Whitsunday Water Quality Monitoring Blueprint for Tourism Operators: Annual report 2022-2023

Jordan Iles, Paula Cartwright, and Nathan Waltham

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A Report for Reef Catchments (Mackay Whitsunday Isaac) Limited

Report No. 23/23

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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; Moran et al., 2023; Waterhouse et al., 2017) 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 was in decline for a number of years since monitoring started in 2007, although the water quality index has improved from 'poor' to 'moderate' since 2019 (Figure 1.1).

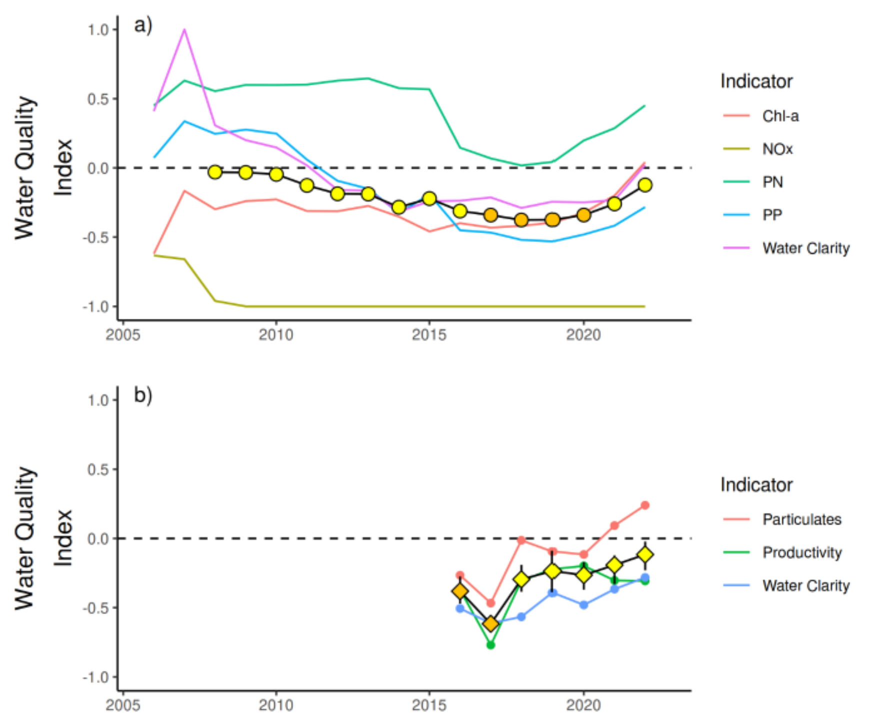

Figure 5-71: The Water Quality Index (WQ Index) for the Mackay-Whitsunday focus region. The WQ Index uses two formulations to communicate: a) long-term trend (based on pre-2015 sampling design) and b) the annual condition (based on post-2015 sampling design). WQ Index colour coding: ● / ◆– 'very good'; ● / ◆ – 'good'; ● / ◆ – 'moderate; ● / ◆ – 'poor'; ● / ◆ – 'very poor'. Indicators or sub-indicators that are used to calculate the WQ Index are shown as coloured lines on each plot. Error bars (vertical black lines) on the WQ Index represent the 95% quantile intervals. Calculations for both formulations are described in Appendix B.

Figure 1.1 Australian Institute of Marine Science (AIMS) Water quality index for the Mackay-Whitsunday focus region. Figure and caption reproduced from the 'Marine Monitoring Program: Annual report for inshore water quality monitoring 2021-2022' (Moran et al., 2023).

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, 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 2022 to February 2023.

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), with TropWATER staff looking after instrument deployment changeovers from August 2022.

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. The 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 2022 and February 2023

Date sampled	Cairn Beach (WH1)	Tongue Bay (WH2)
16/03/2022		True Blue Sailing (logger maintenance)
22/03/2022	Red Cat (water sampling)	
27/03/2022		Ocean Rafting (water sampling)
6/05/2022		Ocean Rafting (water sampling)
8/05/2022	Southern Cross (logger maintenance)	
9/05/2022	Red Cat (water sampling)	
2/06/2022		True Blue Sailing (logger maintenance)
21/06/2022	Whitsunday Bullet (logger maintenance)	
26/06/2022		Ocean Rafting (water sampling)
7/07/2022	Red Cat (water sampling)	
19/08/2022	TropWATER (water sampling & logger maintenance)	TropWATER (water sampling & logger maintenance)
18/11/2022		Ocean Rafting (water sampling)
26/11/2022	Red Cat (water sampling)	
2/02/2023	TropWATER (logger maintenance)	TropWATER (logger maintenance)

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 resulting from 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 01/03/2022 to 28/02/2023 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

TropWATER began transitioning to new IMO loggers (In-Situ Marine Optics, Bibra Lake, WA) in September 2021. MGL loggers (Marine Geophysics Laboratory, James Cook University, Townsville) were previously used across this water quality program. The last of the MGL loggers were removed from service in the Whitsunday region in August 2022 and replaced with the IMO loggers. Data continuity has been maintained for the program as both the MGL and IMO instruments measures water temperature, pressure (depth), photosynthetically active radiation (PAR), and turbidity.

A pair of IMO loggers were deployed on the seafloor at each site to record water quality measurements over the deployment period (Figure 2.3). Each logger independently records water temperature, and pressure at 10-minute intervals. The turbidity logger is also equipped with an optical turbidity sensor (model NTU-LPTBW, In-Situ Marine Optics, Bibra Lake WA) and the light logger is also equipped with a nine-wavelength multispectral light sensor designed for underwater applications (model MS9-LPTBW, Insitu Marine Optics, Bibra Lake WA). Both loggers are programmed to collect at each interval a burst of samples from each sensor at 5 Hz for 10 seconds.

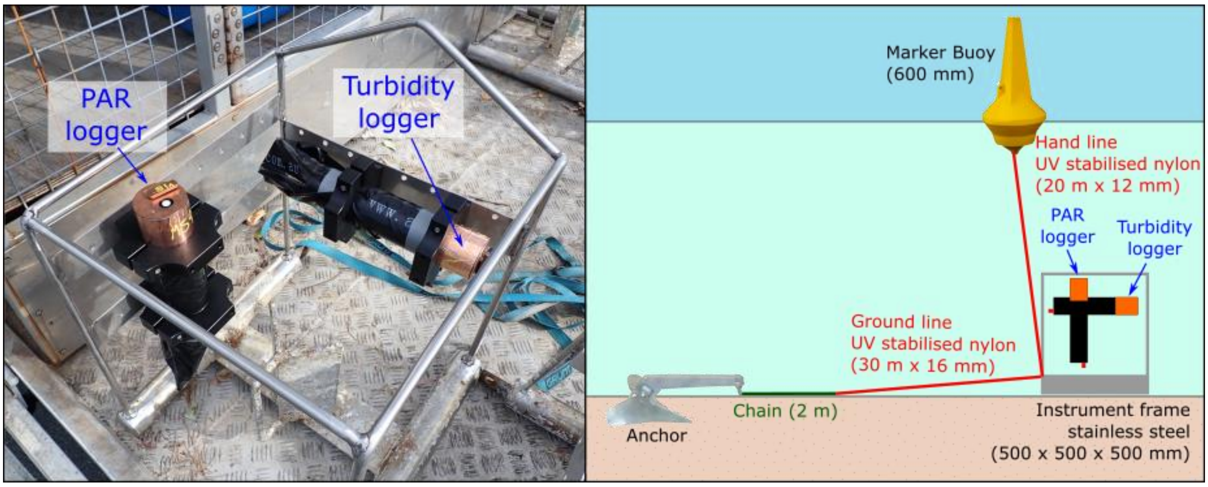

Figure 2.3 ***Diagram showing the mooring configuration for logger instrument deployments***

2.3.1 Water temperature

Water temperature measurements are obtained from a thermistor which protrudes from the base of each IMO logger. 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. 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.

2.3.2 Pressure

A non-vented pressure sensor is located at the base of each IMO logger. The pressure sensor is calibrated to calculate water depth (in meters) above the sensor. Average water depth (m) and RMS depth (m) are calculated for each 10-minute interval from the burst of 50 samples. Root mean square water depth (D_{rms}) – an indicator of wave energy – is calculated at each 10-minute interval with the following equation:

$$D_{rms} = \sqrt{\sum_{n=1}^{50}(D_n - \overline{D})^2/n} \qquad \text{[Equation 1]}$$

Where:

D_n is the nth of the 50 readings,

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

Note: RMS depth does not equal wave height.

2.3.3 Photosynthetically Active Radiation (PAR)

The light sensor consists of nine silicone photodiodes tuned to wavelengths ranging from 400 to 700 nm. Photosynthetically Active Radiation (PAR) is calculated as the integral across the nine wavelengths.

Light data at the seafloor is reported as benthic photosynthetically active radiation (bPAR) (units: µmol photons m^{-2} s^{-1}). The daily light integral (DLI) calculated as:

$$DLI = \sum_{i} bPAR_i * \frac{600}{1000000}$$

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

*b*PAR is the photosynthetically active radiation in µmol photons m^{-2} s^{-1}

i is each *b*PAR reading over a 24-hour period (µmol photons m^{-2} s^{-1})

600 is the time interval between readings (seconds)

1,000,000 is the unit conversion between µmol and mol

2.3.4 Turbidity

The optical turbidity sensor detects the scattering of light by particles suspended in the water column. The turbidity sensor contains an 890 nm infrared LED emitter and an infrared photodiode detector orientated 120° to the emitter, paired together in a synchronous scattered light detection mode. This design rejects ambient light not originating from the LED emitter (i.e., sunlight).

2.3.5 Anti-fouling strategy

Fouling of sensors in the marine environment is a constant battle. Physical sediment deposition, biofouling by barnacles and algae are common causes of fouling. IMO loggers used across this program are equipped with a copper faceplate and mechanical wiper to minimize physical and biological fouling. The sensor head is also wrapped with sacrificial copper tape to further inhibit biofouling of the sensors. The remainder of the logger body is wrapped in an opaque PVC sleeve to protect the temperature and pressure sensors, along with the master mode selector switch and bulkhead cable connector. Loggers are cleaned and serviced between deployments.

2.4 Quality control

Data acquired with IMO loggers go through a two-step automated and manual quality control process. The automated quality control process runs through twelve tests to determine data validity. The manual quality control process is completed by scientists to ‘catch’ any data abnormalities not detected by the automated step. Measurements collected from each sensor are assigned quality control flag values (Table 2.3). Data assigned QC flag 1 (good data) and QC flag 2 (probably good data) are included in the analysis, while data assigned QC flag 3 (suspect data) and QC flag 4 (bad data) are excluded from all analysis.

Table 2.3 Quality control flags assigned to sensor data during the automated and manual quality control steps

Flag description	QC Flag
No quality control	0
Good value	1
Probably good value	2
Suspect value	3
Bad value	4
Changed value	5
Interpolated value	8
Missing value	9

2.5 Water sampling and analysis

Tourism operators were trained in the correct procedures for collecting water sampling over a series of training days. Sampling methodology, sample bottles, preservation techniques and analytical methodology (NATA accredited) were in accordance with standard methods (i.e. DES, 2018; Standards Australia, 1998). Water samples were collected at each site for dissolved nutrients, total nutrients, pH, electrical conductivity/salinity, and total suspended solids. Water collected for dissolved nutrients was immediately passed through a 0.45 µm disposable membrane filter (Sartorius Minisart PES 0.45) fitted to a sterile 60 mL syringe (Livingstone) and placed into 10 mL sample tubes for later analysis in the laboratory. Water collected for total nutrients and pH/salinity were collected in 30 mL sample tubes. Water samples for total suspended sediments and chlorophyll *a* were collected in 1 L bottles. Water for chlorophyll-*a* determination was filtered through a glass-fibre filter (Whatman GF/F) with the addition of approximately 0.2 mL of magnesium carbonate within 12 hours of collection. Filters were then wrapped in aluminium foil and frozen. Nutrient samples were frozen at the earliest opportunity. The remaining water samples (pH/salinity, TSS) were refrigerated before delivery to the TropWATER laboratory.

Water samples are analysed in the laboratory using defined analysis methods and detection limits (Table 2.4). 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-NO_3^- F. Automated Cadmium Reduction Method'. Pigment determinations for chlorophyll *a* 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'. pH and electrical conductivity (EC) were measured in the laboratory with a benchtop meter. 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.

Table 2.4 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	0.2 µg L^{-1}
	Phaeophytin-*a*	10200-H	0.2 µg L^{-1}

3 RESULTS

3.1 Climate

The rainfall onset for the Whitsundays (Hamilton Island) occurred on 21/10/2022 (Figure 3.1). The rainfall onset is calculated as the date when the rainfall total reaches 50 mm since 1st September. The 2022-2023 wet season rainfall of 1203 mm was above average and annual rainfall of 1718 mm was above average (Figure 3.2). There was a notable large rainfall event in mid-January 2023, corresponding with a period of cooler weather across the region (Figure 3.3).

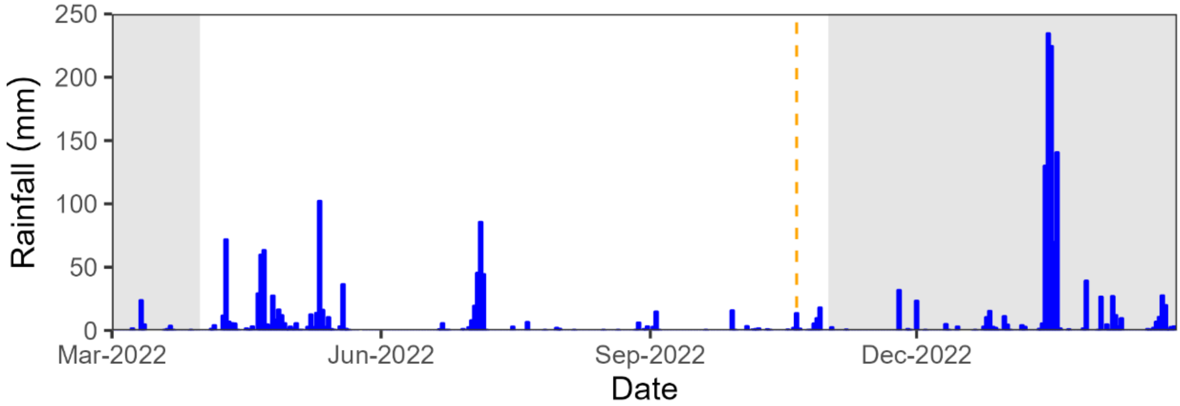

Figure 3.1 ***Daily rainfall recorded at Hamilton Island Airport (station 033106). The nominal wet season period is shown in grey, with the 2022-2023 wet season rainfall onset marked by the orange dashed line. Data source: http://www.bom.gov.au/climate/data***

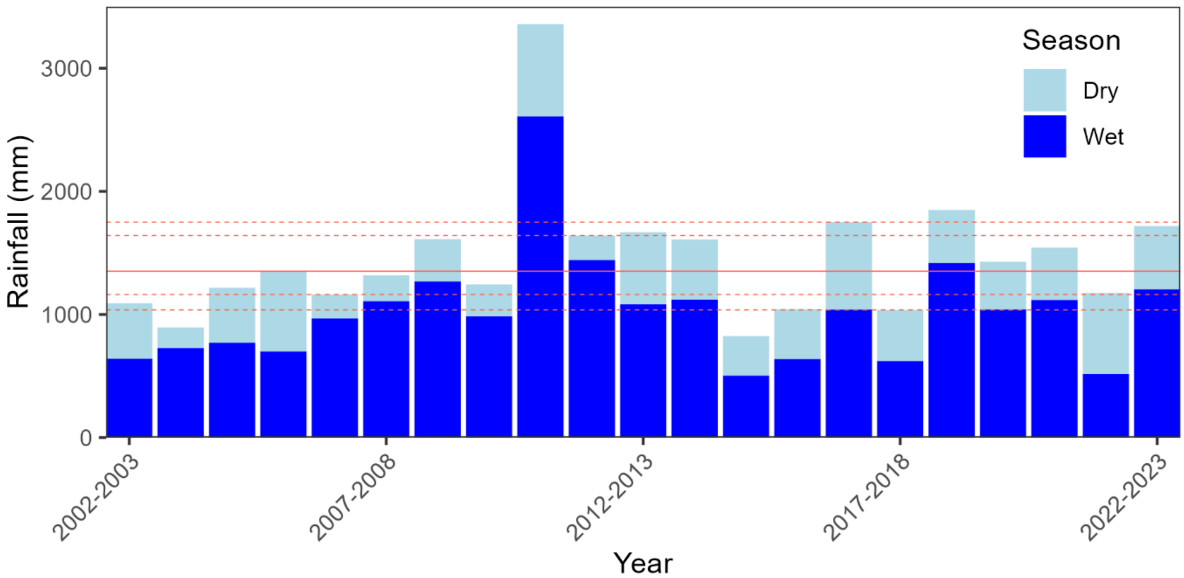

Figure 3.2 ***Annual rainfall by water year for the Whitsunday region during wet season (blue) and dry season (light blue). Totals were calculated for the wet season period 1st November to 31st March for each water year. Water year runs from 1st July to 30th June. Solid red line represents median annual rainfall by water year, dashed lines represent 10th, 25th, 75th, and 90th percentiles. Note: the 2022-2023 dry season rainfall presented (light blue) is an***

underestimate as rainfall data was only available up to April 2023 at time of reporting. Daily rainfall data was obtained from the Hamilton Island Airport weather station (station 033106). Data source: http://www.bom.gov.au/climate/data/

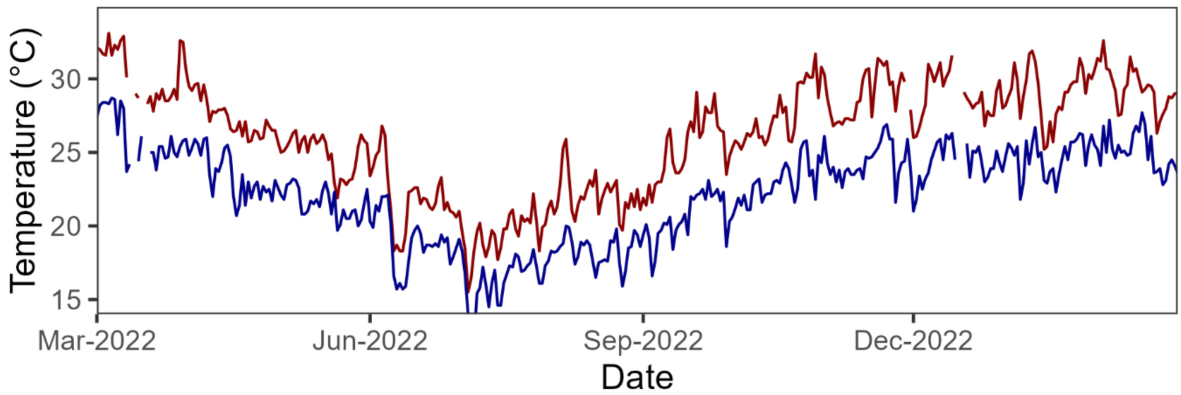

Figure 3.3 Daily maximum (red) and minimum (blue) air temperature observations at Hamilton Island. Observations were drawn from the Bureau of Meteorology weather station at Hamilton Island Airport (station 033106)

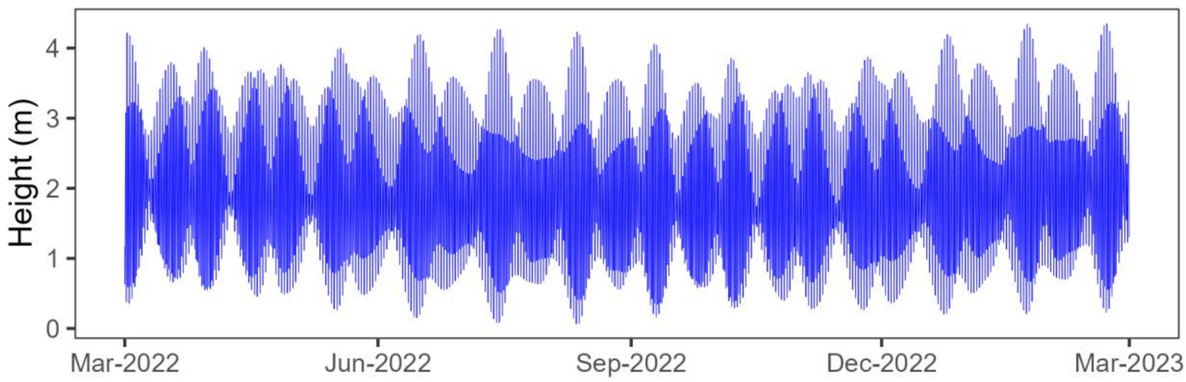

Figure 3.4 Tide height predictions above lowest astronomical tide (LAT) at Shute Harbour (Station P030003A).

3.2 Logger data

3.2.1 Water temperature

Daily median water temperature ranged from 20.8 to 29.9°C at Cairn Beach and 20.6 to 29.6°C at Tongue Bay during the reporting 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. 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.

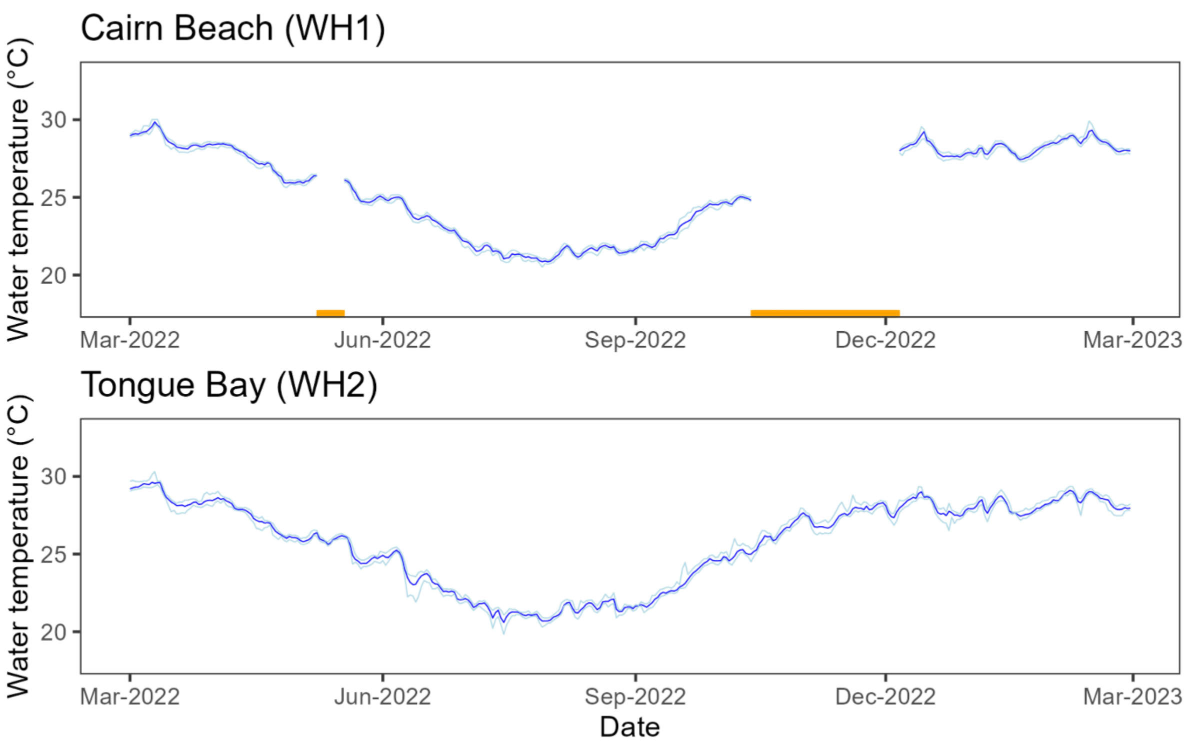

Figure 3.5 ***Water temperature measured by the data logger instruments at Cairn Beach and Tongue Bay. Daily median temperature (blue), and daily minimum and maximum (light blue). Periods of missing data are indicated by the orange bar.***

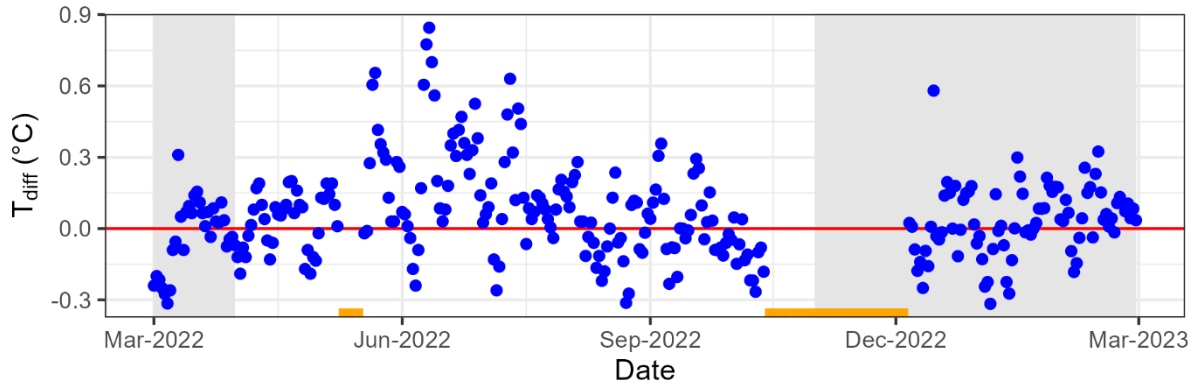

Figure 3.6 Difference in daily median water temperature (T_{diff}) between the Cairn Beach and Tongue Bay sites. The water temperature is warmer at Cairn beach on days when T_{diff} value is positive, and warmer at Tongue Bay when value is negative. Grey shading indicates the nominal wet season. Periods 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 where the logger appears to have been deployed further offshore in 17 m of water in March 2022. Water levels 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 = 0.007 m). Tongue Bay was more exposed to wave energy with a mean RMS wave height of 0.0198 m. The most active period saw RMS wave height of up to 0.082 m at Tongue Bay.

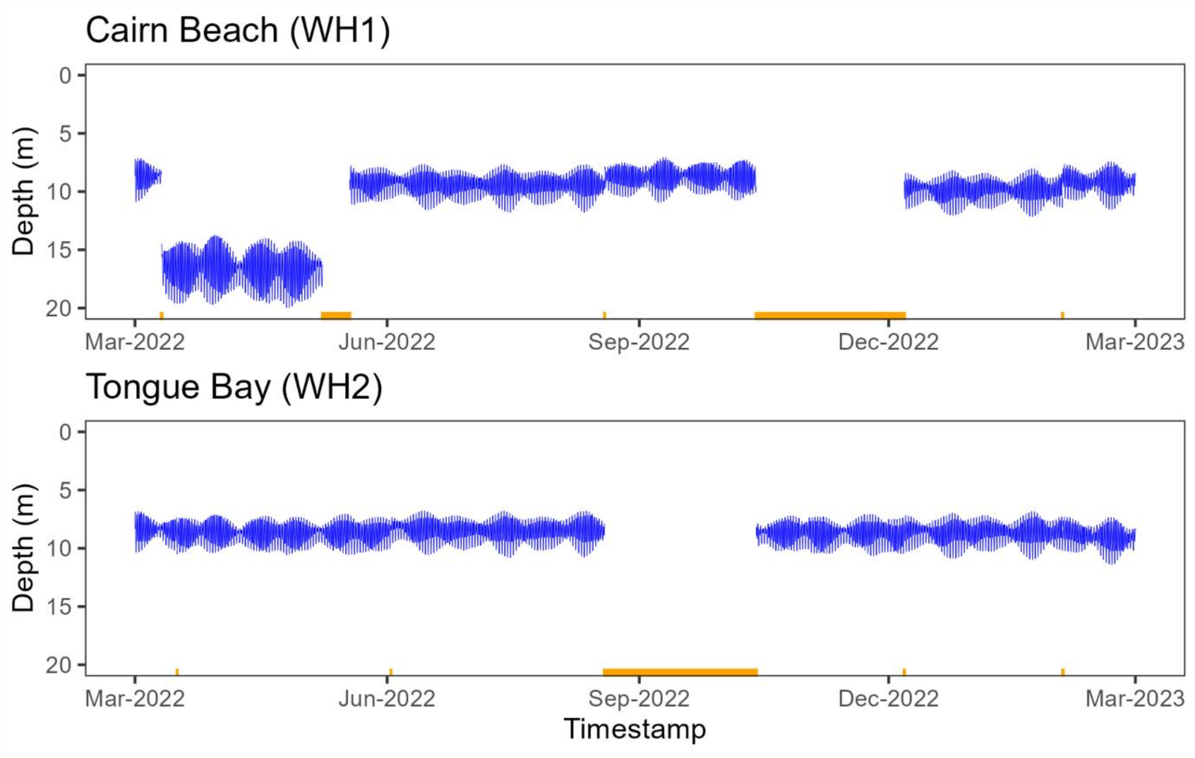

Figure 3.7 ***Water depth measured by the data logger instruments at Cairn Beach and Tongue Bay. Periods of missing data are indicated by the orange bar.***

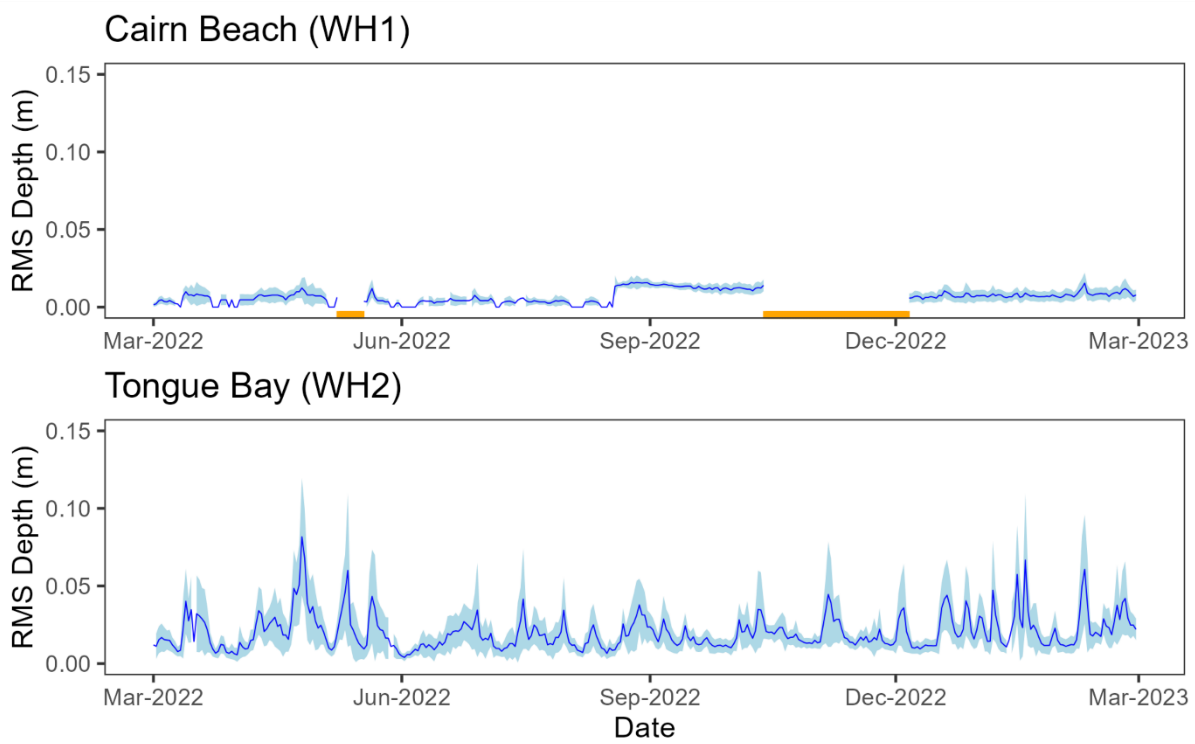

Figure 3.8 ***Root mean squared (RMS) water depth measured by the data logger instruments at Cairn Beach and Tongue Bay. Shown is the daily median value (blue) and interquartile range (light blue). Periods of missing data are indicated by the orange bar.***

3.2.3 Photosynthetically active radiation (bPAR)

Benthic photosynthetically active radiation (bPAR) was measured at the two sites and converted to daily light integral (DLI) (Figure 3.9). The mean daily light integral was 2.54 mol m^{-2} d^{-1} at Cairn Beach and 2.16 mol m^{-2} d^{-1} at Tongue Bay.

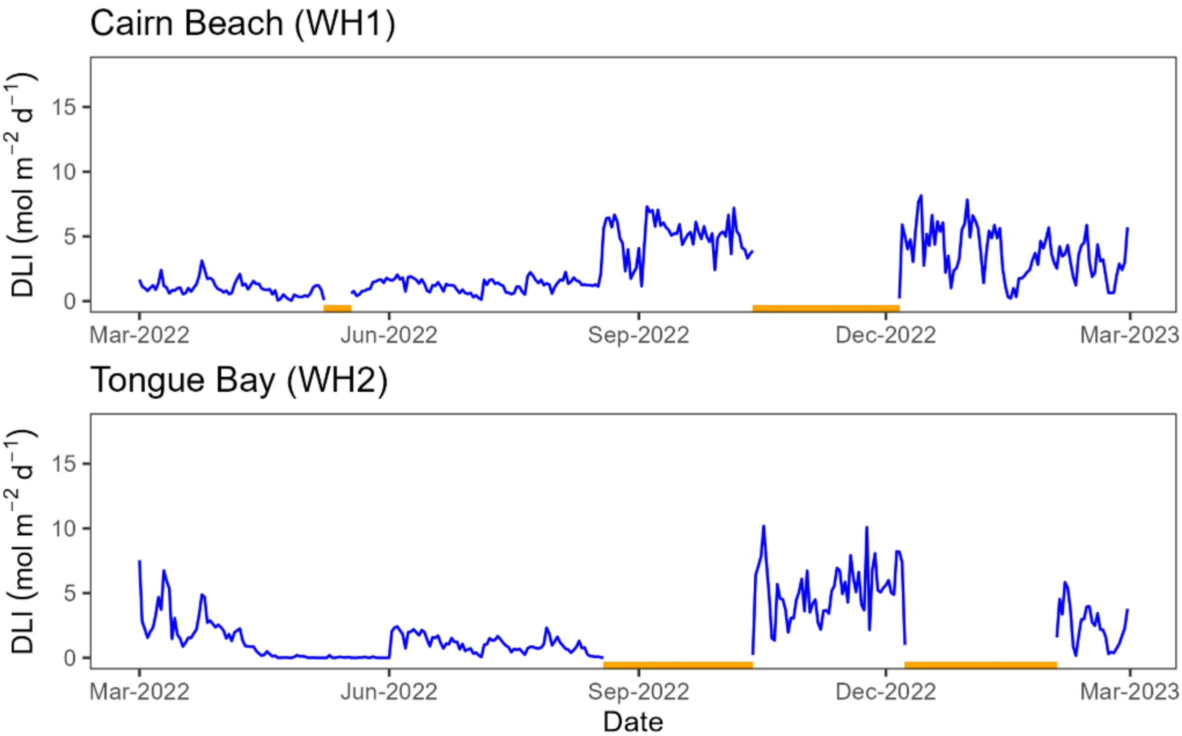

Figure 3.9 Benthic photosynthetically active radiation (bPAR) presented as the daily light integral as measured by the data logger instruments at Cairn Beach and Tongue Bay.

3.2.4 Turbidity

Turbidity ranged from 0 to 150 NTU at the Cairn Beach monitoring site, with a median value of 0.85 NTU over the year (Figure 3.10). Turbidity ranged from 0 to 489 NTU at the Tongue Bay monitoring site, with a median value of 1.10 NTU 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.

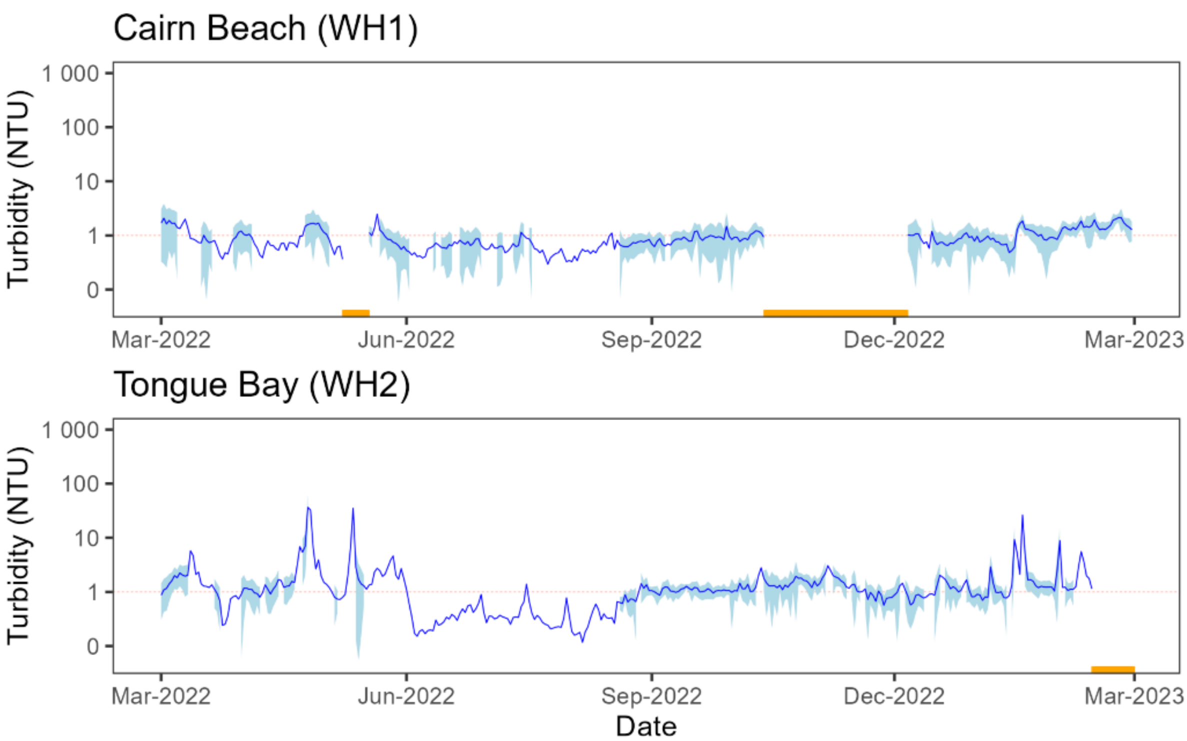

Figure 3.10 Turbidity measured by the data logger instruments at Cairn Beach and Tongue Bay. Note logarithmic scale on y-axis. Shown is the daily mean value (blue) and standard deviation of the mean (light blue). Periods of missing data are indicated by the orange bar.

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 3.2 to 9 m (Figure 3.11). The median Secchi depth was 4.0 m at Cairn Beach and 5.6 m at Tongue Bay. Caution comparing between the sites as Secchi depth was only measured at Cairn beach three times over the 12-month period. Weather and sea conditions varied between sampling trips and sites, although water quality sampling was generally done on calm days with light breezes. The number of tourists involved in the project was recorded by the tourism operators on the field datasheets. There were 231 tourists engaged with the program across the reporting period.

Table 3.1 Water quality measurements and observations recorded by tourism operators as Cairn Beach and Tongue Bay. NR = not recorded.

Site Name	Site Code	Date	Time	Secchi depth	Cloud cover	Wind	Sea surface
				m	%	knots	
Cairn Beach	WH1	22/03/2022	15:50	4	0	15 SE	glass
		9/05/2022	15:25	NR	98	5-10 knots	calm
		7/07/2022	16:00	NR	0	7 k E	calm
		19/08/2022	8:58	6.5	20	<5 k	calm
		26/11/2022	9:54	NR	40	10 k	calm
		2/02/2023	11:21	3.2	5	<5	calm
Tongue Bay	WH2	27/03/2022	11:30	9	30	5-15 SE	small waves
		6/05/2022	14:00	7	10	10-15 SSE	NR
		26/06/2022	11:00	4	100	25 SSE	small waves
		19/08/2022	11:00	7	20	<5 k	calm
		18/11/2022	14:30	4	30	15 ESE	wavelets
		2/02/2023	13:02	4.2	15	<5	calm

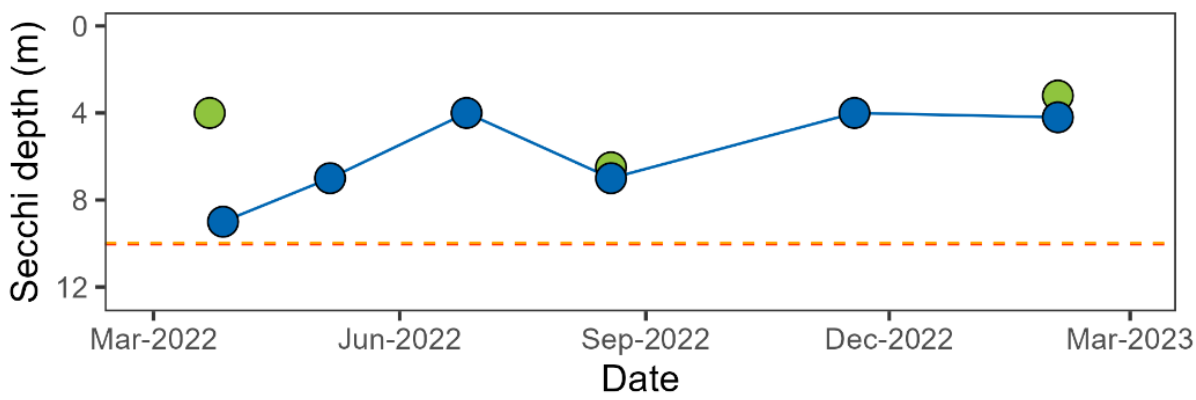

Figure 3.11 Secchi depth measured by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown (both = 10 m).

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 52.2 to 52.8 mS cm^{-1} (median = 52.8 mS cm^{-1}) at Cairn Beach and ranged from 52.2 to 53.3 mS cm^{-1} (median = 52.9 mS cm^{-1}) at Tongue Bay and was within expected range of seawater with limited freshwater inputs. TSS ranged from 0.9 to 1.2 mg L^{-1} (median = 1.2 mg L^{-1}) at Cairn Beach and ranged from 0.9 to 1.8 mg L^{-1} (median = 1.3 mg L^{-1}) at Tongue Bay. pH ranged from 8.14 to 8.24 (median = 8.21) at Cairn Beach and ranged from 8.12 to 8.30 (median = 8.22) at Tongue Bay. pH was within the 20th and 80th percentiles of the DEHP water quality objectives for open coastal waters.

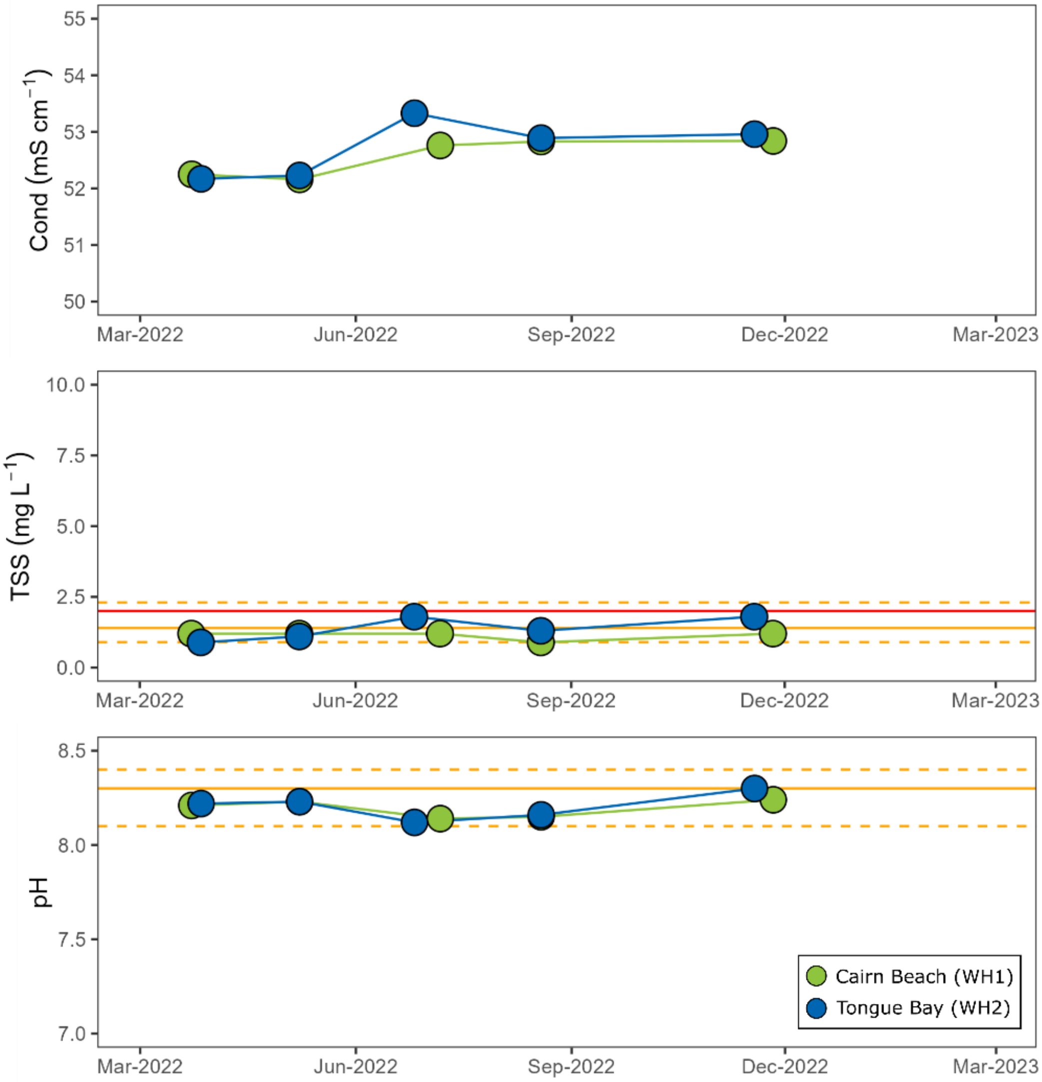

Figure 3.12 ***Electrical conductivity (Cond), total suspended solids (TSS), and pH from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.***

3.3.3 Nutrients

Water samples were analysed for nitrogen and generally exceeded water quality thresholds (Figure 3.13). Total nitrogen concentrations ranged from 107 to 178 µg N L^{-1} (median = 123 µg N L^{-1}) at Cairn Beach and ranged from 105 to 151 µg N L^{-1} (median = 114 µg N L^{-1}) at Tongue Bay. Particulate nitrogen ranged from 14 to 54 µg N L^{-1} (median = 41 µg N L^{-1}) at Cairn Beach and ranged from 9 to 22 µg N L^{-1} (median = 19 µg N L^{-1}) at Tongue Bay. Nitrate-nitrite concentrations ranged from 2 to 3 µg N L^{-1} (median = 3 µg N L^{-1}) at Cairn Beach and ranged from 1 to 2 µg N L^{-1} (median = 2 µg N L^{-1}) at Tongue Bay.

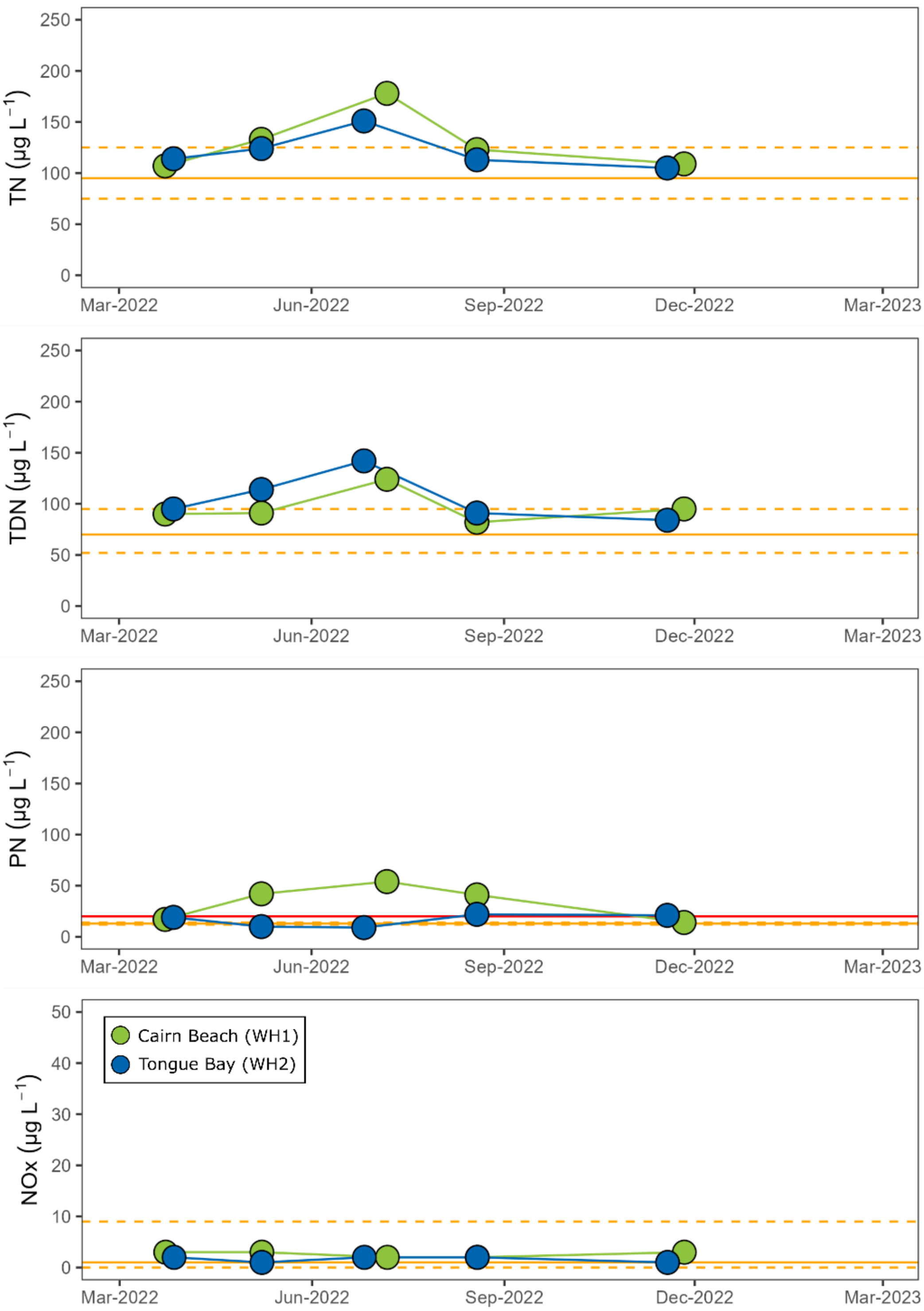

Figure 3.13 Total nitrogen (TN), total dissolved nitrogen (TDN), particulate nitrogen (PN), and nitrate-nitrite (NOx) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). Note different y-axis. The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.

Water samples were analysed for phosphorus and on occasion exceeded WQ thresholds (Figure 3.14). Total phosphorus concentrations ranged from 6 to 11 µg P L^{-1} (median = 8 µg P L^{-1}) at Cairn Beach and ranged from 1 to 2 µg P L^{-1} (median = 1 µg P L^{-1}) at Tongue Bay. Particulate phosphorus concentrations ranged from 0 to 6 µg P L^{-1} (median = 1 µg P L^{-1}) at Cairn Beach and ranged from 1 to 2 µg P L^{-1} (median = 1 µg P L^{-1}) at Tongue Bay.

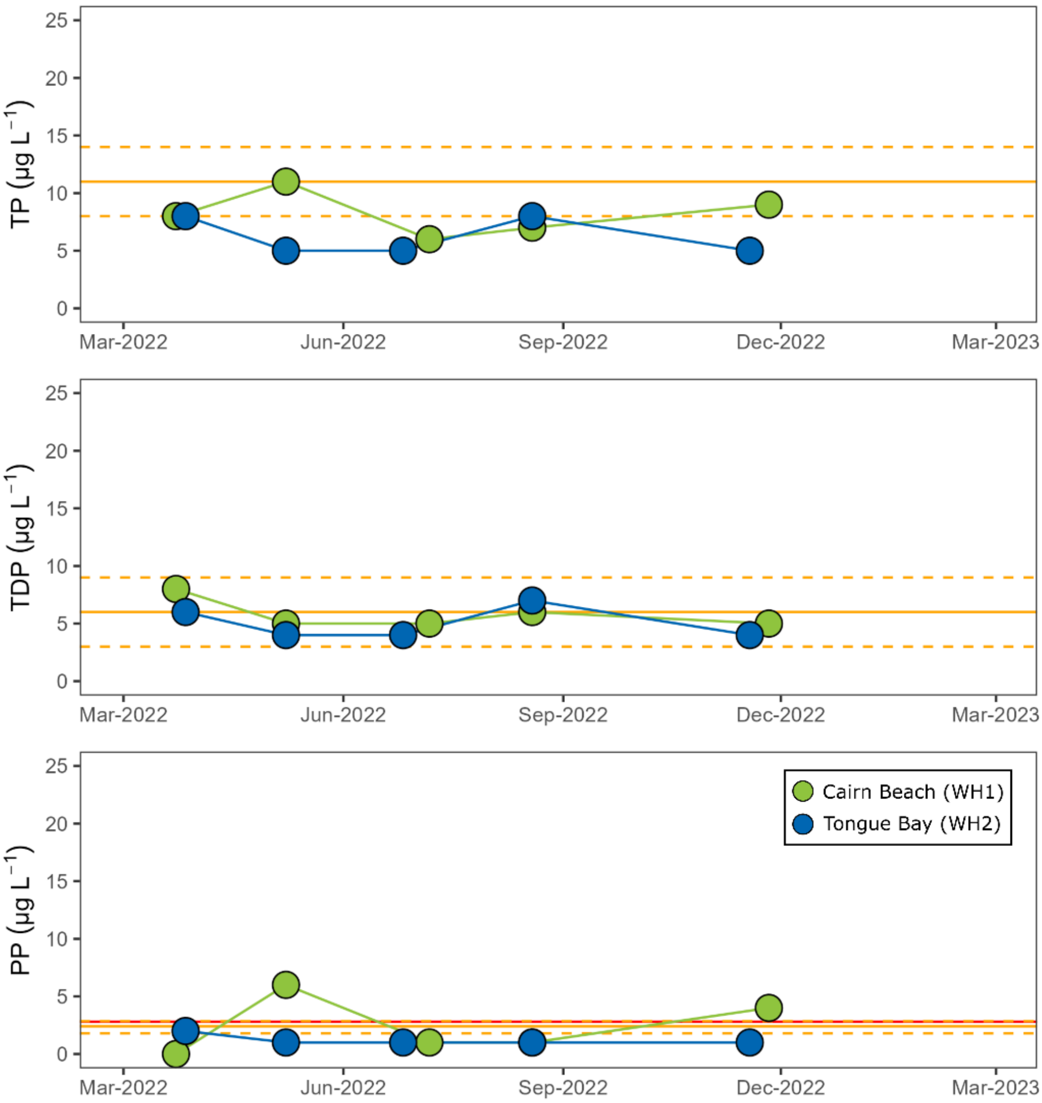

Figure 3.14 ***Total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown***

3.3.4 Chlorophyll *a*

Chlorophyll-*a* concentrations ranged from <0.2 to 0.51 µg L^{-1} (median = 0.34 µg L^{-1}) at Cairn Beach and ranged from 0.3 to 0.51 µg L^{-1} (median = 0.37 µg L^{-1}) at Tongue Bay (Figure 3.15).

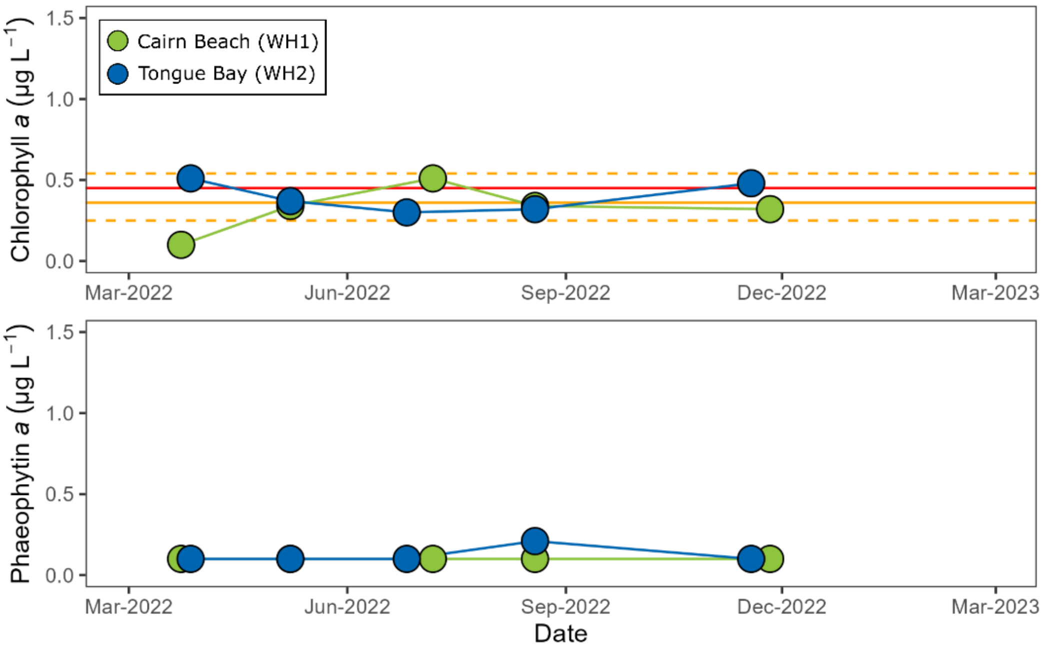

Figure 3.15 ***Chlorophyll-a from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.***

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 01/03/2022 and 28/02/2023. 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 0.0825 (Good) for Cairn Beach, and -0.0395 (Moderate) for Tongue Bay. The nutrients indicator score, which is based on PN, PP and NOx concentrations was -0.333 (Poor) for Cairn beach, and -0.182 (Moderate) for Tongue Bay. The water clarity indicator score, which is based on TSS, turbidity and Secchi depth was -0.389 (Poor) for Cairn Beach, and -0.365 (Poor) for Tongue Bay. The overall regional score based on the aggregated scores of the two sites was calculated to be -0.204 (Moderate) for the 2022-2023 reporting period.

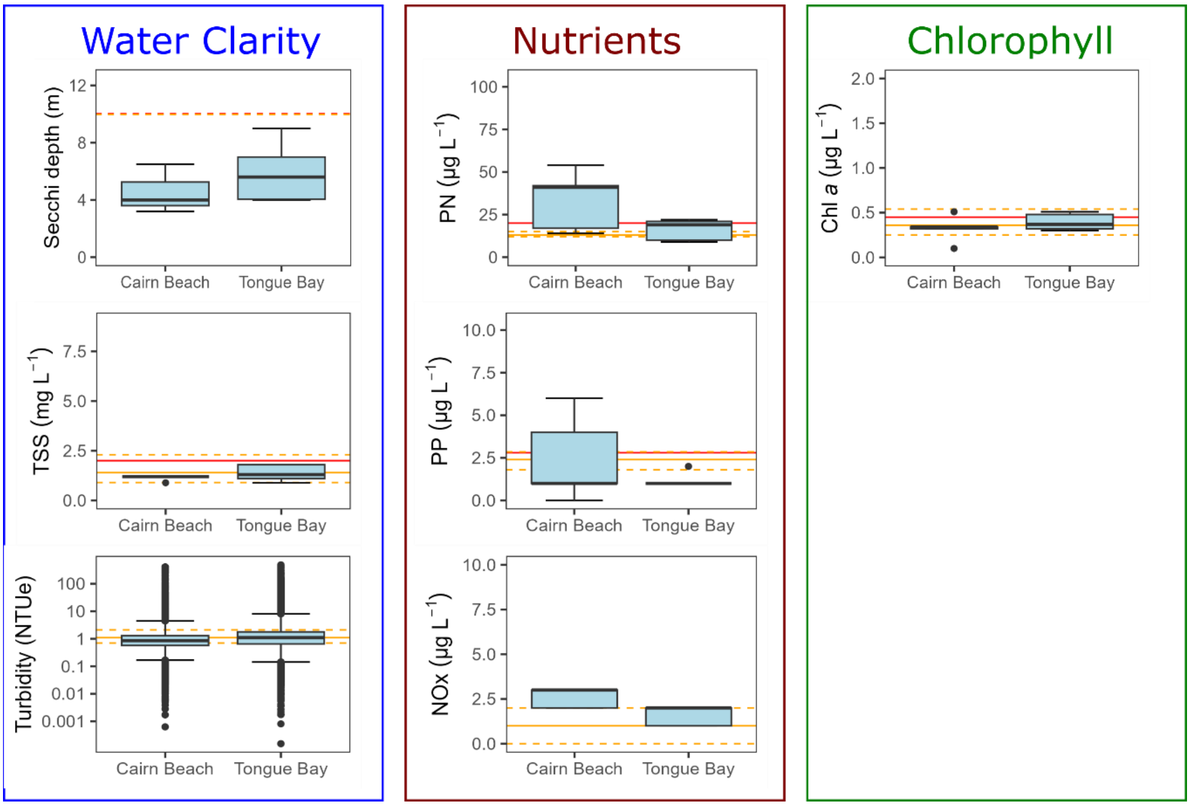

Figure 3.16 ***Boxplots of each of the parameters used to calculate water quality index. The water clarity score is composed of Secchi disk depth, total suspended solids (TSS), and turbidity. The nutrients indicator is composed of particulate nitrogen (PN), particulate phosphorus (PP), and oxidised nitrogen (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.***

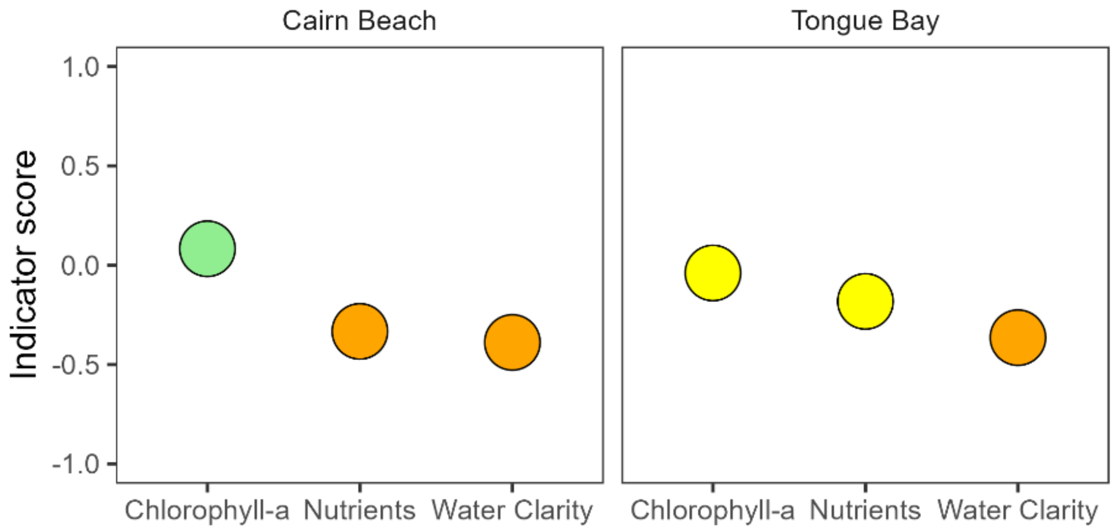

Figure 3.17 Marine offshore water quality indicator scores calculated for Cairn Beach and Tongue Bay for the 2022-2023 reporting period. The indicator scores are colour coded to Very Good (dark green), Good (light green), Moderate (yellow), Poor (orange), and Very Poor (red).

4 DISCUSSION

4.1 Water quality at Whitsunday monitoring sites

Results from the first three years of monitoring have now 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) produces water quality guideline trigger levels based on annual mean values. For 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 are allocated to '*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 the environmental dataset becomes a resource which can be utilized to explore these topics further.

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 = 4 m, Tongue Bay = 5.6 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 1.08 NTU at Cairn Beach and 2.71 NTU 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 1.14 mg L^{-1} at Cairn Beach and 1.38 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, Wu, Fallon, & Lough, 2019). Catchments contributing sediment to the Whitsunday region include the O'Connell and Pioneer Rivers, along with Fitzroy River to the South (Baird, Margvelashvili, & Cantin, 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 temperature was high at both Cairn Beach and Tongue Bay for periods throughout the year. 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 daily 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 2022 (06/03/2022 – 13/03/2022) shortly followed by another fortnight in April 2022 (28/03/2022 – 12/04/2022) which both exceed the guideline trigger value of 1°C above long term maximum temperature at both sites (Figure 4.1). There was a short warm period over 29/10/2022 to 03/11/2022 at Tongue Bay which also exceeded the +1°C threshold. There was no data available for the Cairn Beach site during that period. There were two consecutive days of warm water temperature in mid-December 2022 (14/12/2022 – 15/12/2022) that exceeded the +1°C threshold. 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.

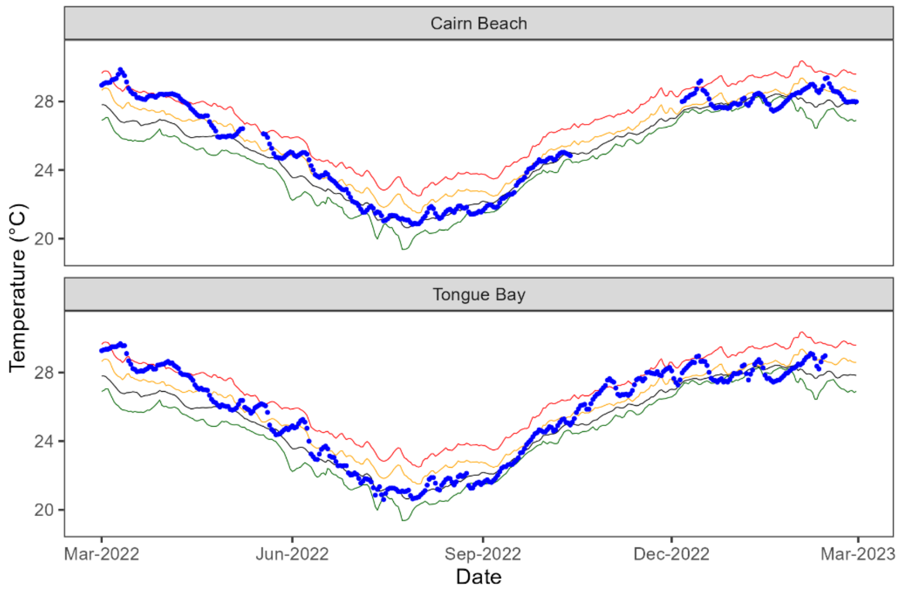

Figure 4.1 Daily mean temperature measured at Cairn Beach and Tongue Bay (blue), compared to daily average (black), minimum (green), maximum (orange), and maximum + 1°C guideline value (red) derived from Hook Island AIMS data.

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 33.6 µg N L^{-1} at Cairn Beach and 16.2 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 2.4 µg P L^{-1} at Cairn Beach and 1.2 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 0.32 µg L^{-1} at Cairn Beach and 0.40 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 acceptable in relation to the guideline trigger values at Cairn Beach and Tongue Bay.

4.1.4 Water quality indices

Comparison of individual water quality indicator scores over the past three years of reporting is made in Figure 4.2. There were improvements in the chlorophyll *a* and water clarity scores at both sites over the past year. There was a decline in the nutrients score at Tongue Bay, and no change at Cairn Beach. Overall, the Whitsunday region's water quality scored as 'moderate' for the 2022-2023 reporting period based on results obtained from the two monitoring sites in this program (Figure 4.3). This outcome appears to be an improvement from the previous water quality scores calculated by the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Card from 2014-2019 which consistently reported poor water quality (Figure 4.4). In contrast, the GBRMPA marine monitoring program (MMP) long-term water quality index for the Whitsundays region went through a long period of decline with a number of years reporting 'poor' water quality since monitoring started in 2007, with water quality improving over recent years to be 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.

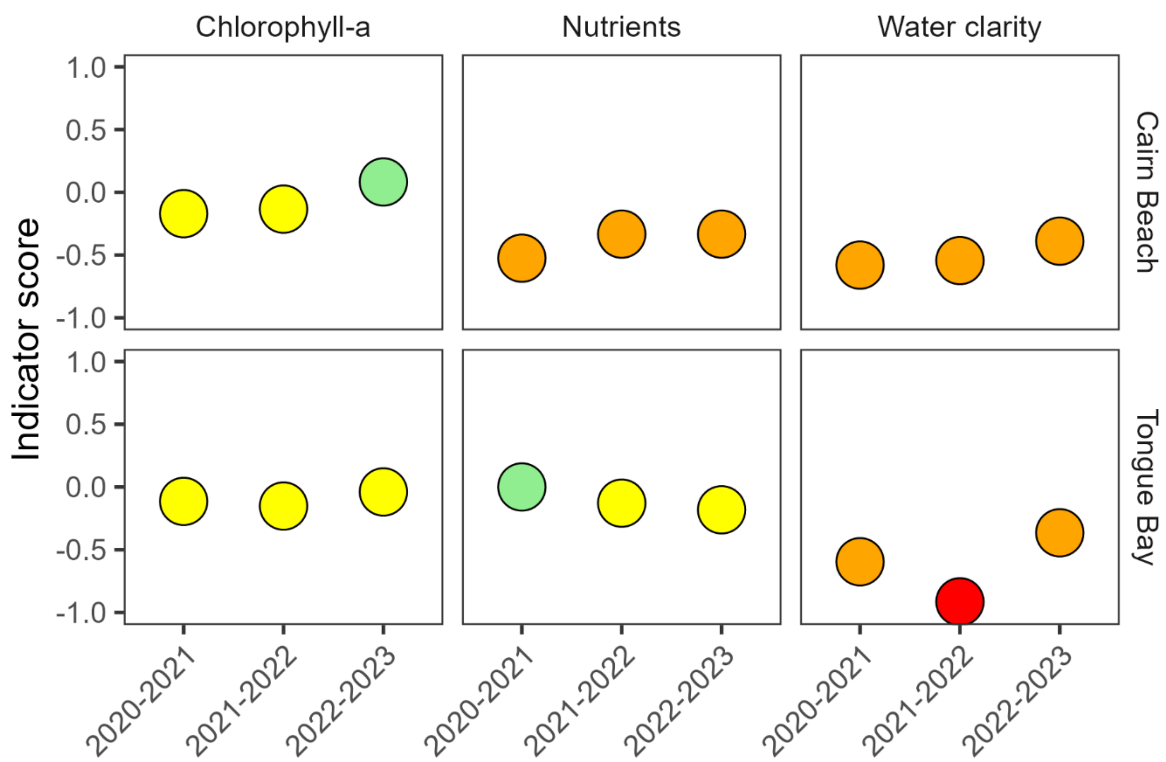

Figure 4.2 Individual marine offshore water quality indicator scores calculated for Cairn Beach and Tongue Bay calculated for this program over the past three reporting years. The indicator scores are colour coded to Very Good (dark green), Good (light green), Moderate (yellow), Poor (orange), and Very Poor (red).

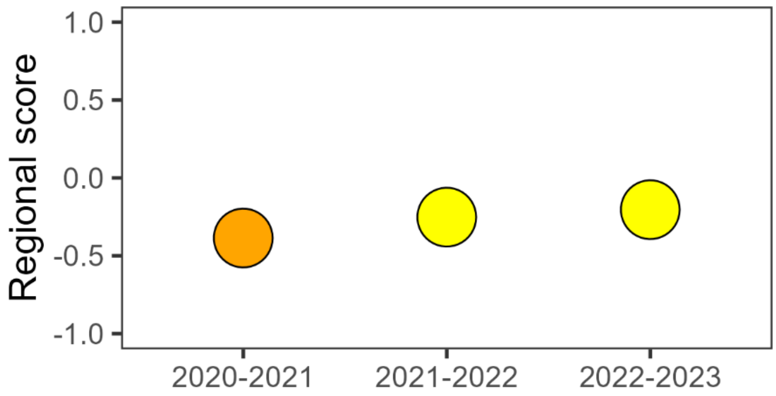

Figure 4.3 ***Regional water quality scores for the past three years as calculated from data acquired through the Whitsunday water quality monitoring blueprint for tourism operators' program. The regional water quality scores are colour coded to Very Good (dark green), Good (light green), Moderate (yellow), Poor (orange), and Very Poor (red).***

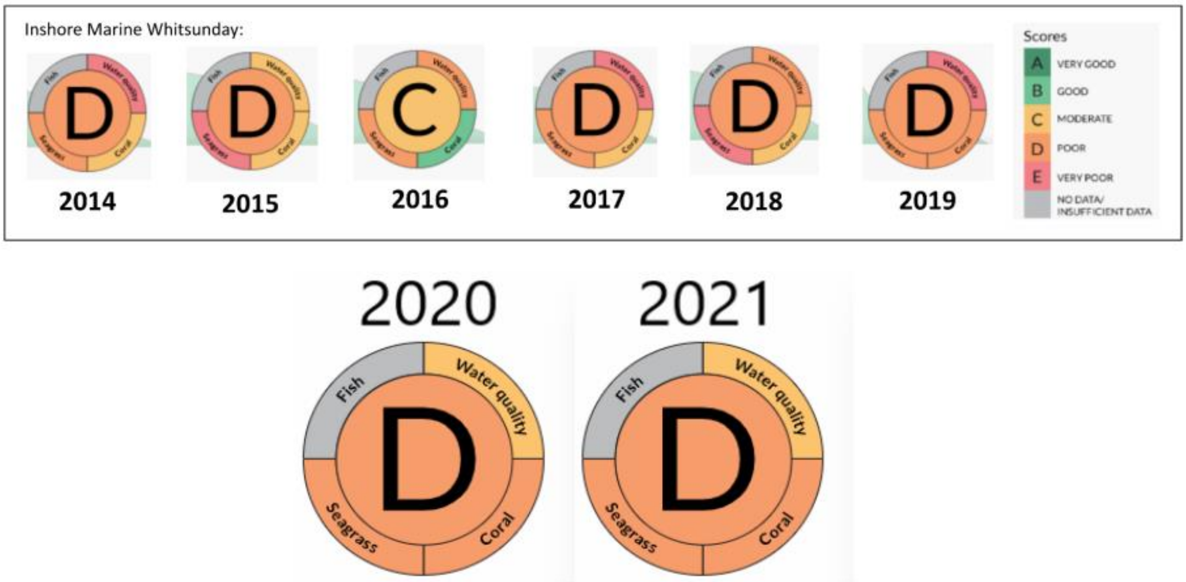

Figure 4.4 ***Results of the Inshore Marine Whitsunday Environmental component of the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Cards from 2014 to 2021. Source: https://healthyriverstoreef.org.au/report-card-results/***

4.2 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 4.5). The temperature and pressure sensors provided data for 82.4% of the time at Cairn Beach, and 90.4% of the time at Tongue Bay. The PAR sensor provided data for 82.4% of the time at Cairn beach and 66.1% of the time at Tongue Bay. The Turbidity sensor provided data for 82.2% of the time at Cairn beach and 86.1% of the time at Tongue Bay. There was a period of missing Cairn Beach logger data from 13/10/2022 to 6/12/2022 due to failure for instruments to initiate when deployed. This accounted for 14.8% of the missing data from Cairn Beach over the reporting period. There was a period of missing Tongue Bay PAR sensor data from 8/12/2022 to 2/02/2023 due to an internal instrument malfunction. The Tongue Bay logger was incorrectly programmed for one deployment (19/08/2022 – 13/10/2022) which resulted in data only being obtained every 30 minutes (usually 10 min interval). This accounted for 10% of the missing data for Tongue Bay over the reporting period. The small remaining amount of ‘missing’ data was due to data exclusion during the quality control flagging process.

Table 4.1 Summary of data recoveries (percent) for each sensor on the logger instrument at Cairn Beach and Tongue Bay over this reporting period

Sensor	Cairn Beach	Tongue Bay
Temperature	82.4	90.4
Pressure	82.4	90.4
PAR	82.4	66.1
Turbidity	82.2	86.1

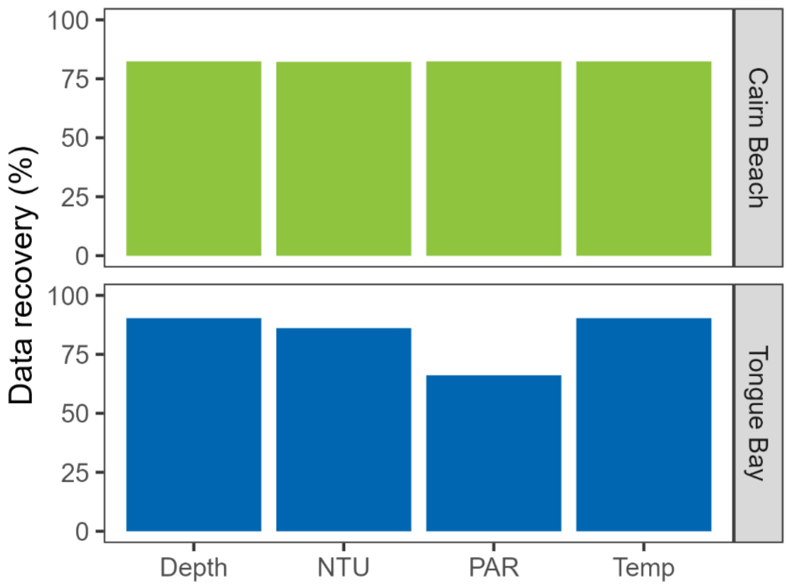

Figure 4.5 Percentage data recovery from each sensor on the MGL logger instruments at Cairn Beach (green) and Tongue Bay (blue).

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 the 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.

4.2.3 Data sufficiency

The water quality monitoring program was initially designed to collect water samples monthly. However, there has been a noticeable decrease in the frequency of water sampling by tourism operators throughout the program's duration. In the 2020-2021 period, 13 water sampling events were conducted, followed by 9 events in 2021-2022, and only 4 events in the 2022-2023 reporting period. This decline could be attributed to a waning interest or reduced capacity among tourism operators to participate in the program. During the first half of 2022, tour operators carried out just three water sampling events, with the final samples collected in November 2022. In August 2022, TropWater field staff stepped in to supplement the water sampling while installing new loggers at the sites. Subsequently, no additional samples were collected by tourism operators until May 2023, resulting in a six-month gap in water sample collection, spanning a significant portion of the 2022-2023 wet season. It is crucial for the program coordinators to maintain motivation and ensure continued engagement from tourism operators in order to sustain the program's effectiveness.

The two water quality monitoring sites from this project increase the density of water quality monitoring sites within the region (Figure 4.6). These sites complement 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 increase 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.

Other sources of data which may be useful to the program include: Long term water temperature data sourced from the AIMS Sea Water Temperature Observing System used here to calculate the 20 year average temperatures for guideline exceedances (AIMS, 2017) and Waverider buoys which 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.

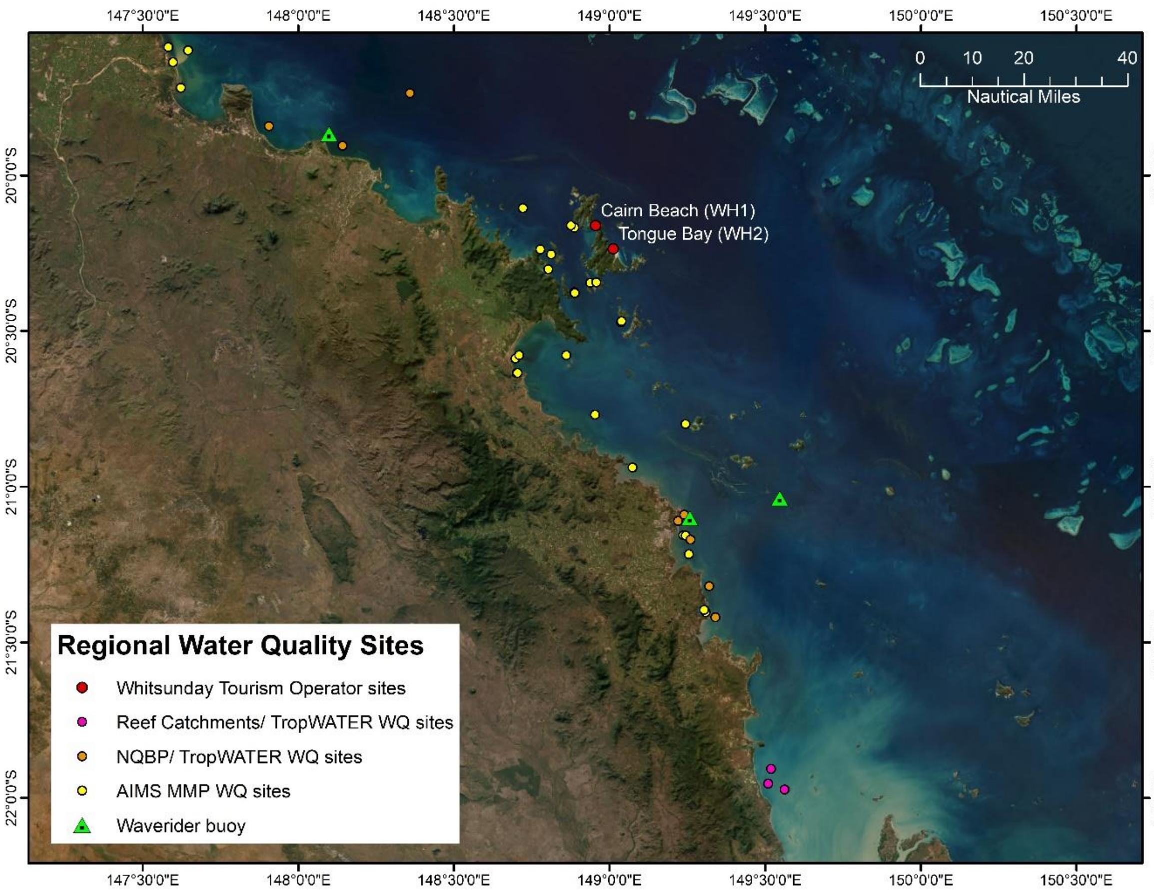

Figure 4.6 ***Monitoring sites from other water quality programs operating in and adjacent to the Whitsunday region***

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, the regional water quality score continued to improve in 2022-2023 compared to the 2020-2021 and 2021-2022 reporting periods. Individual indicator scores for each site indicate the likely contributors to changes in regional water quality between years. Improvements were found in the chlorophyll-*a* indices for both Cairn Beach (from moderate to good) and Tongue Bay (remains moderate). The water clarity indices improved for both Cairn Beach (but remains poor) and Tongue Bay (from very poor to poor). Nutrient indices remained unchanged for Cairn Beach (remains poor) and Tongue Bay (slight deteriorated, remains 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 2022-2023 compared to the previous reporting period. Nitrogen remains a nutrient of concern in the

Whitsunday region (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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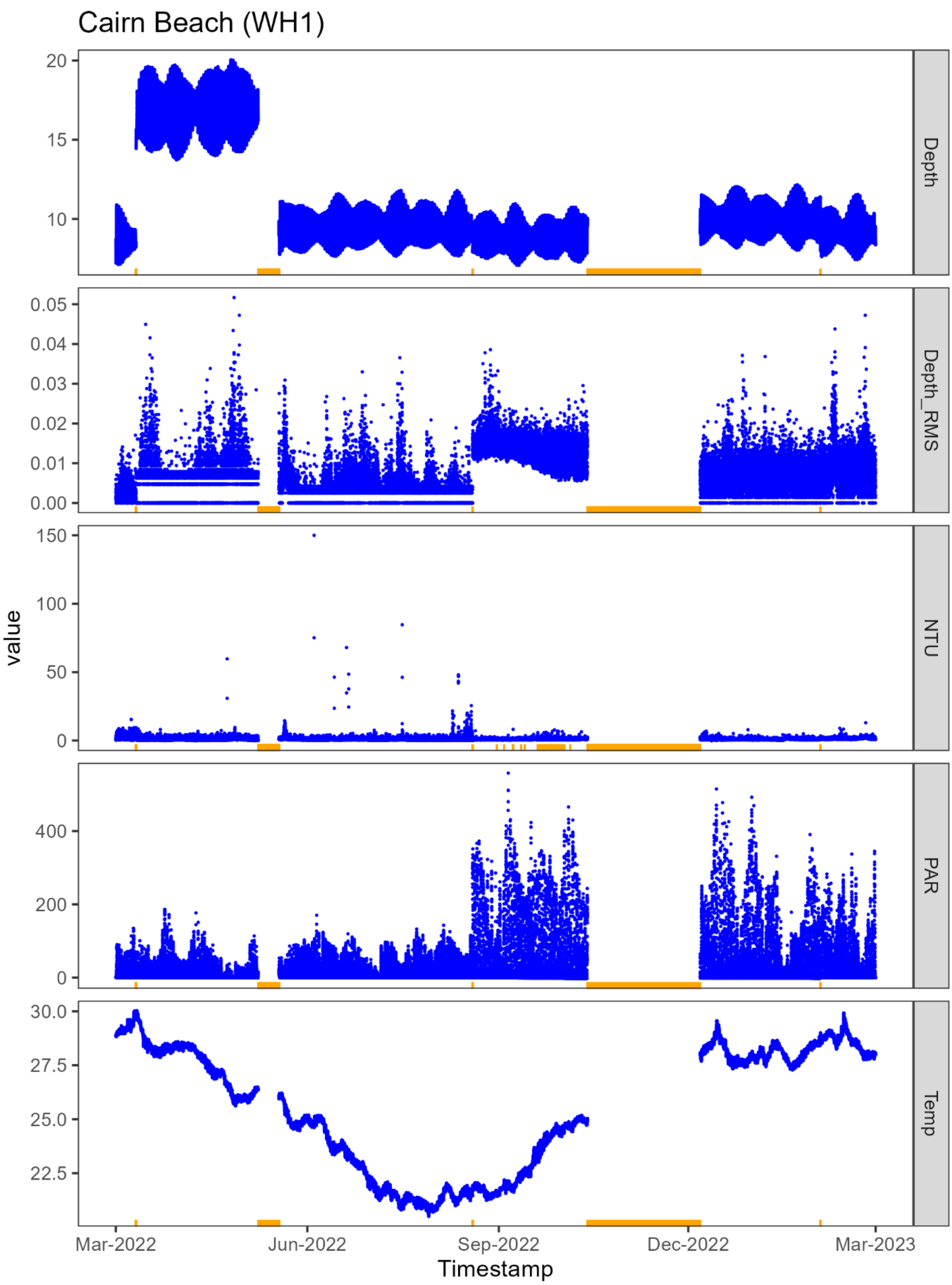
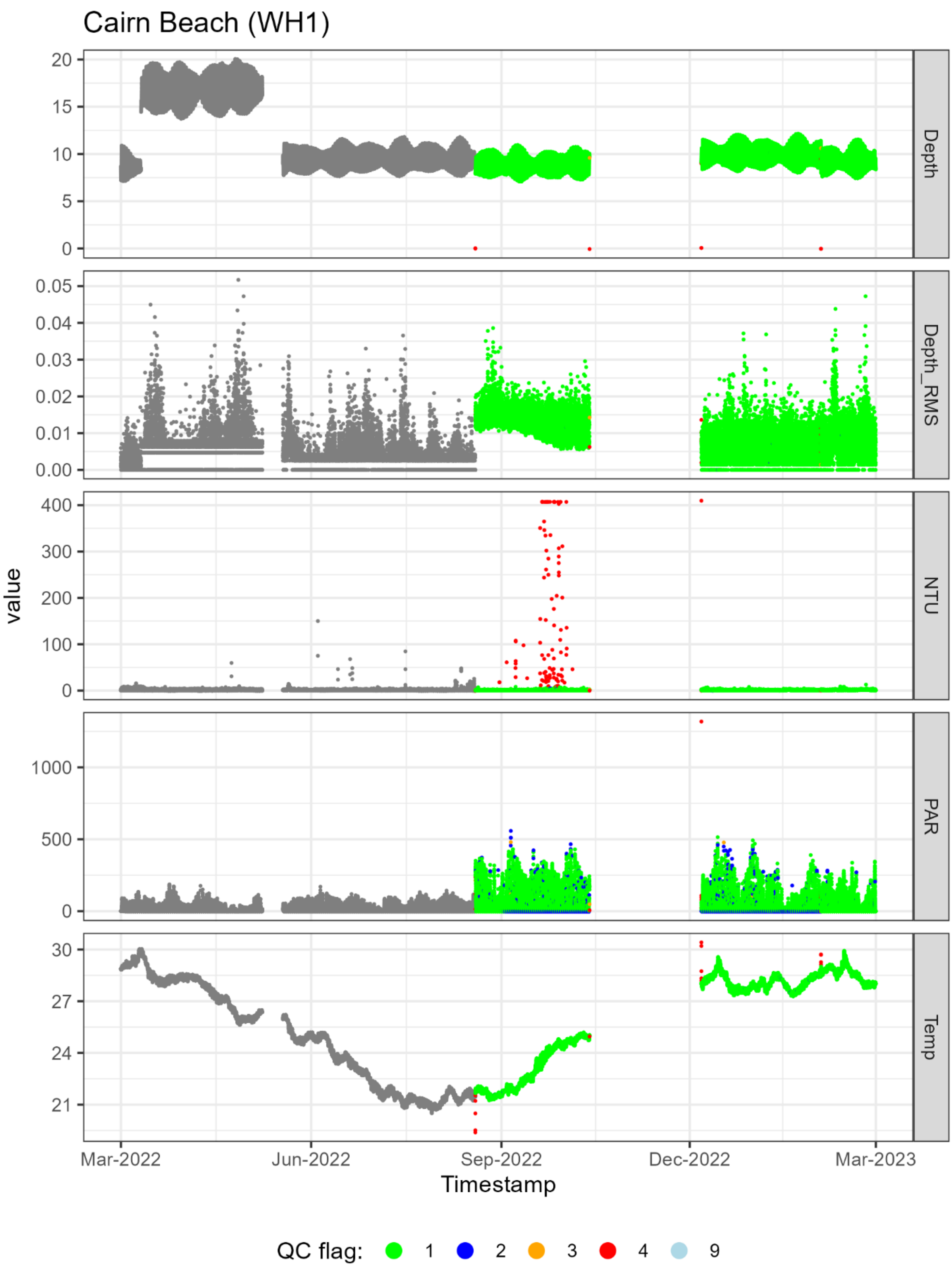
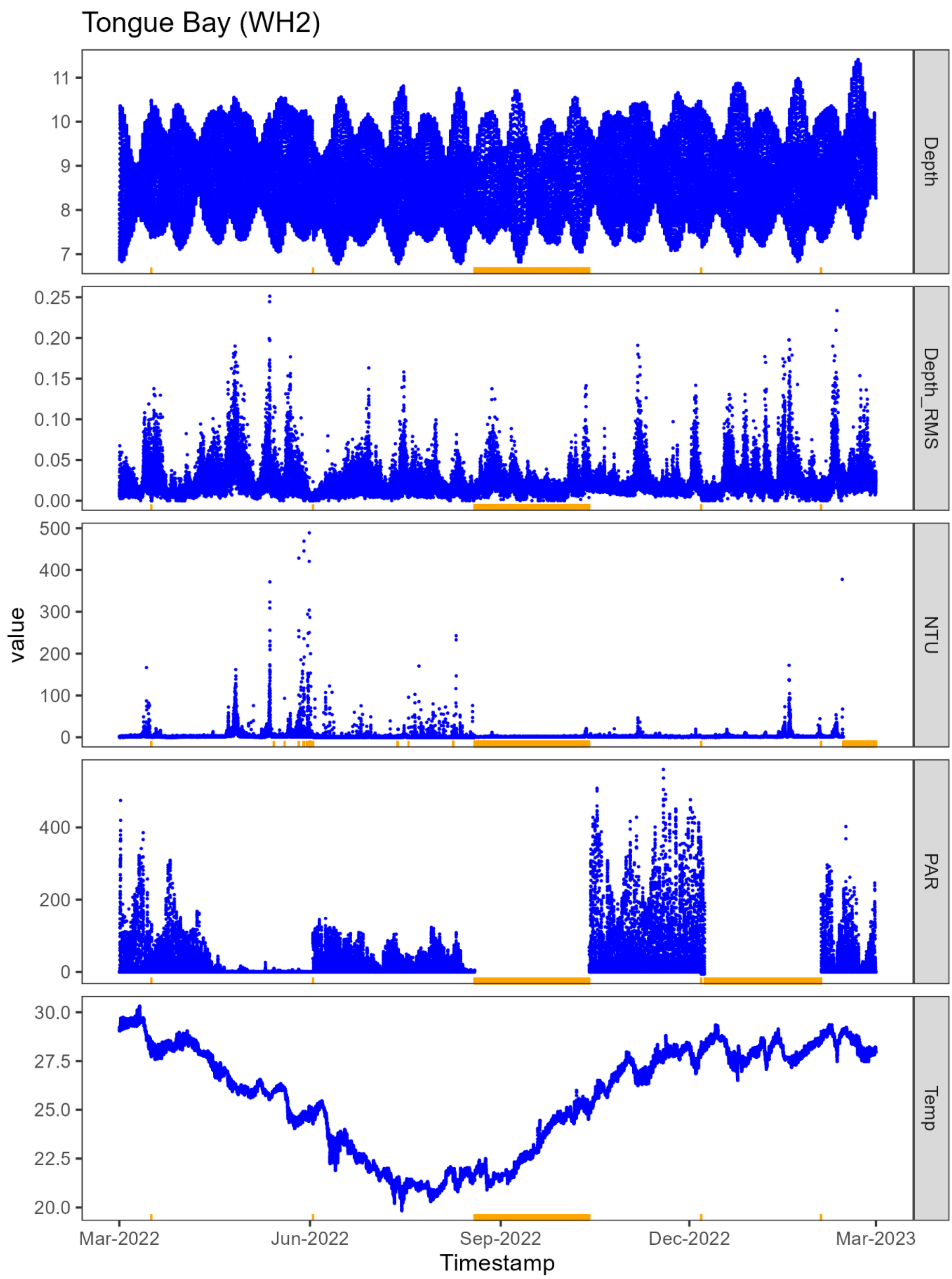
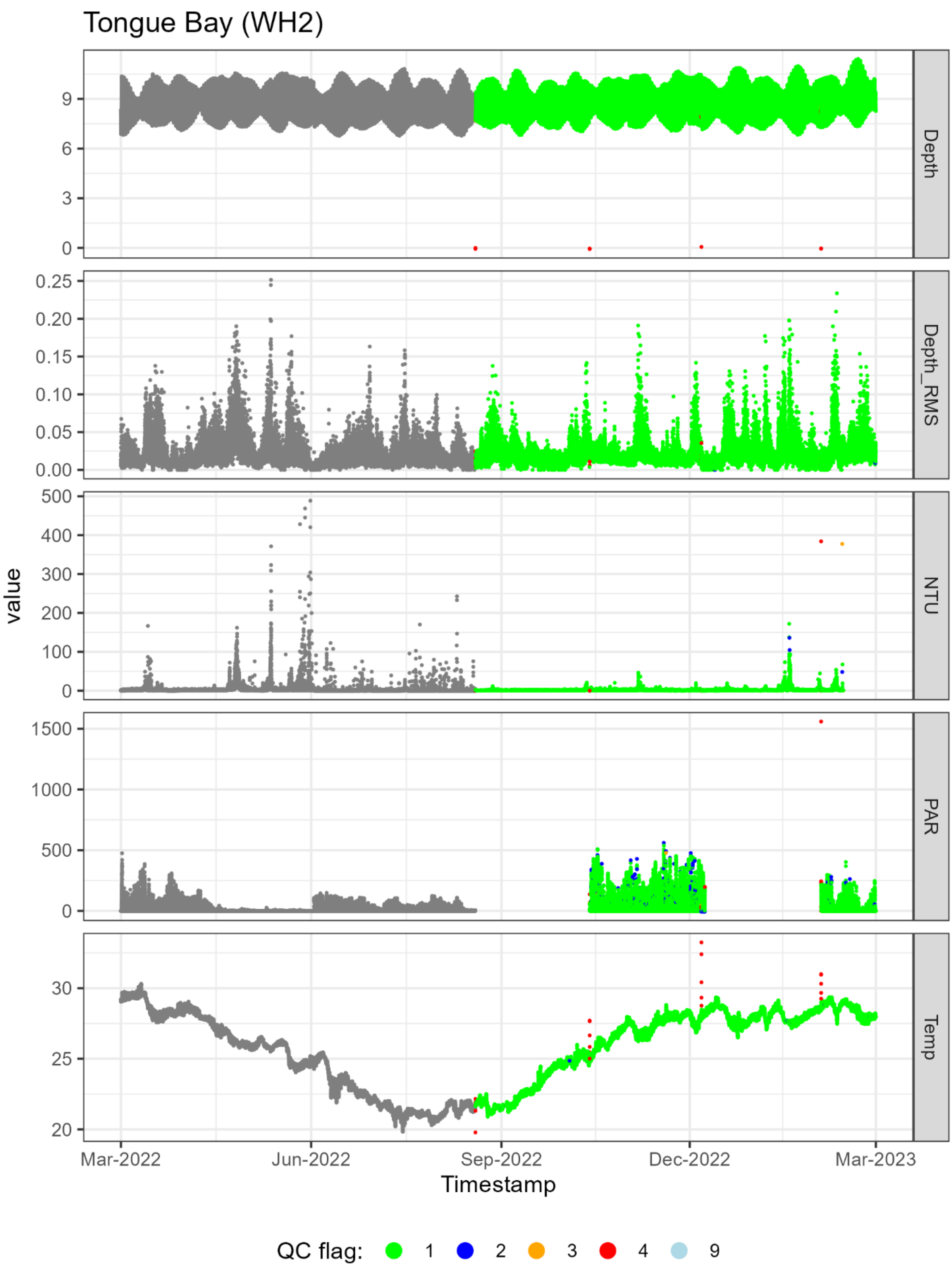
A1 APPENDIX

Raw 10 minute logger data collected from Cairn Beach and Tongue Bay. The first plot for each site displays the data used for this report. Data acquired with IMO loggers go through a two-step automated and manual quality control process. Data assigned QC flag 1 (good data) and QC flag 2 (probably good data) are included in the analysis, while data assigned QC flag 3 (suspect data) and QC flag 4 (bad data) are excluded from all analysis. Periods of missing data either by instrument fault or QC exclusion are indicated by the orange bar. Note: Data obtained by MGL nephelometers only receive rudimentary quality control by MGL and are plotted grey on the following QC flag figures.


Cairn Beach (WH1)
value
Depth
Depth_RMS
NTU
PAR
Temp
20
15
10
0.05
0.04
0.03
0.02
0.01
0.00
150
100
50
0
400
200
0
30.0
27.5
25.0
22.5
Mar-2022
Jun-2022
Sep-2022
Dec-2022
Mar-2023
Timestamp


Cairn Beach (WH1)
Depth
Depth_RMS
NTU
PAR
Temp
value
Timestamp
Mar-2022
Jun-2022
Sep-2022
Dec-2022
Mar-2023
QC flag: 1 2 3 4 9


Tongue Bay (WH2)
11
10
9
8
7
Depth
0.25
0.20
0.15
0.10
0.05
0.00
Depth_RMS
500
400
300
200
100
0
NTU
value
400
200
0
PAR
30.0
27.5
25.0
22.5
20.0
Temp
Mar-2022
Jun-2022
Sep-2022
Dec-2022
Mar-2023
Timestamp


Tongue Bay (WH2)
Depth
Depth_RMS
NTU
PAR
Temp
value
Timestamp
Mar-2022
Jun-2022
Sep-2022
Dec-2022
Mar-2023
QC flag: 1 2 3 4 9

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