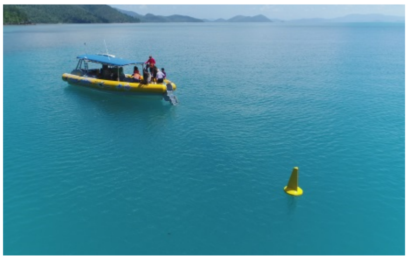
Whitsunday Water Quality Monitoring Blueprint for Tourism Operators: Final report

Jordan Iles and Nathan Waltham

Report No. 21/22

May 2021



Whitsunday Water Quality Monitoring Blueprint for Tourism Operators: Annual report 2020-2021

A Report for Reef Catchments (Mackay Whitsunday Isaac) Limited

Report No. 21/22

May 2021

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1 INTRODUCTION

1.1 Background

The Whitsunday region of the Queensland coast encompasses numerous islands, bays, and inshore reef and is an important gateway to the outer barrier reef. Of concern in the region is an apparent decline in the water quality, demonstrated in water quality monitoring results (Gruber et al., 2019) and supported by anecdotal evidence from local residents and tourism operators. For example, the great Barrier Reef Marine Park Authority (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 currently assessed to be 'moderate' (Figure 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 (Figure 1). 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. The tourism industry have expressed that they often feel in the dark, regarding reef or marine monitoring and its outcomes.

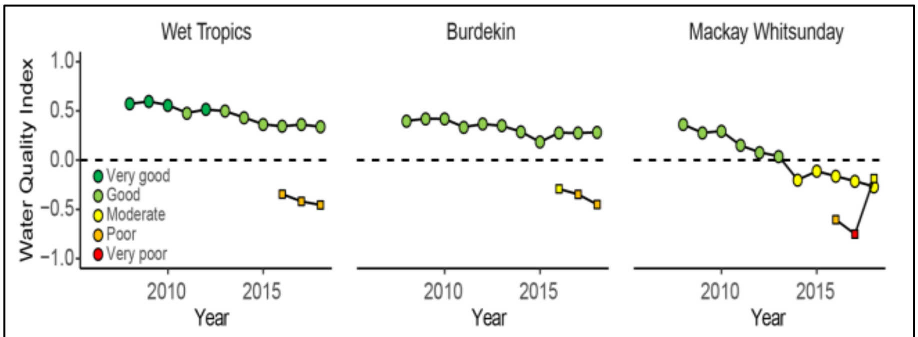


Figure 5. *In situ* water quality index for the Wet Tropics, Burdekin and Mackay Whitsunday regions from 2007-2008 to 2017-2018 circle symbols indicate the 'long-term' trend since the start of monitoring based on an initial program design. From 2015 a revised program design was implemented that includes increased temporal and spatial sampling and compares water quality values to wet and dry season water quality guidelines where available (squares). Colour coding: ■ = very good (> 0.5 to 1), ■ = good (> 0 to 0.5), ■ = moderate (<0 to -0.33), ■ = poor (< -0.33 to -0.66), ■ = very poor (< -0.66 to -1). Data source: (Gruber et al. 2019).

Figure 1. Water quality index. Figure and caption reproduced from the 'Reef water quality report card 2017 and 2018' (GBRMPA, 2019).

1.2 Citizen science project

TropWATER (Centre for Tropical Water and Aquatic Ecosystem Research), 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 the 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 for reef health with water quality 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 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.

1.3 Project aims and objectives

The aim of the citizen science program has been to establish 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.

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 (Figure 2, Table 1). A third site at Blue Pearl Bay (WH3) has also been identified for future expansion of the program. 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 following a schedule (Table 2).

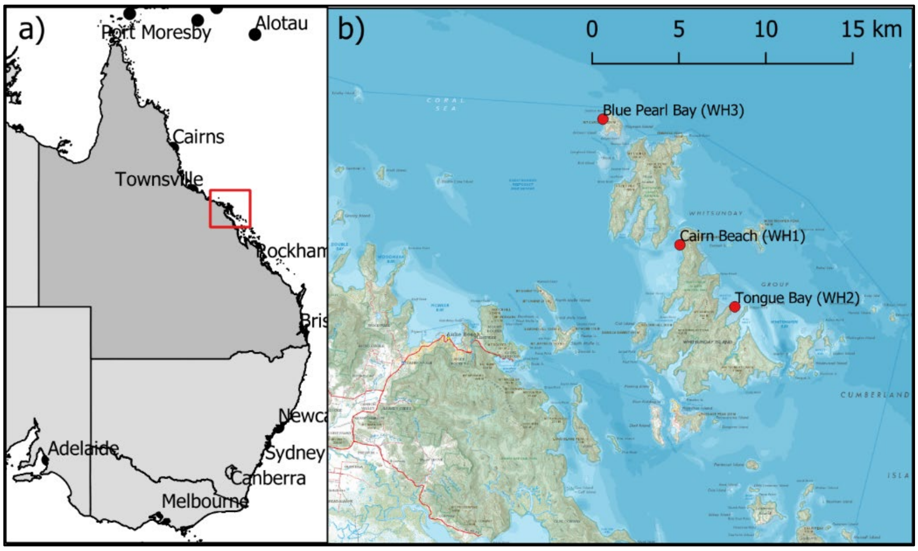


Figure 2. a) The Whitsunday region (red bounding box) is located on the Queensland coast, b) Location of monitoring sites as part of this project in the Whitsunday region. The sites are Cairn Beach (WH1), Tongue Bay (WH2), and Blue Pearl Bay (WH3). Note Blue Pearl Bay may be included as a third site in the future but is currently not monitored. The three monitoring sites are located in 'open coastal' waters.

Table 1. Water quality monitoring site locations selected for the Whitsunday Water Quality Monitoring Blueprint for Tourism Operators program. Note Blue Pearl Bay 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. Monitoring schedule for 2020 and the first quarter of 2021.

Event	Date scheduled	Cairn Beach (WH1)	Tongue Bay (WH2)
a	04/02/2020	Ocean Rafting / TropWATER	Ocean Rafting / TropWATER
b	04/03/2020	True Blue	Red Cat
-	31/03/2020*	Southern Cross	Southern Cross (Bullet Boats)
-	28/04/2020*	Tallship adventures	Ocean Rafting
c	11/05/2020	Ocean Rafting	Ocean Rafting
d#	26/05/2020	Thunder Cat	Red Cat
e	23/06/2020	Ocean Rafting	Ocean Rafting
f	08/08/2020	Ocean Rafting	Ocean Rafting
g	17/09/2020	Ocean Rafting / TropWATER	Ocean Rafting / TropWATER
h	21/10/2020	Southern Cross Sailing / Red Cat	True Blue Sailing
i#	18/11/2020	Red Cat	True Blue Sailing
j	13/12/2020	Red Cat	Ocean Rafting / True Blue Sailing
k	21/01/2021	Red Cat / Southern Cross Sailing	Ocean Rafting / True Blue Sailing
l	05/03/2021	Southern Cross Sailing / Ocean Rafting	Red Cat / True Blue Sailing

*Note: The March and April 2020 monitoring events were postponed due to COVID-19 restrictions.

water sampling only

Two 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 3). 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.

Figure 3. Tourism operators receiving training out on the water and in a class environment. Photos courtesy of Reef Catchments.

2.1.1 Loggers

A nephelometer was deployed on the seafloor at each site to record water quality measurements over the deployment period (Figure 4). 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 a 4 week period.

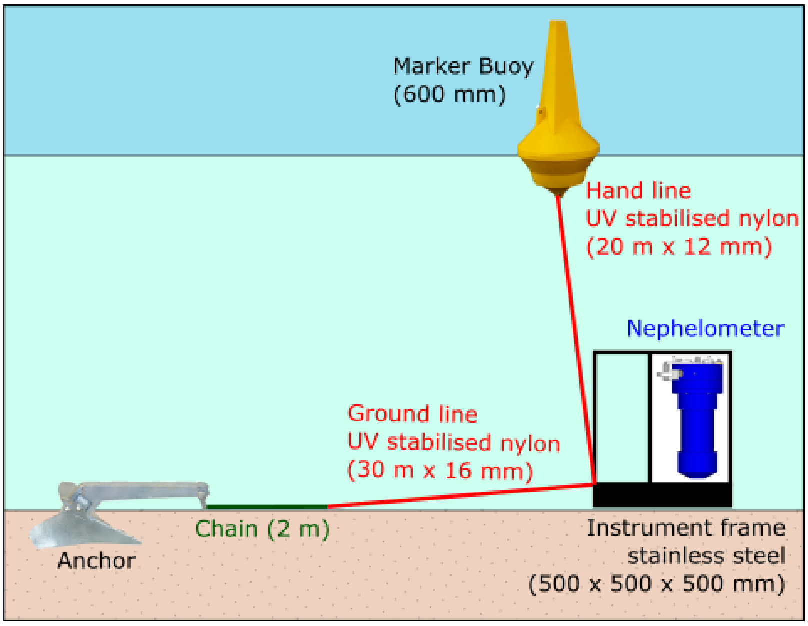


Figure 4. Diagram showing instrument deployments

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.

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.

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 PAR.

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 bio-fouling 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.

2.1.2 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 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 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 millisiemens per centimeter (mS cm^{-1}) in marine settings, but may sometimes be seen reported in microsiemens 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).

2.2 Regional climate

Air temperature (Figure 5) and rainfall observations were obtained from the Bureau of Meteorology Weather station at Hamilton Island Airport (station 033106) for the period 01/01/2020 to 31/03/2021 (Figure 6) and total rainfall calculated for each wet season from 2002 to present (Figure 7). The rainfall onset for the last two years occurred on 27/12/2019 and 08/12/2020 for the Whitsundays (Hamilton Island). The 2020-2021 wet season was an average year with 1117 mm rainfall. There was a period of cool weather and rainfall in late February, and anecdotal evidence at the time of a marine heatwave in early February 2020. The Bureau of Meteorology later reported that "*Sea surface temperatures (SSTs) on the Great Barrier Reef (GBR) during February 2020 were the warmest for any month since instrumental records began in 1900, with temperatures 1.2 °C warmer than the long-term February average (1961–1990)*" (BOM, 2020). Cyclone

Gretel influenced local weather in mid-March 2020 (Figure 8) with tropical cyclone (TC) Gretel being the most significant event during the current monitoring period. TC Niran passed offshore of the region in March 2021 which produced increased wind and wave energy. Tide data was obtained from the Transport and Main Roads Shute Harbour tidal station (P030003A) (Figure 9).

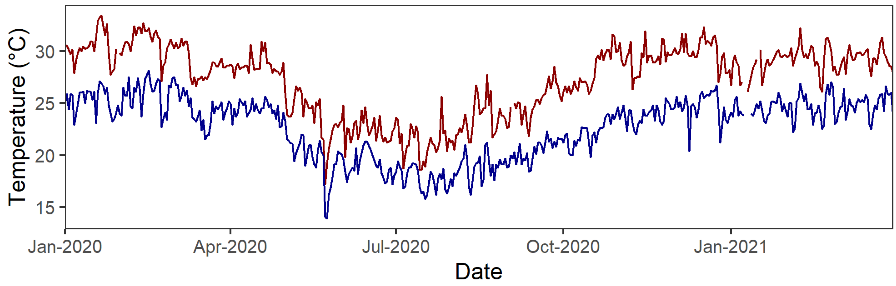


Figure 5. Daily maximum (red) and minimum (blue) temperature observations at Hamilton Island. Observations were drawn from the Bureau of Meteorology weather station at Hamilton Island Airport (station 033106)

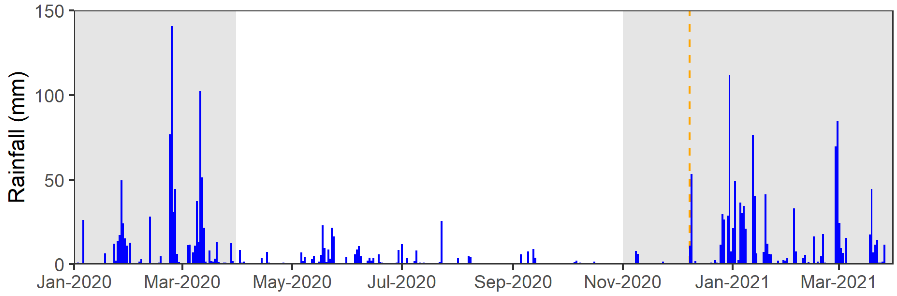


Figure 6. Daily rainfall recorded at Hamilton Island Airport (station 033106). The nominal wet season period is shown in grey, with the 2020-2021 wet season onset marked by the orange dashed line. Data source: http://www.bom.gov.au/climate/data

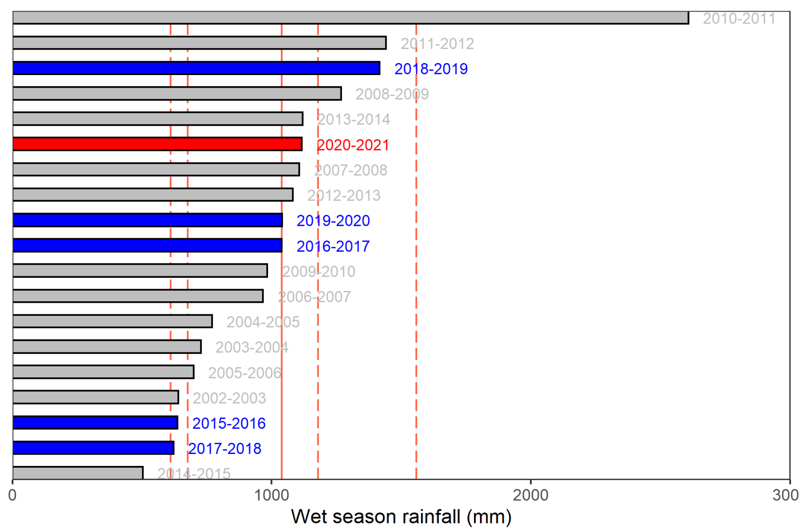


Figure 7. Wet season rainfall for the Whitsunday region ranked in order of decreasing total wet season rainfall (mm). Daily rainfall data was obtained from the Bureau of Meteorology Hamilton Island Airport weather station (Station number 033106). Totals were calculated for the wet season period 1st November to 31st March for each reporting year. Red bar represents the 2020-2021 wet season, blue bars show total rainfall over the previous five wet seasons. Solid red line represents median wet season rainfall 2002-2003 to 2020-2021 and dashed red lines represent 5th, 20th, 80th, and 95th percentiles.

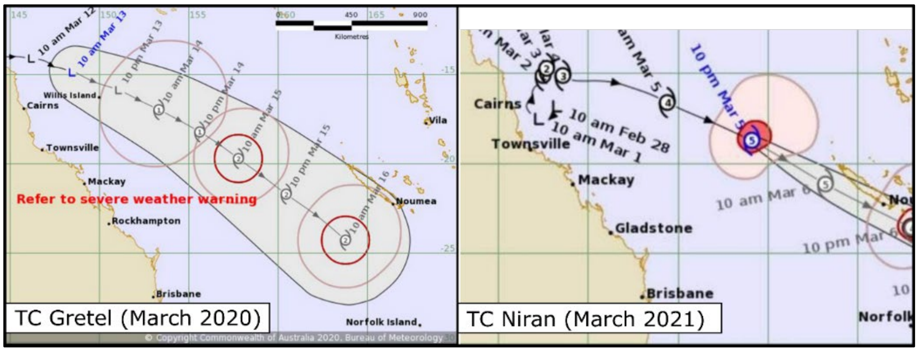


Figure 8. Tropical cyclone Gretel was a major influence for weather in the Whitsunday region in March 2020. While the cyclone remained well offshore it did cause local increased wind and wave activity. TC Niran passed offshore of the region in March 2021 and caused local increased wind and wave activity. Image source: http://www.bom.gov.au

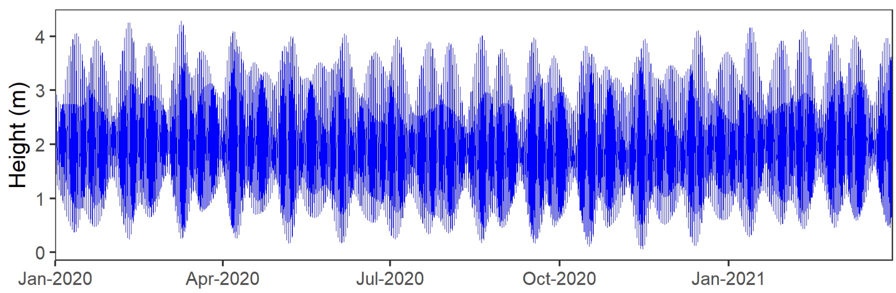


Figure 9. Tide height predictions above LAT at Shute Harbour (Station P030003A).

3 RESULTS

3.1 Logger data

3.1.1 Water temperature

Daily median water temperature ranged from 21.5 to 30.0 °C at Cairn Beach and 21.2 to 30.0 °C at Tongue Bay during the deployment period (Figure 10). Water temperature showed a strong seasonal pattern at both sites. There was a sustained warm period throughout February and the first half of March 2020. Median daily water temperature was similar between sites with generally less than 0.5 °C difference (Figure 11). 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.

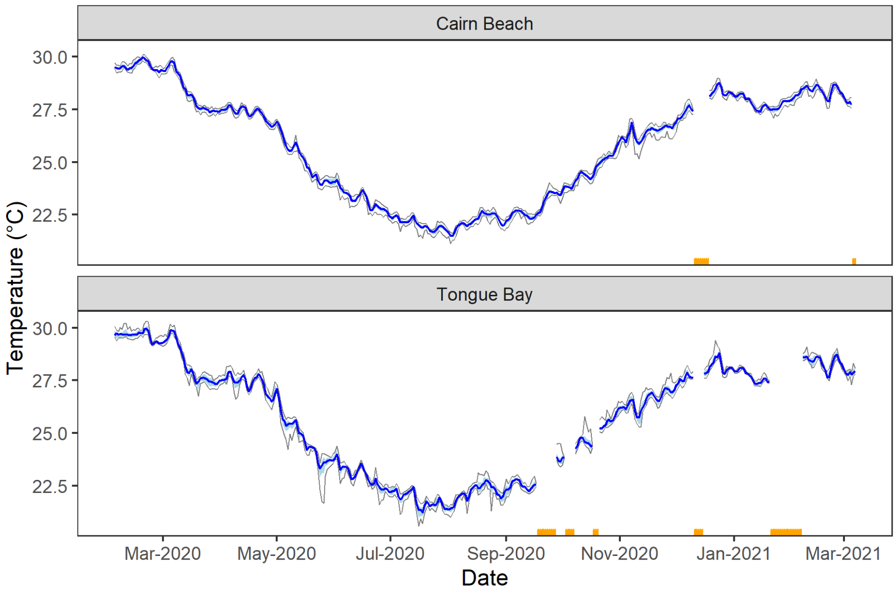


Figure 10. Water temperature measured by the data logger instruments at Cairn Beach and Tongue Bay. Daily median temperature (blue), interquartile range (light blue), and daily minimum and maximum (grey). Periods of missing data are indicated by the orange bar.

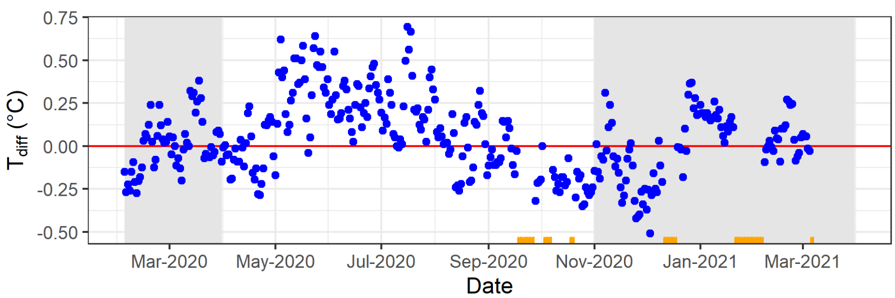


Figure 11. Difference in daily median water temperature (T_{diff}) between the Cairn Beach and Tongue Bay sites. The water temperature is warmer at Cairn beach on days when T_{diff} value is positive, and warmer at Tongue Bay when value is negative. Grey shading indicates the nominal wet season. Periods of missing data are indicated by the orange bar.

3.1.2 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. The logger depth changed between deployments due to slight changes to where the instrument frame was positioned each time it was redeployed. Water level deviation from mean sea level was calculated from the water depth measured by the data logger instruments at Cairn Beach and Tongue Bay (Figure 12). Water level followed the semi-diurnal tide with spring and neap cycles evident. The root means square (RMS) depth is shown in Figure 13. 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 0.0214 m. The most active period saw RMS wave height of up to 0.47 m and aligning with cooler weather and rainfall mid-March. Tropical cyclone Gretel was a major influence for weather in the Whitsunday region in March 2020. While the cyclone remained well offshore it did cause local increased wind and wave activity.

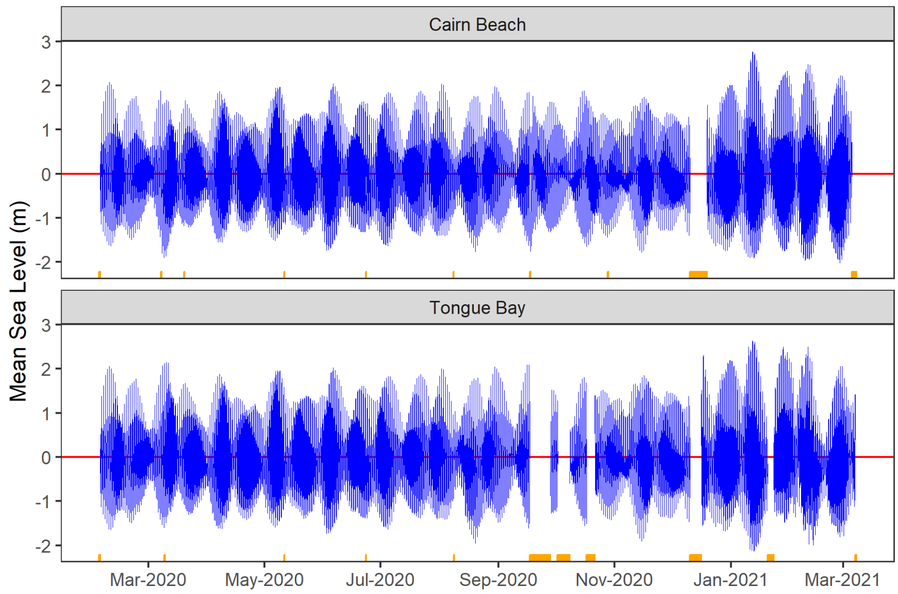


Figure 12. Water level deviation from mean seal level measured by the data logger instruments at Cairn Beach and Tongue Bay. Periods of missing data are indicated by the orange bar.

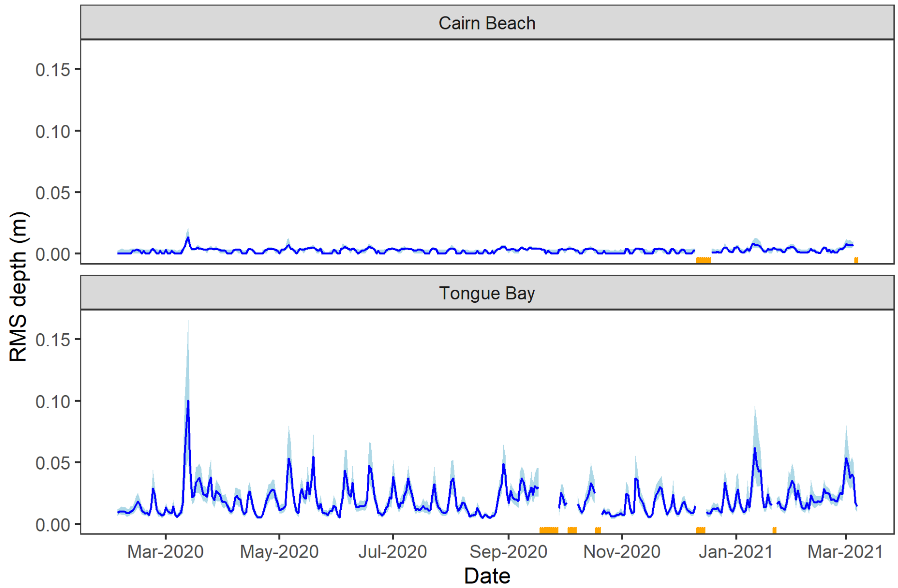


Figure 13. Root mean squared (RMS) water depth measured by the data logger instruments at Cairn Beach and Tongue Bay. Shown is the daily median value (blue) and interquartile range (light blue). Periods of missing data are indicated by the orange bar.

3.1.3 Photosynthetically active radiation (bPAR)

Benthic photosynthetically active radiation (bPAR) was measured at the two sites (Figure 14). The mean daily bPAR was 1.45 mol m^{-2} d^{-1} at Cairn Beach and 1.49 mol m^{-2} d^{-1} at Tongue Bay. Daily bPAR followed the spring-neap tidal cycle, with higher light levels occurring during neap tides and lower levels during spring tides. This cyclical signal can be seen most clearly in the 7 day moving average.

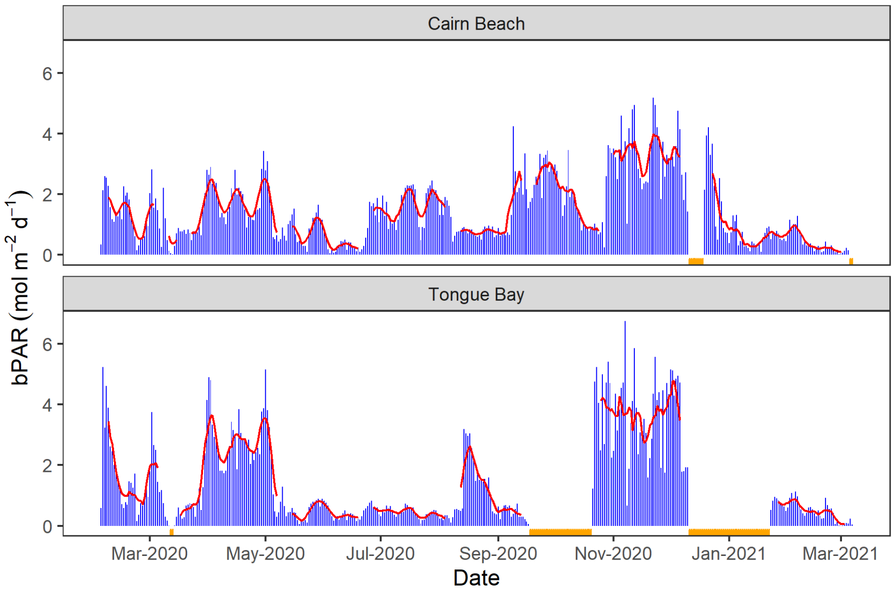


Figure 14. Daily benthic photosynthetically active radiation (bPAR) measured by the data logger instruments at Cairn Beach and Tongue Bay (blue). The 7 day moving average (red) was calculated for each site. Periods of missing data are indicated by the orange bar.

3.1.4 Turbidity

Turbidity ranged from 0 to 116 NTUe at the Cairn Beach monitoring site, with a median value of 1.14 NTUe over the year (Figure 15). Turbidity ranged from 0 to 262 NTUe at the Tongue Bay monitoring site, with a median value of 2.2 NTUe over the year. The Tongue Bay instrument had continuous problems with sensor fouling throughout 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.

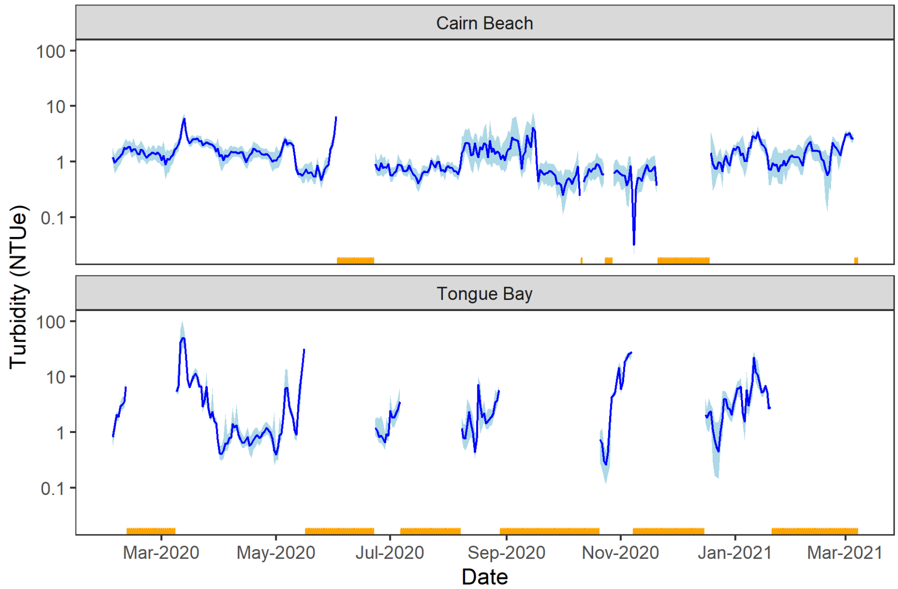


Figure 15. Turbidity measured by the data logger instruments at Cairn Beach and Tongue Bay. Note logarithmic scale on y-axis. Shown is the daily median value (blue) and interquartile range (light blue). Periods of missing data are indicated by the orange bar.

3.2 Water samples

3.2.1 Field observations

The tourism operators recorded observations of conditions on the water at the time of each sampling and maintenance event (Table 4). Secchi disk depth ranged from 2.9 to 12 m (Figure 16). 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 4. Water quality measurements and observations recorded by tourism operators as Cairn Beach and Tongue Bay.

Site Name	Site Code	Date	Time	Secchi depth m	Cloud cover %	Wind knots	Sea surface	Surface scum/slick
Cairn Beach	WH1	04/02/2020	13:45	4.5	15	5 - 10	Calm	Nil
		07/03/2020	17:15	4	80	0 - 5	Flat	Nil
		11/05/2020	08:05	3	75	21 - 25	Light surface chop	Nil

		26/05/2020	11:45	6	5 - 10	5 - 10	Calm	Nil
		23/06/2020	08:15	6	0	5 - 10	Calm	Nil
		08/08/2020	09:15	5.1	100	0	0	Nil
		17/09/2020	09:40	3	70	10 - 15	Choppy	Nil
		24/10/2020	06:15	12#	100	5	Calm	NR
		19/11/2020	10:10	4	30	20	Choppy	Nil
		19/12/2020	16:10	NR	50	15	Calm	Nil
		21/01/2021	15:45	4	90	10	Calm	Nil
		10/03/2021	08:46	6	25	10	Ripple	Nil
Tongue Bay	WH2	04/02/2020	15:00	6.5	10	5 - 10	Calm	Nil
		09/03/2020	10:30	0.3#	80	5	Glass	Nil
		11/05/2020	10:20	3*	5	25	Chop	Nil
		26/05/2020	12:30	5.5	60	5	Calm	Nil
		23/06/2020	09:30	4.2	0	10 - 15	0 - 0.3	Nil
		08/08/2020	10:15	5	80	5	Slight, Ripple	Nil
		17/09/2020	11:20	2.9	90	10 - 15	Choppy	Nil
		21/10/2020	09:55	4	Mild	5 - 10	Slight chop	NR
		18/11/2020	09:22	4	10	5 - 10	1m swell ESE	Nil
		13/12/2020	11:15	3	25	25	Small wavelets	Nil
		21/01/2021	11:00	4	50	20 - 25	Mod wavelets	Nil
		10/03/2021	11:05	4	40	5	Calm	Nil

Note: Likely erroneous measurement, * Note: Secchi depth estimated, NR = not recorded.

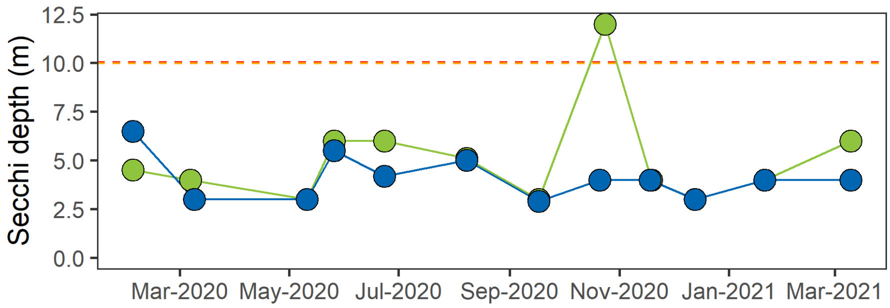


Figure 16. Secchi depth measured by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown (both = 10 m).

3.2.2 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 17). Conductivity ranged from 51.7 to 54.0 mS cm^{-1} (median = 53.2 mS cm^{-1}) at Cairn Beach and ranged from 52.0 to 54.0 mS cm^{-1} (median = 53.3 mS cm^{-1}) at Tongue Bay and was within expected range of seawater with limited freshwater inputs. TSS ranged from 1.0 to 9.3 mg L^{-1} (median = 2.1 mg L^{-1}) at Cairn Beach and ranged from 1.1 to 3.3 mg L^{-1} (median = 2.35 mg L^{-1}) at Tongue Bay. TSS intermittently exceeded both the GBRMPA water quality guideline trigger values and the DEHP water quality objectives. The exceptionally high TSS concentration measured at Cairn Beach in March

2020 corresponded with elevated particulate nutrient concentrations. pH ranged from 8.14 to 8.35 (median = 8.24) at Cairn Beach and ranged from 8.14 to 8.32 (median = 8.23) at Tongue Bay. pH was within the 20th and 80th percentiles of the DEHP water quality objectives for open coastal waters.

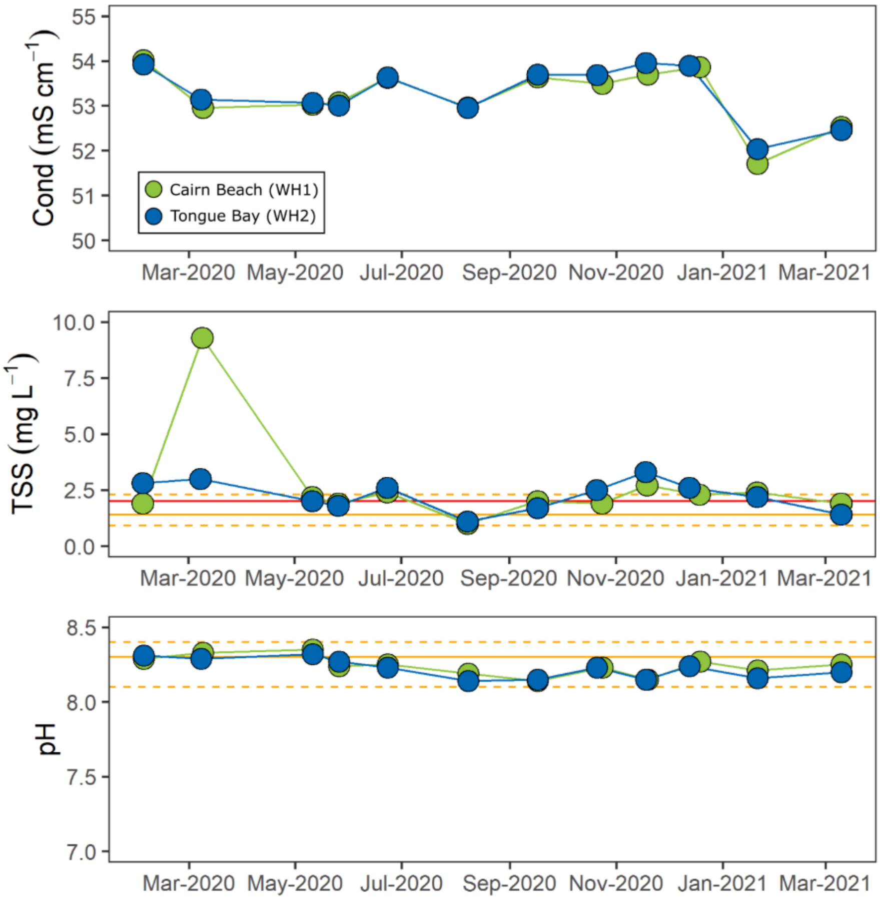


Figure 17. Electrical conductivity (Cond), total suspended solids (TSS), and pH from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown.

3.2.3 Nutrients

Water samples were analysed for nitrogen and generally exceeded water quality thresholds (Figure 18). Total nitrogen concentrations ranged from 85 to 227 µg N L^{-1} (median = 136 µg N L^{-1}) at Cairn Beach and ranged from 94 to 254 µg N L^{-1} (median = 114 µg N L^{-1}) at Tongue Bay. Particulate nitrogen ranged from 1 to 116 µg N L^{-1} (median = 29.5 µg N L^{-1}) at Cairn Beach and ranged from 1 to 116 µg N L^{-1} (median = 29.5 µg N L^{-1}) at Tongue Bay. Concentrations at Cairn Beach in March 2020 were elevated, and corresponded with high TSS concentrations. Nitrate-nitrite concentrations ranged from 0.5 to 11 µg N L^{-1} (median = 5 µg N L^{-1}) at Cairn Beach and ranged from 2 to 5 µg N L^{-1} (median = 3 µg N L^{-1}) at Tongue Bay. Nitrate-nitrite concentrations (indicating directly bioavailable N) were approximately double at Cairn Beach than Tongue Bay on most sampling occasions.

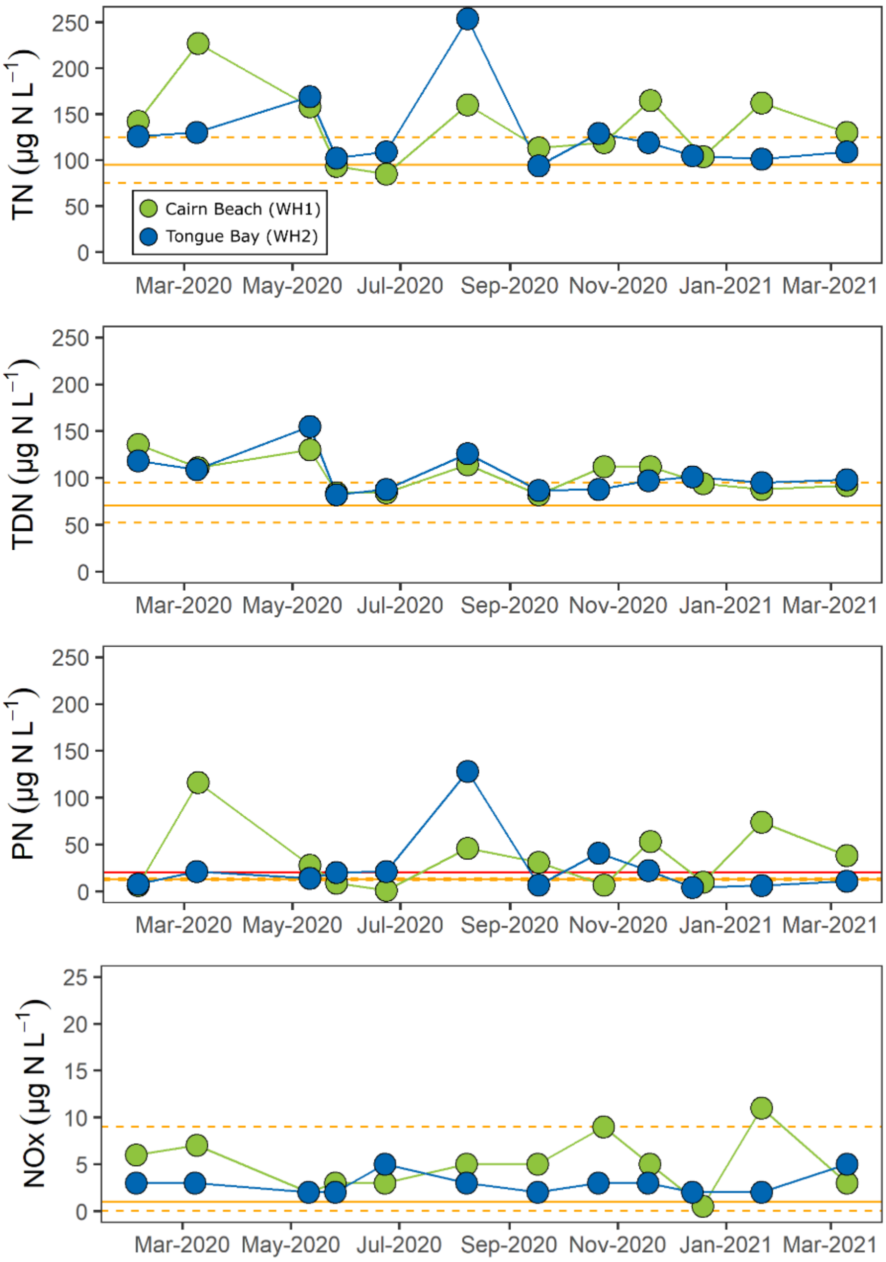


Figure 18. Total nitrogen (TN), total dissolved nitrogen (TDN), particulate nitrogen (PN), and nitrate-nitrite (NOx) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown

Water samples were analysed for phosphorus and generally within acceptable range for WQ thresholds (Figure 19). Total phosphorus concentrations ranged from 6 to 17 µg P L^{-1} (median = 7 µg P L^{-1}) at Cairn Beach and ranged from 6 to 9 µg P L^{-1} (median = 7 µg P L^{-1}) at Tongue Bay. Particulate phosphorus concentrations ranged from 0 to 10 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.

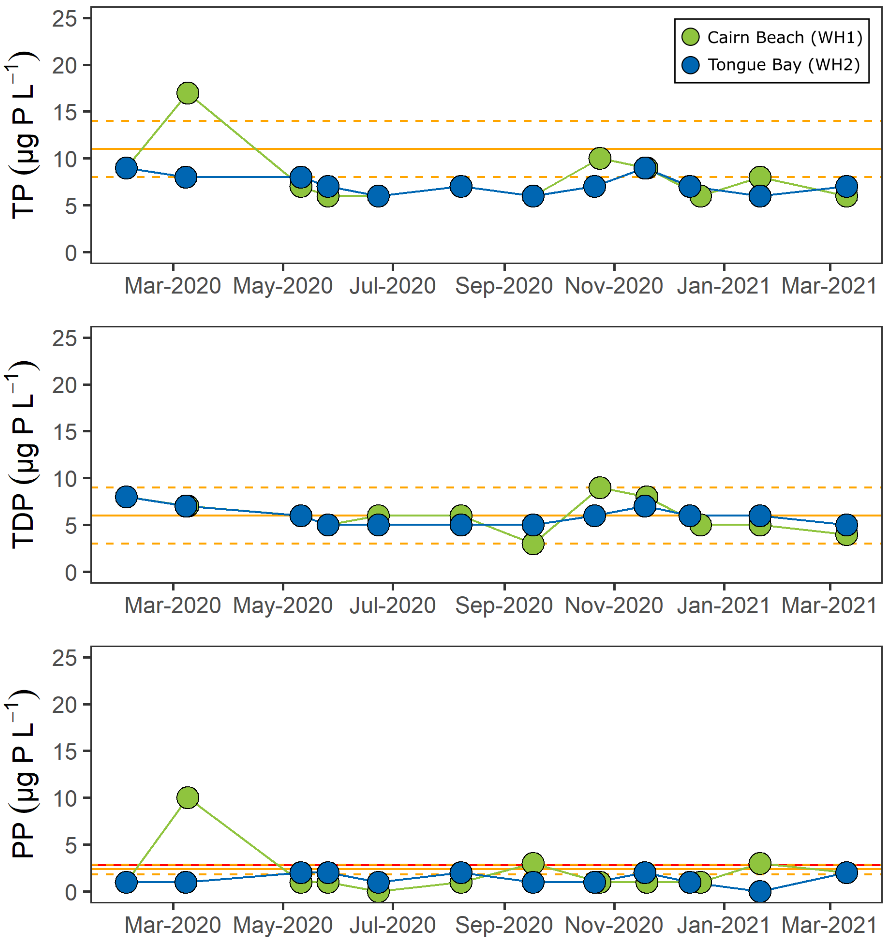


Figure 19. Total phosphorus (TP), total dissolved phosphorus (TDP), and particulate phosphorus (PP) concentrations measured in water samples collected from Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown

3.2.4 Chlorophyll *a*

Chlorophyll-*a* concentrations ranged from <0.20 to 0.65 µg L^{-1} (median = 0.40 µg L^{-1}) at Cairn Beach and ranged from <0.20 to 0.57 µg L^{-1} (median = 0.40 µg L^{-1}) at Tongue Bay (Figure 20). Chlorophyll-*a* was not elevated at Cairn Beach in March 2020 indicating that elevated particulate nutrient concentrations were likely associated with suspended sediments rather than a phytoplankton bloom.

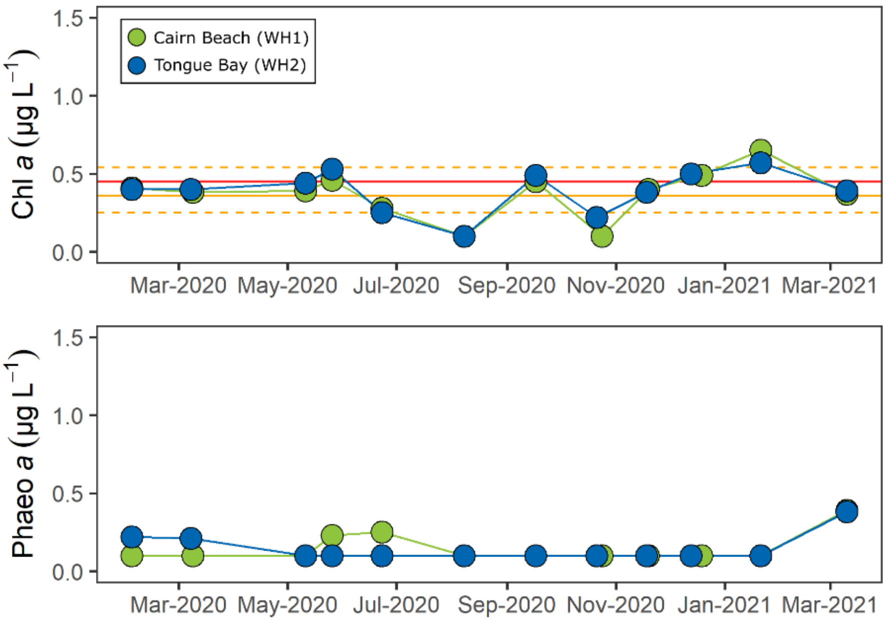


Figure 20. Chlorophyll-*a* and Phaeophytin-*a* from samples collected by tourism operators at Cairn Beach (green) and Tongue Bay (blue). The GBRMPA water quality guideline trigger value (red) and DEHP water quality objectives (orange) are shown

3.2.5 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 04/02/2020 and 10/03/2021. The median value of each parameter was compared to DEHP water quality objective (WQO) median values (Figure 21). 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 22). The chlorophyll-*a* indicator score was -0.134 (Moderate) for Cairn Beach, and -0.152 (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 -0.129 (Moderate) for Tongue Bay. The 'poor' score at Cairn Beach was most influenced by high particulate nitrogen (PP) and dissolved nitrogen oxides (NOx). The water clarity indicator score which is based on TSS, turbidity and Secchi depth was -0.544 (Poor) for Cairn Beach, and -0.915 (Very Poor) for Tongue Bay. The overall regional score based on the aggregated scores of the two sites was calculated to be -0.368 (Poor).

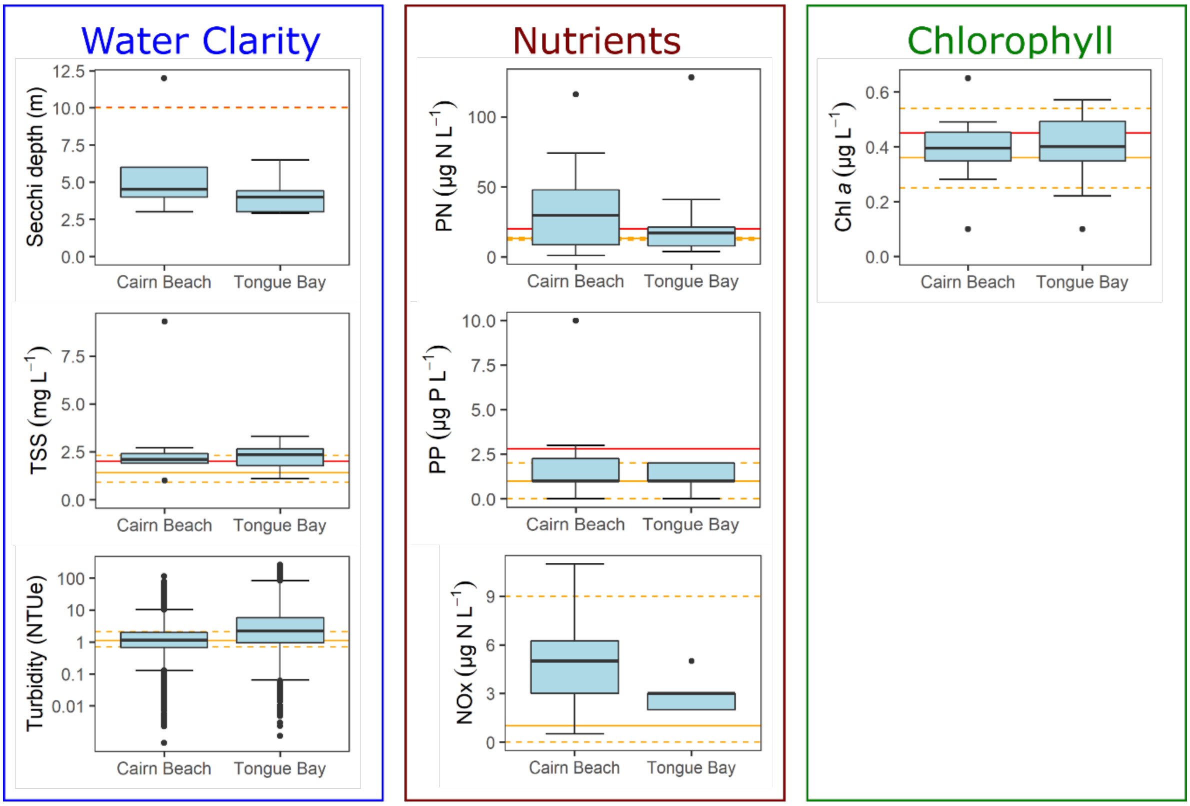


Figure 21. Boxplots of each of the parameters used to calculate water quality index. The water clarity score is composed of Secchi disk depth, total suspended solids (TSS), and turbidity. The nutrients indicator is composed of particulate nitrogen (PN), particulate phosphorus (PP), and oxidised nitrogen (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.

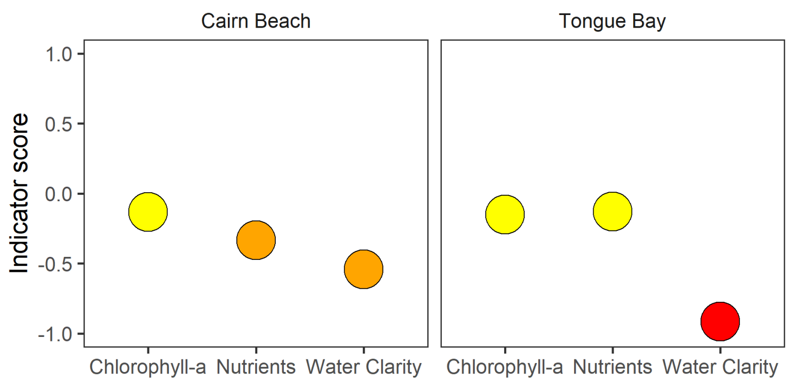


Figure 22. Marine offshore water quality indicator scores calculated for Cairn Beach and Tongue Bay. The indicator scores are colour coded to Very Good (dark green), Good (light green), Moderate (yellow), Poor (orange), and Very Poor (red).

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 this changes over time and link it to the climatic, hydrological, and oceanographic processes driving it. 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 water quality scores calculated by the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Cards over the previous six years from 2014 to 2019 (Figure 23). Over this period the water quality in the Whitsunday region scored from moderate to very poor. 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). 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.

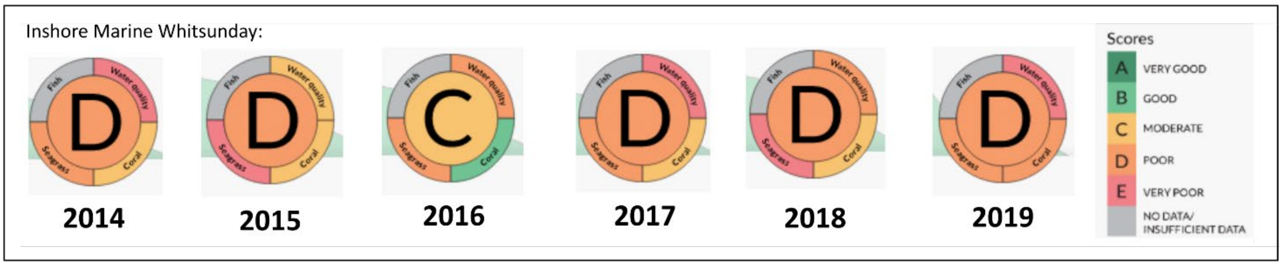


Figure 23. Results of the Inshore Marine Whitsunday Environmental component of the Healthy Rivers to Reef Partnership Mackay-Whitsunday-Isaac Report Cards from 2014 to 2019. Source: https://healthyriverstoreef.org.au/report-card-results/

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 = 4.5 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 1.62 NTUe at Cairn Beach and 5.43 NTUe at Tongue Bay, exceeding the mean annual guideline value. The total suspended solids (TSS) mean annual guideline value is 2 mg L^{-1} for open coastal settings. The mean TSS concentration measured was 2.65 mg L^{-1} at Cairn Beach and 2.25 mg L^{-1} at Tongue Bay. Hence, both sites exceeded the guideline trigger value for total suspended solids. The possible drivers for reduced 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 during February 2020 with an average temperature of 29.6 °C during the monitoring period. 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 throughout February and the first half of March 2020, and throughout April 2020, it did not exceed the guideline trigger value of 1°C above long term maximum temperature (Figure 24). 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. Sea surface temperatures in February 2020 were the warmest for any month since instrumental records began in 1900 (BOM, 2020). Warmer water temperatures can result in coral bleaching, and if the warming continues bleaching can progress to mortality. A mass coral bleaching event occurred throughout the GBR in early 2020 (AIMS, 2020; GBRMPA, 2020). Coral bleaching was detected throughout the Whitsunday Islands region by Reef Check Australia in the months following the February-March 2020 warming event (Cook et al., 2020).

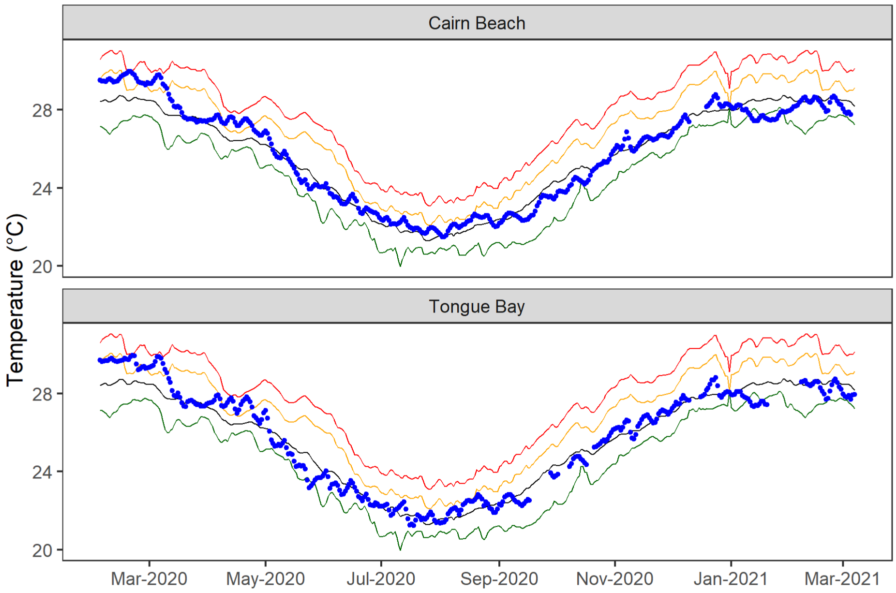


Figure 24. Daily mean temperature measured at Cairn Beach and Tongue Bay (blue), compared to average (black), minimum (green), maximum (orange), and maximum + 1°C guideline value (red) derived from Hook Island AIMS data.

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 35 µg N L^{-1} at Cairn Beach and 25 µg N L^{-1} at Tongue Bay. Hence, PN exceeded the guideline trigger values. The mean particulate phosphorus concentration measured was 2.1 µg P L^{-1} at Cairn Beach and 1.3 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 median concentration of 0.4 µg L^{-1}. 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 not considered elevated in relation to the guideline trigger values.

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 5). 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 and pressure sensors provided data for 96.9% of the time at Cairn Beach, with the missing ~3% accounted for due to the short time each month (approx. 1 hr) between deployments. The temperature and pressure sensors provided data for 88.4 and 92.1 % of the time at Tongue Bay. The lower data recovery at Tongue Bay was due to a malfunction of one of the loggers in September 2020. The photosynthetically active radiation (PAR) and turbidity sensors on the MGL loggers are more susceptible to fouling, and rely on a mechanical wiper to keep the sensors clean throughout the deployment. The PAR and turbidity sensors provided data for 96.9 and 83.2 % of the time at Cairn Beach. The PAR and turbidity sensors provided data for 80.1 and 39.1 % of the time at Tongue Bay. There was consistently poor data recovery from the turbidity sensor at Tongue Bay. The percentage data recovery for each sensor on the logger instruments was also calculated for each deployment at Cairn Beach and Tongue Bay (Figure 25).

Table 5. Summary of data recoveries (percent) for each site since the beginning of the program

Sensor	Cairn Beach	Tongue Bay
Temperature	96.9	88.4
Pressure	96.9	92.1
PAR	96.9	80.1
Turbidity	83.2	39.1

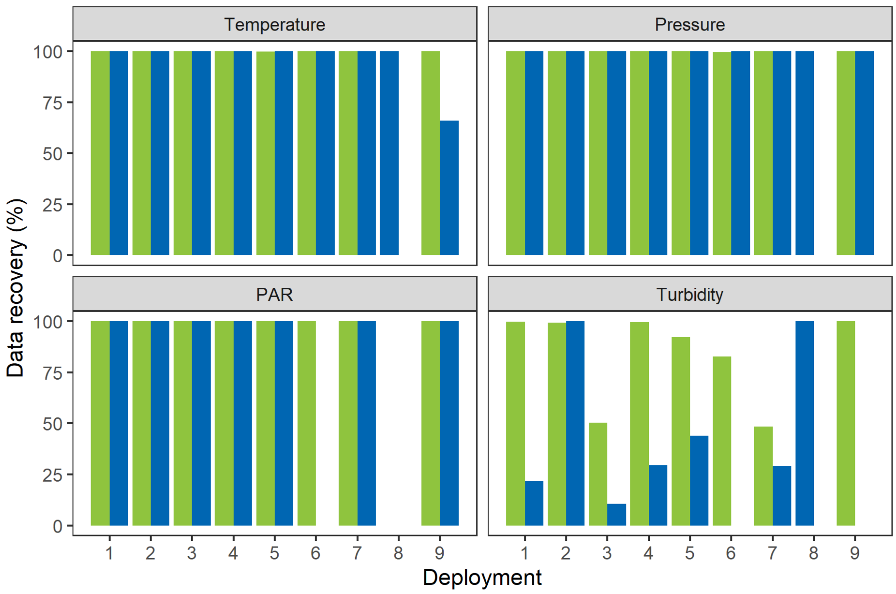


Figure 25. Percentage data recovery from each sensor on the logger instruments for each deployment at Cairn Beach (green) and Tongue Bay (blue).

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

The Secchi disk depth of 0.3 m at Tongue bay WH2 on 09/03/2020 seems unlikely as the comment below says "Perfect conditions, good vis". We would expect the Secchi disk depth to be deeper than 0.3 m considering the visibility was good. This entry has been flagged as a measurement error. Similarly there was an occurrence of 12 m Secchi depth recorded at Cairn beach in October 2020. This depth measurement is much greater than the site depth (8 m) so seems unlikely.

While improvements have been made over the 12 months, there have been numerous occurrences of datasheets being returned by the operators incomplete. It is important that these data sheets are fully completed on the day that the instruments are retrieved and redeployed, and the water samples are collected. Missing information included the information of the logger retrieved and new logger deployed. Recording the logger serial number is critical. Without knowing the serial number of the logger deployed at the site reduces our ability to know which data relates to which site during the downloading stage. The GPS coordinates of the redeployed instruments were also often omitted. The recording of the location of the instrument frame and anchor is critical, particularly in a situation where the surface marker buoy goes missing. As the frames are not placed in exactly same position each time they are redeployed, the GPS coordinates are then used to begin searching the last know location of the instrument with a grappling hook. If the instrument cannot be found after searching with the grappling hook, additional efforts to retrieve the instrument will be necessary. The bottle label was not recorded on the field datasheets. It is important that this information is included on the datasheets, particularly when the laboratory processes the samples. In addition, information was not recorded on the datasheet when the Chlorophyll samples were filtered at the end of the day on one occasion (WH1b). Missing information for the sample were date and time filtered, and the volume filtered. The information was recorded on the envelope which the filter was stored in, but not on the datasheet. 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.

Transport of samples

There was an ongoing problem with sample storage and transport between Airlie Beach and the Townsville analytical laboratories. Samples arrived at the laboratory at ambient temperature (approx. 25°C). It was determined that this may be due to the samples being transported over 4 legs (Airlie > Proserpine, Proserpine > Mackay, Mackay > Townsville, Townsville > JCU TropWATER) meaning that the time in transit is 8+ hours rather than being directly transported (~3.5 hours). The small 10 L eskies are unable to keep the nutrient samples and chlorophyll filters frozen under those conditions. This has been rectified by placing additional ice blocks inside the two 10 L eskies, and transporting the samples between Airlie Beach and Townsville laboratory in a larger esky with additional ice blocks.

4.2.3 Data sufficiency

The two newly established water quality monitoring sites from this project increase the density of water quality monitoring sites within the region (Figure 26). 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 we will be able 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. There is a reporting timing mismatch between this report and MMP and NQBP programs which means it is not yet possible to directly compare similarity between sites. This may be possible in early 2022 when those reports and associated data become available.

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.

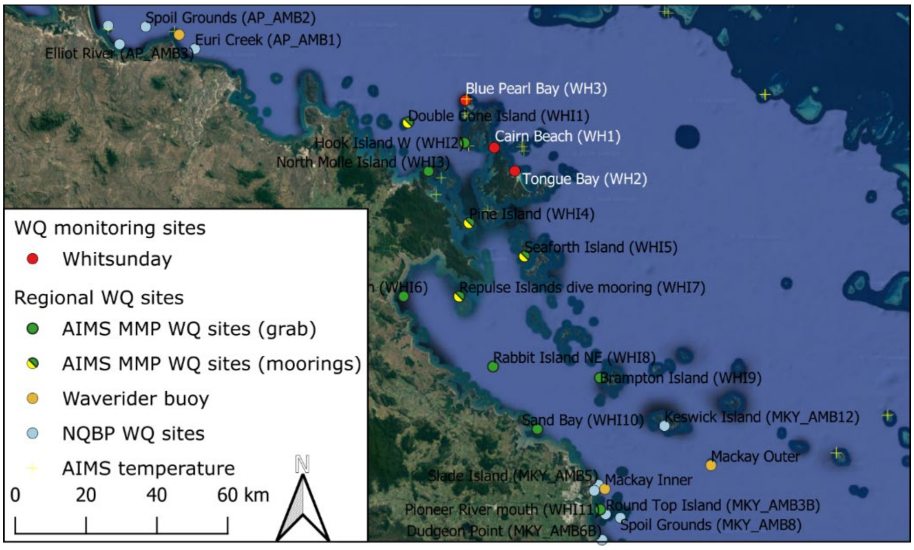


Figure 26. Monitoring sites from other water quality programs operating in and adjacent to the Whitsunday region

4.3 Concluding remarks

The Whitsunday Water Quality Monitoring Blueprint for Tourism Operators has now been in operation for approximately 15 months and will continue to generate useful data for the region, including potentially for use in regional report cards. Tourism operator's eagerness to participate in the program will continue to be a strength of the program.

5 REFERENCES

AIMS. (2017). *AIMS Sea Water Temperature Observing System (AIMS Temperature Logger Program)*.

AIMS. (2020). *Annual Summary Report on coral reef condition for 2019/20*. Australian Institute of Marine Science Retrieved from https://www.aims.gov.au/reef-monitoring/gbr-condition-summary-2019-2020.

Baird, M., Margvelashvili, N., & Cantin, N. (2019). *Historical context and causes of water quality decline in the Whitsunday region*. Retrieved from CSIRO. Oceans and Atmosphere:

BOM. (2020). 2020 marine heatwave on the Great Barrier Reef. Retrieved from http://www.bom.gov.au/environment/doc/2020-GBR-marine-heatwave-factsheet.pdf

Brodie, J., Schroeder, T., Rohde, K., Faithful, J., Masters, B., Dekker, A., . . . Maughan, M. (2010). Dispersal of suspended sediments and nutrients in the Great Barrier Reef lagoon during river-discharge events: conclusions from satellite remote sensing and concurrent flood-plume sampling. *Marine and Freshwater Research, 61*(6). doi:10.1071/mf08030

Bunt, J. A. C., Larcombe, P., & Jago, C. F. (1999). Quantifying the response of optical backscatter devices and transmissometers to variations in suspended particulate matter. *Continental Shelf Research, 19*(9), 1199-1220. doi:10.1016/s0278-4343(99)00018-7

Cantin, N., Wu, Y., Fallon, S., & Lough, J. (2019). *Historical records of terrestrial sediment and flood plume inputs to the Whitsunday Island region from coral skeletons: 1861-2017*. Retrieved from Australian Institute of Marine Science, Townsville, Qld:

Conner, C. S., & De Visser, A. M. (1992). A laboratory investigation of particle size effects on an optical backscatterance sensor. *Marine Geology, 108*(2), 151-159. doi:10.1016/0025-3227(92)90169-i

Cook, N., Calcraft, J., Songcuan, A., Dean, A., Levin, R., Saper, J., . . . Salmond, J. (2020). *Reef Check Australia Great Barrier Reef Season Summary Report 2019-2020*. Retrieved from Reef Check Foundation Ltd.:

DEHP. (2009). *Environmental Protection (Water) Policy 2009. Proserpine River, Whitsunday Island and O'Connell River Basins Environmental Values and Water Quality Objectives*. Retrieved from https://environment.des.qld.gov.au/__data/assets/pdf_file/0023/87611/proserpine-river-ev-wqo.pdf.

DES. (2018). *Monitoring and Sampling Manual: Environmental Protection (Water) Policy*. Brisbane, QLD: Department of Environment and Science (Queensland Government).

GBRMPA. (2010). *Water quality guidelines for the Great Barrier Reef Marine Park 2010 [electronic resource]* In.

GBRMPA. (2019). *Reef water quality report card 2017 and 2018*. Townsviille QLD: Great Barrier Reef Marine Park Authority.

GBRMPA. (2020). Statement: coral bleaching on the Great Barrier Reef 26/03/20 [Press release]. Retrieved from https://www.gbrmpa.gov.au/news-room/latest-news/latest-news/coral-bleaching/2020/statement-coral-bleaching-on-the-great-barrier-reef

Gruber, R., Waterhouse, J., Logan, M., Petus, C., Howley, C., Lewis, S., . . . Neilen, A. (2019). *Marine Monitoring Program: Annual Report for Inshore Water Quality Monitoring 2017-18. Report for the Great Barrier Reef Marine Park Authority.* Townsville: Great Barrier Reef Marine Park Authority.

Larcombe, P., Ridd, P. V., Prytz, A., & Wilson, B. (1995). Factors controlling suspended sediment on inner-shelf coral reefs, Townsville, Australia. *Coral Reefs, 14*(3), 163-171. doi:10.1007/bf00367235

Lønborg, C., Devlin, M., Waterhouse, J., Brinkman, R., Costello, P., da Silva, E., . . . Zagorskis, I. (2016). *Marine Monitoring Program: Annual report for inshore water quality monitoring 2014-2015*. Retrieved from http://hdl.handle.net/11017/3050

Ludwig, K. A., & Hanes, D. M. (1990). A laboratory evaluation of optical backscatterance suspended solids sensors exposed to sand-mud mixtures. *Marine Geology, 94*(1-2), 173-179. doi:10.1016/0025-3227(90)90111-v

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J., & Barnes, D. (2003). Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature, 421*(6924), 727-730. doi:10.1038/nature01361

MWIHRRP. (2021). *Mackay-Whitsunday-Isaac 2020 Report Card Methods Technical Report*. Retrieved from Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership. Proserpine, QLD:

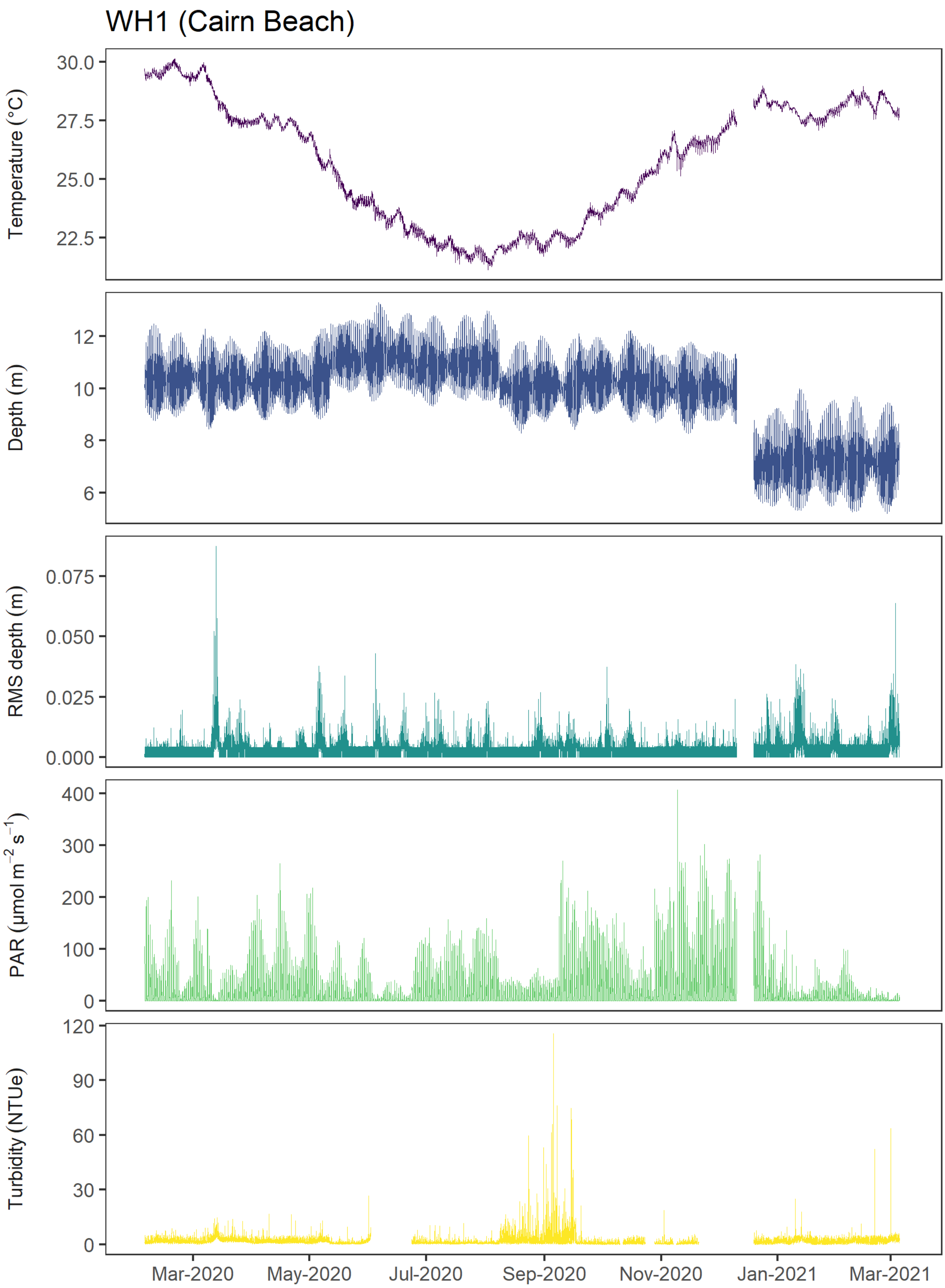
Standards Australia. (1998). Water quality - Sampling - Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. In (Vol. AS/NZS 5667.1-1998). Homebush, NSW: Standards Association of Australia.

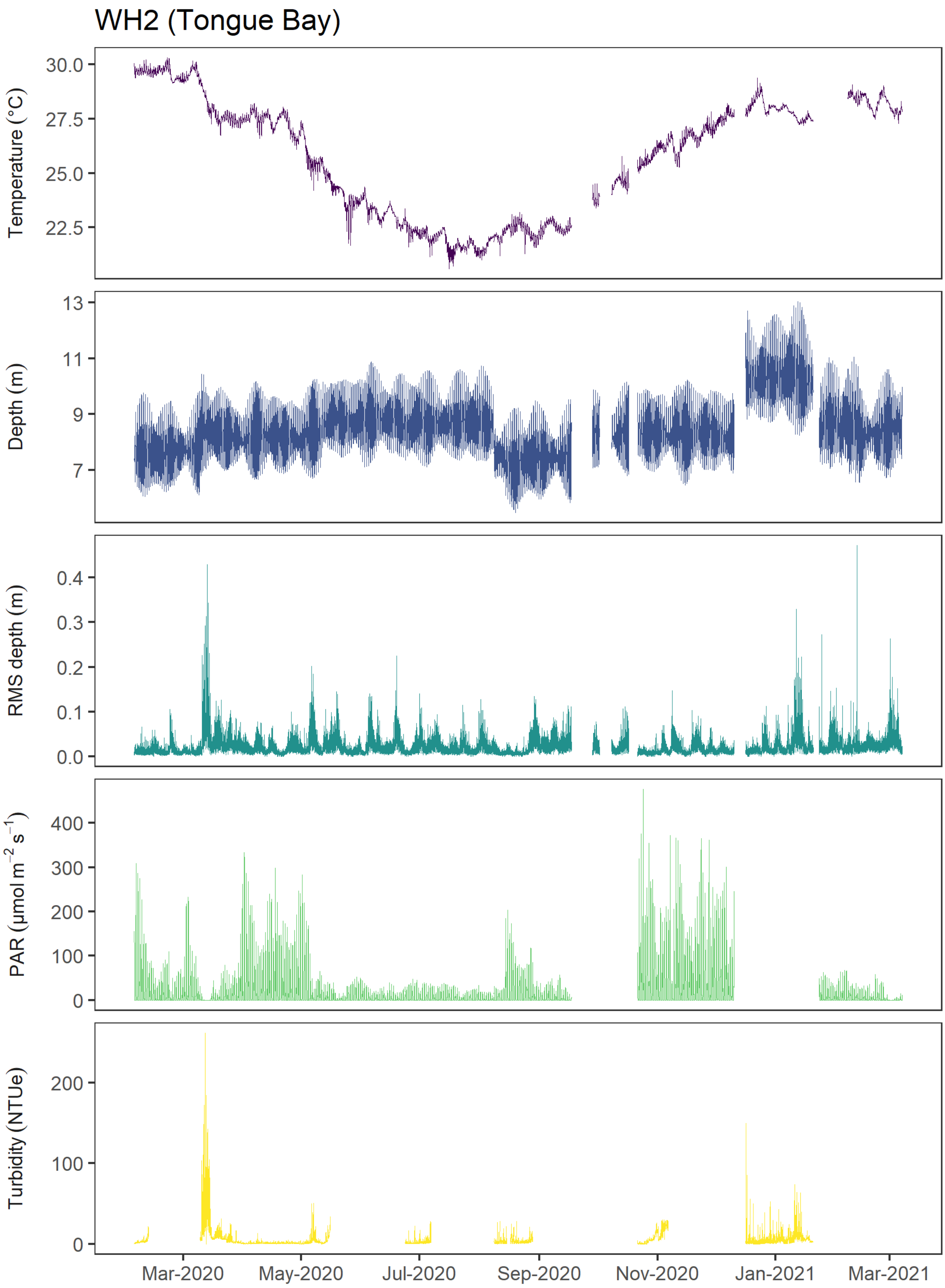
Waterhouse, J., Lønborg, C., Logan, M., Petus, C., Tracey, D., Lewis, S., . . . Schaffelke, B. (2017). *Marine Monitoring Program: Annual report for inshore water quality monitoring 2015-2016*. Retrieved from http://hdl.handle.net/11017/3321

Wolanski, E., Delesalle, B., & Gibbs, R. (1994). Carbonate mud in Mataiva Atoll, French Polynesia: Suspension and export. *Marine Pollution Bulletin, 29*(1-3), 36-41. doi:10.1016/0025-326x(94)90424-3

A1 APPENDIX

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




WH2 (Tongue Bay)
Temperature (°C)
30.0
27.5
25.0
22.5
Depth (m)
13
11
9
7
RMS depth (m)
0.4
0.3
0.2
0.1
0.0
PAR (µmol m-2 s-1)
400
300
200
100
0
Turbidity (NTUe)
200
100
0
Mar-2020
May-2020
Jul-2020
Sep-2020
Nov-2020
Jan-2021
Mar-2021

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