Whitsunday Water Quality Monitoring Blueprint for Tourism Operators: Annual report 2021-2022

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A Report for Reef Catchments (Mackay Whitsunday Isaac) Limited

Report No. 23/17

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1 INTRODUCTION

1.1 Background

The Whitsunday region of the Queensland coast encompasses numerous islands, bays, and inshore reefs, and is an important gateway to the outer Great Barrier Reef (GBR). Of concern in the region is an apparent decline in water quality, as demonstrated in water quality monitoring results (Gruber et al., 2019, Waterhouse et al., 2021) and supported by anecdotal evidence from local residents and tourism operators. For example, the long-term water quality index produced by the Great Barrier Reef Marine Park Authorities (GBRMPA) marine monitoring program (MMP) for the Whitsundays region has been in decline since monitoring started in 2007, with water quality in the region currently assessed to be ‘moderate’ to ‘poor’ (Figure 1-1). The rate of decline in water quality has also been more rapid in the Mackay-Whitsunday region compared to other regions to the north. However, the annual condition index instigated in 2015 which is sensitive to year-to-year variability indicates some improvement in water quality has been made.

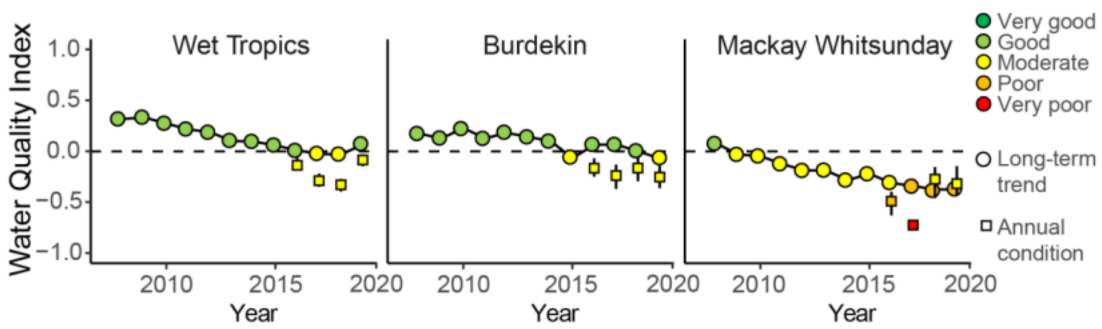

Figure 1: Water Quality Index scores from 2006 to 2019 for the Wet Tropics, Burdekin and Mackay-Whitsunday regions. The Index is calculated to show the long-term trend in water quality since the start of monitoring (circles) based on the initial program design. An updated version communicating annual condition is calculated from 2015 onwards (squares) that includes increased temporal and spatial sampling and relates water quality values to wet and dry season Reef water quality guidelines. The Index includes five variables: water clarity, concentrations of nitrate/nitrite, particulate nitrogen, particulate phosphorus, and chlorophyll *a*. Details of calculations can be found in Appendix D.

Figure 1-1 *Australian Institute of Marine Science (AIMS) Water quality index. Figure and caption reproduced from the ‘Marine Monitoring Program: Annual report for inshore water quality monitoring 2019-20’ (Waterhouse et al., 2021)*

1.2 Citizen science project

The tourism industry has expressed that they often feel in the dark, regarding reef or marine monitoring and its outcomes. In response to this, TropWATER (Centre for Tropical Water and Aquatic Ecosystem Research) at James Cook University, has been commissioned to assist Reef Catchments (Mackay Whitsunday Isaac) and Whitsunday Tourism Operators to establish an ambient marine water quality program for the Whitsunday region as part of a ‘Whitsunday Water Quality Monitoring Blueprint for Tourism Operators’ program. The Whitsunday Water Quality Monitoring Blueprint for Tourism Operators is funded by the partnership between the Australian Government’s Reef Trust and the Great Barrier Reef Foundation, and North Queensland Bulk Ports.

This citizen science project has brought together partners from a cross section of the Whitsunday community, the Partners include Reef Catchments, the Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership, North Queensland Bulk Ports, TropWATER (Centre for Tropical Water and Aquatic Ecosystem Research) at James Cook University (JCU), along with Whitsunday Tourism Operators — Whitsunday Bareboat Operators Association (WBOA) and Whitsunday Charter Boat Industry Association (WCBIA).

The project aims to link together citizen science and research initiatives around water quality and reef health, to collaboratively develop a framework for connecting citizen science work with the regional report card partnership hosted by Reef Catchments. This project focuses on utilising proven research, science experience and methodology to train Whitsunday tourism operators to collect marine monitoring data at key locations. The citizen science program has established two new water quality monitoring sites in the Whitsunday region which are then regularly sampled and maintained by Tourism Operators during their day-to-day activities. The objective of the program is to give Tourism Operators the direct opportunity to engage in the collection of water quality data throughout the region. The tourism community has a vested interest in the long-term health and functionality of the Great Barrier Reef (GBR) and are well positioned to lead solution-based monitoring, evaluation, and effective communication. This annual report covers the 12-month period from March 2021 until February 2022.

2 METHODOLOGY

2.1 Water quality monitoring sites

Two water quality monitoring sites were established in the Whitsunday region in February 2020. Sites were selected at Cairn Beach (WH1) and Tongue Bay (WH2) with input from tourism operators who utilise adjacent regions in their charters (Figure 2-1). An instrument (data logger) was deployed at each site to continuously collect high frequency data. Water sampling was conducted at the two sites approximately every 4 weeks coinciding with site maintenance and instrument swap-outs. The Fieldwork component of the monitoring program was performed by tourism operators at scheduled intervals (Table 2-2).

Figure 2-1 *Location of the Whitsunday monitoring sites Cairn Beach (WH1) and Tongue Bay (WH2), located in the 'open coastal' waters of Whitsunday Island. Inset map shows the location of this section of the Whitsunday region on the Queensland coast (red bounding box).*

Table 2-1 *Water quality monitoring site locations selected for the Whitsunday Water Quality Monitoring Blueprint for Tourism Operators program. Note Blue Pearl Bay, located on Hayman Island, has been identified as part of a future expansion of the program*

Site name	Site code	Depth (m)	Lat	Long	Date established
Cairn Beach	WH1	10.4	-20.233633	149.017825	4/02/2020
Tongue Bay	WH2	7.7	-20.161447	148.955416	4/02/2020
Blue Pearl Bay	WH3	-	-20.233633	149.017825	-

Table 2-2 *Water Quality Monitoring conducted by Whitsunday Tourism Operators (Ocean Rafting, Whitsunday Bullet, Red Cat and True Blue Sailing) for logger maintenance and water sampling at Cairn Beach and Tongue Bay between March 2021 and February 2022*

Date sampled	Cairn Beach (WH1)	Tongue Bay (WH2)
05/03/2021	N/R (Logger)	-
07/03/2021	-	True Blue Sailing (Logger)
10/03/2021	Ocean Rafting (Water)	Red Cat (Water)
17/04/2021	Whitsunday Bullet (Logger)	-
24/04/2021	-	Ocean Rafting (Water)
28/04/2021	True Blue Sailing (Logger)	-
06/05/2021	Red Cat (Water)	-
25/05/2021	TropWATER (Logger &Water)	TropWATER (Logger & Water)
17/06/2021	Red Cat (Water)	-
18/06/2021	-	Ocean Rafting (Water)
09/07/2021	Whitsunday Bullet (Logger)	-
16/07/2021	Red Cat (Water)	-
17/07/2021	-	Ocean Rafting (Water)
21/07/2021	-	True Blue Sailing (Logger)
03/09/2021	-	Ocean Rafting (Water)
14/09/2021	Red Cat (Water)	-
16/09/2021	Whitsunday Bullet (Logger)	-
20/09/2021	-	True Blue (Logger)
28/10/2021	Whitsunday Bullet (Logger)	-
29/10/2021	-	Ocean Rafting (Water)
09/12/2021	Ocean Rafting (Water & Logger)	Ocean Rafting (Water & Logger)
24/01/2022	Whitsunday Bullet (Logger)	-
26/01/2022	-	Ocean Rafting (Water)
02/02/2022	Red Cat (Water)	-

Three sets of training were provided by TropWATER staff to tourism operators. Operators were trained in how to perform instrument maintenance, collect water samples, and complete field datasheets (Figure 2-2). All measurements and samples were collected by tourism operators. The first training session was conducted over two days in February and March 2020. The second training day was completed in September 2020 to train new staff in response to staff turnover as a result of COVID-19 disruptions. A third training day was conducted in September 2021.

Figure 2-2 *Tourism operators receiving training out on the water and in a class environment. Photos courtesy of Reef Catchments.*

2.2 Regional climate

Air temperature and rainfall observations were obtained from the Bureau of Meteorology weather station at Hamilton Island Airport (station 033106) for the period 01/03/2021 to 28/02/2022 and total rainfall calculated for each wet season from 2002 to present. Tide data was obtained from the Department of Transport and Main Roads Shute Harbour tidal station (P030003A).

2.3 Loggers

A MGL nephelometer was deployed on the seafloor at each site to record water quality measurements over the deployment period (Figure 2-3). The instrument measures water temperature, pressure (depth), photosynthetically active radiation (PAR), and turbidity at a 10 min interval. The nephelometer was retrieved and a replacement instrument installed by the tourism operators at an approximately 4-week period (Table 2).

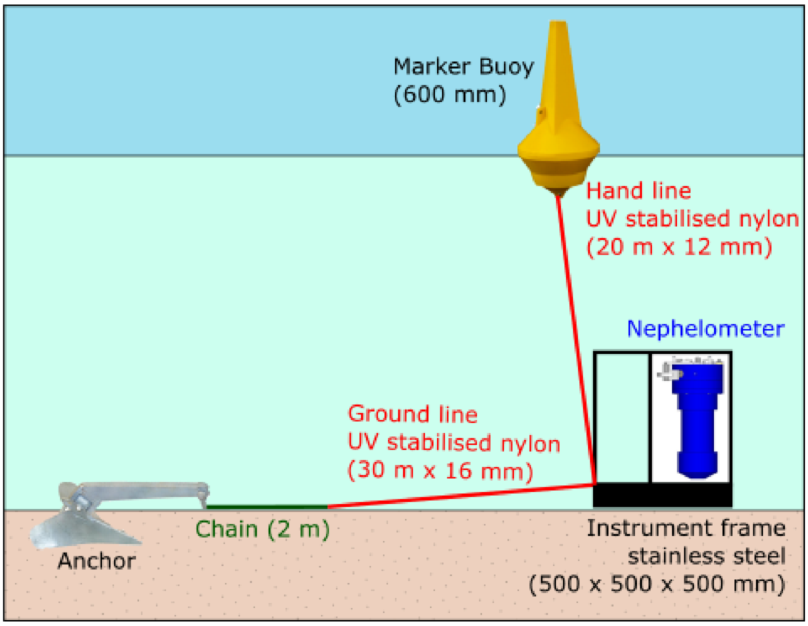

Figure 2-3 *Diagram showing the mooring configuration for logger instrument deployments*

2.3.1 Water temperature

Water temperature values are obtained with a thermistor that records measurements every 10 minutes. The sensor is installed in a bolt that protrudes from the instrument and gives sensitive temperature measurements. Collecting temperature data is useful for examining changes in water temperature in relation to time of day, tidal movements, seasonal patterns, and in response to weather events. Temperature gives an indication of these physical processes occurring and is useful for assessing environmental conditions. Temperature regulates the rate that biological processes occur and is an especially useful parameter to observe in parallel with monitoring for coral bleaching.

2.3.2 Pressure

A pressure sensor is located on the horizontal surface of the 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. Each time a pressure measurement is made the pressure sensor takes 10 measurements over a period of 10 seconds. From these 10 measurements, average water depth (m) and root mean square (RMS) water height are calculated. RMS water height (D_{rms}) is calculated as follows:

$$D_{rms} = \sqrt{\sum_{n=1}^{10}(D_n - \bar{D})^2/n} \qquad \text{[Equation 1]}$$

Where:

D_n is the nth of the 10 readings,

$\bar{D}$ is the mean water depth (m) of the n readings.

The average water depth and 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 turbidity. 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, two sites both have the same surface wave height, site one is 10 m deep and has a measurement of 0.01 RMS water height and site two is 1 m 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.

2.3.3 Photosynthetically Active Radiation (PAR)

A PAR sensor, positioned on the horizontal surface of the water quality logging instrument, takes a PAR measurement at ten (10) minute intervals for a one second period. To determine the daily light integral (DLI) the sum of 10 min PAR measurements (µmol m^{-2} s^{-1}) is multiplied by the measurement interval in seconds (10 min × 60 sec = 600 sec) and divided by 1,000,000 to give DLI (mol m^2 d^{-1}). PAR indicates the amount of light reaching benthic communities where the logger is located and may reflect either weather conditions (i.e., cloud cover, haze), water clarity, or both. Elevated turbidity, algal blooms, or suspended sediment in the water column will cause an increase in the amount of light attenuated through the water column, and hence a reduction in benthic PAR.

2.3.4 Turbidity

The sensor is located on the side of the logger, pointing parallel light-emitting diodes (LED) and transmitted through a fibre optic bundle. The backscatter probe takes 250 samples in an eight second period to attain an accurate turbidity value. The logger is programmed to take these measurements at 10-minute intervals. The sensor interface is cleaned hourly by a mechanical wiper allowing for long deployment periods where biofouling would otherwise compromise measurements.

Turbidity is an indicator of water clarity, with higher turbidity readings indicating lower water clarity, while readings approaching zero indicate clear water. The international turbidity standard ISO7027 defines NTU for 90 degree scatter, however, the Marine Geophysics Laboratory instruments used throughout this monitoring program obtain an NTU equivalent value (NTUe) using 180 degree backscatter to allow for more effective cleaning (Larcombe et al., 1995). Because particle size influences the angular scattering functions of incident light (Bunt et al., 1999; Conner & De Visser, 1992; Ludwig & Hanes, 1990; Wolanski et al., 1994), instruments using different scattering angles may provide different units of turbidity. Hence, direct comparison between instruments obtaining turbidity in different units is not possible. Nonetheless turbidity is useful in observing relative changes in water clarity.

2.4 Analysis of water samples

Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e. DES, 2018; Standards Australia, 1998). Field collected water samples were stored on ice in eskies immediately during field trips aboard the vessel, and transported back to refrigeration, before delivery to the TropWATER laboratory. Water was passed through a 0.45 µm disposable membrane filter (Sartorius), fitted to a sterile 60 mL syringe (Livingstone), and placed into 10 mL sample tubes for nutrient analysis in the laboratory. Unfiltered sample for total nitrogen and total phosphorus analysis were frozen in a 60 mL tube. All samples are kept in the dark and cold until processing in the laboratory, except nutrients which are stored frozen until processing.

Water for chlorophyll-*a* 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 are then wrapped in aluminium foil and frozen. Pigment determinations from acetone extracts of the filters were completed using spectrophotometry, method described in 'Standard Methods for the Examination of Water and Wastewater, 10200 H. Chlorophyll'. The concentration of Chlorophyll *a* in the water column is used as an indicator of the amount of phytoplankton (algae) present.

Water samples are analysed using defined analysis methods and detection limits (Table 2-3). In summary, all nutrients were analysed using colorimetric method on OI Analytical Flow IV Segmented Flow Analysers. Total nitrogen (TN), total phosphorus (TP), total dissolved nitrogen (TDN) and total dissolved phosphorus (TP) are analysed simultaneously using nitrogen and phosphorous methods after alkaline persulphate digestion, following methods as presented in 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method' and in 'Standard Methods for the Examination of Water and Wastewater, 4500-P F. Automated Ascorbic Acid Reduction Method'. Nitrate-nitrite (NO_x) was analysed using the methods 'Standard Methods for the Examination of Water and Wastewater, 4500-NO3- F. Automated Cadmium Reduction Method'.

Table 2-3 *Water analyses performed during the ambient marine water quality monitoring program. The method used and limit of reporting (LOR) is provided for each parameter.*

Group	Parameter	APHA method number	LOR
Routine water quality analyses			
	pH	4500-H^+ B	-
	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), total dissolved nitrogen (TDN), total phosphorus (TP), and total dissolved phosphorus (TDP)	Simultaneous 4500-NO_3^- F and 4500-P F analyses after alkaline persulphate digestion	10 µg N L^{-1}, 1 µg P L^{-1}
	Nitrate-nitrite (NO_x)	4500-NO_3^- F	1 µg N L^{-1}
Chlorophyll			
	Chlorophyll-*a*	10200-H	0.1 µg L^{-1}
	Phaeophytin-*a*	10200-H	0.2 µg L^{-1}

pH and electrical conductivity (EC) were measured in the laboratory with a benchtop meter. pH is a measure of how acidic or basic a solution is. pH < 7 indicating more acidic conditions, and pH > 7 more basic conditions. Seawater typically has a pH of 8.2 but ranges pH 7.5 to 8.5. A decrease in pH in the coastal marine environment may be an indication of freshwater mixing (i.e., short term events), changes in dissolved carbon dioxide concentrations causing ocean acidification (longer term changes in water chemistry), or to a lesser extent changes in temperature or salinity. Electrical conductivity (EC) is a measure of the electrical conductance of a solution and is reported in milli-Siemens per centimeter (mS cm^{-1}) in marine settings but may sometimes be seen reported in micro-Siemens per centimeter (µS cm^{-1}) – generally for freshwater settings. An increase in the amount of salts in solution results in an increase in EC. Therefore, EC generally correlates with salinity. EC is reported in place of salinity as it is a much more straightforward parameter to measure and is not affected by the types of salts present in the seawater. Total suspended solids (TSS) is a measure of the total amount of solid material in the water. TSS was determined gravimetrically by filtering a known amount of seawater with a glass fibre filter and weighing the residual solids retained on the filter following oven drying. TSS in marine settings mostly consists of sediment particles, although a proportion of TSS may also be made up of organic particles of biological origin (e.g., algae, bacteria, detrital material).

3 RESULTS

3.1 Climate

The rainfall onset for the Whitsundays (Hamilton Island) occurred on 18/11/2021 (Figure 3-1). The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. The 2021-2022 wet season rainfall was below the long-term average at 515.8 mm and annual rainfall was also below average (Figure 3-2). There was a period of unseasonably cool weather in October 2021, where temperatures dropped to similar levels as seen in June (Austral Winter). Late December saw another cool period that was immediately followed by the warmest period of the year in early January (Figure 3-3).

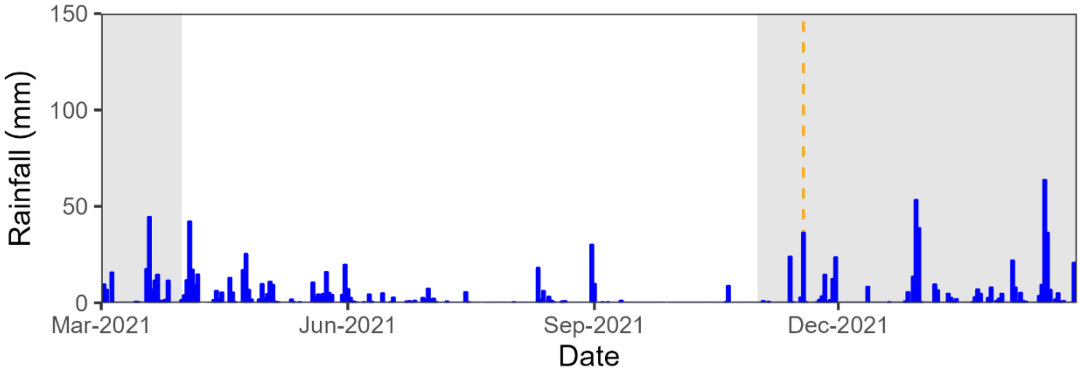

Figure 3-1 *Daily rainfall recorded at Hamilton Island Airport (station 033106). The nominal wet season period is shown in grey, with the 2021-2022 wet season onset marked by the orange dashed line. Data source: http://www.bom.gov.au/climate/data*

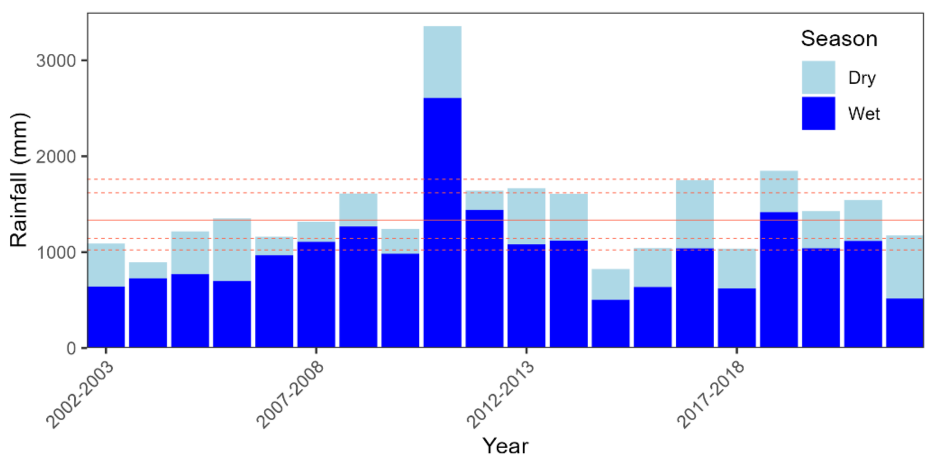

Figure 3-2 *Annual rainfall by water year for the Whitsunday region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Daily rainfall data was obtained from the Hamilton Island Airport weather station (station 033106). Data source: http://www.bom.gov.au/climate/data/*

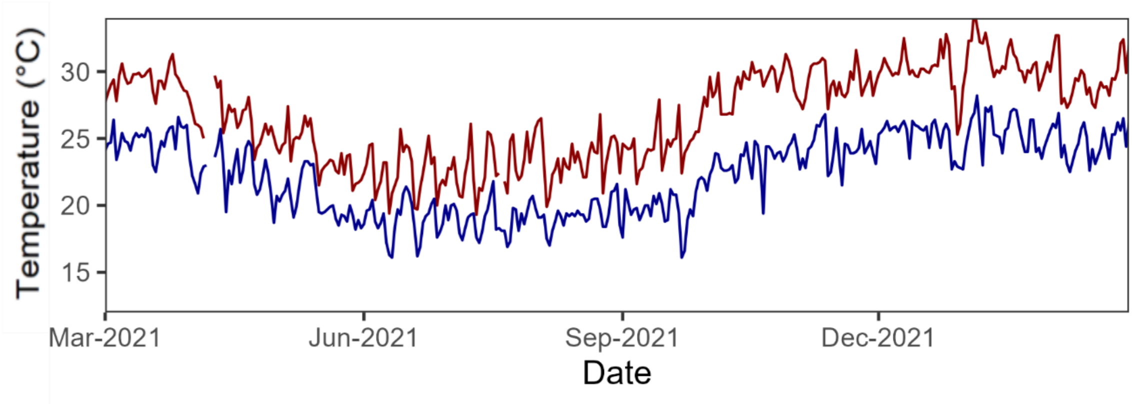

Figure 3-3 *Daily maximum (red) and minimum (blue) temperature observations at Hamilton Island. Observations were drawn from the Bureau of Meteorology weather station at Hamilton Island Airport (station 033106)*

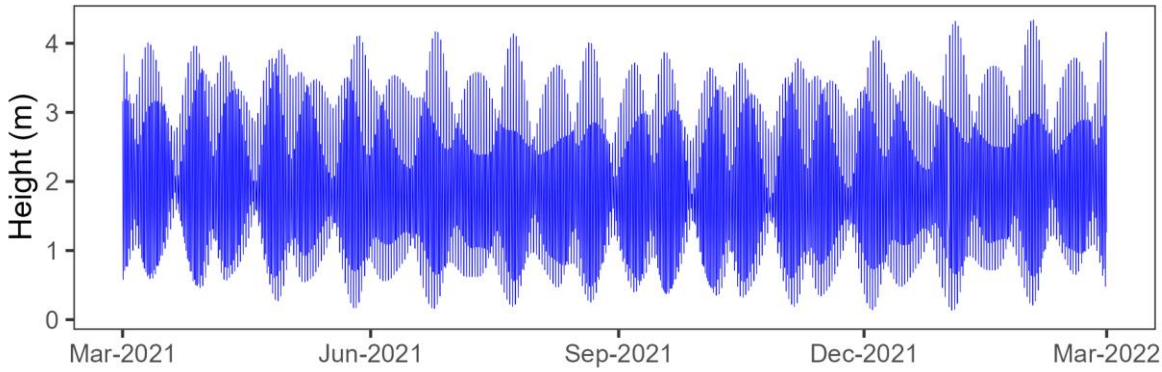

Figure 3-4 *Tide height predictions above LAT at Shute Harbour (Station P030003A).*

3.2 Logger data

3.2.1 Water temperature

Daily median water temperature ranged from 21.9 to 29.6 °C at Cairn Beach and 21.5 to 30.1 °C at Tongue Bay during the deployment period (Figure 3-5). Water temperature showed a strong seasonal pattern at both sites. Median daily water temperature was similar between sites with generally less than 0.5 °C difference (Figure 3-6). There appeared to be a seasonal pattern in temperature differences between the two sites, with water temperature comparatively warmer at Cairn Beach in winter, and warmer at Tongue Bay during summer. A longer dataset would be required to tease out if this pattern is significant. Sub-daily fluctuations in water temperature were likely attributed to a combination of both diel (day/night) and tidal influences.

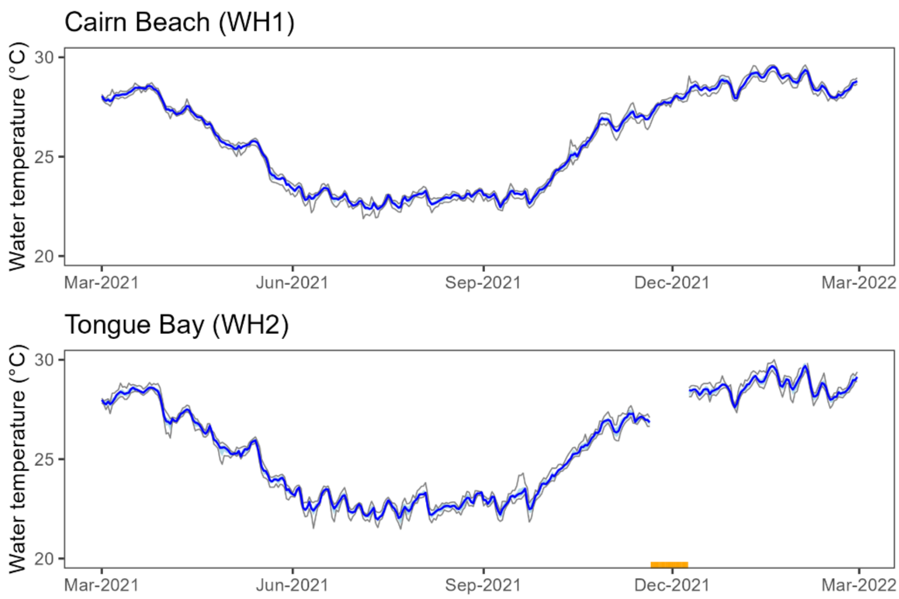

Figure 3-5 *Water temperature measured by the data logger instruments at Cairn Beach and Tongue Bay. Daily median temperature (blue), interquartile range (light blue), and daily minimum and maximum (grey). Periods of missing data are indicated by the orange bar.*

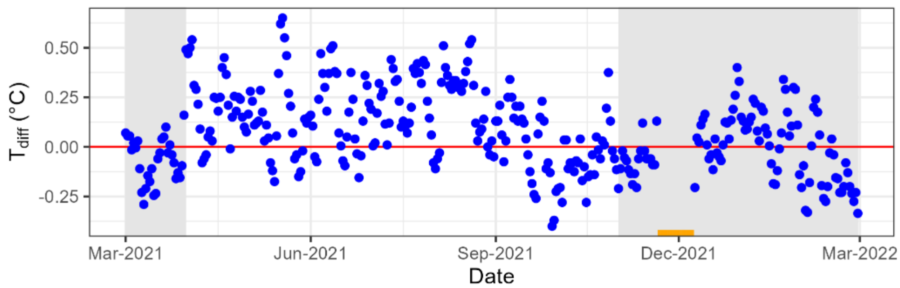

Figure 3-6 *Difference in daily median water temperature (T_{diff}) between the Cairn Beach and Tongue Bay sites. The water temperature is warmer at Cairn beach on days when T_{diff} value is positive, and warmer at Tongue Bay when value is negative. Grey shading indicates the nominal wet season. Periods of missing data are indicated by the orange bar.*

3.2.2 Water depth and wave height

The location where the loggers were deployed was in approximately 10 m of water at Cairn Beach and 8 m at Tongue Bay (Figure 3-7). The logger depth changed between deployments due to slight changes to where the instrument frame was positioned each time it was redeployed. This was more apparent at the Cairn Beach site. Water level followed the semi-diurnal tide with spring and neap cycles evident. The root means square (RMS) depth is shown in Figure 3-8. RMS depth is an indicator of wave energy on the seafloor. There was very little wave activity at the Cairn Beach site with daily median RMS depth generally less than 0.005 m throughout the year (average = 0.003 m). Tongue Bay was more exposed to wave energy with a mean RMS wave height of 0.0171 m. The most active period saw RMS wave height of up to 0.36 m.

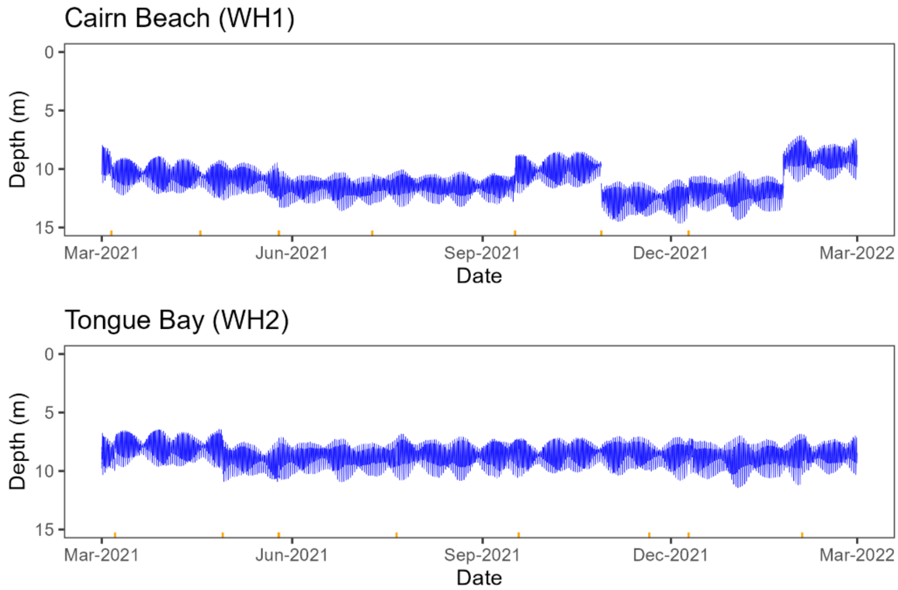

Figure 3-7 *Water depth measured by the data logger instruments at Cairn Beach and Tongue Bay. Periods of missing data are indicated by the orange bar.*

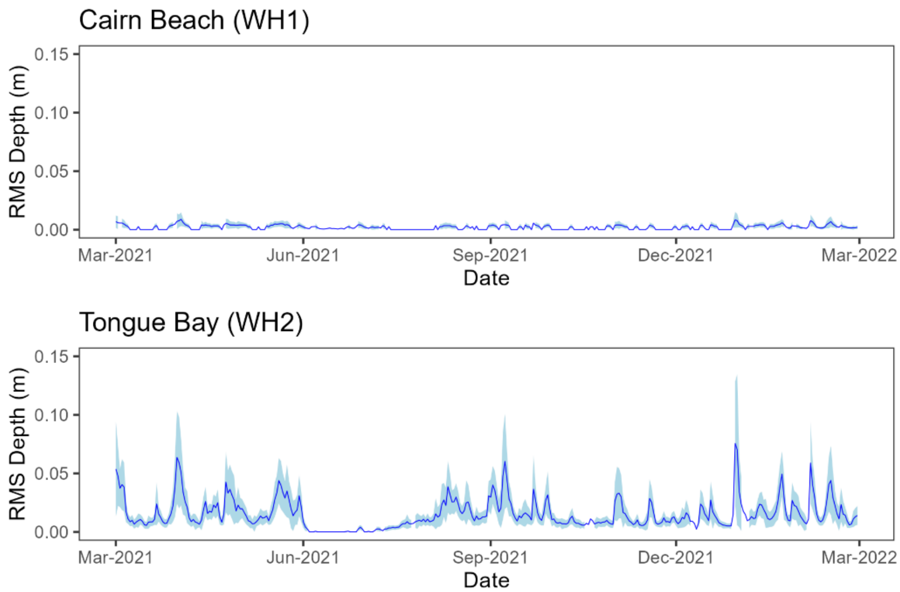

Figure 3-8 *Root mean squared (RMS) water depth measured by the data logger instruments at Cairn Beach and Tongue Bay. Shown is the daily median value (blue) and interquartile range (light blue). Periods of missing data are indicated by the orange bar.*

3.2.3 Photosynthetically active radiation (bPAR)

Benthic photosynthetically active radiation (bPAR) was measured at the two sites (Figure 3-9). The mean daily bPAR was 1.21 mol m^{-2} d^{-1} at Cairn Beach and 1.95 mol m^{-2} d^{-1} at Tongue Bay. Note that there are erroneously high values in February/March at Tongue Bay that are likely to be attributed to instrument error or a deployment irregularity.

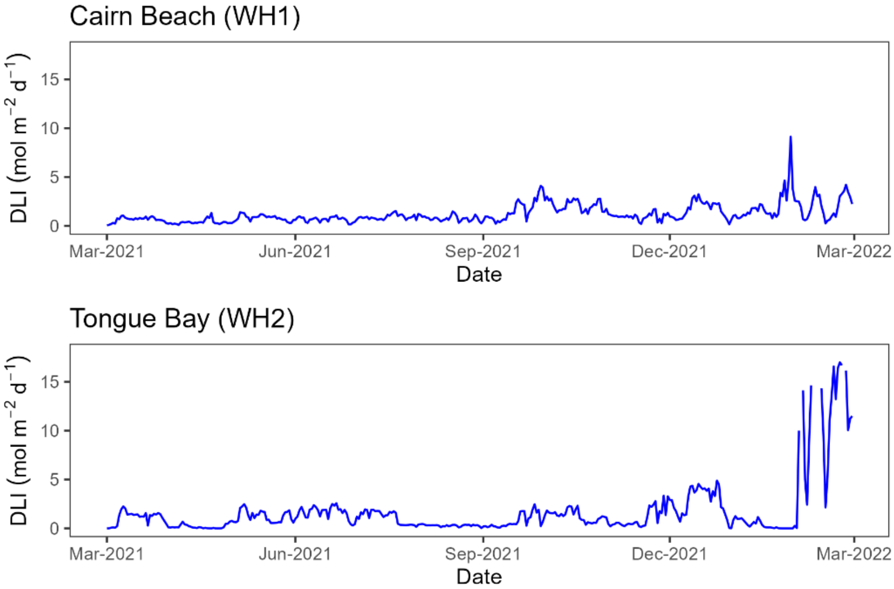

Figure 3-9 *Benthic photosynthetically active radiation (bPAR) presented as the daily light integral as measured by the data logger instruments at Cairn Beach and Tongue Bay. (Note that February/March unusually high values may be due to instrument error).*

3.2.4 Turbidity

Turbidity ranged from 0 to 72.5 NTUe at the Cairn Beach monitoring site, with a median value of 0.67 NTUe over the year (Figure 3-10). Turbidity ranged from 0 to 158 NTUe at the Tongue Bay monitoring site, with a median value of 0.46 NTUe over the year. Turbidity was generally driven by a combination of wave energy (high turbidity corresponds with spikes in RMS), and spring-neap tidal cycle, with higher turbidity more likely during spring phase of the tidal cycle.

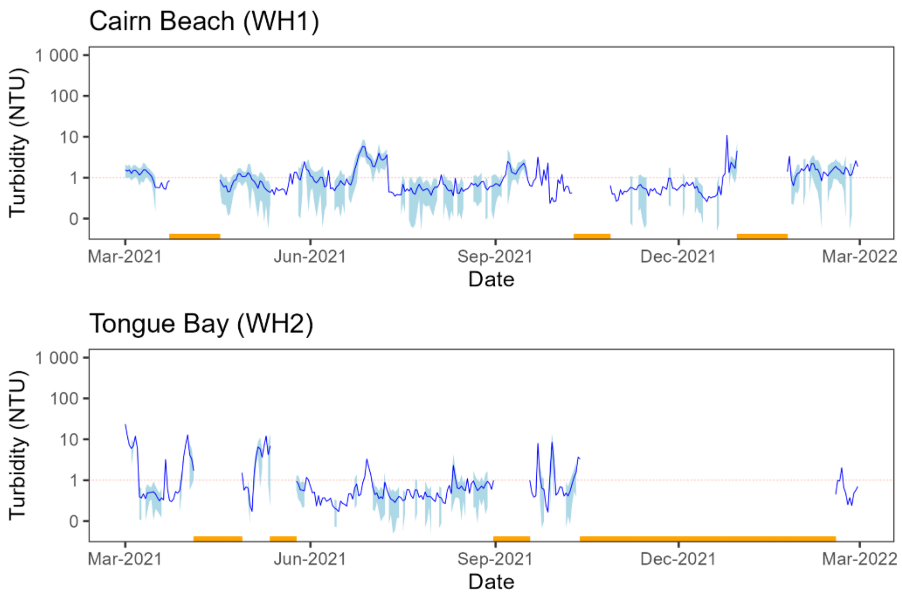

Figure 3-10 *Turbidity measured by the data logger instruments at Cairn Beach and Tongue Bay. Note logarithmic scale on y-axis. Shown is the daily mean value (blue) and standard deviation of the mean (light blue). Periods of missing data are indicated by the orange bar.*

3.3 Water samples

3.3.1 Field observations

The tourism operators recorded observations of conditions on the water at the time of each sampling and maintenance event (Table 3-1). Secchi disk depth ranged from 2.9 to 12 m (Figure 3-11). The median Secchi depth was 4.5 m for Cairn Beach and 4.0 m at Tongue Bay. There was no significant difference in Secchi depth between the two sites (one-way ANOVA: ($F(1,21) = 0.92$, $P = 0.17$). Weather and sea conditions varied between sampling trips and sites, although water quality sampling was generally done on calm days with light breezes. Tourist involvement was recorded on the field datasheets from May 2020 onwards. A total of 13 tourists were recorded on the field datasheets to have been involved in the project. There were 3 tourists with Ocean Rafting in August 2020, and 10 tourists with True Blue Sailing in October 2020.

Table 3-1 *Water quality measurements and observations recorded by tourism operators as Cairn Beach and Tongue Bay.*

Site Name	Site Code	Date	Time	Secchi depth	Cloud cover	Wind	Sea surface	Surface scum/slick
				m	%	knots		
Cairn Beach	WH1	16/03/2021	08:46	5.5	25	10	Ripples	Nil
		06/05/2021	10:00	7	20	2	Clear	Nil
		25/05/2021	11:30	4	50	0 - 5	Wavelets	Nil
		17/06/2021	10:00	6	5 - 10	4	Calm	Nil
		17/07/2021	16:00	7	15	3-8	0.5 m	20%

		14/09/2021	16:00	NR	0	2	Calm	Nil
		09/12/2021	10:05	4	20	3	Calm	Trich
		02/02/2022	NR	NR	5	5	Smooth	Trich
Tongue Bay	WH2	10/03/2021	11:05	4	40	5	Calm	Nil
		24/04/2021	10:30	3	100	5	Glass	Nil
		25/05/2021	10:45	3.6	60	10	Wavelets	Nil
		18/06/2021	14:00	7	0	5 - 10	Small wavelets	Nil
		17/07/2021	14:00	4	0	0	-	Nil
		03/09/2021	11:15	3	80	20	Wavelets	Nil
		29/10/2021	12:15	3	10	5 - 10	-	Trich
		09/12/2021	12:12	6.2	40	8	Slight waves /calm	Slick
		26/01/2022	12:30	4	20	20	1m swell ESE	Nil

NR = not recorded. Trich = *Trichodesmium spp.*

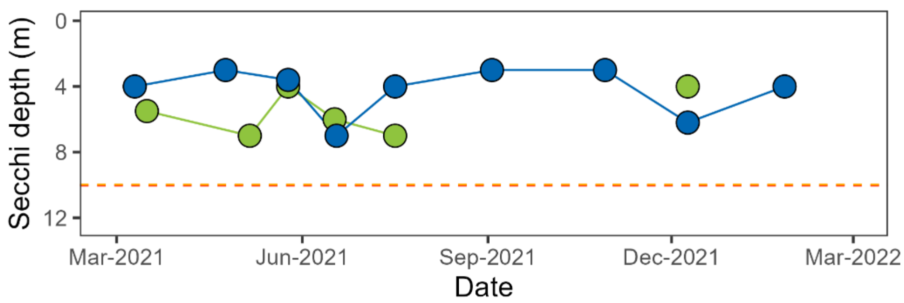

Figure 3-11 *Secchi depth measured by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown (both = 10 m).*

3.3.2 Physico-chemical parameters

Water samples collected from the monitoring sites were measured in the laboratory for electrical conductivity, total suspended solids (TSS), and pH (Figure 3-12). Conductivity ranged from 51.6 to 53.1 mS cm^{-1} (median = 52.5 mS cm^{-1}) at Cairn Beach and ranged from 51.6 to 53.2 mS cm^{-1} (median = 52.3 mS cm^{-1}) at Tongue Bay and was within expected range of seawater with limited freshwater inputs. TSS ranged from 1.4 to 3 mg L^{-1} (median = 1.8 mg L^{-1}) at Cairn Beach and ranged from 1.1 to 2.2 mg L^{-1} (median = 1.6 mg L^{-1}) at Tongue Bay. pH ranged from 8.13 to 8.32 (median = 8.17) at Cairn Beach and ranged from 8.1 to 8.27 (median = 8.15) at Tongue Bay. pH was within the 20th and 80th percentiles of the DEHP water quality objectives for open coastal waters.

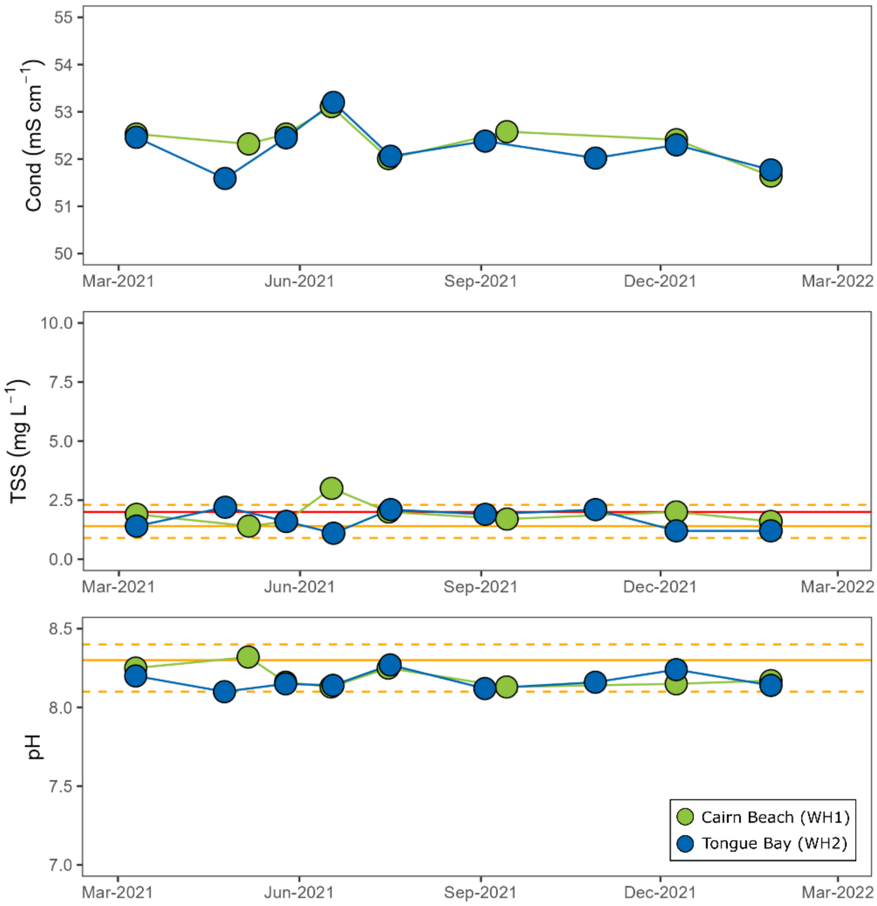

Figure 3-12 *Electrical conductivity (Cond), total suspended solids (TSS), and pH from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.*

3.3.3 Nutrients

Water samples were analysed for nitrogen and generally exceeded water quality thresholds (Figure 3-13). Total nitrogen concentrations ranged from 92 to 184 µg N L^{-1} (median = 120 µg N L^{-1}) at Cairn Beach and ranged from 96 to 124 µg N L^{-1} (median = 109µg N L^{-1}) at Tongue Bay. Particulate nitrogen ranged from 4 to 79 µg N L^{-1} (median = 14.5 µg N L^{-1}) at Cairn Beach and ranged from 4 to 37 µg N L^{-1} (median = 13 µg N L^{-1}) at Tongue Bay. Nitrate-nitrite concentrations ranged from 0.5 to 26 µg N L^{-1} (median = 3 µg N L^{-1}) at Cairn Beach and ranged from 0.5 to 5 µg N L^{-1} (median = 2 µg N L^{-1}) at Tongue Bay.

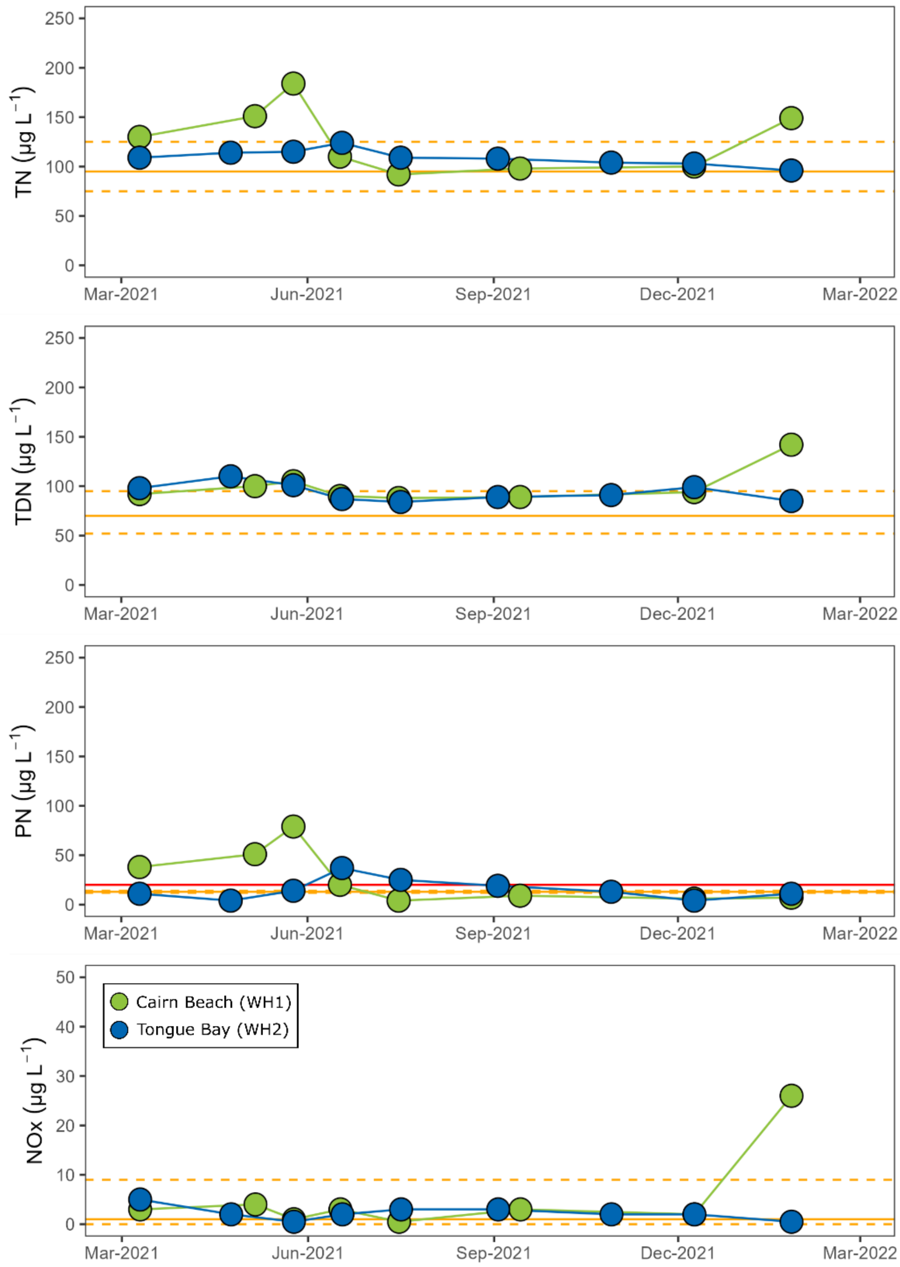

Figure 3-13 *Total nitrogen (TN), total dissolved nitrogen (TDN), particulate nitrogen (PN), and nitrate-nitrite (NOx) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). Note different y-axis. The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.*

Water samples were analysed for phosphorus and generally within acceptable range for WQ thresholds (Figure 3-14). Total phosphorus concentrations ranged from 4 to 8 µg P L^{-1} (median = 5.5 µg P L^{-1}) at Cairn Beach and ranged from 3 to 8 µg P L^{-1} (median = 6 µg P L^{-1}) at Tongue Bay. Particulate phosphorus concentrations ranged from 1 to 3 µg P L^{-1} (median = 1 µg P L^{-1}) at Cairn Beach and ranged from 0 to 2 µg P L^{-1} (median = 1 µg P L^{-1}) at Tongue Bay.

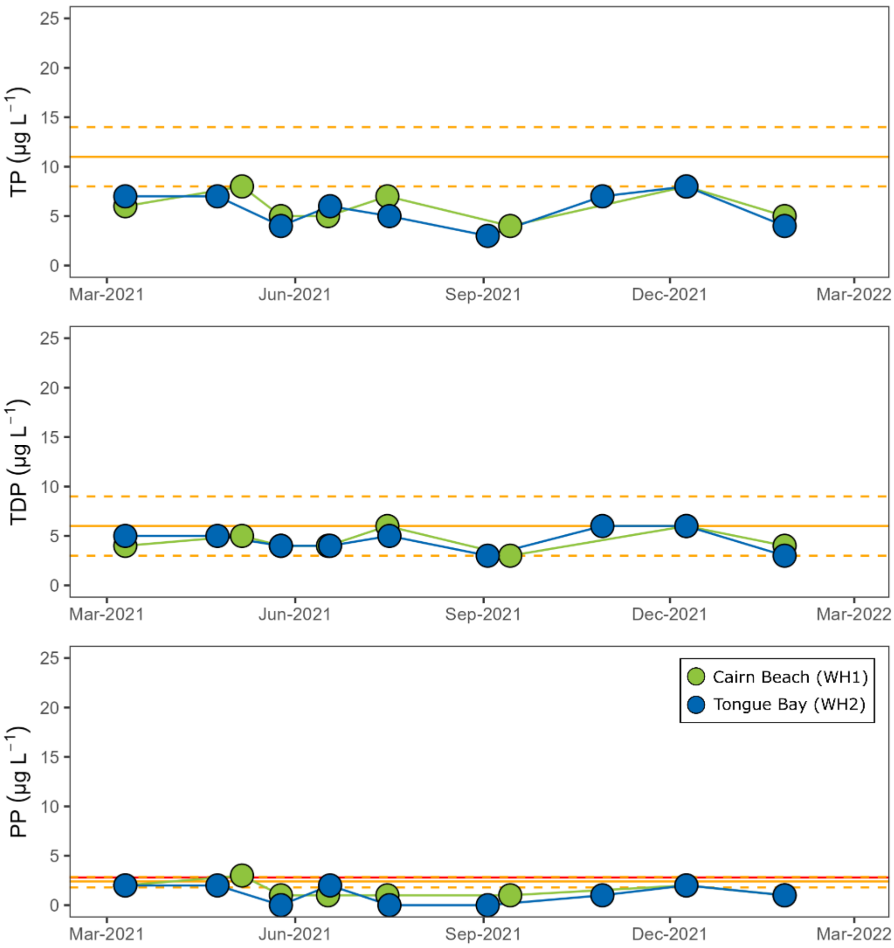

Figure 3-14 *Total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown*

3.3.4 Chlorophyll *a*

Chlorophyll-*a* concentrations ranged from 0.31 to 1.49 µg L^{-1} (median = 0.405 µg L^{-1}) at Cairn Beach and ranged from <0.20 to 0.81 µg L^{-1} (median = 0.39 µg L^{-1}) at Tongue Bay (Figure 3-15).

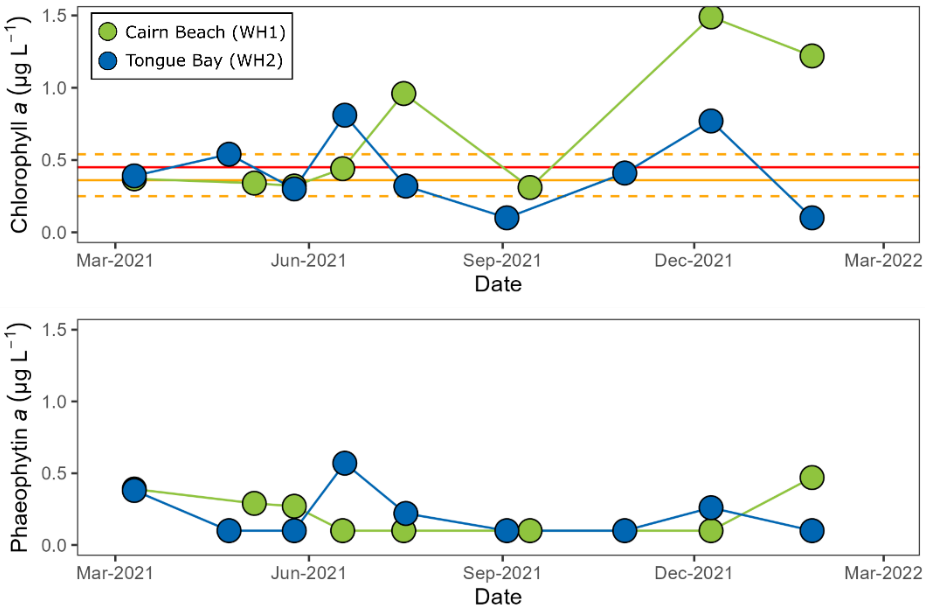

Figure 3-15 *Chlorophyll-a from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.*

3.3.5 Water quality indices

An Inshore Water quality index was calculated following the methodology used in the Mackay-Whitsunday-Isaac 2020 Report Card (MWIHRRP, 2021), based on the methodology developed by Lønborg et al. (2016) and Waterhouse et al. (2017). The reported concentrations used were sourced from the Proserpine River, Whitsunday Island, and O'Connell River Basins

> *"Nutrient scores for inshore zones are based upon reported concentrations of oxidised nitrogen (NO_x), particulate phosphorus (PP) and particulate nitrogen (PN), while the water clarity indicator category is informed by Secchi depth, TSS and turbidity indicators. Condition scores are calculated by comparing annual means or medians to guideline values (with the appropriate statistic identified within the guidelines), for each indicator at each site within a zone. Preliminary scores are aggregated across sites and indicators to produce the final nutrients, Chl-a and water clarity indicator category scores within a zone."*

Water quality indices were calculated from the results of twelve sampling events between 01/03/2021 and 28/02/2022. The median value of each parameter was compared to DEHP water quality objective (WQO) median values (Figure 3-16). Condition scores were calculated for chlorophyll-*a*, nutrients, and water clarity indicators following the methodology used in the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac report cards (MWIHRRP, 2021) (Figure 3-17). The chlorophyll-*a* indicator score was -0.170 (Moderate) for Cairn Beach, and -0.115 (Moderate) for Tongue Bay. The nutrients indicator score, which is based on PN, PP and NOx concentrations was -0.0525 (Moderate) for Cairn beach, and 0 (Moderate) for Tongue Bay. The water clarity indicator score, which is based on TSS, turbidity and Secchi depth was -0.580 (Poor) for Cairn Beach, and -0.596 (Poor) for Tongue Bay. The overall regional score based on the aggregated scores of the two sites was calculated to be -0.252 (Moderate).

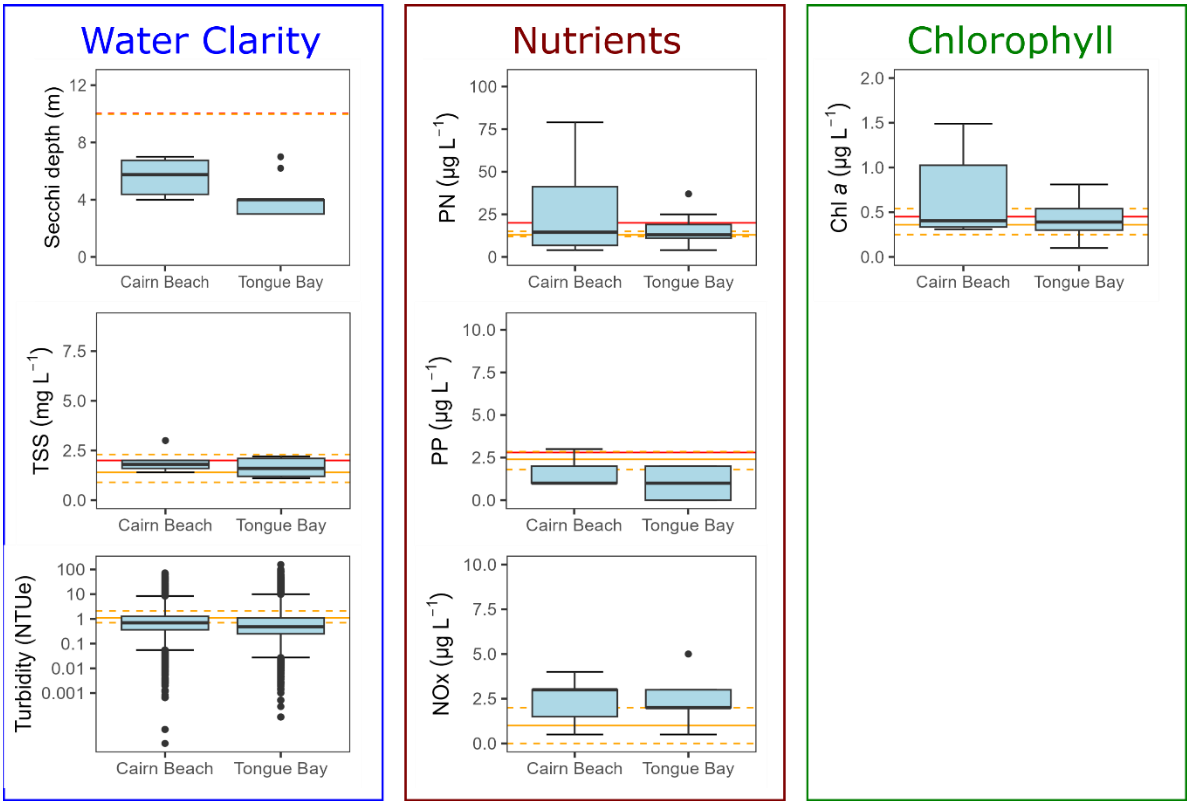

Figure 3-16 *Boxplots of each of the parameters used to calculate water quality index. The water clarity score is composed of Secchi disk depth, total suspended solids (TSS), and turbidity. The nutrients indicator is composed of particulate nitrogen (PN), particulate phosphorus (PP), and oxidised nitrogen (NOx) concentrations. The chlorophyll score is composed of chlorophyll-a (Chl a) concentration. Note the y-axis on the turbidity plot is logarithmic (log_{10}). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives median (orange line) and are shown.*

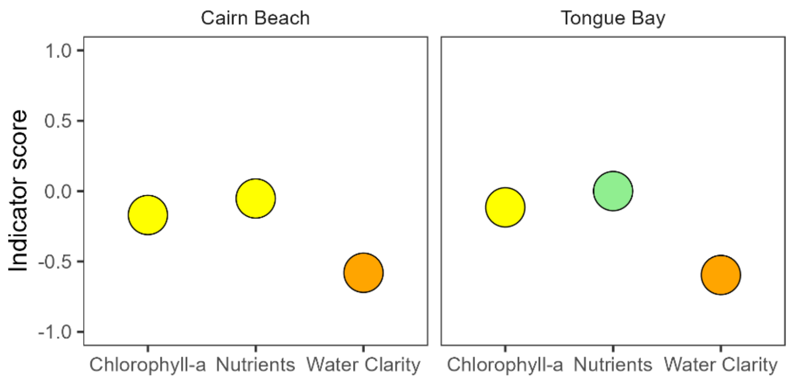

Figure 3-17 *Marine offshore water quality indicator scores calculated for Cairn Beach and Tongue Bay for the reporting period. The indicator scores are colour coded to Very Good (dark green), Good (light green), Moderate (yellow), Poor (orange), and Very Poor (red).*

4 DISCUSSION

4.1 Water quality at Whitsunday sites

Results from the first year of monitoring have been compared to the GBRMPA water quality guideline trigger values (GBRMPA, 2010) and DEHP water quality objectives for Whitsunday Island (DEHP, 2009). The Great Barrier Reef Marine Park Authority (GBRMPA) produce water quality guideline trigger levels based on annual mean values. For the purpose of comparing water quality data to DEHP water quality objectives the sites at Cairn Beach (WH1) and Tongue Bay (WH2) are classed as open coastal waters. Specifically, the two sites were located in '*HEV2381 high ecological value open coastal waters (Whitsundays - south to Thomas Island) seaward of the plume line shown in WQ1222*'. Annual median values are compared to the DEHP water quality objectives.

The water quality monitoring program is a tool to assess and track the ambient water quality conditions across the region. Results of the program may be used to indicate whether measures to improve regional water quality (such as DIN and sediment reduction targets) are effective at achieving their purpose. The program is not designed to specifically determine what is driving water quality conditions but may be helpful in a local context to understand the regional processes which influence water quality. For example, by monitoring water temperature we can observe local changes which are important to the habitat and biota but need much broader scaled tools to understand the climatic drivers causing an observed local increase in water temperature. In this case we rely on more resourced agencies such as the Bureau of Meteorology to explain these larger scale processes. Similarly, by monitoring water clarity at a site scale we are then able to track how changes over time are driven by certain climatic, hydrological, and oceanographic processes. As monitoring programs such as this one mature, the additional temporal element of the data collected will help to further link conditions to processes, and in itself the environmental dataset becomes a resource which can be utilized to explore these topics further.

Comparison to report card scores: Overall, the Whitsunday region's water quality scored as 'poor' based on results obtained from the two monitoring sites in this program. This outcome appears to fit with previous water quality scores calculated by the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Card from 2014-2019 that ranged from 'moderate' to 'very poor', however, the over two most recent report cards, 2020 and 2021, the regions water quality index improved to achieve a 'moderate' score (Figure 4-1). In contrast, the GBRMPA marine monitoring program (MMP) long-term water quality index for the Whitsundays region has been in decline since monitoring started in 2007, with water quality in the region most recently assessed to be 'moderate' (Figure 1-1). While the MMP water quality index cannot be directly compared to the scores calculated in this report due to differences in how the scores and WQ index are calculated, they do show that sub-optimal water quality in the Whitsunday region has been and is an ongoing long-term issue. Continual monitoring into future years will allow the program to assess whether water quality at these two sites continue to track similarly to nearby monitoring sites from the other programs. While water quality scores this year are similar, the location of the Cairn Beach and Tongue Bay sites are unique from other water quality monitoring sites in the region as they fall in the high ecological value waters situated offshore of the plume line.

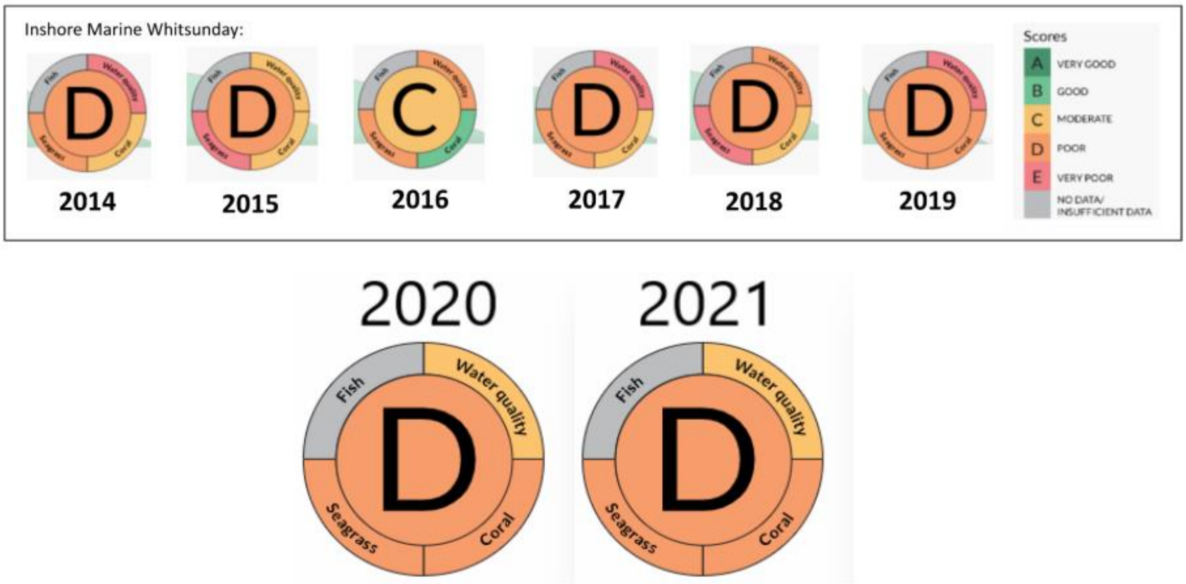

Figure 4-1 *Results of the Inshore Marine Whitsunday Environmental component of the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Cards from 2014 to 2021. Source: https://healthyriverstoreef.org.au/report-card-results/*

4.1.1 Water clarity

The Secchi disk depth mean annual trigger level is 10 m for open coastal, hence the median values reported in this study (Cairn Beach = 5.75 m, Tongue Bay = 4.0 m) exceed this trigger level (i.e., a shallower Secchi depth = lower water clarity). The turbidity mean annual guideline value is 1.5 NTU. The mean annual turbidity value was 1.06 NTUe at Cairn Beach and 1.52 NTUe at Tongue Bay. The total suspended solids (TSS) mean annual guideline value is 2 mg L^{-1} for open coastal settings. The mean TSS concentration measured was 1.90 mg L^{-1} at Cairn Beach and 1.64 mg L^{-1} at Tongue Bay. Hence, neither site exceeded the guideline trigger value for total suspended solids. The possible drivers that affect water clarity at these sites include wave resuspension, transport of sediment with tidal currents, increased sediment transport from rivers, and/or redistribution of sediment within the marine environment. There is evidence of the spring-neap tidal cycles being a significant driver of water clarity during the monitoring period at these sites, with lower light conditions (bPAR) and higher turbidity occurring when tidal currents are stronger during the spring tides. Periods of higher wave activity (RMS depth) were also precursors for increased turbidity and decreased water clarity. The two sites in this program are located offshore of the plume line, hence in lieu of any major river discharge events during the monitoring period the daily to weekly changes in turbidity detected by the loggers are likely due to resuspension of materials already deposited in the area rather than 'fresh' sediment contributed from rivers. However, the contribution of anthropogenic derived sediment, and the extent to which this exacerbates natural sediment resuspension, is unclear. Hence, it is difficult to isolate whether the measured turbidity and TSS is primarily due to either resuspension or riverine inputs from the logger data alone. For example, sediment delivery from rivers has risen since European settlement (McCulloch et al., 2003), and 'wet years' throughout longer-term decadal wet-dry climatic cycles generally see increased sediment delivery (Brodie et al., 2010; Cantin et al., 2019). Catchments contributing sediment to the Whitsunday region include the O'Connell and Pioneer Rivers, along with Fitzroy River to the South (Baird et al., 2019). To fully assess these kinds of questions we would need to turn to much broader scoped studies which incorporate sediment budgets, sediment transport models, and geochemical tracer studies.

4.1.2 Water temperature

The GBRMPA water quality guideline trigger level for sea temperature is set at increases of no more than 1 °C above the long-term average maximum (GBRMPA, 2010). There is no long-term (20 year) data for the two sites in this study, so we are unable to directly assess how measured water temperature compares to the guidelines. Nonetheless it was evident that water temp was high at both Cairn Beach and Tongue Bay for approximately one week in March 2021. The Australian Institute of Marine Science (AIMS) has been monitoring water temperature at nearby sites dating back multiple years as part of their Sea Water Temperature Observing System. The temperatures measured in this study are comparable to maximum mean monthly temperatures recorded by AIMS over previous years. Comparison to long term Hook Island temperature data (AIMS) shows temperature was above average for approximately one week in March 2021 and exceed the guideline trigger value of 1°C above long term maximum temperature at both sites (Figure 4-2). There was an unseasonal warm period at the end of July 2021 where water temperature exceeded the guideline trigger value of 1°C above long term maximum temperature at both sites. Note that the guideline trigger value should be interpreted from long term (20 year) data of the actual site of interest. In this case a nearby proxy has been used (Hook Island – AIMS) with a 7 ½ year dataset. Hence, interpretation of the Cairn Beach and Tongue Bay temperature records from this program against guideline values should be viewed as an exploratory exercise only. Warmer water temperatures can result in coral bleaching, and if the warming continues bleaching can progress to mortality.

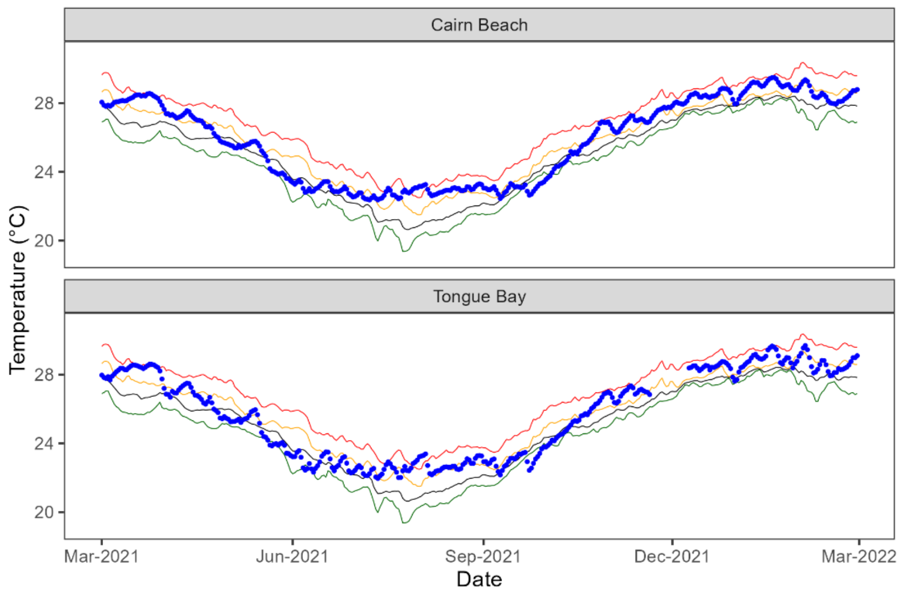

Figure 4-2 *Daily mean temperature measured at Cairn Beach and Tongue Bay (blue), compared to average (black), minimum (green), maximum (orange), and maximum + 1°C guideline value (red) derived from Hook Island AIMS data.*

4.1.3 Nutrients and Chlorophyll *a*

The GBRMPA mean annual guideline trigger values for nutrients are 20 µg N L^{-1} for particulate nitrogen (PN) and 2.8 µg P L^{-1} for particulate phosphorus (PP) with a ±20 % seasonal adjustment (GBRMPA, 2010). The mean particulate nitrogen concentration measured was 26.75 µg N L^{-1} at Cairn Beach and 15.3 µg N L^{-1} at Tongue Bay. Hence, PN exceeded the guideline trigger values at Cairn Beach but not at Tongue Bay. The mean particulate phosphorus concentration measured was 1.5 µg P L^{-1} at Cairn Beach and 1.1 µg P L^{-1} at Tongue Bay. PP did not exceed the guideline trigger value. Excess nitrogen in the system may originate from terrestrial sources, for example from fertilizer runoff, organic matter, urban areas, and attached to sediments.

Chlorophyll-*a* values measured in the Whitsunday were similar between sites with a mean concentration of 0.68 µg L^{-1} at Cairn Beach and 0.42 µg L^{-1} at Tongue Bay. The GBRMPA guideline trigger value for Chlorophyll *a* is 0.45 µg L^{-1} calculated as mean annual value. The Chlorophyll guideline values are adjusted for season with the value being ~40% higher in summer (~0.63 µg L^{-1}) and ~30% lower in winter (~0.32 µg L^{-1}) than mean annual values (GBRMPA, 2010). Hence, the Chlorophyll-*a* values during the monitoring period were considered elevated in relation to the guideline trigger values at Cairn Beach but not at Tongue Bay.

4.2 Monitoring and Evaluation

As part of ongoing monitoring and evaluation of the Whitsunday Water Quality Monitoring Blueprint for Tourism Operators, the program to date has been assessed against the following three criteria:

1. What is the percentage data recovery from the logger instruments for each deployment? Were there any technical issues with data acquisition (i.e., sensor fouling, instrument malfunction)?
2. Is the quality of data collected at each site sufficient? (i.e., all required measurement parameters have been recorded in the field, water samples have been collected and transported correctly, identification and removal of erroneous logger data and outliers, frequency of measurements is sufficient)
3. Is the monitoring data collected at the sites sufficient for providing additional water quality information for the region (long term comparison to each other and MMP sites)?

4.2.1 Data recovery

Data recovery from the loggers ranged between sensors at each site (Table 4-1, Figure 4-3). Generally, the water temperature and pressure sensors (which is used to calculate depth and RMS depth) gave good records for the duration of deployments. The temperature sensors provided data for 99.9 % of the time at Cairn Beach, and 94.8 % of the time at Tongue Bay. There was a period of missing temperature data for Tongue Bay in Nov-dec 2021 due to instrument malfunction. The pressure and PAR sensors provided data for 100 % of the time at both Cairn Beach and Tongue Bay. The turbidity sensors on the MGL loggers are susceptible to fouling and rely on a mechanical wiper to keep the sensors clean throughout the deployment. The turbidity sensors provided data for 81.1 % of the time at Cairn Beach and 50.2 % of the time at Tongue Bay.

Table 4-1 *Summary of data recoveries (percent) for each sensor on the MGL logger instrument at Cairn Beach and Tongue Bay over this reporting period*

Sensor	Cairn Beach	Tongue Bay
Temperature	99.9	94.8
Pressure	100	100
PAR	100	100
Turbidity	81.1	50.2

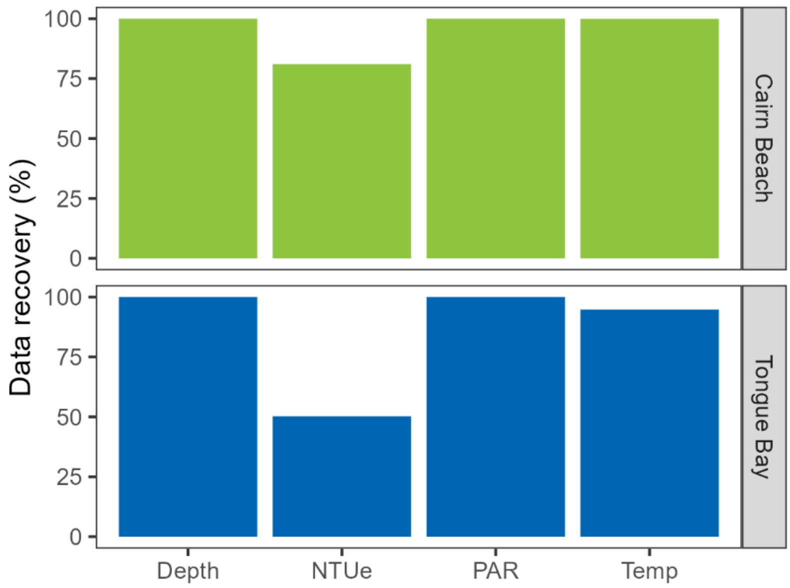

Figure 4-3 *Percentage data recovery from each sensor on the MGL logger instruments at Cairn Beach (green) and Tongue Bay (blue).*

4.2.2 Data quality

Water samples

Analysis of water samples was conducted in the TropWATER laboratory at the JCU Townsville campus. The laboratory has QA/QC procedures in place which cover sampling handling and analysis once the samples are received by the laboratory. The values reported for all parameters fell within expected natural range (i.e. no obvious contamination).

Tourism operators

This water quality monitoring program is a citizen science initiative designed to give tourism operators from the Whitsundays greater input into the stewardship of the region's environmental assets and attractions. It should be noted that water quality monitoring requires a methodological approach and a high degree of care and planning, conditions which may be hard to achieve as part of a busy hospitality-focused charter. Despite the training and support given by TropWATER scientists and Reef Catchments staff there were numerous issues that affected the quality of the data outcomes. Some of these issues were due to high staff turnover during Covid-19 that left fewer trained personnel to conduct the monitoring. While improvements have been made over the 12 months, there have still been numerous occurrences of datasheets being returned by the operators incomplete. It is recommended that water sampling teams be reminded of the need to fill out field data sheets in full, in order to reduce any problems with the post processing of data in the laboratory and office. The process of completing the field data sheets was covered during the training, however, additional follow up checks might be necessary in order to prevent these problems occurring in the future.

4.2.3 Data sufficiency

The two water quality monitoring sites from this project increase the density of water quality monitoring sites within the region (Figure 4-4). These sites compliment the numerous water quality monitoring sites, including instruments which log data, throughout the Whitsunday region. The marine monitoring program (MMP) coordinated by the Australian Institute of Marine Science (AIMS) has 11 water quality sites, of which

4 are moorings with instrumentation. The data from these AIMS sites are released on an annual basis following extensive quality control and reporting. Only 3 of these AIMS sites are within the Whitsunday Zone as defined by the Partnership/report card. Hence, the two additional sites from this program increases the number of sites available within the zone to 5 for calculating water quality scores for the report card. North Queensland Bulk Ports (NQBP) have established ambient marine water quality monitoring sites adjacent to port facilities to the north and south of the Whitsunday region. As this project matures the end users may wish to compare the data from the two sites in this project to the nearby MMP and NQBP sites to determine whether sites are suitably dissimilar to other sites within the region.

Long term water temperature data was sourced from the AIMS Sea Water Temperature Observing System which has been used here to calculate the 20 year average temperatures for guideline exceedances (AIMS, 2017). Waverider buoys are located to the north (Abbot Point) and south (Mackay Inner, Mackay Outer, Hay Point) of the Whitsunday region. These buoys provide wave height and water temperature data which may be compared to water temperatures measured at the Whitsunday sites to assess whether trends and anomalies in water temperature are due to local or regional patterns.

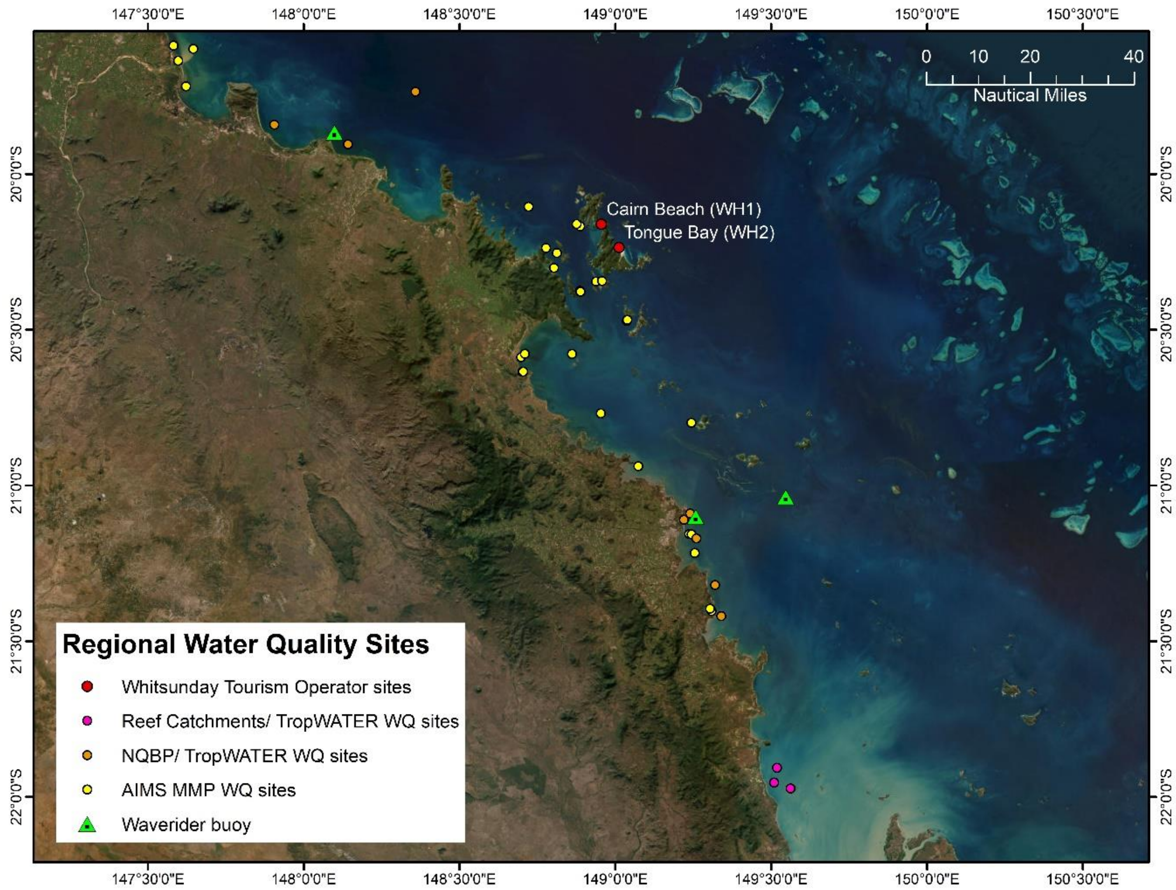

Figure 4-4 *Monitoring sites from other water quality programs operating in and adjacent to the Whitsunday region*

4.3 Concluding remarks

The Whitsunday Water Quality Monitoring Blueprint for Tourism Operators has been in operation since 2020 and will continue to generate useful data for the region and potentially contributing to regional report cards once levels of confidence are improved. Tourism operator's eagerness to participate and complete the water sampling proficiently is crucial for the long-term success of the program.

Overall, water quality indices improved in 2021-2022 compared to the 2020-2021 reporting period. Improvements were found in the nutrient indices for both Cairn Beach (from poor to moderate) and Tongue Bay (from moderate to good). Water clarity indices improved at Tongue Bay (from poor to moderate), however did not change at Cairn Beach (still poor). Chlorophyll-*a* indices for Cairn Beach and Tongue Bay also remained unchanged (moderate). The improvements in some indices can be attributed to both a reduced amount, and lower intensity of rainfall, as well as an absence of major meteorological events (e.g., tropical cyclones, troughs) over 2021-2022 compared to the previous reporting period. Nitrogen remains a nutrient of concern in the Whitsundays (as it is throughout the Great Barrier Reef lagoon) and constitutes a major water quality challenge for environmental managers and policy makers responsible for stewardship of the region.

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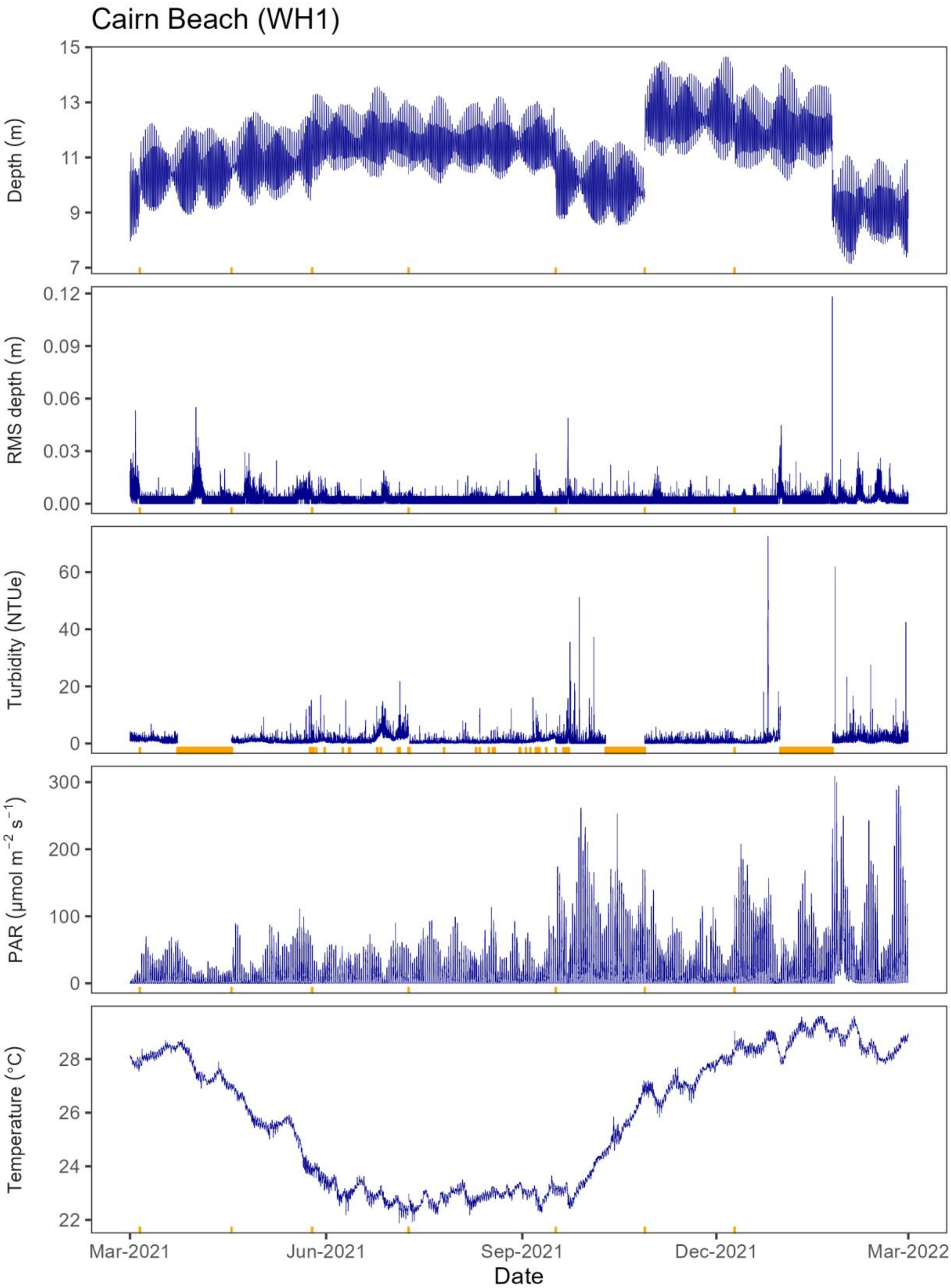
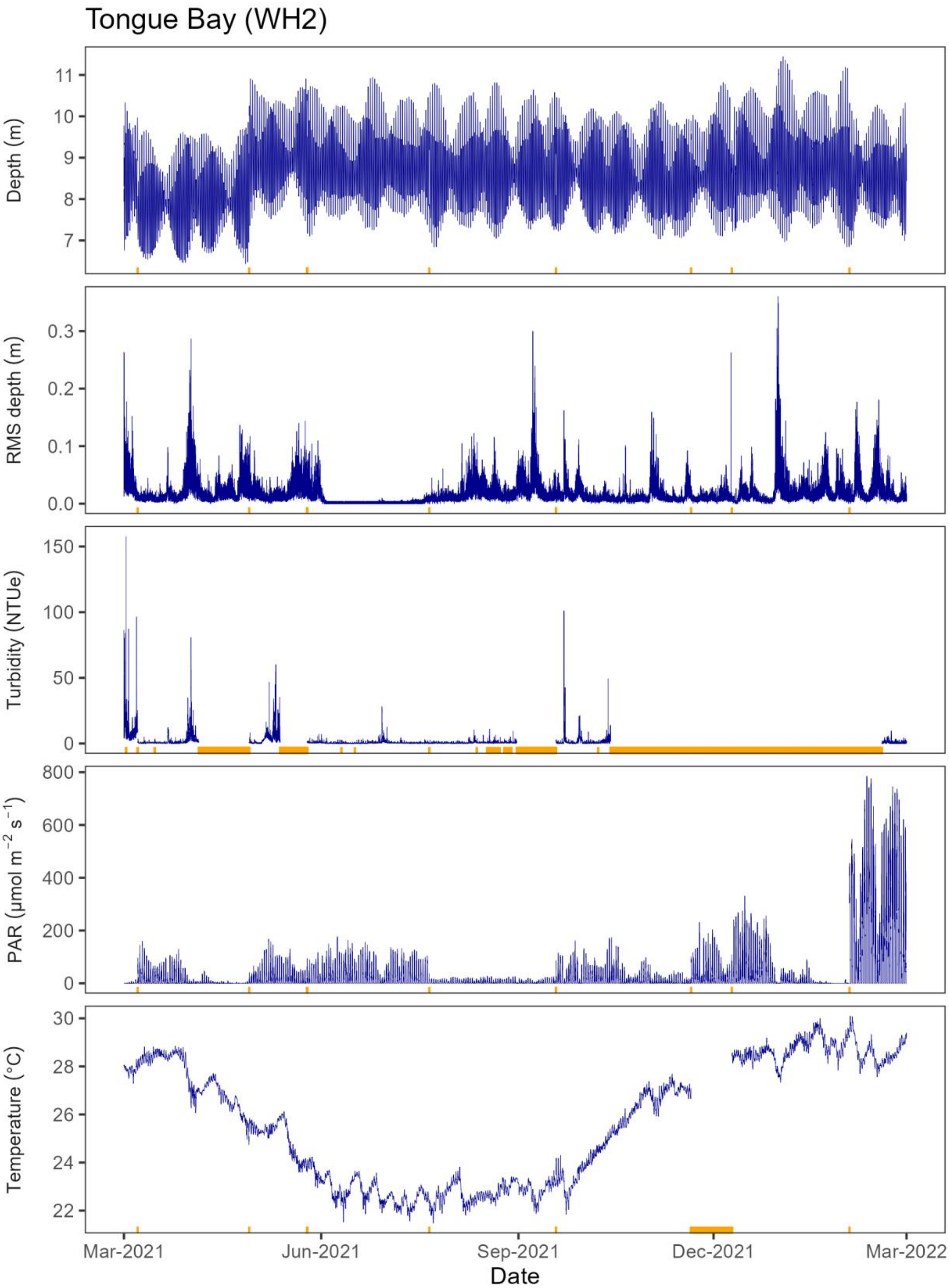
A1 APPENDIX

Raw 10 minute logger data collected from Cairn Beach and Tongue Bay




Tongue Bay (WH2)
Depth (m)
RMS depth (m)
Turbidity (NTUe)
PAR (µmol m⁻² s⁻¹)
Temperature (°C)
Mar-2021
Jun-2021
Sep-2021
Dec-2021
Mar-2022
Date

Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER)

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