.4	<5	<0.0001

Camp Island	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	2.8	<5	<0.0001
Holbourne Is	Sep-2021	<0.1	<0.2	2	<0.2	<0.5	1.5	<5	<0.0001
Euri Creek	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.6	<5	<0.0001
Camp Island	Mar-2022	<0.1	<0.2	<1	<0.2	<0.5	1.5	<5	<0.0001
Holbourne Is	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 are presented in Table 3-2. No pesticides were detected in the early wet season. During the late 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. A full list of pesticide results is included in Appendix A1.1 (mass per sample) and A1.2 (concentration).

Table 3.3-2. Pesticide mass per sampler and water concentration recovered from passive samplers deployed at Euri Creek (AP_AMB1). Due to analytical constraints water concentration is only calculated for select analytes. A hyphen (-) denotes where concentration was not calculated.

	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})
2-4 D	<5.00	<0.990	<5.00	<0.810
Ametryn	<5.00	<1.79	<5.00	<1.46
Atrazine	<1.00	<0.240	1.87	0.36
Diketonitrile	<0.100	-	0.32	-
Diuron	<1.00	<0.280	1.86	0.43
Fipronil	<0.500	<0.100	<0.500	<0.080
Fluroxypyr	<1.00	-	<1.00	-
Haloxyfop	<1.00	<0.120	<1.00	<0.100
Hexazinone	<1.00	<0.230	1.49	0.28
Imidacloprid	<1.00	-	<1.00	-
MCPA	<5.00	<0.720	<5.00	<0.590
Metolachlor	<1.00	<0.230	<1.00	<0.190
Metribuzin	<1.00	-	<1.00	-
Metsulfuron-methyl	<1.00	-	<1.00	-
Pendimethalin	<5.00	-	<5.00	-
Prometryn	<1.00	<0.390	<1.00	<0.320
Simazine	<1.00	<0.160	<1.00	<0.130
Tebuthiuron	<1.00	<0.180	1.12	0.17
Terbuthylazine	<1.00	<0.220	<1.00	<0.180
Triclopyr	<5.00	<0.600	<5.00	<0.490

3.3.7 Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

No Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) were detected at Euri Creek (AP_AMB1) during the early- or late- wet season sampling periods (Table 3-3). A full list of PFAS results are included in Appendix A1.3.

Table 3.3-3. Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) mass per sampler and water concentration recovered from passive samplers deployed at Euri Creek (AP_AMB1).

			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

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. The 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 2.

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.

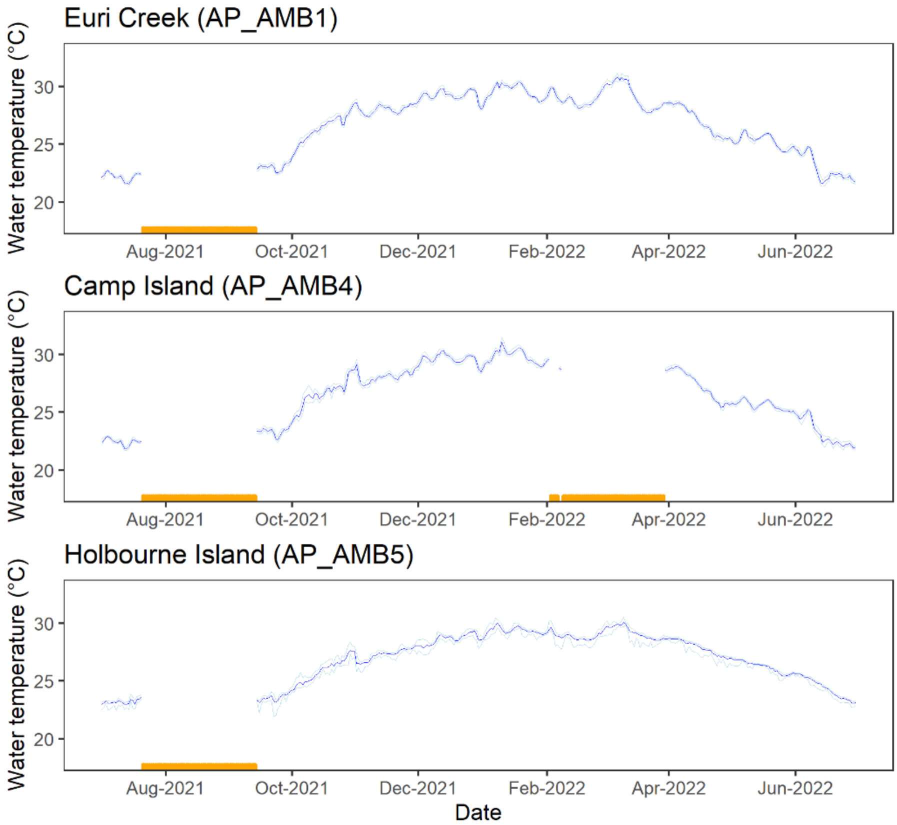

Figure 3-13. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the Bowen region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18 – 3.20.

3.4.2 Water depth

The daily mean tidal range for each site is presented in Figure 3-14. The Bowen region is mixed semidiurnal mesotidal, with daily tidal range measured to be from 0.81 to 3.4 m during the reporting period. There was a storm surge event at Holbourne Island in February 2022, where tidal range exceeded five metres.

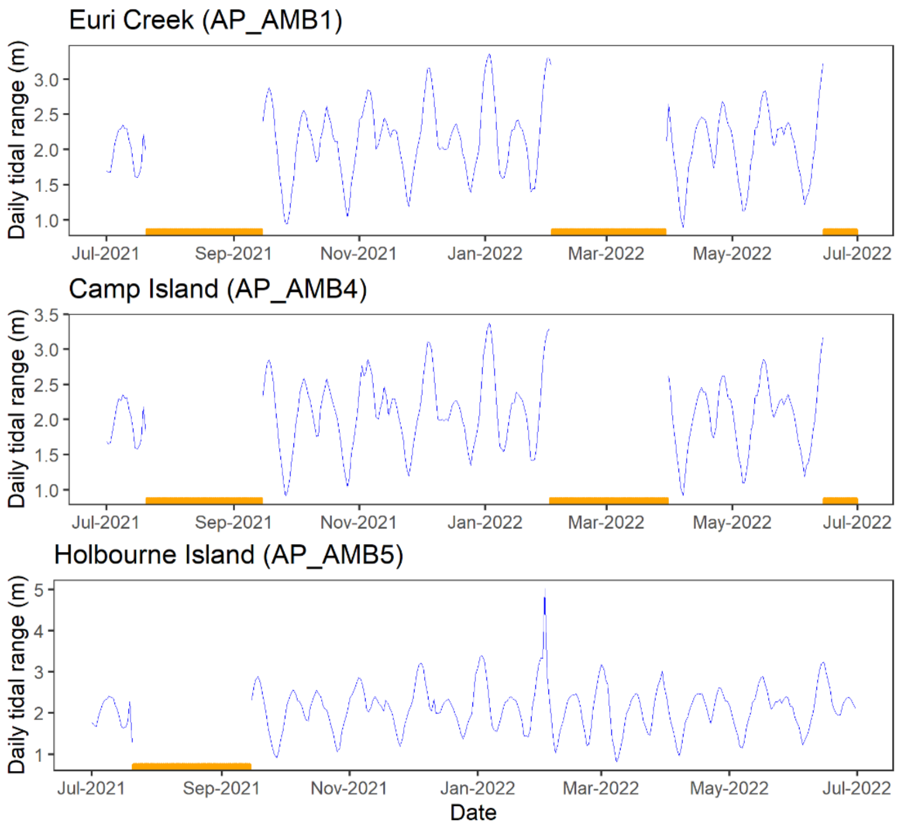

Figure 3-14. Daily tidal range measured at Abbot Point monitoring sites. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18 – 3.20.

3.4.3 Wave activity

Euri Creek and Camp Island are both located along the exposed coastline and had similar wave exposure, while Holbourne Island is a sheltered site and wave activity was lower. Notable high energy periods were found in early November 2021 and late April - early May 2022 (Figure 3-15).

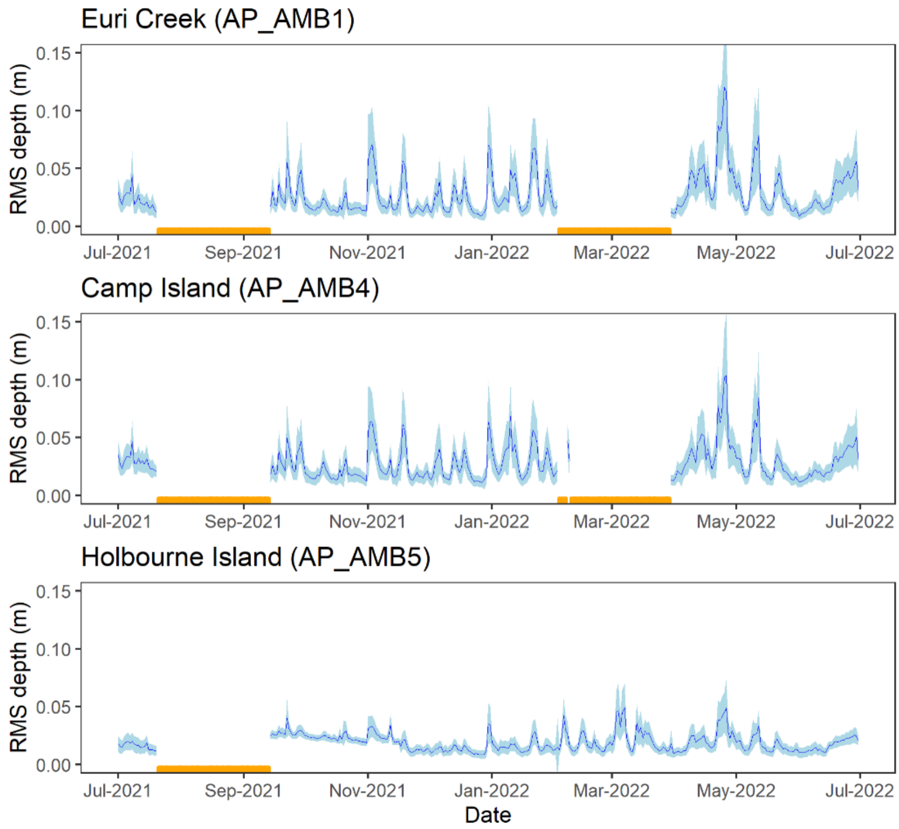

Figure 3-15. RMS depth measured at Bowen monitoring sites. Values presented are daily mean (blue line) +/- standard deviation (light blue). Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3-18– 3.20.

3.4.4 Turbidity

Turbidity measured at water quality monitoring sites in the Bowen region is presented in Figure 3-16. There were periods of high turbidity in November 2021, March 2022, and May 2022 affecting the inshore sites Euri Creek and Camp Island. The offshore site Holbourne Island was unaffected. This corresponded with periods of high wave activity as is evident in the heightened RMS depth values for those periods (Figure 3-15). 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).

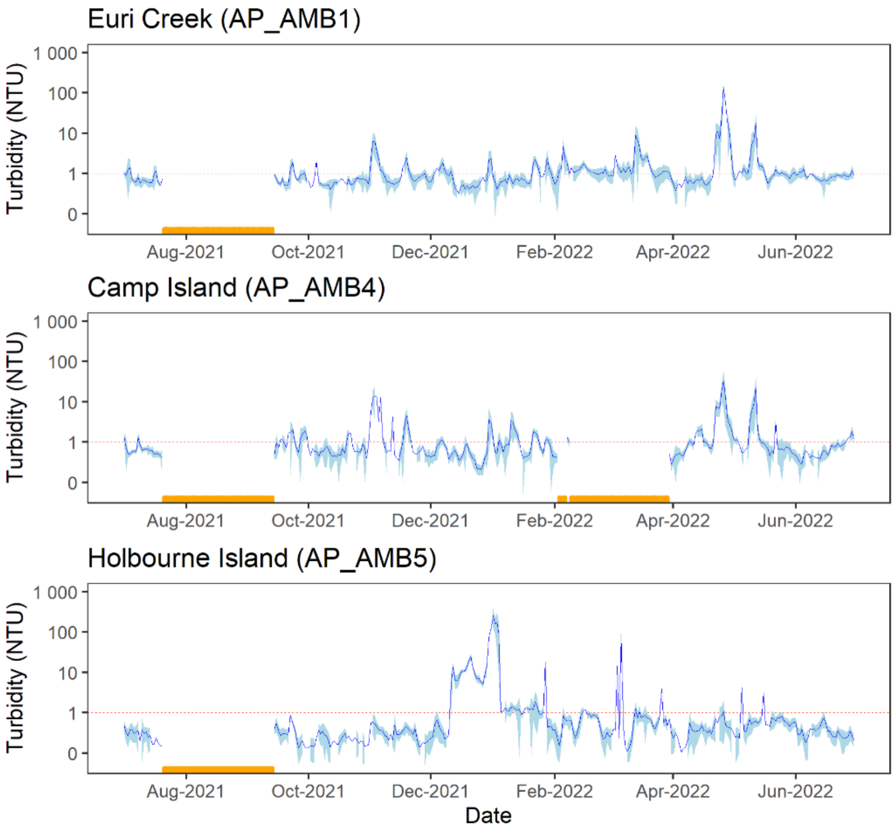

Figure 3-16. Turbidity measured at water quality monitoring sites in the Bowen region. Results presented are daily mean (blue line) and standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters. Periods of missing data are 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 – 3.20.

Table 3.4-1. Monthly mean, median, and standard deviation for turbidity (NTU) measured at three water quality monitoring sites in the Bowen region. Note the high standard deviations at Camp Island and Euri Creek in November 2021 and April 2022 respectively, indicating that there were shorter periods of very high turbidity during those times. Unlike Figure 3-16, the values in this table have undergone quality control.

	Euri Creek			Camp Island			Holbourne Island		
Month	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD
July 2021	0.70	0.62	0.46	0.61	0.56	0.34	0.70	0.29	1.03
Aug 2021	0.34	0.24	0.48	0.34	0.24	0.48	4.13	4.16	1.06
Sept 2021	0.88	0.71	0.59	1.09	0.79	2.26	0.33	0.28	0.30
Oct 2021	0.66	0.55	3.10	0.68	0.55	1.97	0.21	0.17	0.16
Nov 2021	1.45	0.82	2.08	2.96	0.66	17.86	0.33	0.30	0.23
Dec 2021	0.86	0.63	0.89	0.73	0.51	0.96	0.35	0.26	0.31
Jan 2022	0.92	0.72	0.73	1.08	0.80	1.00	0.43	0.37	0.26
Feb 2022	1.32	1.16	1.10	0.67	0.54	0.35	0.58	0.55	0.44
Mar 2022	1.88	1.17	3.99	0.36	0.28	0.65	0.64	0.52	6.54

Apr 2022	9.57	0.72	34.58	3.80	1.03	8.64	0.41	0.33	0.39
May 2022	1.92	0.99	3.92	2.06	0.75	7.88	0.74	0.52	8.13
June 2022	0.88	0.83	0.36	0.65	0.51	0.67	0.35	0.30	0.23

3.4.5 Photosynthetically active radiation (PAR)

PAR was highly variable at all sites throughout the reporting period with Holbourne Island having the highest PAR overall (Figure 3-17). Periods of low light in November 2021 and April/May 2022 at Euri Creek and Camp Island correspond with periods of high turbidity at these sites.

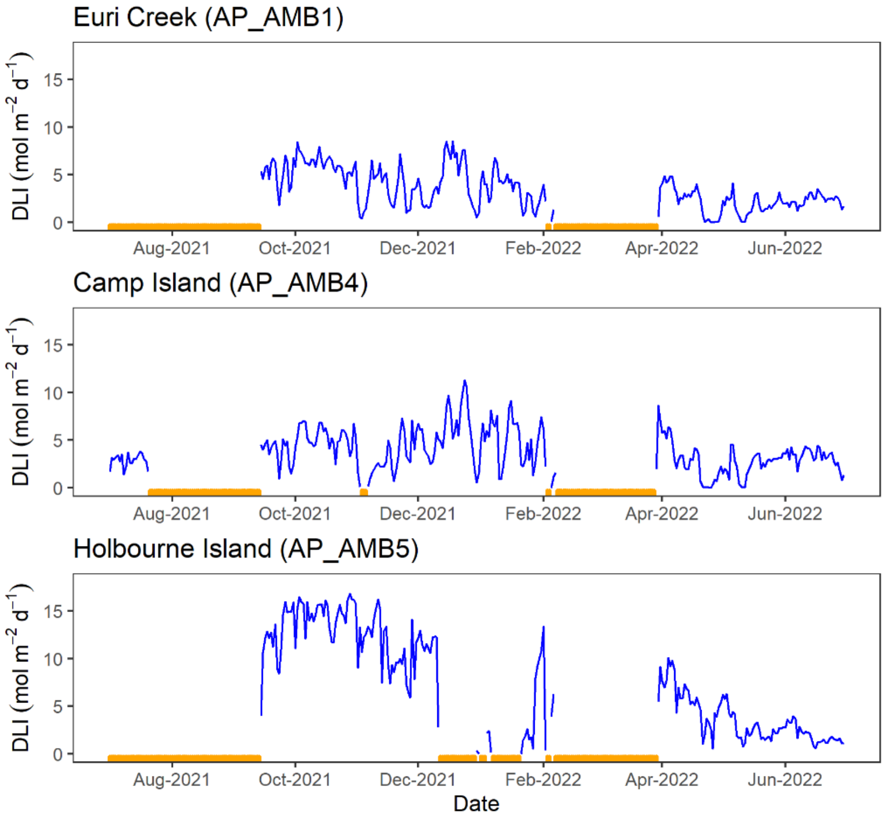

Figure 3-17. Daily light integral (mol photons m^{-2} d^{-1}) of photosynthetically active radiation measured at water quality monitoring sites in the Bowen region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from September 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18-3.20.

3.4.6 Combined IMO and MGL quality-controlled data

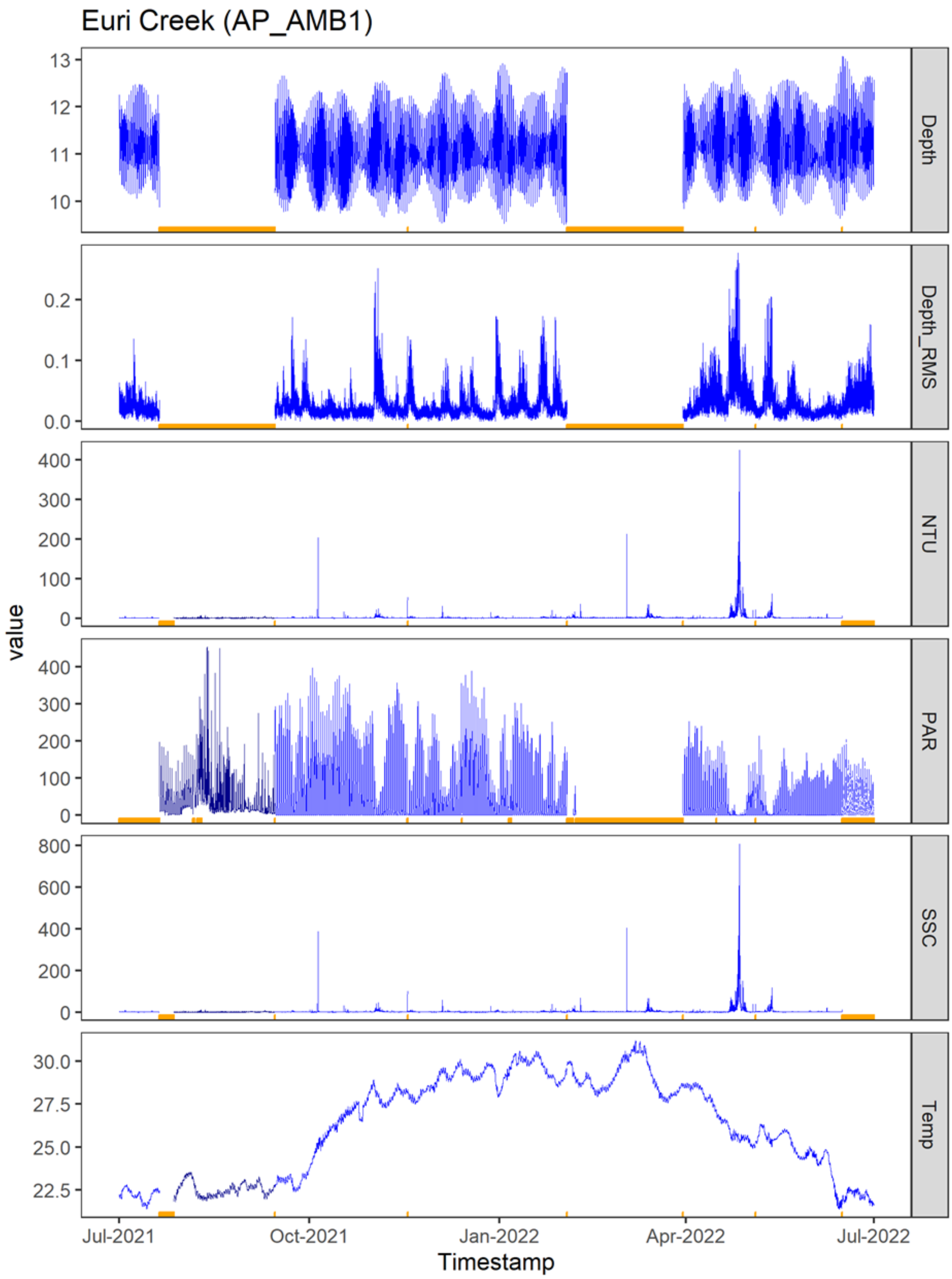

Figure 3-18. Data collected at Euri Creek with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes data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

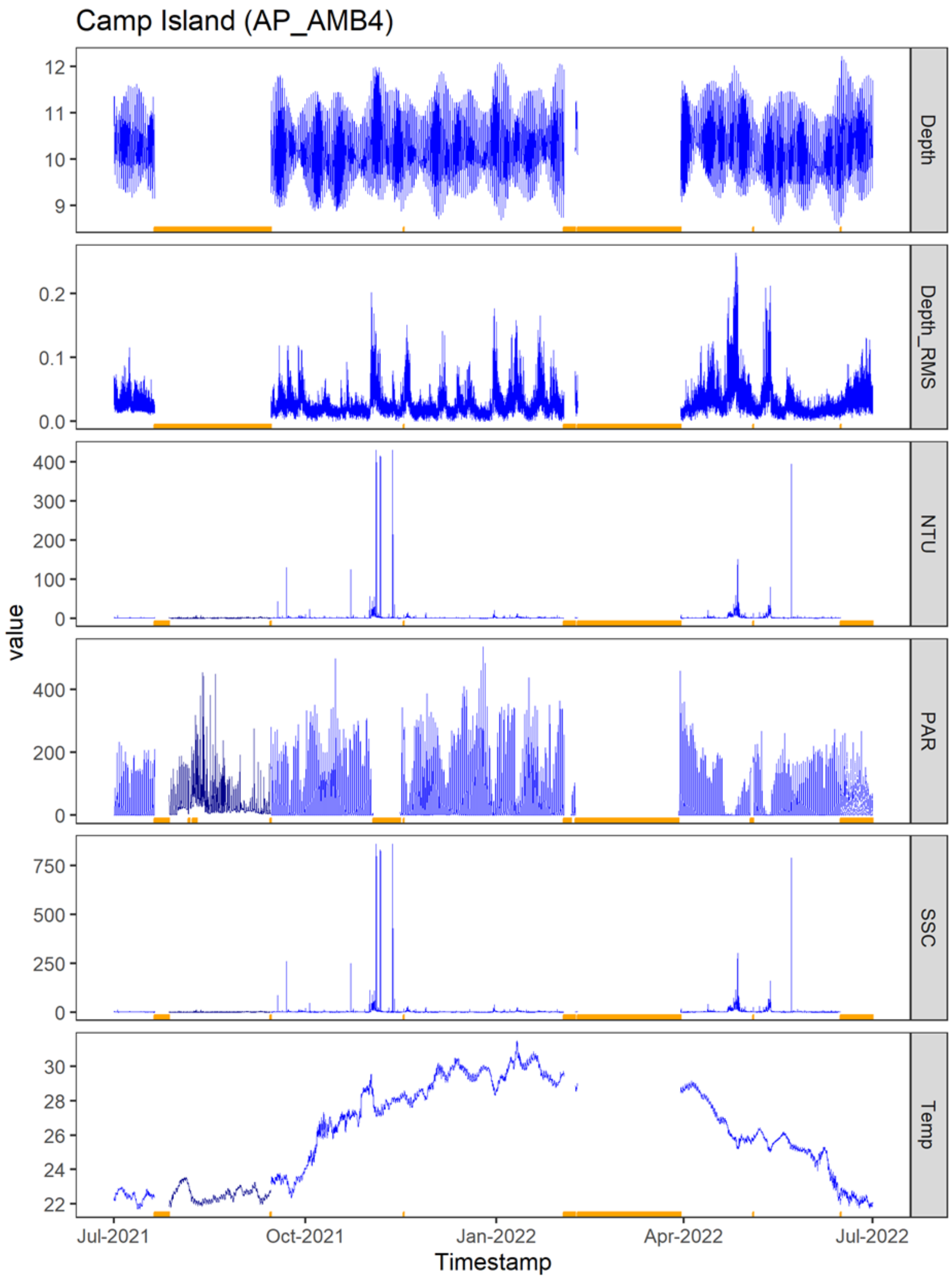

Figure 3-19. Data collected at Camp Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021. Data presented excludes data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

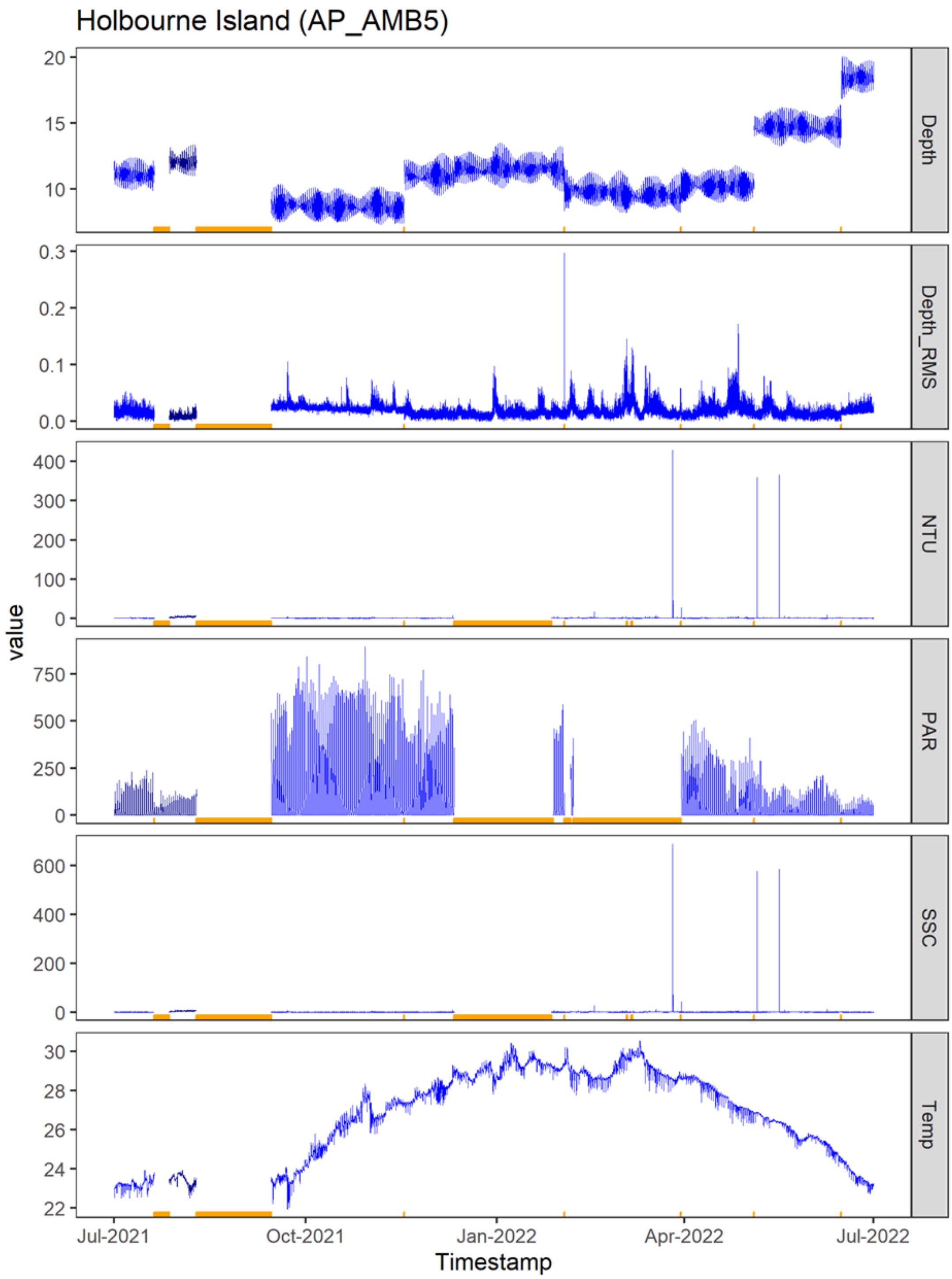

Figure 3-20. Data collected at Holbourne Island with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 14/09/2021.Note: Holbourne Island has a steep drop off close to shore. Small changes in logger frame deployment location can lead to differences in depth as is evident in the logged depth data for this site. 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. Full descriptions 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.

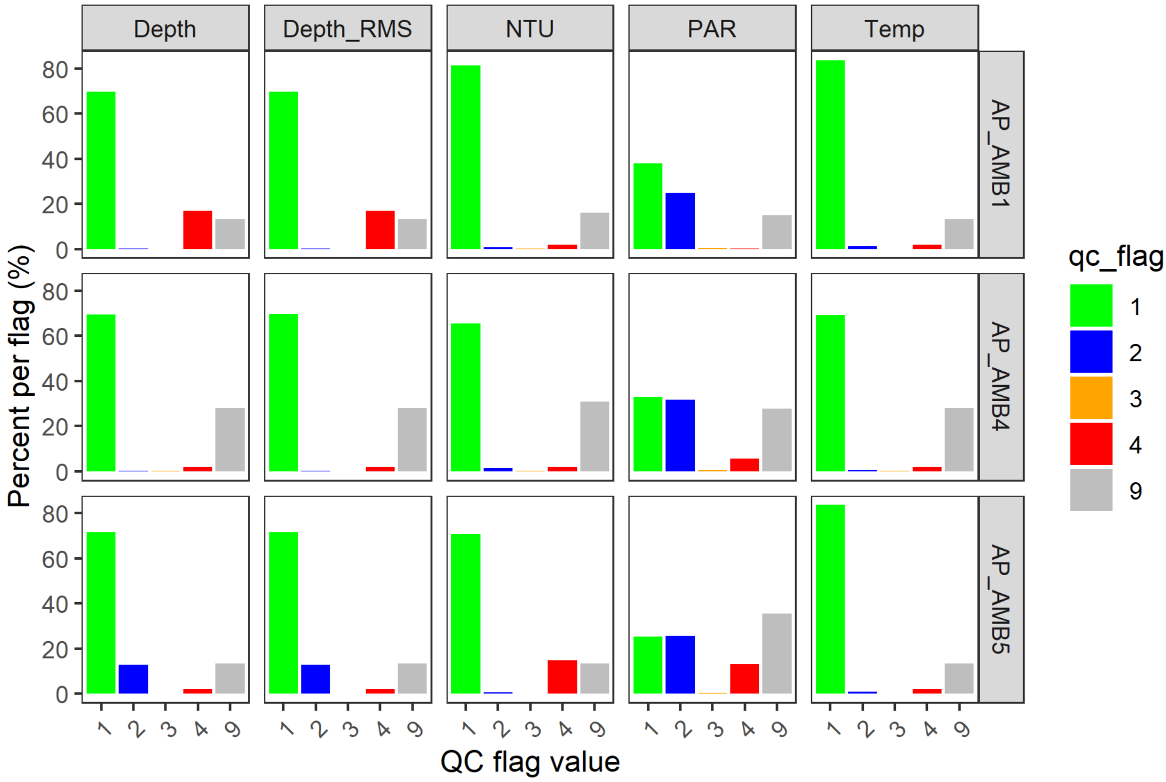

Figure 3-21. Data recovery and qc flags at each of the three Abbot Point logger sites, Euri Creek (AP_AMB1), Camp Island (AP_AMB4) and Holbourne Island (AP_AMB5), over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2)blue) indicates a 'probably good value'; flag 3 (yellow) indicates '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 less rainfall – 543.2 mm, when compared to the previous year (2020-2021). The total annual rainfall however was slightly above the long-term (100 year) median with 810.8 mm. This is an important factor to consider when interpreting data during this monitoring period. Comparison of these data with future (and past) years will be important 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. There was a large rainfall event in late January, and again in late April, with associated stream discharge events from the Don River. These climate events can lead to recognisable signals in the turbidity and PAR logger data, not only from the river flow, but from the associated metocean conditions, such as wind-driven waves, which are a major driver of sediment resuspension.

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, though the variation in temperature is smaller than in other regions along the east coast of Queensland.
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 at Camp Island (March and June 2022) and increased with depth at Holbourne Island (April 2022). The increase with depth is not a usual occurrence and may have been associated with coral reef biological activity. Mixing is particularly important when considering dissolved oxygen concentrations, which is known to reach critical levels for fish in coastal waters elsewhere in Queensland.
3. All three sites showed elevated particulate nitrogen (PN), particulate phosphorus (PP) and Chlorophyll-a concentrations that exceeded guideline values on several sampling occasions. This pattern continues and requires further discussion with relevant authorities to address the source of nutrient supply.
4. 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 the Great Barrier Reef coastal environments, where 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) can be examined, providing more detailed insight into the rainfall and water quality relationships in 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 the two coastal inshore sites but differed at the offshore coral reef site Holbourne Island. The sheltered island is known for its clear water, with Secchi disc depths of up to 20 m during the reporting period, and PAR here is amongst the highest across all NQBP water quality monitoring sites in Queensland. 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 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 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 rainfall during the current program was above median values, wet season rainfall was the lowest in some years. The distribution of rainfall during the season is 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 remote region of northern Australia.

5 References

Brodie, J., Grech, A., Pressey, B., Day, J., Dale, A., Morrison, T., & Wenger, A. (2019). The future of the Great Barrier Reef: the water quality imperative. In *Coasts and Estuaries* (pp. 477-499). Elsevier.

Cartwright, P. J., Iles, J. A., Mattone, C., O'Callaghan, M., & Waltham, N. (2022). *Turbidity (NTU) to Suspended Sediment Concentration (SSC) Conversion Protocol* (Report 22/35). Retrieved from Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER): https://www.tropwater.com/wp-content/uploads/2022/07/22-35-Turbidity-NTU-to-Suspended-Sediment-Concentration-SSC-Conversion-Protocol_Technical-Report.pdf

Chartrand, K. M., Ralph, P. J., Petrou, K., & Rasheed, M. A. (2012). Development of a light-based seagrass management approach for the Gladstone Western Basin Dredging Program. *Fisheries Queensland, Cairns*, 126.

Erftemeijer, P. L. A., B. Riegl, B. W. Hoeksema, Todd, P. A**.** (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin 64*, 1737-1765.

Fabricius, K. E., G. De'ath, C. Humphrey, I. Zagorskis, Schaffelke, B. (2013) Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. *Estuarine, Coastal and Shelf Science 116*, 57-65.

Great Barrier Reef Marine Park Authority (2010). *Water quality guidelines for the Great Barrier Reef Marine Park*. Great Barrier Reef Marine Park Authority Retrieved from http://hdl.handle.net/11017/432

Great Barrier Reef Marine Park Authority (2014) *Great Barrier Reef Outlook Report 2014*. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Jones, R., Pineda, M.-C., Luter, H. M., Fisher, R., Francis, D., Klonowski, W., & Slivkoff, M. (2021). Underwater Light Characteristics of Turbid Coral Reefs of the Inner Central Great Barrier Reef. *Frontiers in Marine Science, 8*. doi:10.3389/fmars.2021.727206.

Kirk, J. T. O. (1985). Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. *Hydrobiologia, 125*, 195-208.

NOAA. (2020). Manual for Real_Time Oceanographic Data Quality COntrol Flags (version 1.2). https://repository.library.noaa.gov/view/noaa/24982

Queensland Government. (2018). Reef 2050 Water Quality Improvement Plan: 2017–2022. Retrieved from https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0017/46115/reef-2050-water-quality-improvement-plan-2017-22.pdf

Reef Water Quality Protection Plan Secretariat (2013b) *Reef Water Quality Protection Plan. Securing the Health and Resilience of the Great Barrier Reef World Heritage Area and Adjacent Catchments*. Reef Water Quality Protection Plan Secretariat, Brisbane, Australia.

Schaffelke, B., Carleton, J., Skuza, M., Zagorskis, I., & Furnas, M. J. (2012). Water quality in the inshore Great Barrier Reef lagoon: Implications for long-term monitoring and management. *Mar Pollut Bull, 65*(4-9), 249-260. doi:10.1016/j.marpolbul.2011.10.031

Sofonia, J. J., Unsworth, R. K. F. (2010) Development of water quality thresholds during dredging for the protection of benthic primary producer habitats. *Journal of Environmental Monitoring 12*, 159-163.

Waterhouse, J., Schaffelke, B., Bartley, R., Eberhard, R., Brodie, J., Star, M., . . . Kroon, F. (2017). *2017 scientific consensus statement: Land use impacts on Great Barrier Reef water quality and ecosystem condition*. Queensland Government Retrieved from https://www.reefplan.qld.gov.au/__data/assets/pdf_file/0029/45992/2017-scientific-consensus-statement-summary.pdf

Appendix 1. Passive sampler results

A1.1 ED-PPCP mass per sample

Table A 1. Results (mass per sampler) from ED-PPCP sampler deployed at Euri Creek in the early(November/December) and late (April) wet season of 2021-22.

ED PPCP Mass per Sampler (ng)				
Site Name		AP-AMB1 Euri Creek		
Deployment Date		17/11/2021	30/03/2022	
Retrieval Date		13/12/2021	4/05/2022	
Days Deployed		26	35	
Flow Rate (cm/s)		40.7	28.5	
Sample Name	LOR	TRP1121_ED_2	TRP0322_ED_2	TRP0322_ED_2_DUP
2,4,5-T	1.00	<1.00	<1.00	<1.00
2,4-D	5.00	<5.00	<5.00	<5.00
3,4 Dichloroaniline	1.00	<1.00	<1.00	<1.00
Acesulfame	1.00	<1.00	<1.00	<1.00
Ametryn	5.00	<5.00	<5.00	<5.00
Ametryn hydroxy	1.00	<1.00	<1.00	<1.00
Atenolol	1.00	<1.00	<1.00	<1.00
Atorvastatin	1.00	<1.00	<1.00	<1.00
Atrazine	1.00	<1.00	1.87	<1.00
Atrazine desethyl	1.00	<1.00	<1.00	<1.00
Atrazine desisopropyl	1.00	<1.00	<1.00	<1.00
Bendiocarb	0.500	<0.500	<0.500	<0.500
Bromacil	1.00	<1.00	<1.00	<1.00
Bromoxynil	1.00	<1.00	<1.00	<1.00
Caffeine	*33.9	<33.9	<33.9	<33.9
Carbamazepine	1.00	<1.00	<1.00	<1.00
Carbaryl	0.500	<0.500	<0.500	<0.500
Carbendazim	1.00	<1.00	<1.00	<1.00
Codeine	1.00	<1.00	<1.00	<1.00
Cyproconazole	1.00	<1.00	<1.00	<1.00
DCPMU	0.100	<0.100	<0.100	<0.100
DCPU	0.500	<0.500	<0.500	<0.500
DEET	*52.3	<52.3	<52.3	<52.3
Diazinon	0.100	<0.100	<0.100	<0.100
Diclofenac	0.100	<0.100	<0.100	<0.100
Difenoconazole	5.00	<5.00	<5.00	<5.00
Diketonitrile	0.100	<0.100	0.320	<0.100
Diuron	1.00	<1.00	1.86	1.72
Fipronil	0.500	<0.500	<0.500	<0.500
Fluazifop	0.100	<0.100	<0.100	<0.100
Fluazinam	50.0	<50.0	<50.0	<50.0
Fluometuron	1.00	<1.00	<1.00	<1.00
Fluroxypyr	1.00	<1.00	<1.00	<1.00
Gabapentin	1.00	<1.00	<1.00	<1.00
Haloxyfop	1.00	<1.00	<1.00	<1.00
Hexazinone	1.00	<1.00	1.49	1.47
Hydrochlorthiazide	1.00	<1.00	<1.00	<1.00
Imazapic	1.00	<1.00	<1.00	<1.00
Imazapyr	1.50	<1.50	<1.50	<1.50
Imazethapyr	1.00	<1.00	<1.00	<1.00
Imidacloprid	1.00	<1.00	<1.00	<1.00
Iopromide	0.500	<0.500	<0.500	<0.500
Malathion	1.00	<1.00	<1.00	<1.00
MCPA	5.00	<5.00	<5.00	<5.00
Metalaxyl	0.100	<0.100	<0.100	<0.100
Methidathion	5.00	<5.00	<5.00	<5.00
Methomyl	1.00	<1.00	<1.00	<1.00
Metolachlor (S+R)	1.00	<1.00	<1.00	<1.00
Metribuzin	1.00	<1.00	<1.00	<1.00
Metsulfuron methyl	1.00	<1.00	<1.00	<1.00
Naproxen	1.00	<1.00	<1.00	<1.00
Oryzalin	0.700	<0.700	<0.700	<0.700
Oxazepam	0.500	<0.500	<0.500	<0.500
Paracetamol	1.00	<1.00	<1.00	<1.00
Paraxanthine	*3.68	7.61	<3.68	<3.68
Pencycuron	10.0	<10.0	<10.0	<10.0
Pendimethalin	5.00	<5.00	<5.00	<5.00
Picloram	5.00	<5.00	<5.00	<5.00
Prometryn	1.00	<1.00	<1.00	<1.00
Propachlor	0.800	<0.800	<0.800	<0.800
Propazine	1.00	<1.00	<1.00	<1.00
Propiconazole	1.00	<1.00	<1.00	<1.00
Propoxur	1.00	<1.00	<1.00	<1.00
Pyrimethanil	0.500	<0.500	<0.500	<0.500
Salicylic acid	35.0	<35.0	<35.0	<35.0
Simazine	1.00	<1.00	<1.00	<1.00
Simazine hydroxy	1.00	<1.00	<1.00	<1.00
Sulfadiazine	0.500	<0.500	<0.500	<0.500
Sulfamethoxazole	0.100	<0.100	<0.100	<0.100
Sulfoxaflor	0.500	<0.500	<0.500	<0.500
Tadalafil	0.100	<0.100	<0.100	<0.100
Tebuconazole	1.00	<1.00	<1.00	<1.00
Tebuthiuron	1.00	<1.00	1.12	1.10
Temazepam	1.00	<1.00	<1.00	<1.00
Terbuthylazine	1.00	<1.00	<1.00	<1.00
Terbuthylazine desethyl	1.00	<1.00	<1.00	<1.00
Thiamethoxam	0.700	<0.700	<0.700	<0.700
Triclopyr	5.00	<5.00	<5.00	<5.00
Trimethoprim	0.100	<0.100	<0.100	<0.100
Venlafaxine	1.00	<1.00	<1.00	<1.00
Verapamil	0.100	<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 average blank value plus three times the standard deviation

A1.2 ED-PPCP water concentration

Table A 2. Results (water concentration) from ED-PPCP sampler deployed at Euri Creek in the early(November/December) and late (April) wet season of 2021-22.

Atrazine Relative Rs	(Multiple Items)

ED PPCP Water Concentration (ng/L)			
Site Name	AP-AMB1 Euri Creek		
Deployment Date	17/11/2021	30/03/2022	
Retrieval Date	13/12/2021	4/05/2022	
Days Deployed	26	35	
Flow Rate (cm/s)	40.7	28.5	
Sample Name	TRP1121_ED_2	TRP0322_ED_2	TRP0322_ED_2_DUP
2,4-D	<0.990	<0.810	<0.810
Ametryn	<1.79	<1.46	<1.46
Atrazine	<0.240	0.360	<0.190
Atrazine desethyl	<0.280	<0.230	<0.230
Bromacil	<0.160	<0.130	<0.130
Caffeine	<4.70	<3.84	<3.84
Carbamazepine	<0.150	<0.120	<0.120
Carbendazim	<0.280	<0.230	<0.230
Codeine	<0.300	<0.240	<0.240
DEET	<9.08	<7.41	<7.41
Diazinon	<0.050	<0.040	<0.040
Diclofenac	<0.040	<0.030	<0.030
Diuron	<0.280	0.430	0.400
Fipronil	<0.100	<0.080	<0.080
Fluometuron	<0.170	<0.140	<0.140
Haloxyfop	<0.120	<0.100	<0.100
Hexazinone	<0.230	0.280	0.280
Hydrochlorthiazide	<0.220	<0.180	<0.180
MCPA	<0.720	<0.590	<0.590
Metolachlor (S+R)	<0.230	<0.190	<0.190
Prometryn	<0.390	<0.320	<0.320
Propoxur	<0.190	<0.160	<0.160
Simazine	<0.160	<0.130	<0.130
Sulfamethoxazole	<0.030	<0.030	<0.030
Tebuthiuron	<0.180	0.170	0.160
Terbuthylazine	<0.220	<0.180	<0.180
Triclopyr	<0.600	<0.490	<0.490
Trimethoprim	<0.100	<0.080	<0.080

A1.3 PE-PFAS mass per sampler

Table A 3. Results (mass per sampler) of the PE-PFAS sampler deployed at Euri Creek in the early (November/December) and late (April/May) wet season of 2021-22.

PFAS Category	Analyte		LOR						
		Site Name		Euri Creek					
		Deployed Date		17/11/2021			########		
		Retrieved Date		13/12/2021			04/05/2022		
		Days Deployed		26			35		
		Site Code		AP-AMB1			AP-AMB1		
		Sample Name		TRP1121_PE_2A	121_PE_2_	121_PE_2_	P0322_PE_	)322_PE_2	322_PE_2_DUP2
		QAEHS Acronym							
Perfluoroalkyl Carboxylic Acids (PFCAs)	Perfluorobutanoic acid	PFBA	*0.760	<0.760	<0.760	<0.760	<0.760	<0.760	<0.760
	Perfluoropentanoic acid	PFPeA	0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorohexanoic acid	PFHxA	*0.160	<0.160	<0.160	<0.160	<0.160	<0.160	<0.160
	Perfluoroheptanoic acid	PFHpA	*0.430	<0.430	<0.430	<0.430	<0.430	<0.430	<0.430
	Perfluorooctanoic acid	PFOA	*0.400	<0.400	<0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorononanoic acid	PFNA	*0.170	<0.170	<0.170	<0.170	<0.170	<0.170	<0.170
	Perfluorodecanoic acid	PFDA	*3.69	<3.69	<3.69	<3.69	<3.69	<3.69	<3.69
	Perfluoroundecanoic acid	PFUnDA	0.400	<0.400	<0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorododecanoic acid	PFDoDA	0.400	<0.400	<0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorotridecanoic acid	PFTriDA	0.400	<0.400	<0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorotetradecanoic acid	PFTeDA	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
	Perfluorohexadecanoic acid	PFHxDA	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
	Perfluorooctadecanoic acid	PFODA	1.00	<1.00	<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	<0.100	<0.100
	Perfluoropentane sulfonate	PFPeS	0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorohexane sulfonate	PFHxS	*0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
	Perfluoroheptane sulfonate	PFHpS	0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorooctane sulfonate	PFOS	*0.290	<0.290	<0.290	<0.290	<0.290	<0.290	<0.290
	Perfluorononane sulfonate	PFNS	0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
	Perfluorodecane sulfonate	PFDS	0.400	<0.400	<0.400	<0.400	<0.400	<0.400	<0.400
	Perfluorododecane sulfonate	PFDoDS	1.00	<1.00	<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	<0.100	<0.100
Perfluoroalkane Sulfonamides	Perfluorooctane sulfonamide	FOSA	0.400	<0.400	<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	<0.400	<0.400
	N-ethyl perfluorooctane sulfonamide	N-EtFOSA	0.400	<0.400	<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	<0.400	<0.400
	N-ethyl perfluorooctane sulfonamide ethanol	N-EtFOSE	0.400	<0.400	<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	<0.400	<0.400
	N-ethyl-fluorooctane sulfonamidoacetic acid	N-EtFOSAA	0.400	<0.400	<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	<0.400	<0.400
Fluorotelomer Sulfonates	4:2-Fluorotelomer sulfonate	4:2 FTS	0.100	<0.100	<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	<0.100	<0.100
	8:2-Fluorotelomer sulfonate	8:2 FTS	0.400	<0.400	<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	<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 Euri Creek in the early (November/December) and late (April/May) wet season of 2021-22.

PFAS Category	Analyte							
		Site Name	Euri Creek					
		Deployed Da	########			########		
		Retrieved Da	13/12/2021			04/05/2022		
		Days Deploy	26			35		
		Site Code	AP-AMB1			AP-AMB1		
		Sample Nam	P1121_PE_	121_PE_2_	121_PE_2_	P0322_PE_	)322_PE_2	322_PE_2_DUP2
		\EHS Acronym						
Perfluoroalkyl Carboxylic Acids (PFCAs)	Perfluorobutanoic acid	PFBA	<5.34	<5.34	<5.34	<3.97	<3.97	<3.97
	Perfluoropentanoic acid	PFPeA	<0.870	<0.870	<0.870	<0.646	<0.646	<0.646
	Perfluorohexanoic acid	PFHxA	<0.067	<0.067	<0.067	<0.050	<0.050	<0.050
	Perfluoroheptanoic acid	PFHpA	<0.740	<0.740	<0.740	<0.549	<0.549	<0.549
	Perfluorooctanoic acid	PFOA	<0.861	<0.861	<0.861	<0.640	<0.640	<0.640
	Perfluorononanoic acid	PFNA	<0.283	<0.283	<0.283	<0.210	<0.210	<0.210
	Perfluorodecanoic acid	PFDA	<4.62	<4.62	<4.62	<3.43	<3.43	<3.43
Perfluoroalkane Sulfonates	Perfluorobutane sulfonate	PFBS	<0.130	<0.130	<0.130	<0.096	<0.096	<0.096
	Perfluorohexane sulfonate	PFHxS	<0.339	<0.339	<0.339	<0.252	<0.252	<0.252
	Perfluorooctane sulfonate	PFOS	<0.477	<0.477	<0.477	<0.355	<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 A1-3 show the logger data from this report with the QC flags applied.

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 technical report with detailed descriptions of the quality control procedures as applied to the data in this project will be published in early 2023.

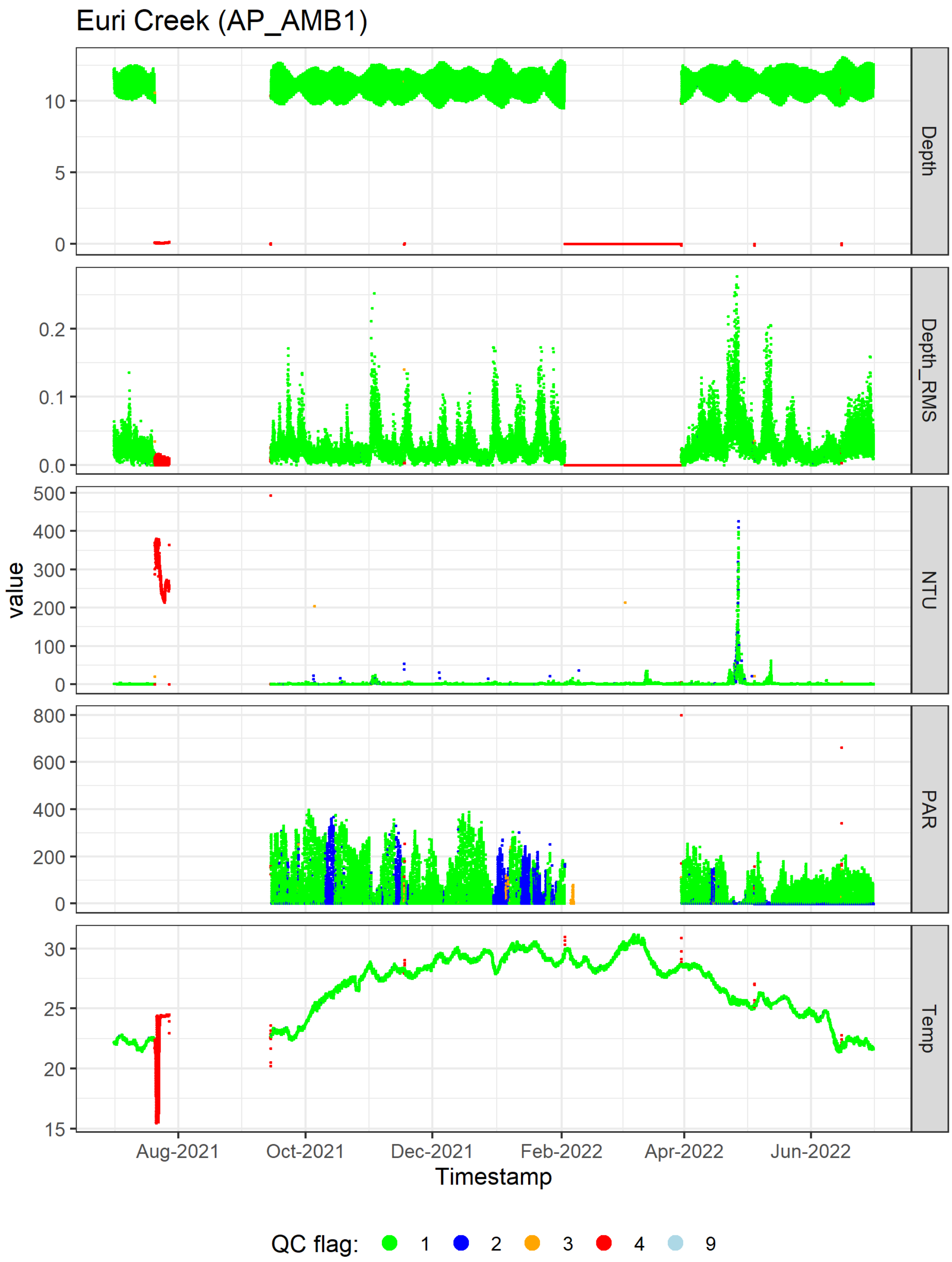

Figure A 1. Raw data collected at Euri Creek with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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

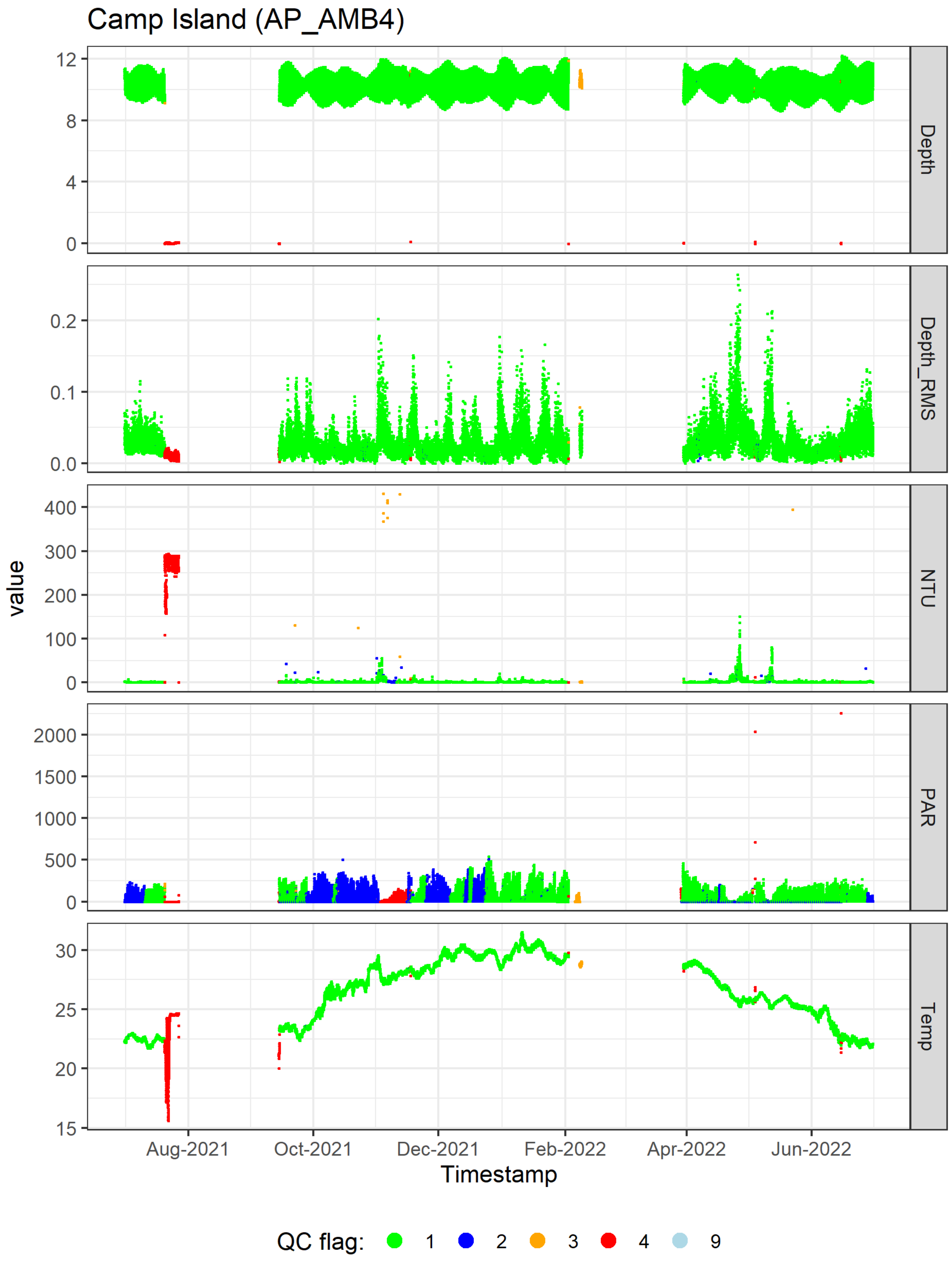

Figure A 2. Raw data collected at Camp Island with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing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

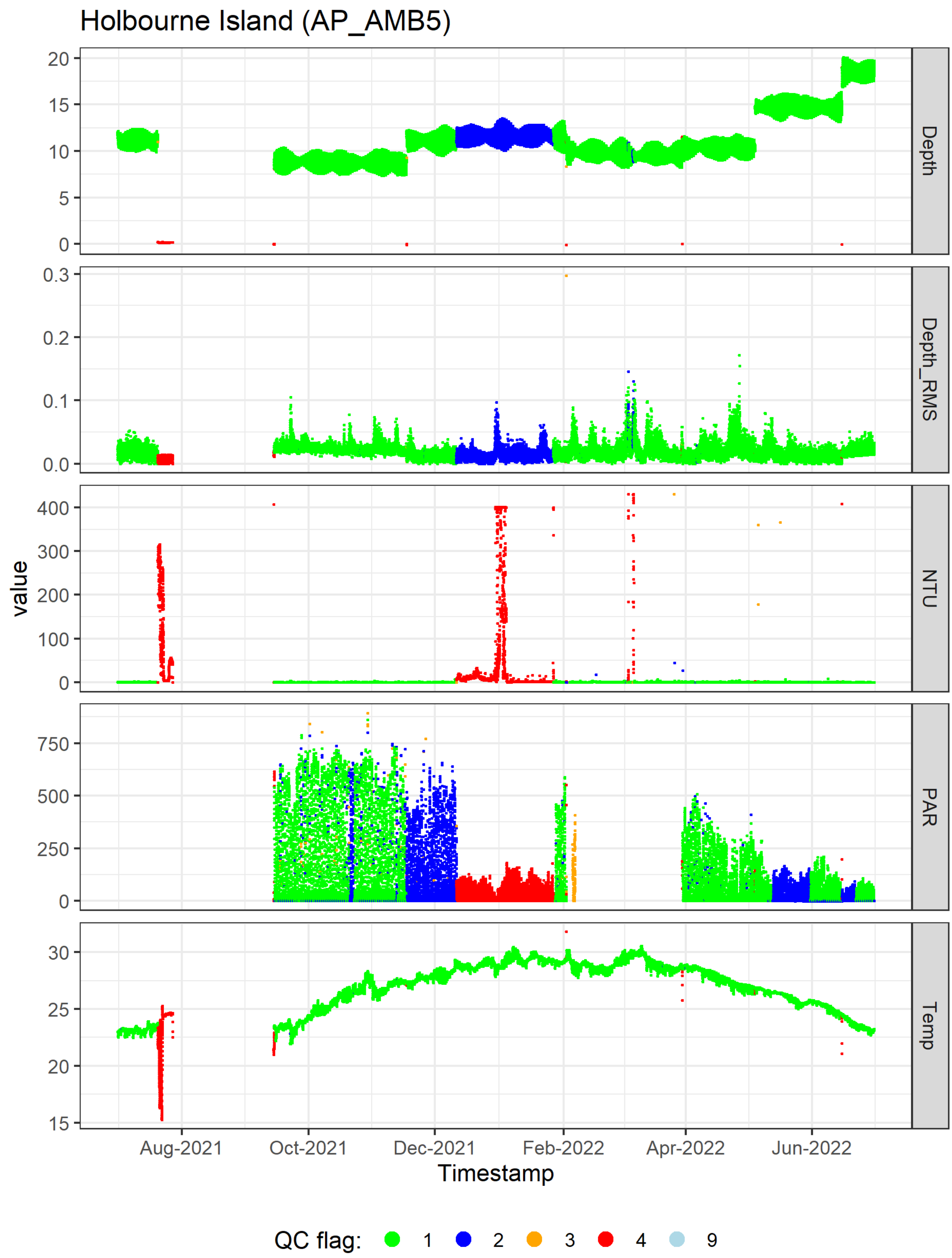

Figure A 3. Raw data collected at Holbourne Island with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) =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