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

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A Report for North Queensland Bulk Ports Corporation

Report No. 22/61

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The report may be cited as:
Waltham NJ, Iles, JA, Cartwright, P. 2022, 'Port of Weipa Ambient Marine Water Quality Monitoring Program: Annual Report 2021-2022', Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 22/61, James Cook University, Townsville, pp. 36.

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Executive Summary

Background

1. North Queensland Bulk Ports (NQBP) has implemented an ambient marine water quality monitoring program in the region surrounding the Port of Weipa. The program encompasses 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 Weipa region.
2. In September 2021, a major investment by NQBP allowed the roll out of new state-of-the-art water quality loggers across the region that will allow more reliable data logging and a broader range of data acquisition, with 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 the third wettest year in Weipa (2448 mm) since the Bureau of Meteorology data began here in 1992.
2. There was a large rainfall and stream discharge event in early February caused by a low-pressure trough that crossed through the Gulf of Carpentaria, and brought wave heights up to 3.7 m. The largest wave event of the year however was on December 29, 2021, when Cyclone Seth crossed the Gulf south of Weipa leading to wave heights over 5m in Albatross Bay.

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 and a halocline, where surface waters were brackish water, was present after heavy rainfall events.
3. Particulate nitrogen (PN) and particulate phosphorus (PP) concentrations exceeded guideline values on many sampling occasions and there was an anomalously high nitrogen event in March 2022.
4. Chlorophyll-*a* concentrations exceeded guideline values during all surveys at all 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 on both sampling occasions. 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.

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 highest in the harbour site South Channel compared to both estuarine sites, with Leithen Point showing the lowest light levels during the entire year.
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 in this remote region of northern Australia.

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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 Weipa. 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, 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 seagrass and other coastal habitats. 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 is a major concern for the future of coastal and marine ecosystems in Queensland (Brodie et al., 2019). While major impact events such as cyclones and marine heatwaves generally cause the most destruction to the coastal habitats, water quality is the primary determinant for both resilience to, and recovery of ecosystems in the face of these events (Lam et al., 2018; McNeil et al., 2019). Water quality risks to coastal ecosystems include an increased load of fine sediments (Erftemeijer et al., 2012), nutrients (nitrogen and phosphorous), and pesticides/ herbicides that originate from diffuse agricultural and industrial sources (Waterhouse et al., 2017; Dennison et. al., 1993). 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 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 coastal ecosystems 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 that are applicable along all Queensland coasts.

1.2 Program objectives

The goal of the program is to characterise the ambient marine water quality monitoring within the region within and adjacent to Port of Weipa. This report provides a review and analysis of data collected between 01/07/2021 and 30/06/2022. These data are part of a longer-term commitment to monitor and characterise receiving water quality conditions, to support future planned asset management and protection of this coastal port. 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 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 Weipa is situated on the western side of Cape York Peninsula in northern Queensland (Figure 2.1). It is located within the township of Weipa, where the Embley, Mission and Pine River's converge and discharge into the Gulf of Carpentaria. The port has a series of operational and associated loading/unloading facilities. The port is operated by North Queensland Bulk Ports Corporation (NQBP). Along with other NQBP ports in Queensland, Port of Weipa requires routine maintenance dredging to maintain declared navigational depths within the swing basin and berth areas, departure path and aprons. Any dredging activity necessary in the operating ports in the region are undertaken in accordance with Commonwealth and State approvals.

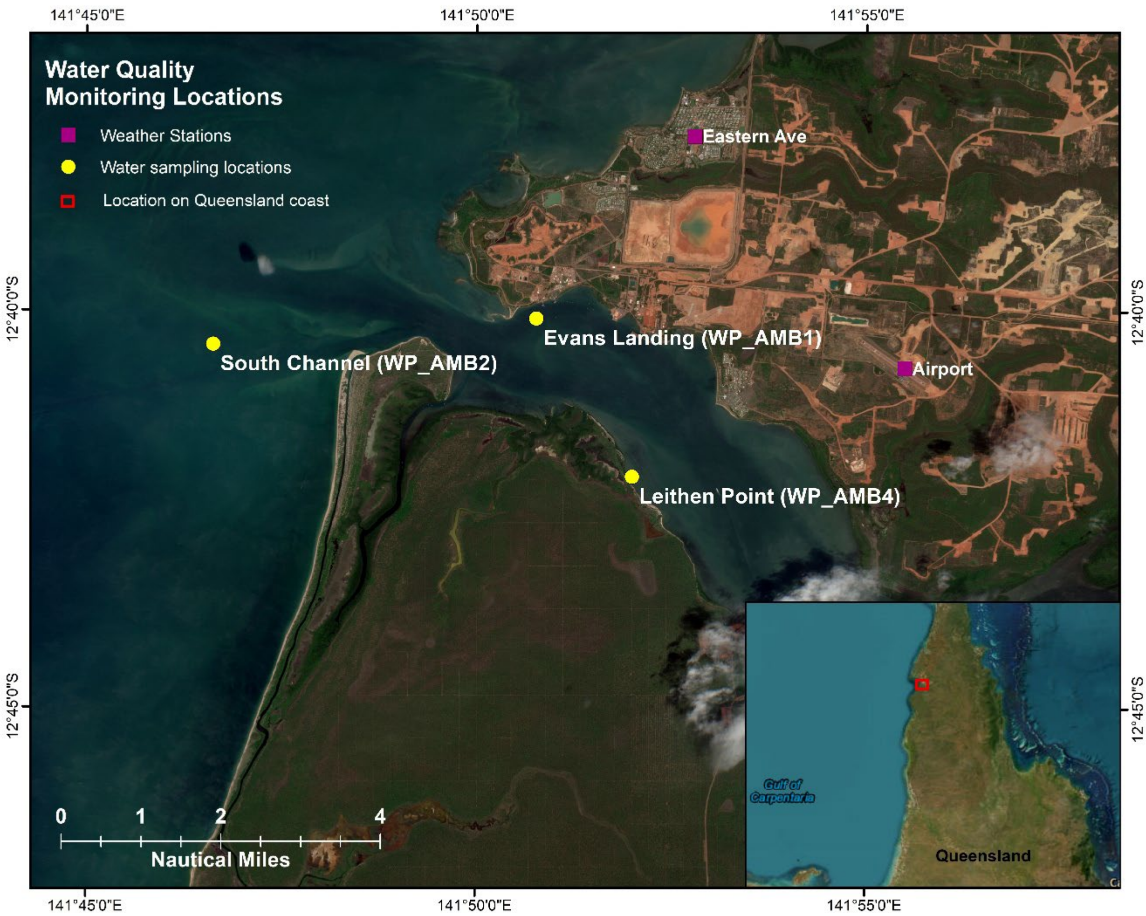

Figure 2-1. Map of Weipa showing location of water quality monitoring sites (yellow circles) and meteorological stations (purple squares), utilised in the 2021-2022 reporting period.

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 Albatross Bay Wave Buoy located 6 nautical miles offshore from South Channel (WP_AMB2, Figure 2-1).

2.3 Monitoring and sampling design

The Weipa region has three active ambient marine water quality monitoring sites (Figure 2.1, Table 2.1). Two sites, Evans Landing (WP_AMB1) and Leithen Point (WP_AMB4) are located in the Embley River estuary, with another site, South Channel (WP_AMB2) located in Albatross Bay to the south of the river channel. 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 2-1. Site locations and main features

Site name	Site code	Latitude	Longitude	Depth (m)	Site features
Evans Landing	WP_AMB1	-19.908817	148.138047	5	Seagrass
South Channel	WP_AMB2	-19.842807	147.904126	4.2	Seagrass
Leithen Point	WP_AMB4	-19.724934	148.354198	4.6	Seagrass

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 2-2. Field dates for water sampling, logger maintenance, metal detection and pesticide sampling at the three monitoring locations.

Date	Water sampling	Logger maintenance	Metals sampling	Pesticides/ herbicides
2021-07-05	Yes	Yes	No	No
2021-08-21	Yes	Yes	Yes	No
2021-10-26	Yes	Yes	No	No
2022-01-04	Yes	Yes	Yes	Yes
2022-03-03	Yes	Yes	No	No
2022-04-13	Yes	Yes	No	No
2022-06-16	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 January 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). Testing for pesticides/herbicides (Low LOR suite (EP234(A-I)) including diuron, ametryn, atrazine, and terbutryn was conducted during the wet season (Table 2-5). Note that pesticides are suspected to be in low concentrations during periods of low rainfall runoff, and only detectable following rainfall, therefore, no dry season testing took place during the reporting period.

Table 2-3. Water quality parameters that were analysed using water samples collected at three locations in the Weipa region, 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 analysed using water samples collected at three locations in the Weipa region.

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/ pesticides and herbicides that were analysed using water samples collected at three locations in the Weipa region, and the methods and reporting limits of the laboratory analysis.

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}

Pesticides/herbicides			
	Organophosphate pesticides	In house LC/MS method: EP234A	0.0002-0.001 µg L^{-1}
	Thiocarbamates and Carbamates - Thiobencarb	In house LC/MS method: EP234B	0.0002 µg L^{-1}
	Dinitroanilines - Pendimethalin	In house LC/MS method: EP234C	0.001 µg L^{-1}
	Triazinone Herbicides - Hexazinone	In house LC/MS method: EP234D	0.0002 µg L^{-1}
	Conazole and Aminopyrimidine Fungicides - Propiconazole, Hexaconazole, Difenoconazole, Flusilazole, Penconazole	In house LC/MS method: EP234E	0.0002 µg L^{-1}
	Phenylurea Thizdiazolurea Uracil and Sulfonylurea Herbicides - Diuron, Ametryn, Atrazine, Cyanazine, Prometryn, Propazine, Simazine, Terbuthylazine, Terbutryn	In house LC/MS method: EP234F	0.0002 µg L^{-1}

2.5 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 2-2. 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 2-6. 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 late October 2021, there is a period of approximately four 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 Weipa 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 1.

3 Results and Discussion

3.1 Rainfall and river flows

Daily rainfall for the Weipa region is shown in Figure 3.1. The first rainfall greater than 5 mm for the water year occurred on 23rd October 2021, with the rainfall onset occurring on 19th 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 2158.2 mm, while total rainfall for the water year was 2448 mm (Figure 3.2). This is higher than the median wet season rainfall calculated for wet seasons since 1992, and the total annual rainfall was in the top ten percentile of rainfall recorded over that same 30-year period.

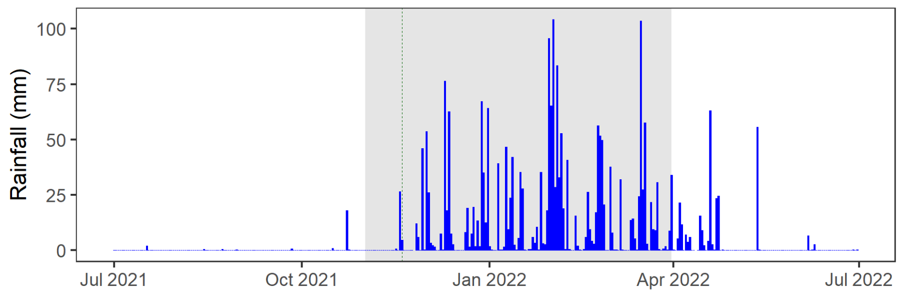

Figure 3-1. Rainfall recorded at Weipa Aero (station 027045) for the 2021-2022 water year. The nominal wet season period is shaded grey. Green vertical dash indicates northern rainfall onset. Data source: http://www.bom.gov.au/climate/data/

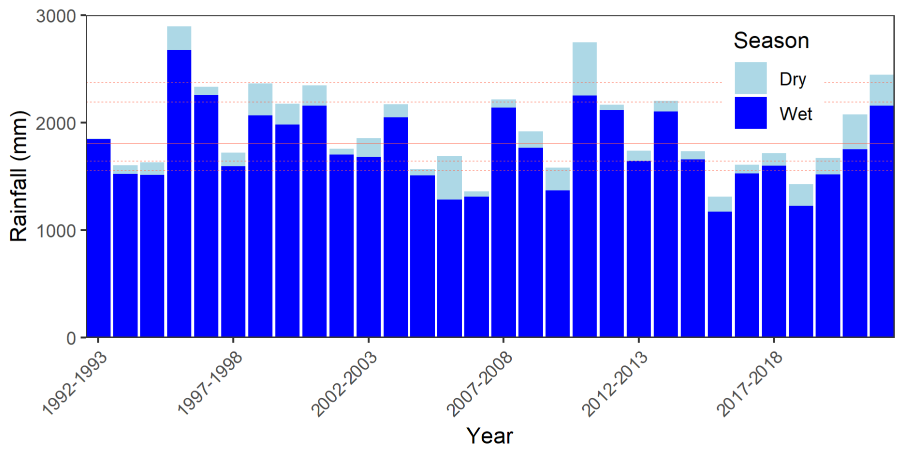

Figure 3-2. Annual rainfall by water year for the Weipa region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Daily rainfall data was obtained from the Weipa Aero (station 027045). Data source: http://www.bom.gov.au/climate/data/

The only local river gauging station near to Weipa is on the Watson River, which is located ~75 km south and does not discharge into the Mission River system where the Port is located. Therefore, although Watson River discharge has been used throughout this report to provide context for Port water quality conditions, results regarding the influence of water discharge on water quality variability should be interpreted with caution.

The hydrograph for Watson River shows onset of stream discharge on 08/12/2021 with a small pulse. This was followed by steady flows from the 29/12/2021 that increased to heavy flows with a notable discharge event in early February from 02/02/2022 (Figure 3.3). Total discharge for the 2021-2022 water year was 519.6 GL.

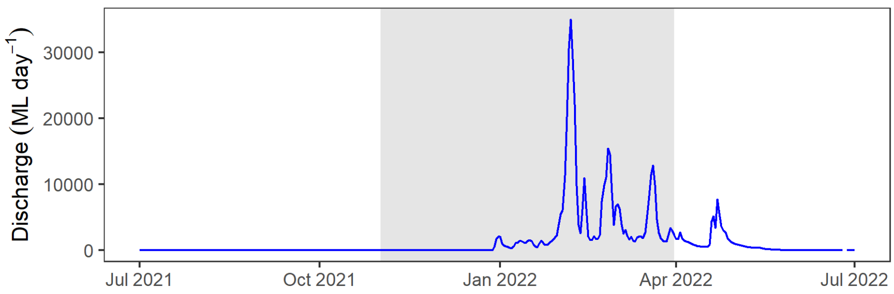

Figure 3-3. Stream discharge (GL d^{-1}) from the Watson River (station 923001A) during the 2021-2022 reporting period. The nominal wet season period is shaded grey. Data source: https://water-monitoring.information.qld.gov.au/

3.2 Oceanographic conditions

Waves detected at Weipa were predominantly 0.3 to 0.8 m in height and from a south-westerly direction (Figure 3-4). Austral Summer showed the highest wave activity which was primarily from a westerly direction while Austral Winter showed the next highest wave activity but with a shift towards south westerly swells. (Figure 3-5). There was a very high wave event associated with a low that crossed directly over Weipa on 29 December 2021, leading to wave heights over 5 metres.

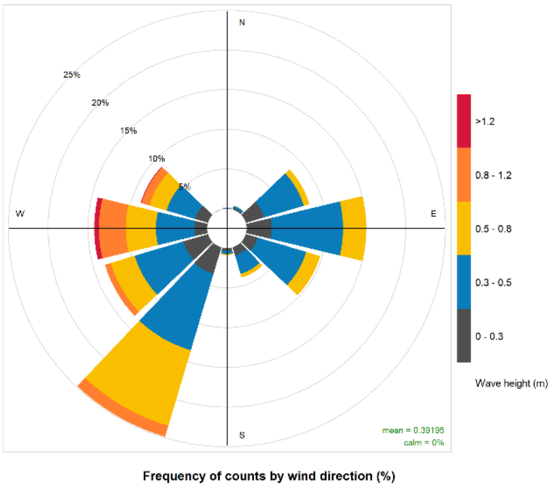

Figure 3-4. Frequency of counts by wave direction (%), and significant wave height (m) at the Weipa wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

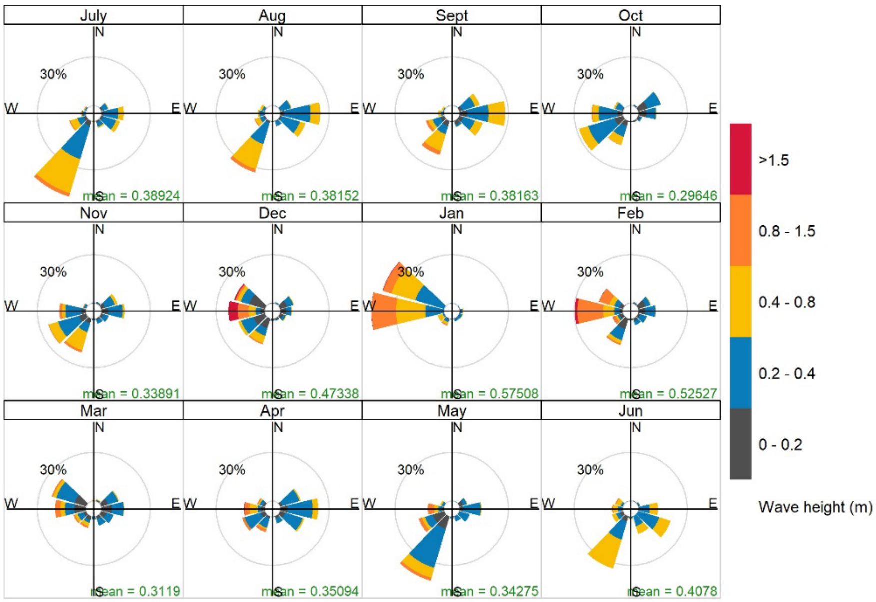

Figure 3-5. Frequency of counts by wave direction (%), and significant wave height (m) at the Weipa wave buoy station between July 1, 2021, and June 30, 2022. Data source: https://www.qld.gov.au/environment/coasts-waterways/beach/monitoring

3.3 Water quality

3.3.1 Physiochemical

The water column at estuarine sites Evans Landing and Leithen Point was often stratified, with dissolved oxygen (DO) saturation higher in the upper water column and decreasing with depth (Figure 3-6). In contrast, South Channel, situated in the harbour, was more well mixed, with consistent DO throughout the water column. Electrical conductivity (EC) was highly variable at the three locations ranging from 26.7 to 56.9 mS cm^{-1} with the highest salinity found in January and July, and the lowest salinity in November and May (Figure 3-7). A halocline was present during March and May 2022, following periods of high rainfall, where the top of the water column was fresher than the middle and bottom waters and salinity at all depths was the lowest of the year. Water temperature ranged between 27.0 and 30.8 °C (Figure 3-8). There is only a mild seasonal effect on water temperatures in the region, with high water temperatures observed during surveys in the summer months, and slightly cooler 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 7.8 and 8.4 across all sites throughout the year (Figure 3-9).

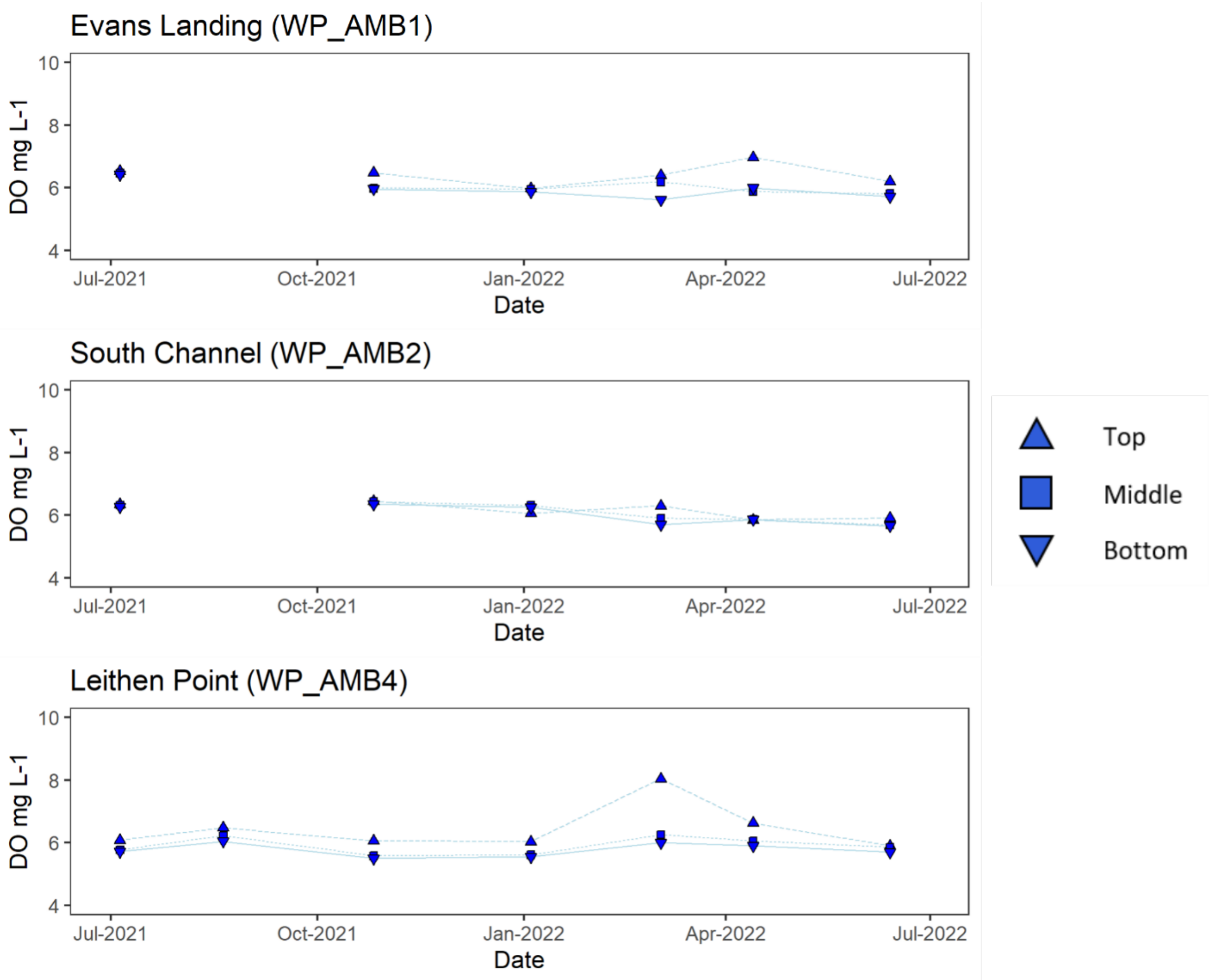

Figure 3-6. Dissolved oxygen concentration (mg/L) at three water quality monitoring sites in the Weipa region showing results for the top, middle, and bottom water. Missing data at two sites in August 2021 was due to instrument failure.

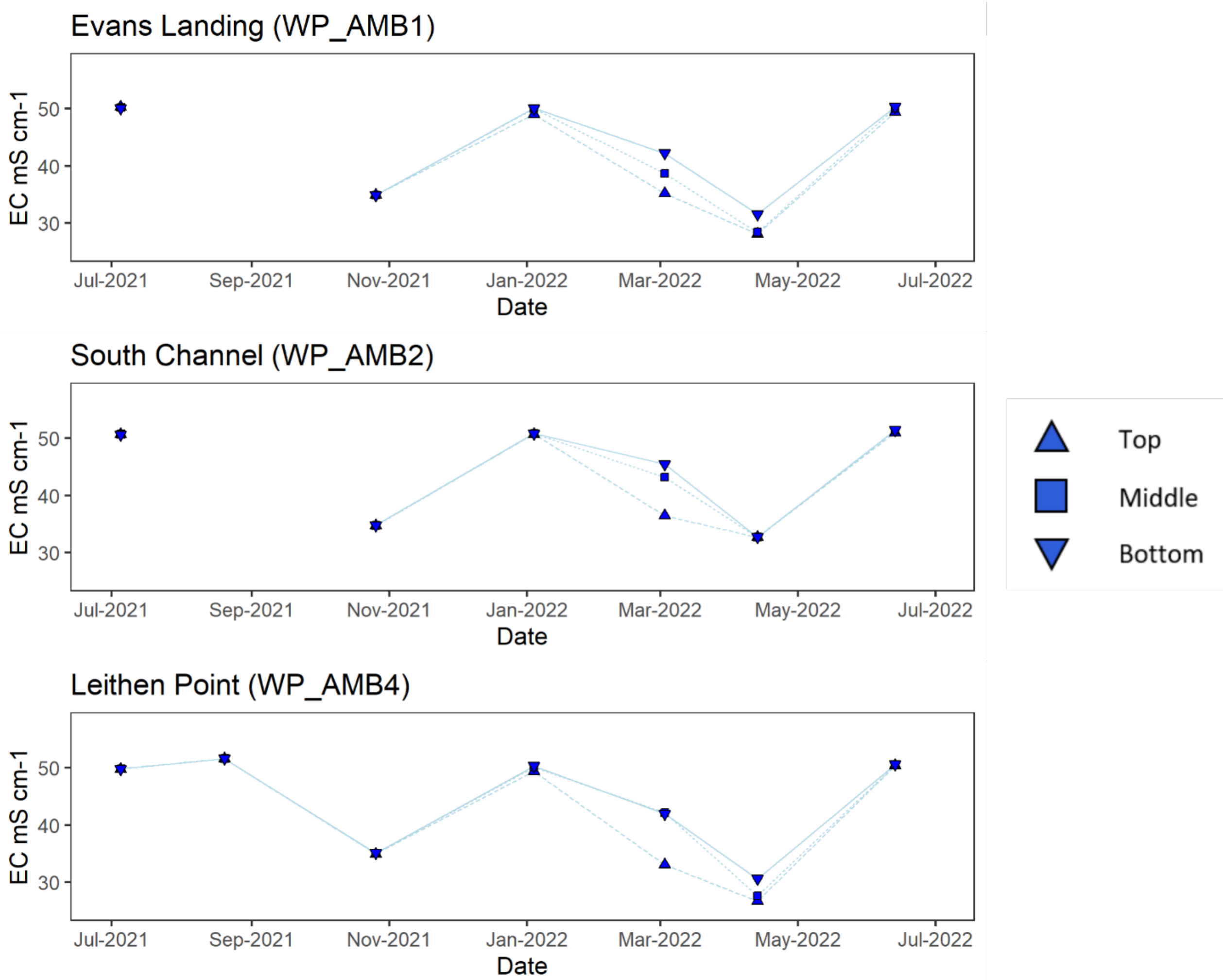

Figure 3-7. Electrical conductivity recorded at three depths at the three water quality sites in the Weipa region showing results for the top, middle, and bottom water. Missing data at two sites in August 2021 was due to instrument failure.

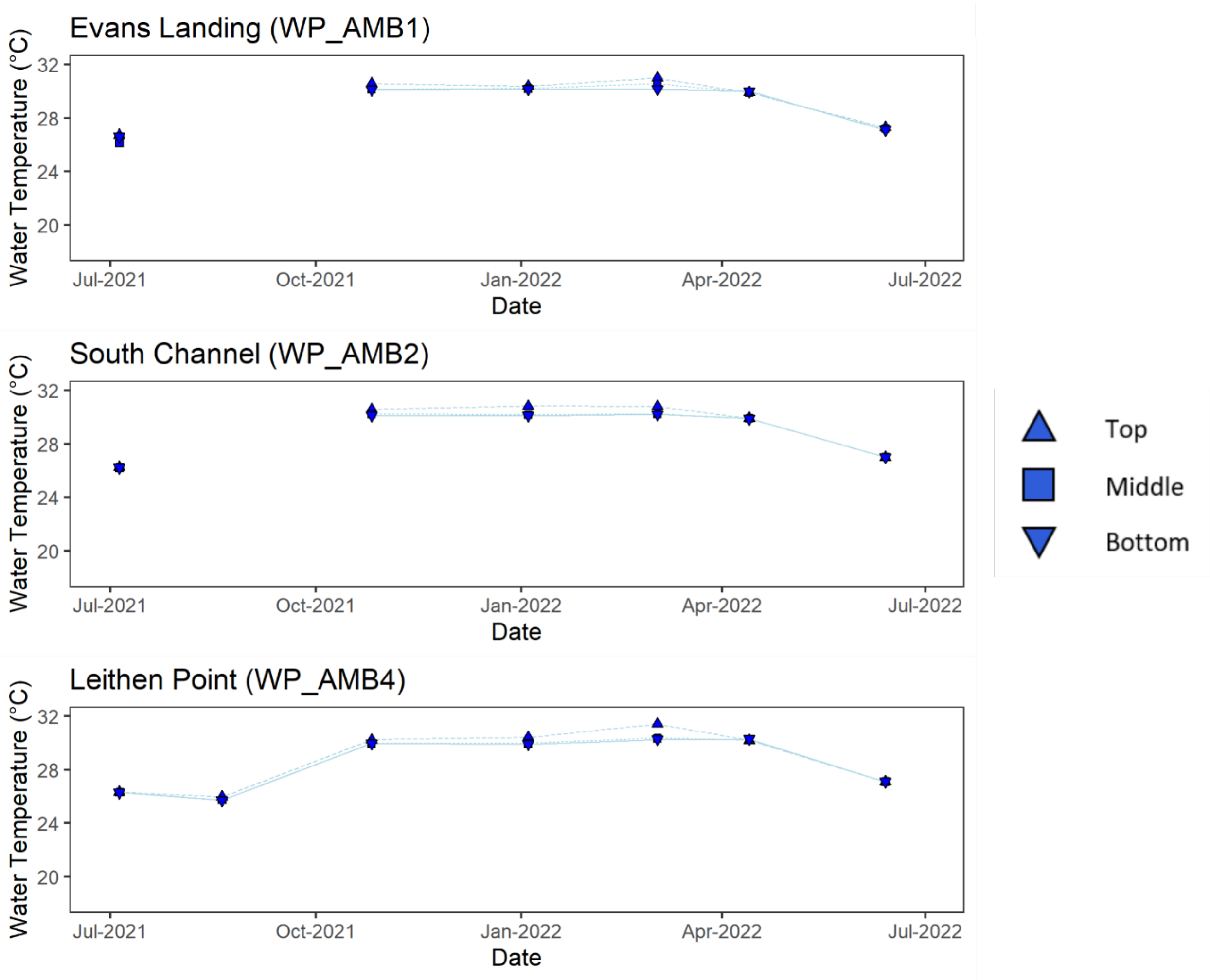

Figure 3-8. Water temperature recorded at three depths in the Weipa region showing results for the top, middle, and bottom water. Missing data at two sites in August 2021 was due to instrument failure.

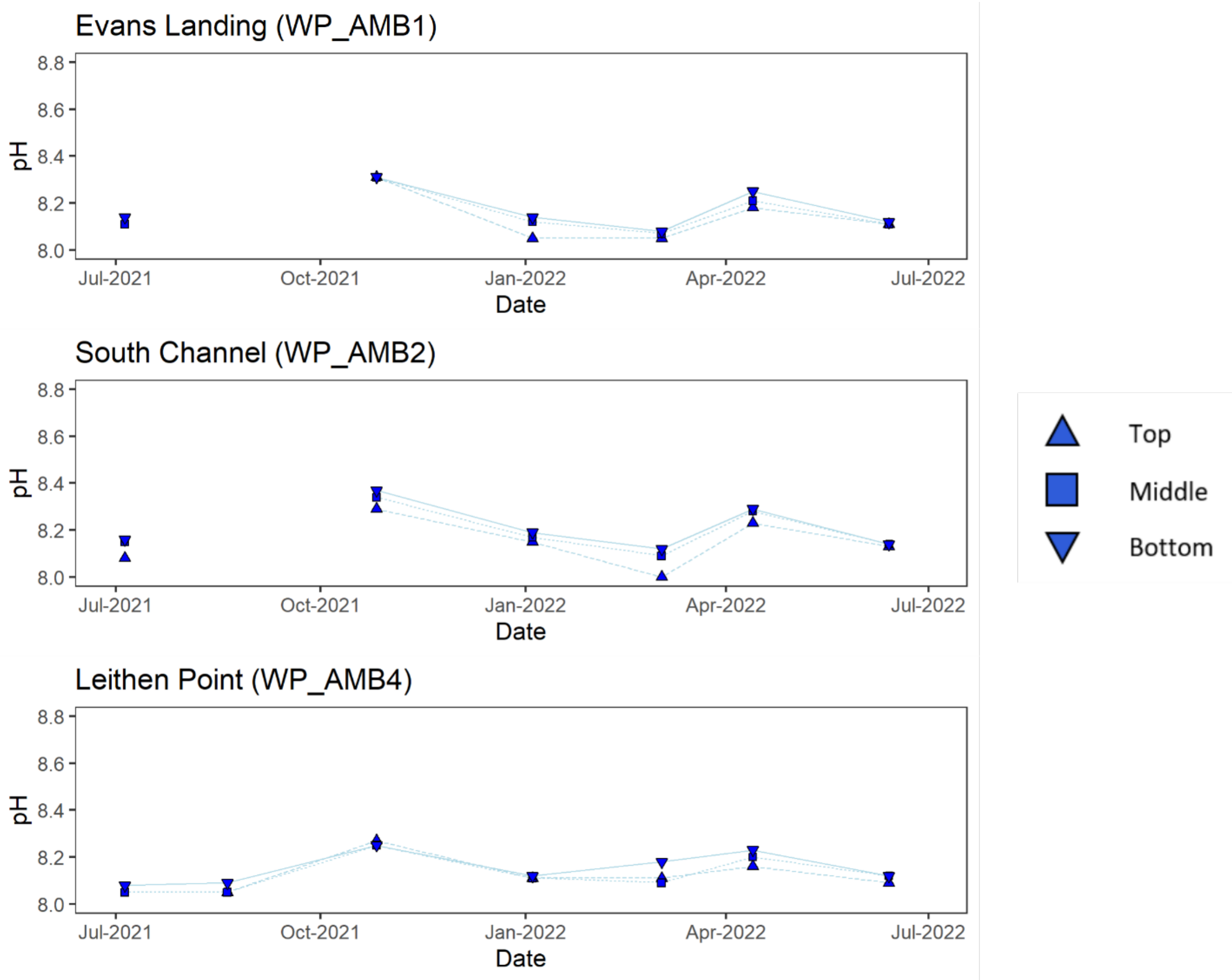

Figure 3-9. pH recorded at three depths in the Weipa region showing results for the top, middle, and bottom water. Missing data at two sites in August 2021 was due to instrument failure.

3.3.2 Nutrients

Particulate nitrogen (PN) concentrations ranged from 5 to 65 µg L^{-1} , with an anomalously high value of 433 µg L^{-1} in March 2022 (Figure 3-10). Mean PN across the three sites exceeded the GBRMPA guideline trigger value of 20 µg L^{-1} on all sampling occasions except August 2021 and June 2022.

Particulate phosphorus (PP) concentrations ranged from <1 to 13 µg L^{-1} (Figure 3-10). Mean PP was above the GBRMPA guideline trigger value of 2.8 µg L^{-1} for all sampling events except for April 2022.

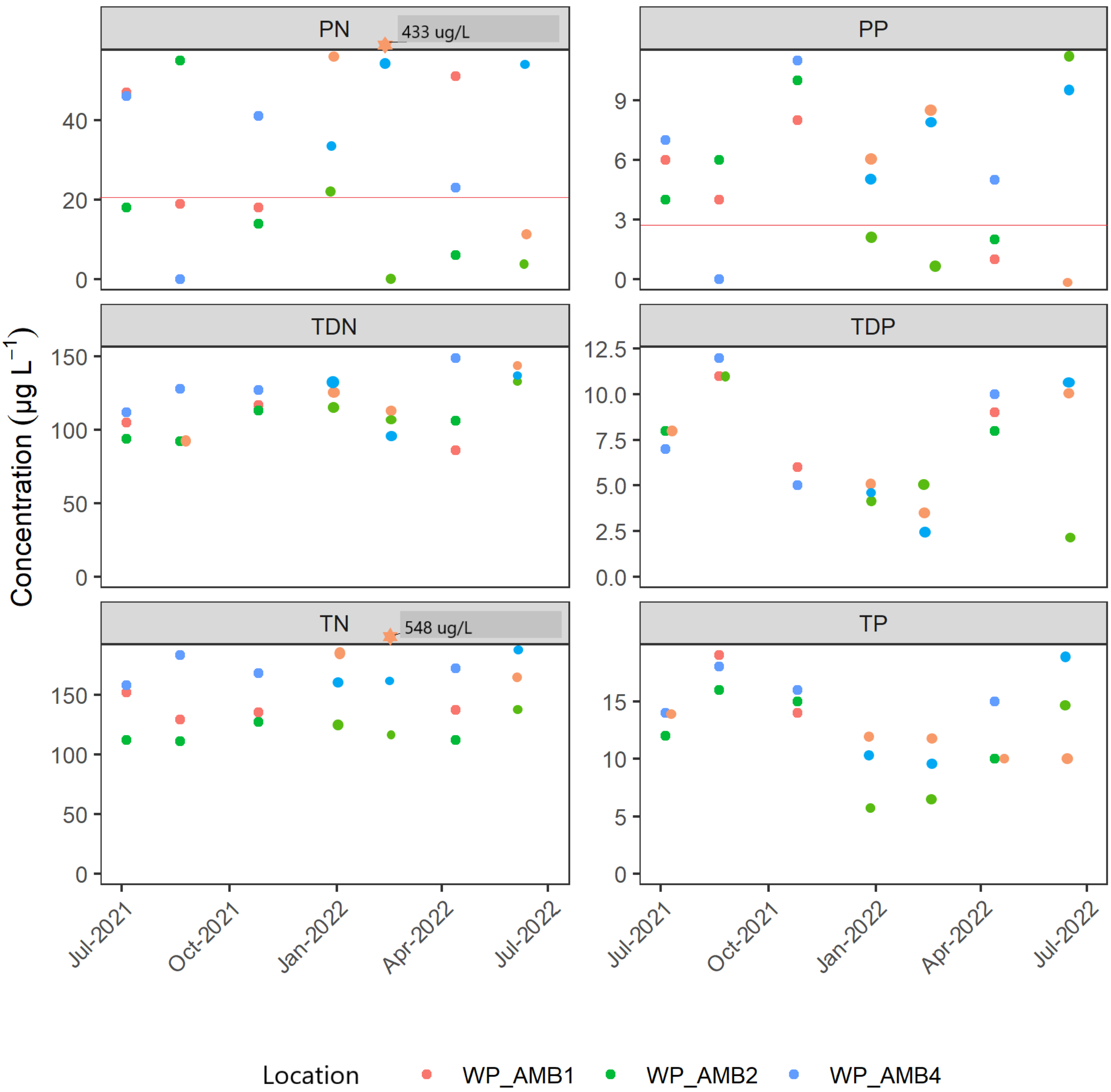

Figure 3-10. Particulate Nitrogen (PN), Total Dissolved Nitrogen (TDN), Total Nitrogen (TN), Particulate Phosphorous (PP), Total Dissolved Phosphorous (TDP) and Total Phosphorous (TP) concentrations measured in water samples collected from the three water quality sites in the Weipa region. Horizontal red line indicates the GBRMPA open coastal guideline trigger value for Particulate Nitrogen and Particulate Phosphorous. Stars indicate outliers/anomalous high values.

3.3.3 Water clarity

Secchi depth ranged from 1.0 m to 4.5 m over the reporting period (Figure 3-11).

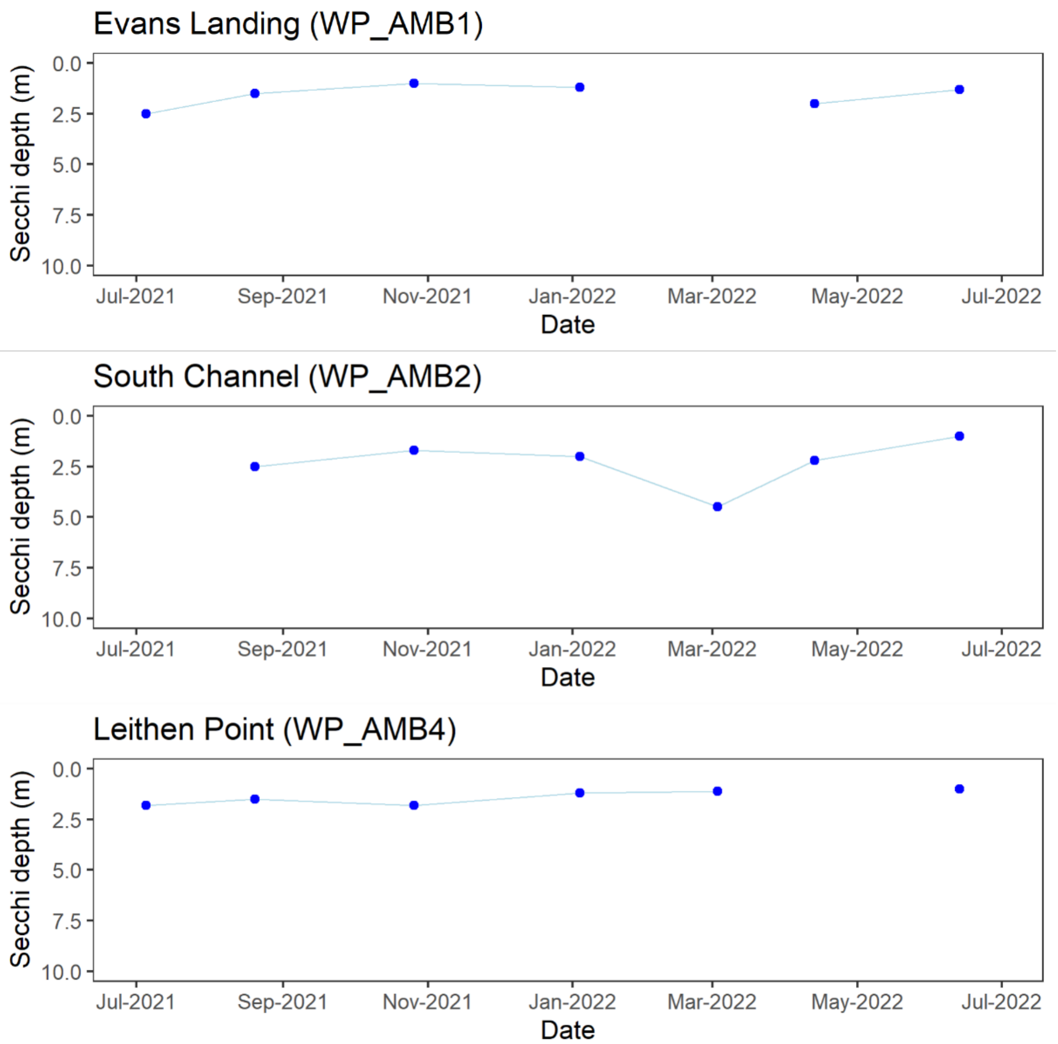

Figure 3-11. Secchi disk depth recorded at the three Weipa water quality sites throughout the reporting period.

3.3.4 Chlorophyll a

Chlorophyll-*a* showed high variability between both location and time of year with concentrations ranging from 0.68 to 5.67 µg L^{-1} across the three sampling sites (Figure 3-12). Harbour site South Channel and estuarine site Evans Landing both displayed a large spike in chlorophyll in January 2022 (4.26 µg L^{-1} and 5.67 µg L^{-1}) respectively.

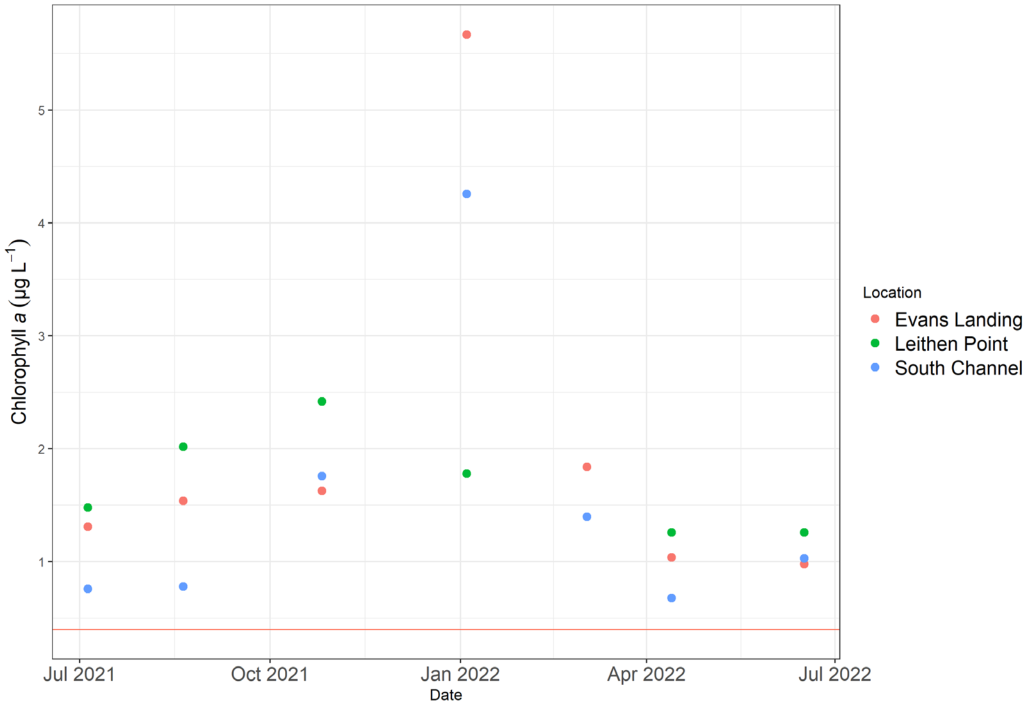

Figure 3-12. Chlorophyll-a concentrations measured in water samples collected from the three Weipa water quality sites throughout the reporting period. Horizontal red line indicates the GBRMPA open coastal guideline trigger value of 0.3 µg L^{-1}.

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 August 2021 and at Evans Landing in March 2022, 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 all sites were below these values.

Table 3-1. Heavy metal concentrations measured in water samples collected from three water quality sites in the Weipa 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
Evans Landing	Aug-2021	<0.1	<0.2	2	<0.2	<0.5	2.1	<5	<0.0001

South Channel	Aug-2021	<0.1	<0.2	2	<0.2	<0.5	2.2	<5	<0.0001
Leithen Point	Aug-2021	<0.1	<0.2	2	<0.2	<0.5	2.1	<5	<0.0001
Evans Landing	Mar-2022	<0.1	<0.2	2	<0.2	0.6	2	<5	<0.0001
South Channel	Mar-2022	<0.1	<0.2	1	<0.2	<0.5	1.9	<5	<0.0001
Leithen Point	Mar-2022	<0.1	<0.2	1	<0.2	0.6	2.1	<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. The herbicides Chlorpyrifos, Diazinon, Hexazinone, and Ametryn were also not detected (< LOD). There was no pesticide analysis conducted in the late wet season.

Table 3-2. Pesticide results from water samples taken in the early wet season from three locations in the Weipa region.

Analyte (µg/L)	WP_AMB1 Evans Landing	WP_AMB2 South Channel	WP_AMB4 Leithen Point
Chlorpyrifos	<0.001	<0.001	<0.001
Malathion	<0.001	<0.001	<0.001
Diazinon	<0.0002	<0.0002	<0.0002
Pirimiphos-methyl	<0.0002	<0.0002	<0.0002
Thiobencarb	<0.0002	<0.0002	<0.0002
Pendimethalin	<0.001	<0.001	<0.001
Hexazinone	<0.0002	<0.0002	<0.0002
Propiconazole	<0.0002	<0.0002	<0.0002
Hexaconazole	<0.0002	<0.0002	<0.0002
Difenoconazole	<0.0002	<0.0002	<0.0002
Tebuconazole	<0.0002	<0.0002	<0.0002
Flusilazole	<0.0002	<0.0002	<0.0002
Penconazole	<0.0002	<0.0002	<0.0002
Diuron	<0.0002	<0.0002	<0.0002
Ametryn	<0.0002	<0.0002	<0.0002
Atrazine	<0.0002	<0.0002	<0.0002
Cyanazine	<0.0002	<0.0002	<0.0002
Prometryn	<0.0002	<0.0002	<0.0002
Propazine	<0.0002	<0.0002	<0.0002

Simazine	<0.0002	<0.0002	<0.0002
Terbuthylazine	<0.0002	<0.0002	<0.0002
Terbutryn	<0.0002	<0.0002	<0.0002

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 on October 26, 2021. Section 3.4.6 will then present combined plots of the new IMO logger data with the old MGL logger data (July-October 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 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.

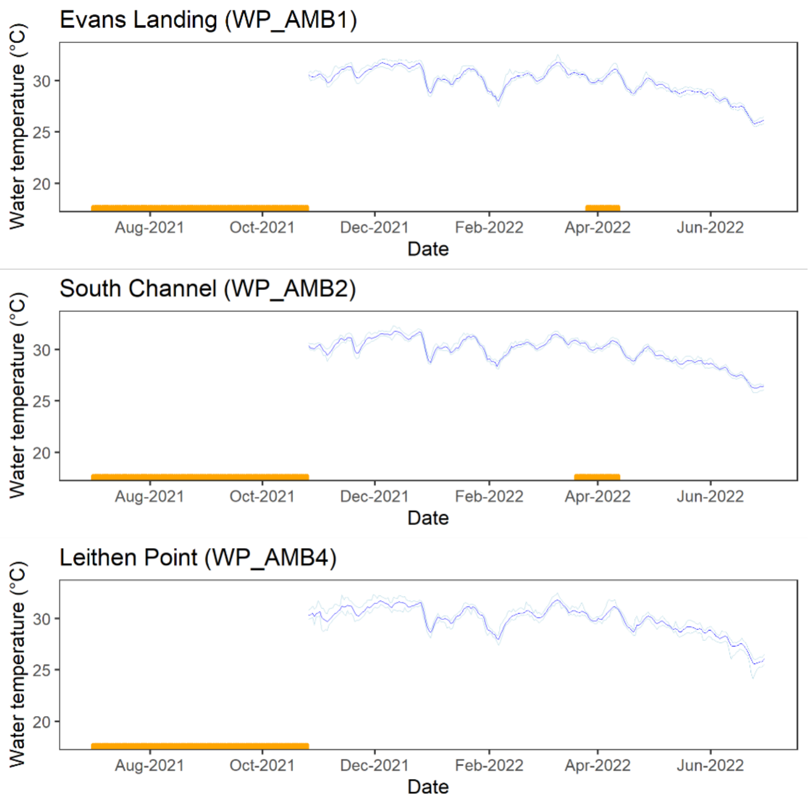

Figure 3-13. Daily mean water temperature (blue) and daily minimum and maximum (light blue) measured at water quality monitoring sites in the Weipa region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from October 26, 2021. For plots with 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 Weipa region is mixed semidiurnal mesotidal, with daily tidal range measured to be from 0.67 to 2.74 m during the reporting period. Tidal range was highest in early January 2022

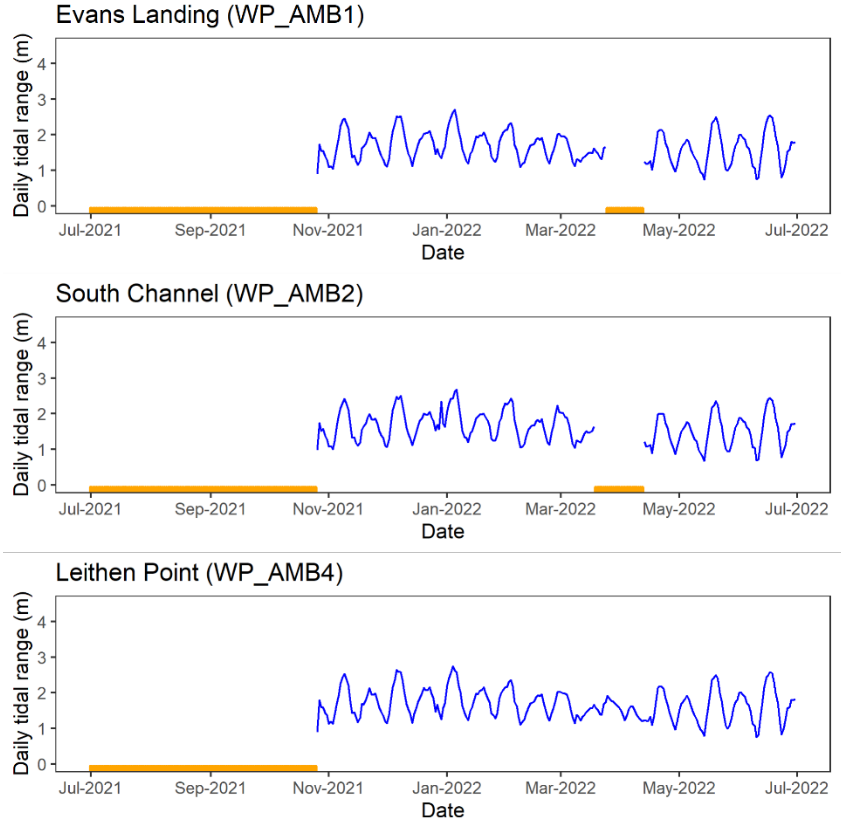

Figure 3-14. Daily tidal range measured at Weipa monitoring sites. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from October 26, 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18 – 3.20.

3.4.3 Wave activity (RMS depth)

RMS depth was higher in the harbour site, South Channel, compared to the two estuarine sites, with energy decreasing with distance up the estuary (Figure 3-15). There was a strong signal from Cyclone Seth evident at the end of December, particularly at South Channel, with other peaks in February and March.

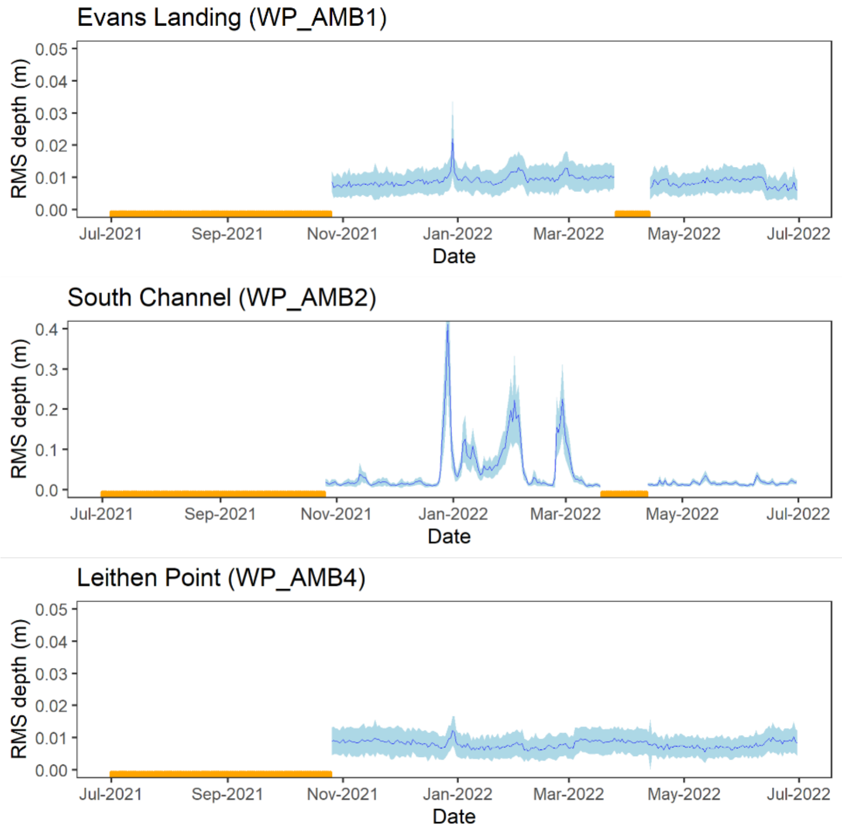

Figure 3-15. RMS depth measured at Weipa monitoring sites. Values presented are daily mean (blue line) +/- standard deviation (light blue). Note the different scale for y-axis at South Channel. These plots contain only the IMO data collected from October 26, 2021. For plots with both IMO and MGL logger data please see Figures 3-18– 3.20.

3.4.4 Turbidity

Turbidity measured at water quality monitoring sites in the Weipa region is presented in Figure 3-16. There were periods of high turbidity from December 2021 to March 2022 at all sites. These correspond with periods of high wave activity, e.g., Cyclone Seth in late December, as is evident in the heightened RMS depth values for those periods. Turbidity at all 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).

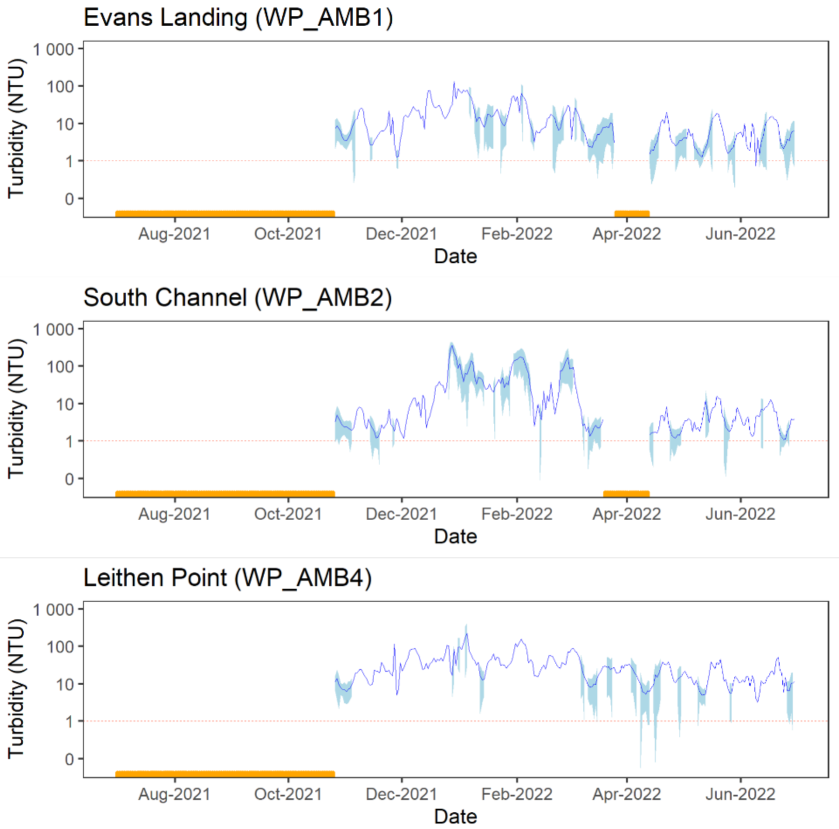

Figure 3-16. Turbidity measured at water quality monitoring sites in the Weipa region. Results presented are daily mean (blue line) and standard deviation (light blue). Y-axis is in log scale. Red dashed line indicates the GBRMPA turbidity guideline value for coastal waters. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from October 26, 2021. For quality-controlled plots with both IMO and MGL logger data please see Figures 3.18 – 3.20.

Table 3-3. 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 3-17, the values in this table have undergone quality control.

	Evans Landing (WP_AMB1)			South Channel (WP_AMB2)			Leithen Point (WP_AMB4)		
Month	Mean	Med	SD	Mean	Med	SD	Mean	Med	SD
July 2021	4.79	2.32	6.03	3.89	0.92	7.03	22.82	8.57	34.55
Aug 2021	4.70	3.41	4.31	3.18	2.12	3.27	17.15	7.25	27.94
Sept 2021	4.52	3.20	4.56	36.71	11.15	47.13	7.43	4.02	11.95
Oct 2021	4.01	3.10	3.86	33.62	20.02	40.20	13.95	9.15	17.01
Nov 2021	8.50	2.74	26.46	3.25	1.58	8.20	20.99	5.74	56.31
Dec 2021	31.67	6.94	70.07	53.59	4.00	109.36	51.92	15.32	84.70
Jan 2022	30.90	13.95	51.06	59.14	36.19	64.70	58.12	23.49	89.30

Feb 2022	18.53	7.17	34.82	61.14	16.57	91.71	53.20	21.32	85.56
Mar 2022	8.88	4.48	14.51	19.24	2.74	43.89	31.14	14.22	48.25
Apr 2022	5.94	2.29	11.06	2.53	1.27	4.43	18.61	8.55	26.49
May 2022	5.60	2.39	12.24	5.26	2.34	10.62	16.51	6.42	35.73
June 2022	6.48	2.36	21.02	4.51	2.09	7.69	14.83	4.81	43.39

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 February 2022 correspond with periods of increased turbidity and rainfall.

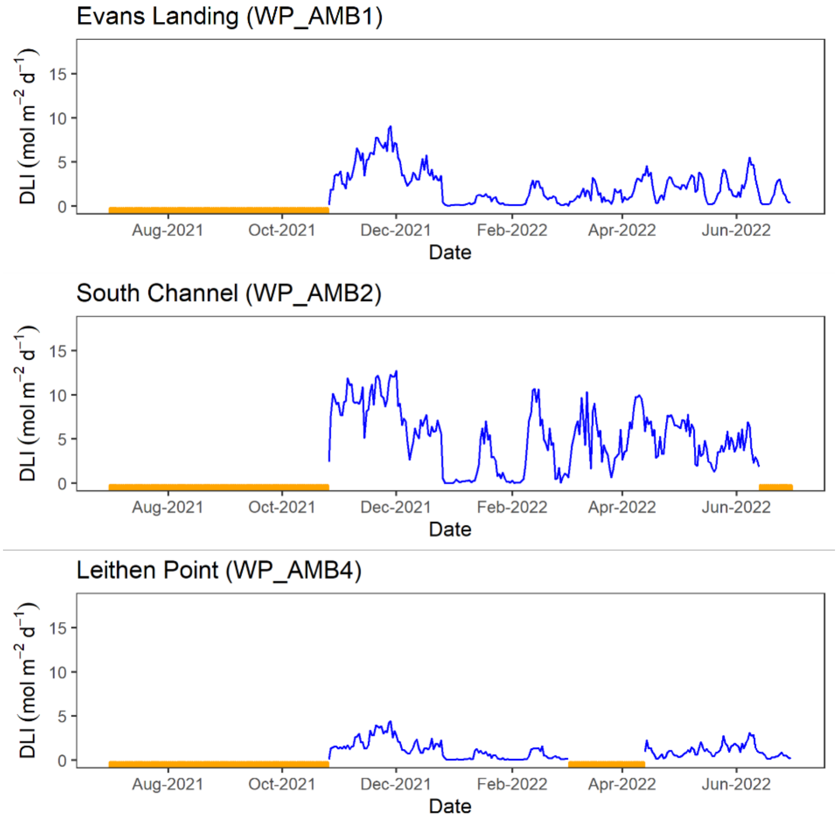

Figure 3-17. Daily light integral (mol photons m^{-2} d^{-1}) of photosynthetically active radiation measured at water quality monitoring sites in the Weipa region. Periods of missing data are indicated by the orange bar. Note: these plots contain only the IMO data collected from October 26, 2021. For 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

Figures 3-18 – 3-20 display data from the previous used MGL loggers and the newly implemented IMO loggers.

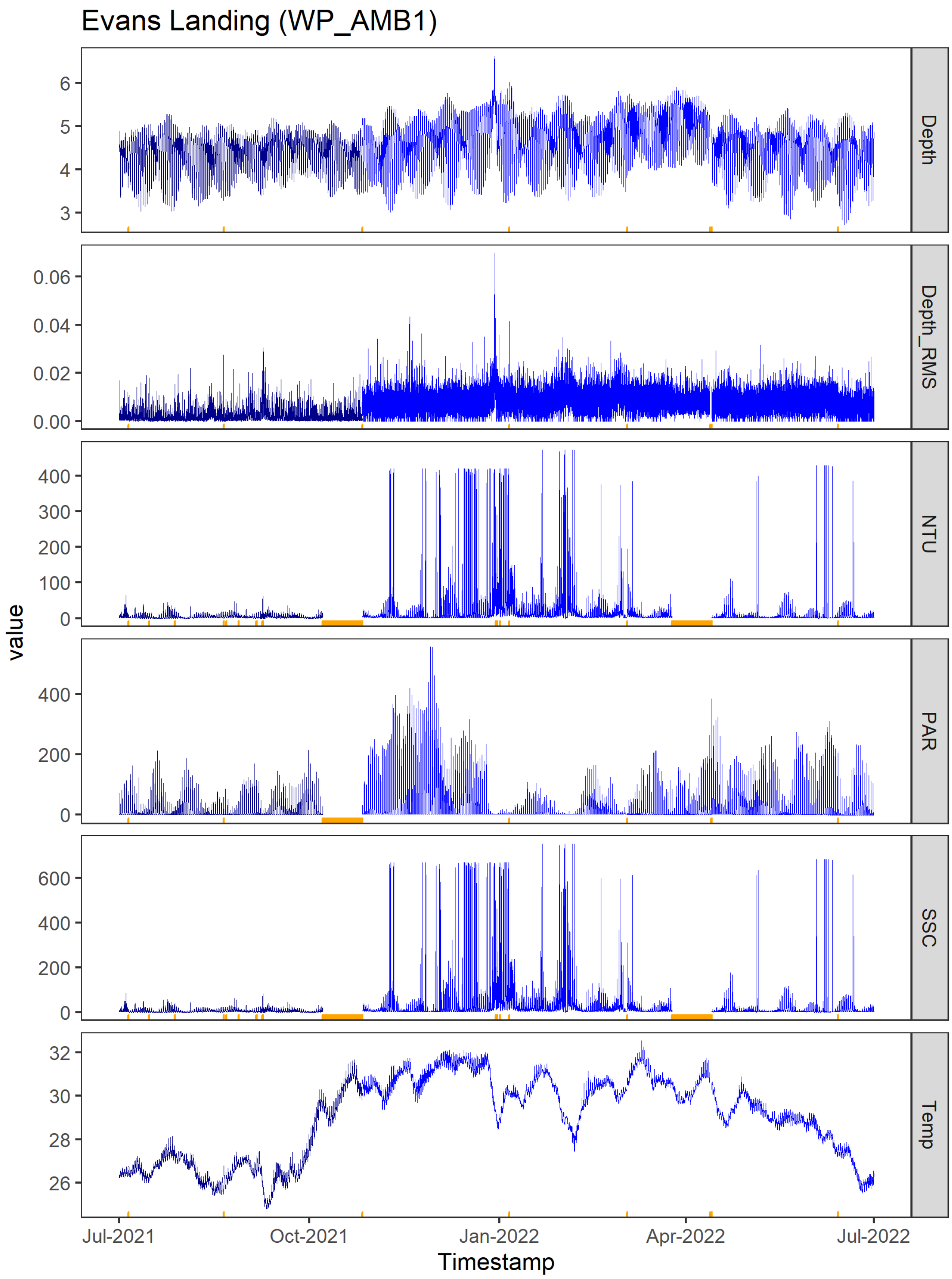

Figure 3-18. Data collected at Evans Landing with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 26/10/2021. Data presented excludes data 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 1.

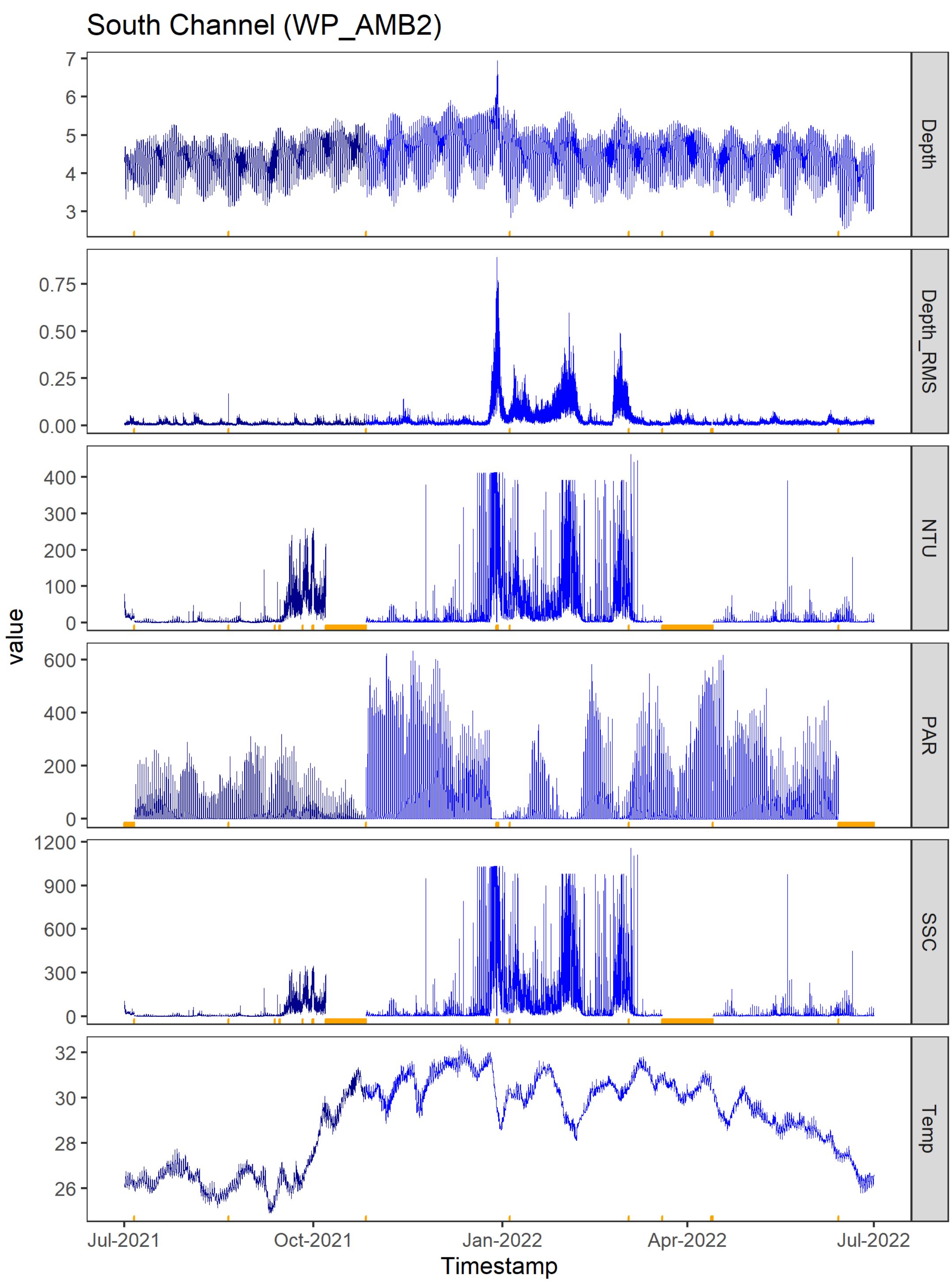

Figure 3-19. Data collected at South Channel with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 26/10/2021. Data presented excludes data 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 1.

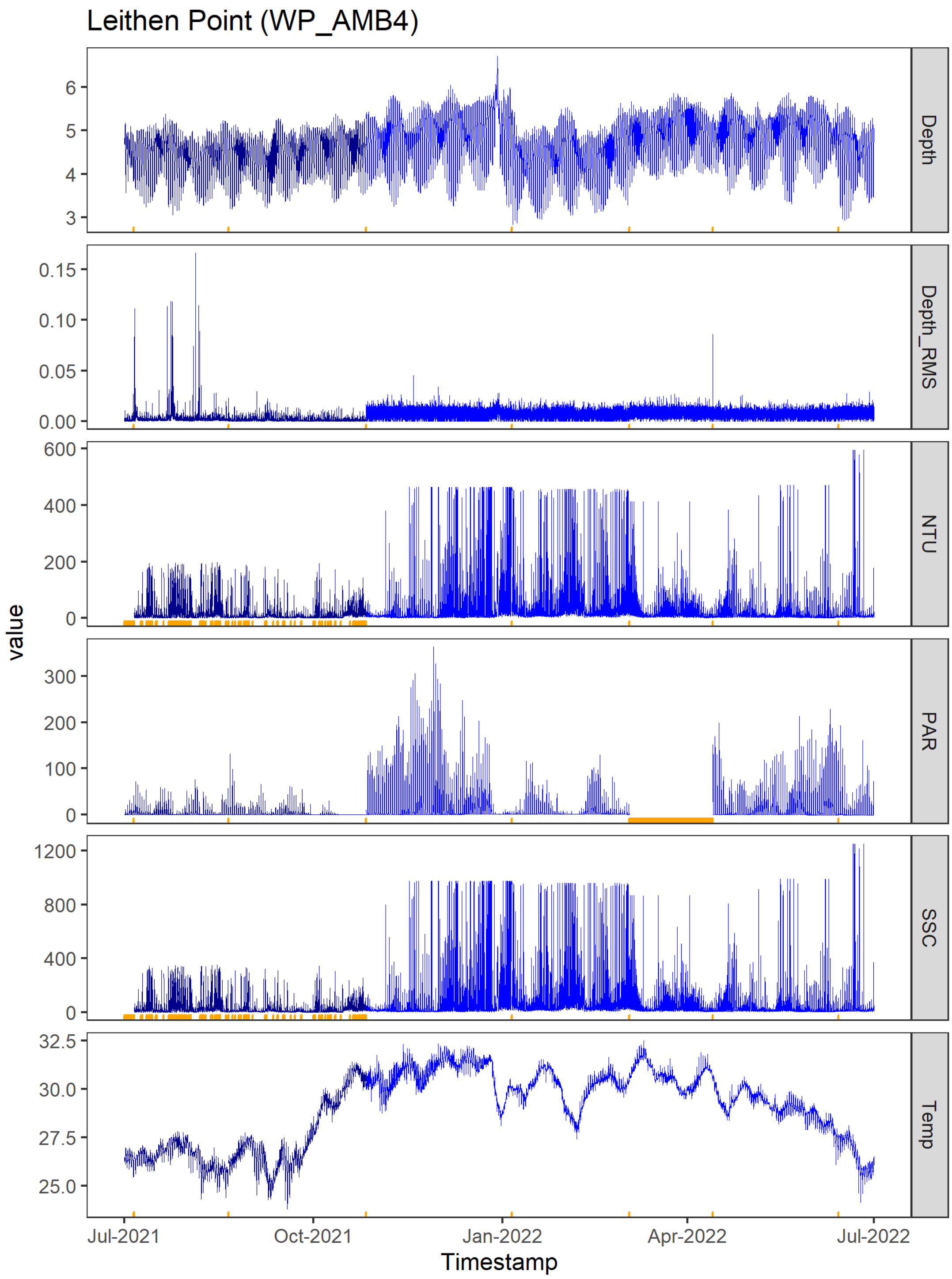

Figure 3-20. Data collected at Leithen Point with dataloggers supplied by Insitu Marine Optics (IMO) (blue) and nephelometers supplied by marine geophysics laboratory (MGL) (dark blue). The MGL loggers were discontinued and replaced by IMO loggers at this site on 26/10/2021. Data presented excludes data 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 1.

3.4.7 Data Recovery

Data recovery and quality control flagging for insitu loggers varied across the sites (Figure 3-21). Data flagged as red (qc 4) was removed as bad data. Full descriptions of the QC flags are provided in Appendix 1.

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

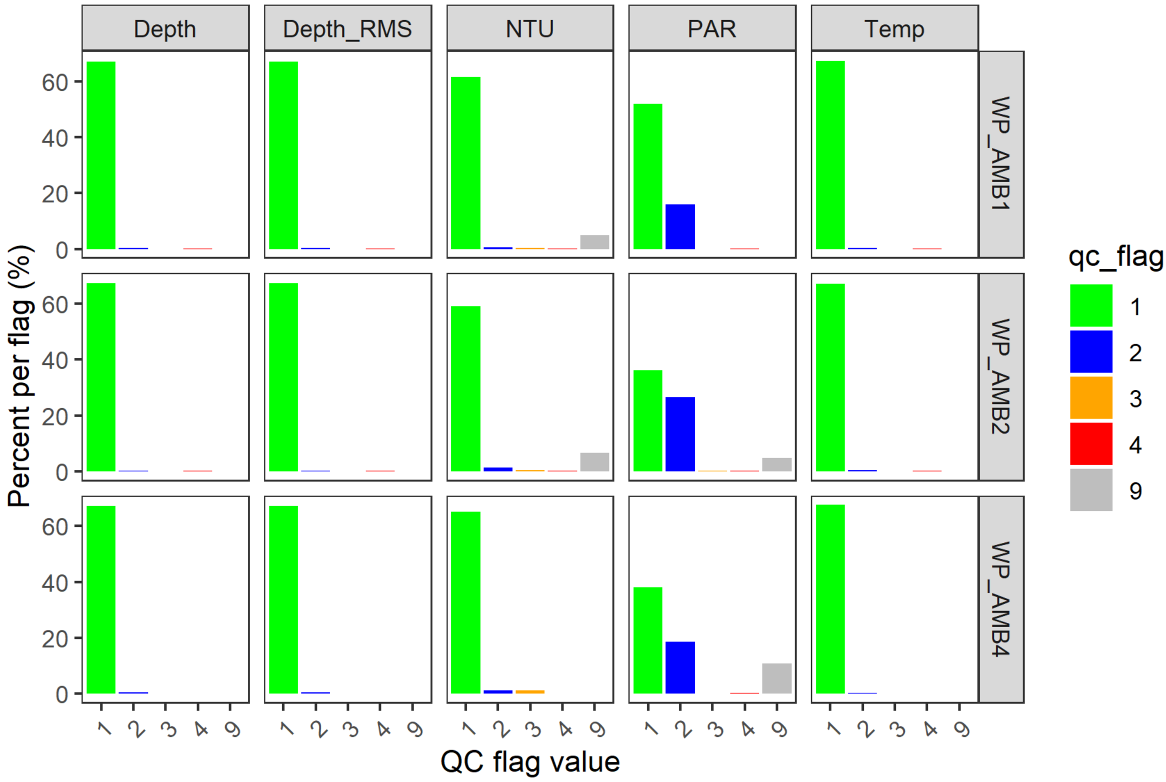

Figure 3-21. Data recovery and qc flags at each of the three Weipa logger sites over the reporting period. Flag 1 (green) indicates a 'good value'; flag 2)blue) indicates a 'probably good value'; flag 3 (yellow) indicates 'probably bad value', flag 4 (red) indicates a 'bad value' and flag 9 (grey) indicates data that is missing.

4 Conclusions and Recommendations

4.1 Conclusions

4.1.1 Climatic conditions

1. The 2021-2022 wet season received higher rainfall when compared to the previous year's monitoring (2020-2021). The wet season rainfall total was 2158.2mm, while total rainfall for the water year was 2448 mm, making the total annual rainfall in the top ten percentile of rainfall recorded over the past 30 years. 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. Cyclone Seth passed through the Gulf in late December 2021 and had a large impact on wind-driven waves in the region, which a major driver of sediment resuspension.
3. Early February saw a very large rainfall event which affected the physio-chemical parameters of water quality.

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 can sometimes be stratified, 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 elsewhere 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 or, indeed, whether there is a need for local guidelines. It may be that GBRMPA guidelines do not apply here but this can only be determined with long-term ambient water quality data.
4. Chlorophyll-*a* concentrations exceed guideline values during all surveys and at all 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. There were periods of dredging in Weipa where turbidity levels exceeded the thresholds of the loggers' upper range (~450 NTU) for short periods. In response to this, the logger pool has been increased to include loggers specifically calibrated for a higher range (up to 1000 NTU). It is anticipated that these loggers will be deployed during future dredging campaigns to improve data capture.
3. 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 port area.

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 cyclone Seth in late December 2021, 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 with distance into the estuary. 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 wet season rainfall during the current program was within the top 10% 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 remote region of northern Australia.

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Appendix 1. Quality control procedures

To complement the new loggers that were introduced into the program in the 2021-22 reporting year, a new quality control (QC) process for water quality data has been implemented. The QC process is science-based, sourced from public documentation, and based on the quality assurance of Real Time Oceanographic (QARTOD) program (NOAA, 2020), which is adopted by CSIRO, IMOS, and AIMS. Data goes through both automated and manual quality control steps. The 12 automated control tests are outlined in Table A5.

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

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

Dependent on the outcome of these QA tests, data may be flagged ‘good data’ (green), ‘probably good data’ (blue), ‘probably bad data’ (yellow) and ‘bad data’ (red).

There are four sensors on each logger: Temperature, Depth, Tilt, and either turbidity (NTU) or photosynthetically active radiation (PAR). For each sensor on the logger the ‘worst’ flag from QC rules 1 to 12 is reported for each 10-minute time interval. Figures A 1 – A 3 show the logger data from this report with the QC flags applied.

The end user can decide 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 and tests as applied to the data in this project will be published in early 2023.

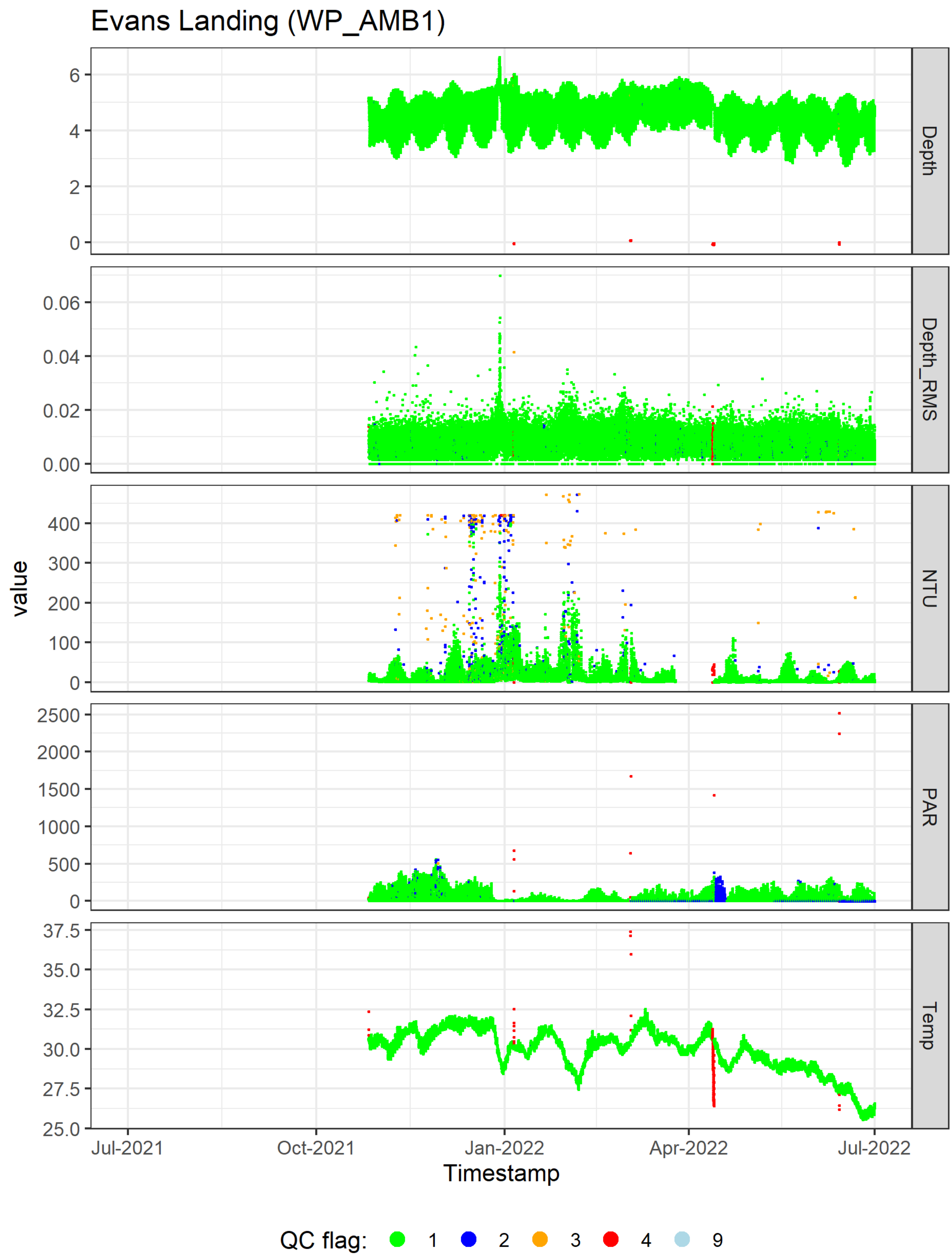

Figure A 1. Raw data collected at Evans Landing (WP_AMB1) with IMO loggers. Passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

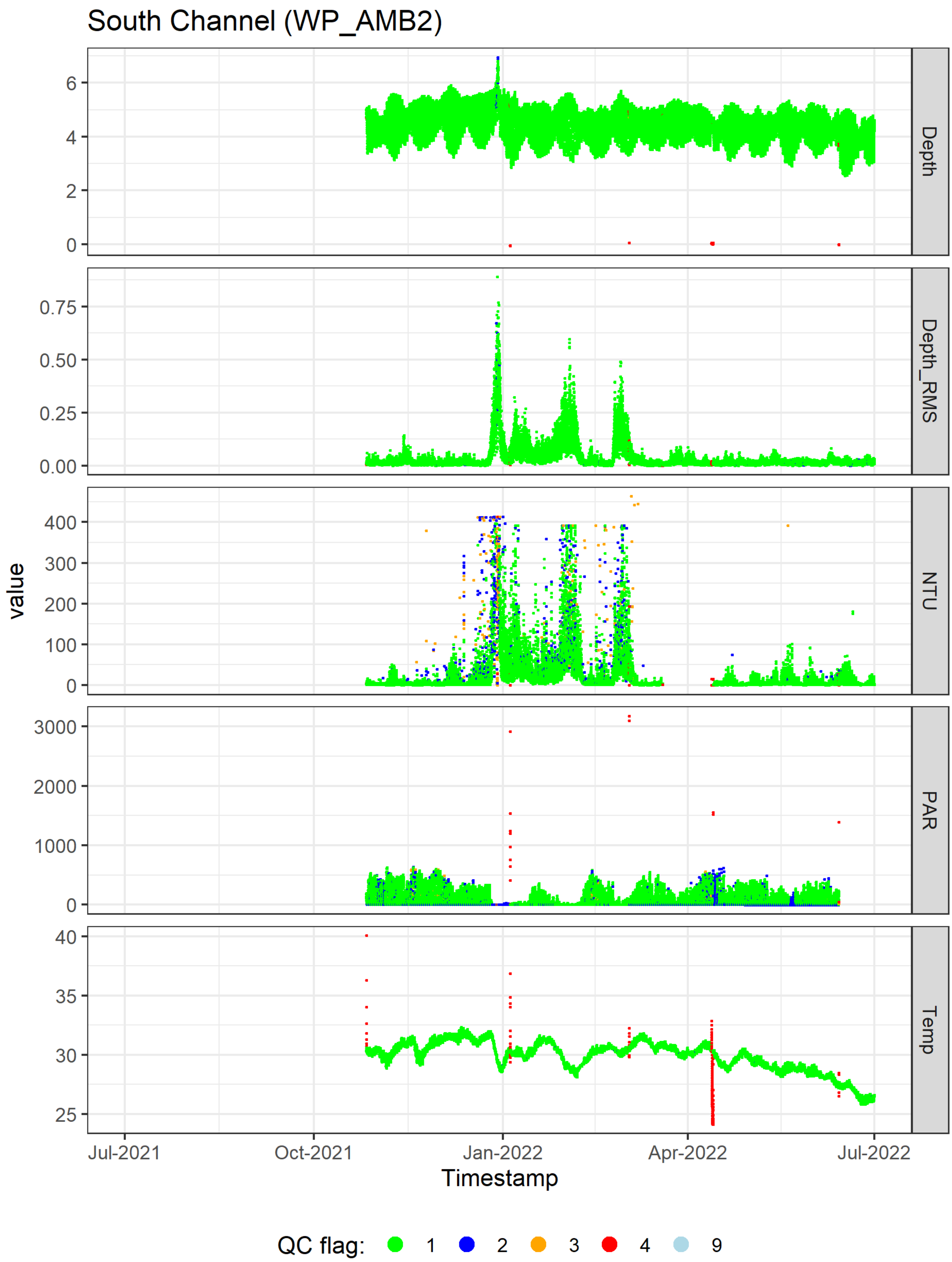

Figure A 2. Raw data collected at South Channel (WP_AMB2) with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.

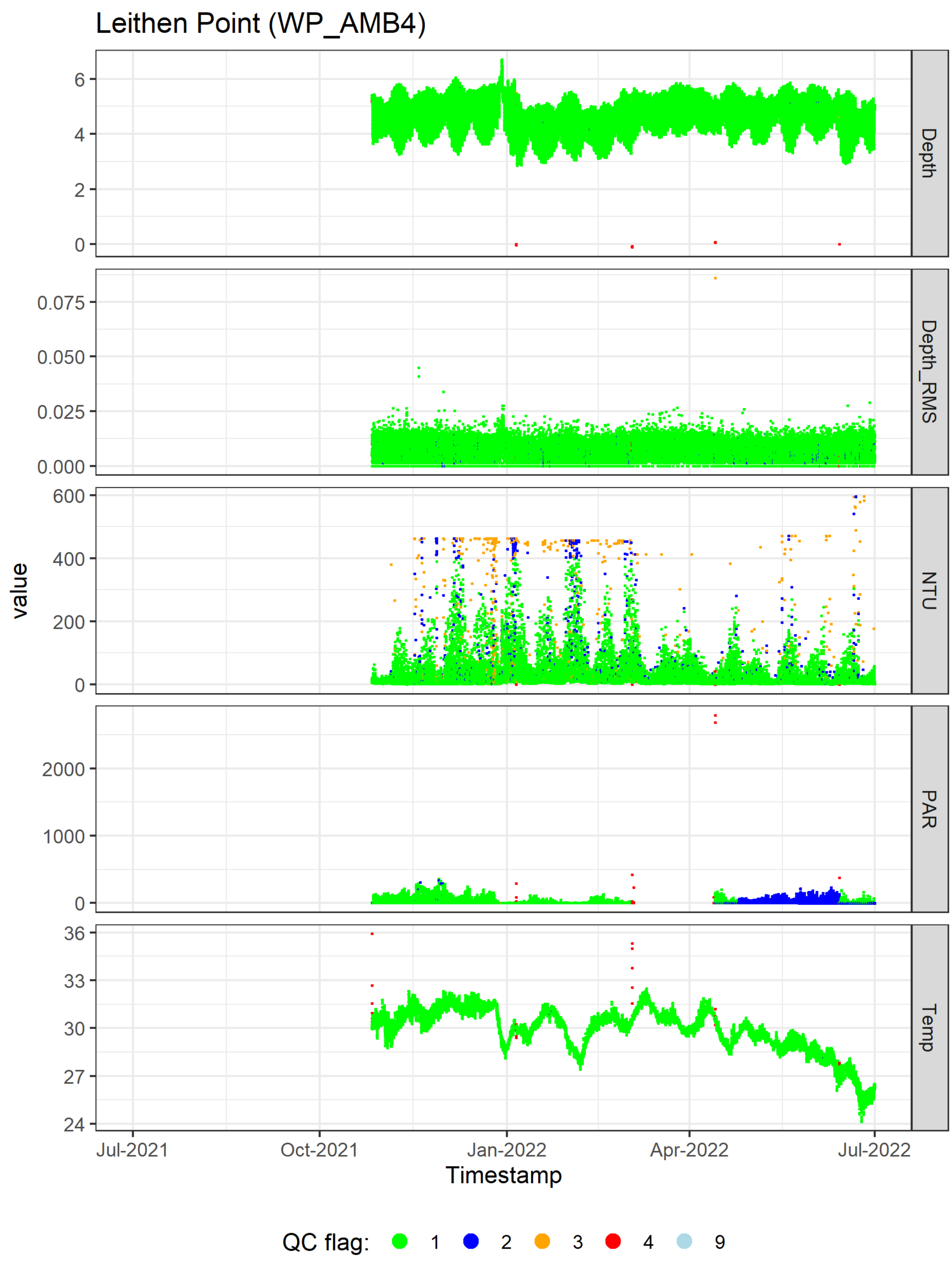

Figure A 3. Raw data collected at Leithen Point (WP_AMB4) with IMO loggers, passed through automated and manual quality control (QC) steps. Symbol colour indicates QC flag designation where: 1 (green) = Good data, 2 (blue) = Probably good data, 3 (orange) = Suspect data, 4 (red) = Bad data, 9 (light blue) = Missing data.