Abbot Point Ambient Water Quality Monitoring

July 2016 to June 2017

North Queensland Bulk Ports

October 2017

Phone: 61 7 4972 7530 | Unit 3, 165 Auckland St | PO Box 1267, Gladstone QLD 4680 |

www.visionenvironment.com.au

REPORT CONTRIBUTORS

Role	Team member
Project Management	Leonie Andersen, Felicity Melville
Fieldwork	Matt Frapple, Ralph Alquezar, Mark Jensen, James Sadler, Carsten Wolff, Col Andersen
Reporting & Review	Felicity Melville, James Sadler, Carsten Wolff

CITATION

This report should be cited as:

Vision Environment (2017). *Abbot Point Ambient Water Quality Monitoring: July 2016 to June 2017. North Queensland Bulk Ports*. Vision Environment, Gladstone Australia.

DOCUMENT CONTROL

Document draft	*Originated by*	*Edit and review*	*Date*
Draft issued for internal review	FM	JS, CW	13/09/2017
Draft issued to Client	FM	JS, CW	20/09/2017
Final issued to client	NQBP	FM	17/10/2017

DISCLAIMER

Certified System Quality ISO 9001 SAI GLOBAL
Certified System Health & Safety AS 4801 SAI GLOBAL
Certified System Health & Safety OHSAS 18001 SAI GLOBAL
Certified System Environment ISO 14001 SAI GLOBAL

FILE REFERENCE

17102017 FINAL Abbot Point Ambient Water Quality Monitoring Report July 2016 to June 2017_VE.docx

Table of Contents

List of Tables

List of Figures

Acronyms

APHA	American Public Health Association
AWQG	Australian Water Quality Guidelines
BOM	Bureau of Meteorology
BPAR	Benthic Photosynthetically Active Radiation
BTEXN	Benzene, Toluene, Ethylene, Xylene and Napthalene
DO	Dissolved Oxygen
DNRM	Department of Natural Resources and Mines
DSITIA	Department of Science, Information Technology, Innovation and the Arts, Queensland
EHP	Department of Environment and Heritage Protection
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
HSEQ	Health, Safety, Environment and Quality
K_d	Light attenuation coefficient
LSD	Least Squares Difference
LOR	Limits of Reporting
MS	Management System
NOx	Oxidised nitrogen (includes nitrate and nitrite)
NTU	Nephelometric Turbidity Units
NQBP	North Queensland Bulk Ports
PAR	Photosynthetically Active Radiation
QWQG	Queensland Water Quality Guidelines
SMART	Self-Monitoring Algorithm in Real Time
TC	Tropical Cyclone
TDP	Total Daily PAR
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
VE	Vision Environment
WBDDP	Western Basin Dredging and Disposal Project
WQO	Water Quality Objective

SUMMARY

Continued baseline water quality monitoring at Abbot Point over a 12 month period from July 2016 to June 2017 has provided the following summarised results:

- Rainfall during the 12 month period was higher than the long-term average, with both the Wet and Dry Seasons recording higher than average rainfall. The most significant rainfall period was recorded in late March 2017 during the advent of Tropical Cyclone (TC) Debbie, which made landfall as a Category 4 system near Airlie Beach. Over 380 mm of rainfall was recorded on the 28 and 29 March at Bowen, with winds of 148km/h and significant wave heights of 2.3m. High river flow from the Don and Elliot Rivers and Euri Creek were recorded in subsequent days.
- Winds were found to be predominantly north-easterly from mid-September 2016 to mid-January 2017, with south-easterly winds dominating during the remaining months. Wave height patterns paralleled wind speed patterns and were the predominant driver of sediment resuspension events during non-rainfall periods.
- The passing of TC Debbie had a large impact on benthic and surface turbidity, as well as sediment resuspension and benthic photosynthetic active radiation (PAR).
- Overall, turbidity across the six sites was significantly higher during the Wet Season than during the Dry Season, although the majority of values were within a small range. Most mean turbidity values were higher than the Queensland Water Quality Guideline (QWQG) of 1 NTU, as recorded in previous monitoring programs, although the trigger value established for open coastal waters could be considered conservative in relation to the Abbot Point background environment. Higher wind speeds, which increased wave heights, resulted in higher turbidity values particularly during TC Debbie, suggesting that turbidity near Abbot Point is predominantly wind and wave-driven. Sedimentation results supported this with increased sediment resuspension (flux) in periods of high wind and waves, compared to there being little response to tidal phases and rainfall.
- Patterns of sediment movement (e.g. deposition or erosion) were also highly influenced by wind direction, particularly at the shallower AMB1 and AMB4 sites. Notwithstanding the large wind direction change during TC Debbie, the seasonal wind direction change in mid-September altered overall erosion at AMB1 to deposition, which reversed upon the mid-January wind direction change.
- Overall, benthic PAR (BPAR) levels across the monitoring sites were predominantly impacted by the depth of the site. Shallower sites recorded significantly higher BPAR, than deeper sites. Significantly higher ambient PAR and BPAR levels were also recorded during the Wet Season than during the Dry Season, despite the significantly lower turbidity recorded during the Dry Season.
- Significant seasonality was evident for water temperature, as expected. Conductivity remained reasonably stable across the year and sites, with the exception of a freshwater surface layer recorded at AMB1 Surface with the advent of TC Debbie and its associated rainfall. mixing of the water column within a few days of TC Debbie resulted in the removal of the salinity halocline, with conductivity levels at AMB1 Surface back to typical marine levels by early April 2017
- The pH and dissolved oxygen (DO) levels remained reasonably stable across all sites, although diurnal fluctuations at AMB5 were regularly recorded, similar to what was recorded during the 2015/2016 monitoring program. These consistent fluctuations (higher pH and DO during the day, and lower during the night) are thought to be caused

by the adjacent coral reef and increased activity of coral associated, photosynthetic organisms.

- Depth profiling of physicochemical parameters determined that the waters were generally well-mixed, as found in previous monitoring programs.
- Water quality analyses undertaken in April 2017 (post TC Debbie) found higher total suspended solids and phosphorus in the water column, while nitrogen concentrations were generally highest during October 2016. Exceedances of the QWQG were recorded during each survey except July 2016, but little biological impact was recorded, with only two sites exhibiting chlorophyll a concentrations above QWQG through the four monitoring occasions.
- Dissolved metal and organics (hydrocarbons, BTEXN and herbicides) concentrations were mostly below laboratory reporting limits or were low where recorded, and well below Australian Water Quality Guidelines (AWQG).

Overall, higher quality continuous physicochemical data were recorded from the AMB1 Surface site than the benthic sites. Surface logger data is typically less noisy and more reliable than benthic data. The ramp-up to telemetry during construction phases is comparatively simple for surface loggers compared to benthic loggers. In the shallow environment of Abbot Point where the water column is well mixed, surface loggers would provide more cost effective and higher quality data than benthic loggers. It is recommended that future monitoring programs make greater utilisation of surface loggers, rather than benthic loggers, particularly in the lead-up to highly publicised and scrutinised construction programs.

1. INTRODUCTION

The Port of Abbot Point is Australia's most northern coal port (NQBP, 2012), and is located within the Great Barrier Reef (GBR) lagoon between Cape Upstart and Bowen. The port consists of coal handling and stockpile areas, rail facilities, conveyors, two berths and ship loaders, which are located along a single trestle jetty stretching 2.8 km offshore (NQBP, 2012).

North Queensland Bulk Ports (NQBP) sought the implementation of an ambient marine water quality monitoring program at Abbot Point as part of their Environment and Sustainability Plan. The monitoring program has been designed to monitor ambient conditions during periods when no development is being undertaken, with the inbuilt flexibility to ramp up during development to ensure that any potential impacts on sensitive receptors are able to be effectively managed. Previous monitoring programs undertaken at Abbot Point identified a high level of seasonal variability in water quality, influenced by rainfall and resulting runoff, as well as climatic events such as cyclones (GHD, 2009, 2010, 2012, Worley Parsons, 2014).

Vision Environment (VE) commenced monitoring in October 2015, with the program including the use of continuous benthic loggers to measure physicochemical parameters, benthic light and sedimentation/sediment transport, as well as water quality chemical analysis and physicochemical depth profiling. Sites extend 27 km along the Abbot Point coastline, from Camp Island in the northwest to the mouth of the Don River towards the southeast, extending offshore to Holbourne Island. Sites in the network align with key sensitive receptor habitats (e.g. corals and seagrass) along with key features in the study region (e.g. river flows).

This report presents the data collected from July 2016 to June 2017. A summary of climatic conditions (Wet Season: 1 November to 30 April and Dry Season: 1 May to 31 October as defined by the Department of Environment and Heritage Protection (EHP, 2013a, b) and the Department of Science, Information Technology, Innovation and the Arts (DSITIA, 2014)) during this period is provided, including an interpretation of the factors that may have influenced the Abbot Point marine environment. A comparison of results with appropriate water quality guidelines is provided for reference.

1.1 Sampling Rationale

One of the most important physicochemical parameters to measure in coastal waters where development occurs is water clarity. In this program, water clarity was determined by measuring total suspended solids (TSS), turbidity, Benthic Photosynthetic Active Radiation (BPAR) and sedimentation (in the form of bed level changes resulting from deposition and erosion processes).

1.1.1 TSS & Turbidity

TSS refers to the amount of organic and inorganic non-dissolved solids within the water column (APHA, 2005), with a higher concentration of solids leading to lower water clarity. However, this parameter cannot be measured *in situ*, requiring laboratory analyses to obtain a result. Turbidity is an expression of the optical property of light to be scattered and absorbed rather than transmitted through the water sample (APHA 2005). The higher the amount of suspended and colloidal matter within the water column, the higher the amount of light scattering, and thus the higher the turbidity. Discrete and continuous (logged) turbidity (and other physicochemistry) measurements can be gained *in situ* through the use of water quality meters. Water quality meters are able to be telemetered, thus enabling the delivery of real time turbidity data for compliance and management purposes as required.

1.1.2 BPAR

The measurement of BPAR provides information on whether the water clarity is sufficient to permit adequate light to reach the phototrophic organisms on the seafloor, to meet growth requirements and maintain health (GBRMPA, 2010). The benthic environment can be particularly susceptible to resuspension of sediments due to natural and anthropogenic influences. High levels of sediment in the water column has the potential to not only cause a reduction of light (and therefore decrease primary productivity) but also to smother benthic habitats such as coral reefs (De'ath and Fabricius, 2008, GBRMPA, 2010) and impeded growth of seagrass meadows.

1.1.3 Sedimentation Rates

Sediment deposition and erosion is the process of benthic sediment movement or transportation from one area to another. This process may be accelerated by natural forces such as tides, wind and cyclones, or by anthropogenic activities such as dredging. Measuring sedimentation rates, which includes the level of sediment flux in addition to cumulative bed level change, can assist in understanding sediment transport processes.

1.1.4 Physicochemical Parameters

Other physicochemical parameters measured in this program include pH, conductivity/salinity, temperature, and dissolved oxygen (DO). The pH is a measure of the acidity of water, which has the potential to be impacted by a number of variables, including the precipitation, coagulation and disturbance of benthic sediments (APHA 2005). A change in pH can have a direct toxic effect on aquatic biota (ANZECC/ARMCANZ, 2000) and may also alter metal bioavailability to aquatic organisms. Exposure of benthic sediments during development, particularly those with acid-sulfate soils, has the potential to increase the amount of acidity in the water column if not properly managed.

Conductivity is the ability of water to conduct an electrical current, which is affected by the presence of inorganic dissolved solids, such as salts (APHA, 2005). Conductivity (a stressor rather than toxicant) provides an indication of the amount of catchment rainfall entering the system. Temperature is an important parameter to measure in the coastal waters of northern Australia, as corals can suffer stress when water temperatures increase above normal maxima (GBRMPA, 2010).

Dissolved oxygen is the amount of gaseous oxygen (% saturation) that has dissolved in water. Measurements of DO can assist in the validation of the presence of algal blooms. While these physicochemical parameters rarely directly measure potential development impacts, they can provide information on natural and anthropogenic effects which may be causing underlying stress to the ecosystem (ANZECC/ARMCANZ, 2000).

1.1.5 Water Sampling

A number of other water quality parameters may be affected during development projects and are therefore important to measure during baseline conditions. Phosphorus and nitrogen are essential for the growth of organisms (APHA, 2005). High nutrient concentrations are not necessarily considered to be directly toxic to aquatic organisms, but can directly affect the ecosystem and biota (ANZECC/ARMCANZ, 2000). Eutrophication (excess nutrients) can stimulate the growth of macrophytes and algae (including toxic cyanobacteria), which can result in an increase in chlorophyll *a* in the water column. Chlorophyll *a* is a green pigment found in plants, which is utilised in photosynthesis (USEPA, 1997), and is measured as an indicator of algal biomass (APHA, 2005).

Algal blooms can contribute to the TSS concentration in the water column and therefore result in a reduction in water clarity. Nuisance blooms have the potential to result in adverse impacts to the aquatic ecosystem through toxic effects (mortality and/or displacement of species), reduced light availability to benthic species, excessive fluctuations in pH, reduction in DO (following mortality and degradation of organic matter) and changes in biodiversity (Valiela *et al.*, 1997).

Total metals are the concentration of metals (elements) determined in an unfiltered sample (including metals bound to sediments and colloidal particles), while 'dissolved' metals are those still detected in water when passed through a 0.45 µm membrane filter (APHA, 2005). Some metals are essential to plant and animal growth but can become toxic at elevated concentrations (APHA 2005). Dissolved metals are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ, 2000), and have been measured in this program. The disturbance and resuspension of potential contaminants in benthic sediments can result in the addition of metals to the water column (Erftemeijer and Lewis III, 2006). Changes in water chemistry (e.g. decrease in pH), also have the potential to result in an increase in metal bioavailability by increasing the proportion of dissolved metals (those no longer bound to sediments and thus potentially more bioavailable).

2. METHODOLOGY

2.1 Site Selection

The location of monitoring sites was guided by the results of computer models, which indicated the potential zones of impact if proposed dredging activity was to go ahead (GHD, 2012), in addition to results gained from the previous monitoring program (Worley Parsons, 2014). Sites were located in order to capture an understanding of ambient water quality conditions, as well as being able to define any changes related to future potential development activities (such as dredging).

From October 2015 to February 2017, six sites (Figure 1, Table 1) were monitored. After a review of the program in late 2016, the program and the instrumentation that were utilised were revised. The changes implemented in February 2017 included:

- Cessation of all sampling at AMB6;
- Deployment of a surface physicochemical logging station at AMB1;
- Removal of benthic physicochemical logging stations at AMB3;
- Removal of sedimentation logging at AMB2 and installation at AMB4;
- Removal of PAR logging at AMB2 and AMB3;
- TSS sampling undertaken quarterly instead of biannually;
- Removal of biannual total metal sampling at AMB2 and AMB5, but addition of biannual dissolved metal sampling at AMB1, AMB3 and AMB4; and
- Maintenance conducted every second month as opposed to quarterly (weather pending).

Table 2 summarises the filed instrumentation utilised and the sampling regime undertaken during both phases of the project (October 2015 to February 2017, and February to June 2017).

Table 1 Location of water quality monitoring sites.
GPS coordinates captured in WGS84, degrees decimal minutes. Description outlines the potential impact zoning of the sites if the proposed dredging was to commence, as per modified GHD (2012).

Site	Depth (m)	Coordinates	Description
AMB1	9.0	S19 54.281 E148 08.510	Background comparison for seagrass habitat and source effects from the Don River
AMB2	12.2	S19 50.663 E148 00.464	Background comparison during ambient monitoring but potentially high impact site during periods of development
AMB3	3.9	S19 53.534 E147 56.210	Background comparison (potential wetlands and aquaculture discharges)
AMB4	8.5	S19 50.503 E147 54.346	Zone of influence (not within predicted plume area) and adjacent to coral communities
AMB5	6.3	S19 44.145 E148 21.557	Background (adjacent to coral habitats)
AMB6	13.1	S19 52.297 E148 06.292	Zone of influence (not within predicted plume area)

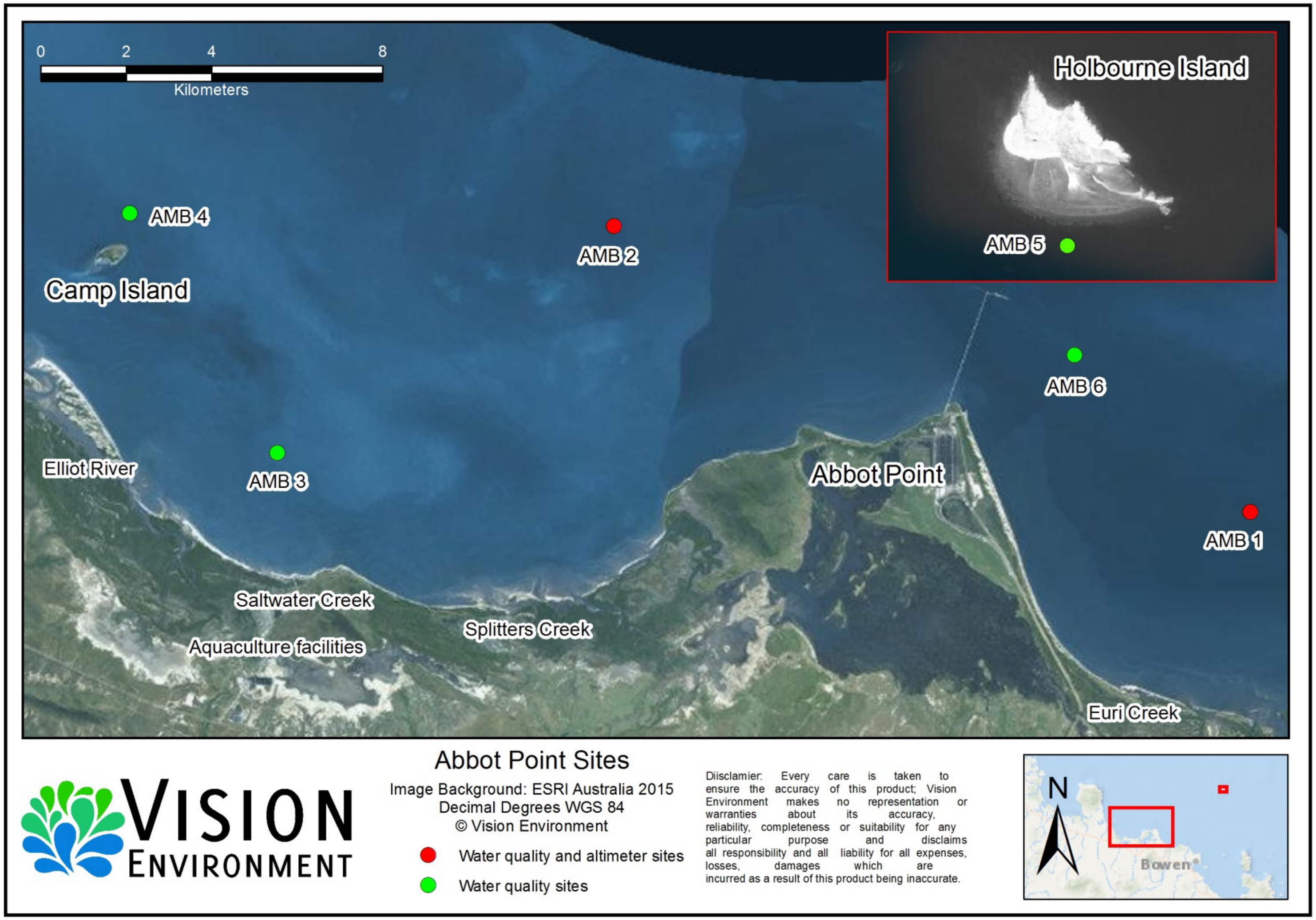

Figure 1 Location of Abbott Point monitoring sites.

Table 2 Summary of sites & ambient sampling regime October 2015 to June 2017.
Physicochemistry includes the following parameters: temperature, pH, conductivity, turbidity and dissolved oxygen. Water samples are collected from the subsurface (0.5 m depth). Note the disparity of collected data at each site due to revision of the program in February 2017.

Sampling Regime		**AMB1**	**AMB2**	**AMB3**	**AMB4**	**AMB5**	**AMB6**
Continuous benthic loggers	Oct 15 to Feb 17	Physicochemistry, BPAR & Sedimentation	Physicochemistry, BPAR & Sedimentation	Physicochemistry & BPAR	Physicochemistry & BPAR	Physicochemistry & BPAR	Physicochemistry & BPAR
	Feb to Jun 17	Physicochemistry, BPAR & Sedimentation	Physicochemistry	-	Physicochemistry, BPAR & Sedimentation	Physicochemistry & BPAR	-
Continuous surface logger	Oct 15 to Feb 17	-	-	-	-	-	-
	Feb to Jun 17	Physicochemistry	-	-	-	-	-
Depth-profiling	Oct 15 to Feb 17	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
	Feb to Jun 17	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	-
Nutrient & Chlorophyll Sampling	Oct 15 to Feb 17	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly
	Feb to Jun 17	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	-
TSS Sampling	Oct 15 to Feb 17	Biannually	Biannually	Biannually	Biannually	Biannually	Biannually
	Feb to Jun 17	Quarterly	Quarterly	Quarterly	Quarterly	Quarterly	-
Total Metal Sampling	Oct 15 to Feb 17	-	-	-	-	-	-
	Feb to Jun 17	Biannually	-	Biannually	Biannually	-	-
Dissolved Metal Sampling	Oct 15 to Feb 17	Biannually	Biannually	Biannually	Biannually	Biannually	Biannually
	Feb to Jun 17	Biannually	-	Biannually	Biannually		
Organics Sampling	Oct 15 to Feb 17	Biannually	Biannually	-	Biannually	-	-
	Feb to Jun 17	Biannually	Biannually	-	Biannually	-	-

2.2 Field Instrumentation

2.2.1 Continuous Benthic Physicochemistry Loggers

Autonomous dataloggers (Hydrolab DS5X sondes with self-cleaning wipers) were programed to record temperature (°C), conductivity (mS/cm, normalised to 25°C), salinity (ppt), pH, turbidity (NTU) and DO (% saturation) powered by external batteries. Antifouling measures for the sondes included wrapping individual probes with copper tape and copper mesh (sparing sensor), and replacing the DS5X wiper with a more robust external wiper.

Triplicate sondes were fixed into a custom metal deployment frame, locked by SCUBA divers into a fixed metal triangle and anchored to the benthos by plough anchors (Figure 2). Sub-surface marker buoys with an accurate GPS coordinate were utilised to minimise boat strike or tampering. The vertical orientation of the monitoring station was assured through the use of the anchored triangular sub-frames.

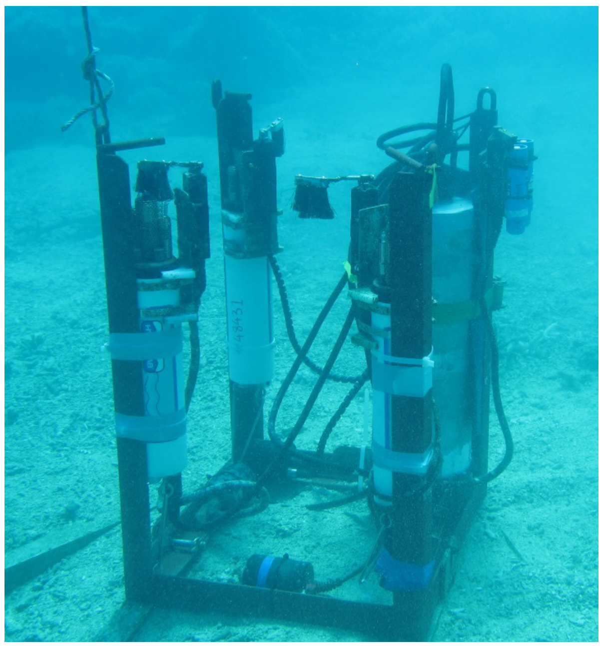

Figure 2 Benthic loggers deployed by SCUBA divers and fixed on deployment frames.

Logger exchange was scheduled every two to three months (pending weather conditions), where the deployment frame was retrieved by divers and taken to the surface to exchange the loggers. The recorded data was then downloaded at VE base. Each logger was calibrated and tested prior to deployment as per the VE Health, Safety, Environment and Quality (HSEQ) Management System protocols. Calibration methodology included two-point calibrations for turbidity (1 and 20 NTU), conductivity (0 and 58.0 mS/cm), and pH (7 and 10), in addition to a one-point calibration for DO (100% saturation at ambient atmospheric pressure). Post-calibration testing involved a log test for turbidity in a 10 NTU solution, logging at 10 minute intervals over a 24 hour period. Turbidity values at 10 NTU ± 1 NTU during the log-test were considered acceptable.

2.2.2 Continuous Surface Physicochemistry Loggers

Autonomous dataloggers (Hydrolab HL4 sondes with self-cleaning wipers) were placed into secured, antifouled PVC tubes, which were inserted into the base of a modified Special Marker buoy (Figure 3). The sondes were programed to record the same parameters as the benthic sondes, approximately 0.75 m below the sea surface. Sondes were powered by solar panels installed on the buoy.

Similar to the benthic sondes, logger exchange occurred every two to three months, with the recorded data downloaded at VE base. Newly deployed loggers were calibrated and tested prior to deployment.

Figure 3 Surface physicochemistry logger deployed at AMB1

2.2.3 Continuous BPAR Loggers

Dual autonomous light loggers (Odyssey submersible photosynthetic irradiance recording system) with external hydrowipers were placed in the benthic frame alongside the physicochemistry loggers (Figure 4), recording benthic photosynthetically active radiation (BPAR) at 15 minute intervals. Loggers were exchanged during the physicochemistry logger exchange and the recorded data downloaded at the VE base.

In order to record daily ambient changes in total available photosynthetically active radiation (PAR), dual autonomous light loggers were also deployed on land at Bowen Base (an unshaded antenna at Aussie Reef Dive, Howard St, Bowen). The inclusion of the Bowen Base data allowed for variation in daily ambient PAR (e.g. due to cloud cover) to be accounted for, thus acting as a 'control' PAR site and aiding in the interpretation of BPAR levels at Abbot Point . The Bowen Base loggers recorded decreased levels of sunlight during overcast days, which assisted in the interpretation of some fluctuations in BPAR within the dataset. While small scale daily weather patterns such as scattered cloud were not consistent across Bowen and Abbot Point, substantial overall daily changes were recorded and significant reductions in ambient PAR were accounted for.

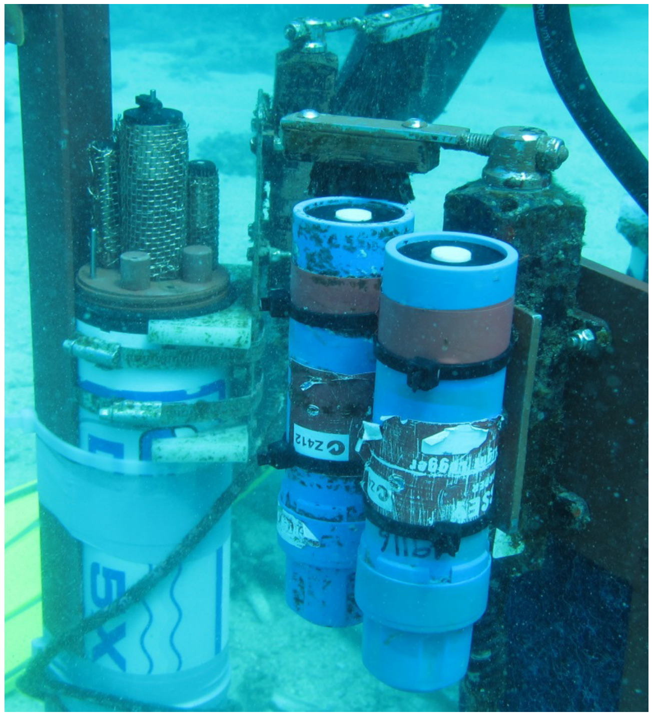

Figure 4 PAR loggers deployed adjacent to continuous physicochemistry loggers.

2.2.4 Altimeters

Acoustic altimeters (Figure 5) were used to obtain bed level measurements every 15 minutes, using a high frequency acoustic sensor and an inbuilt data logging device. Altimeters were mounted in duplicate, cross-current and adjacent to the physicochemistry and BPAR logger frames, between 200 and 600 mm above the seabed. External hydrowipers were installed to eliminate transducer interference caused by fouling. Altimeters were exchanged during the physicochemistry logger exchange and the recorded data downloaded at VE base.

Figure 5 ALTUS altimeters deployed adjacent to continuous physicochemistry and BPAR logger frames.

2.3 Depth Profiling

Physicochemical parameters (temperature, conductivity, salinity, pH, turbidity and DO) were measured through the water column at 0.5 to 1.0 m depth intervals (depending on overall water depth) to the benthos, using a ProDSS (Figure 6) multi-parameter water meter. Down-welling PAR (measured in micromoles per square metre per second (µmol/m^2/s)) was measured concurrently using a LI-COR LI192SA Underwater Quantum Sensor in a lowering frame (Figure 6) and a LI-189 or LI1500 Quantum Radiometer Photometer, until the benthos was reached or light intensity was <10 µmol/s/m^2.

Figure 6 a) Depth profiling using the YSI ProDSS and the LI-COR LI192SA Underwater Quantum Sensor; and b) Collection of water samples for analysis using an acid-washed Nalgene bottle in a perspex pole sampler.

2.4 Water Sampling

Water sampling was carried as per the Vision Environment HSEQ Management System protocols. Samples were collected in accordance with standard protocols derived from worldwide authorities, including:

- Australian and New Zealand Standards for water quality and sediment sampling (AS/NZS, 1998a, b, c);
- The American Public Health Association Standard Methods for the Examination of Water and Wastewater (APHA, 2005);
- Australian and New Zealand Water Quality Guidelines (ANZECC, 1992, 1998, ANZECC/ARMCANZ, 2000);
- The Queensland Water Quality Guidelines (DERM, 2009); and
- The Department of Environmental Resource Management Monitoring and Sampling Manual (DERM, 2010).

Water samples for analyses were collected from 0.5 m depth using a Perspex pole sampler to which a 1 L Nalgene bottle was attached (Figure 6). Prior to sample collection at each site, the Nalgene bottle was triple rinsed in site water. Nalgene bottles were acid-washed with hydrochloric acid in the VE laboratory clean room, prior to sampling. Powder free gloves were worn to avoid contamination.

Samples which required filtration (dissolved metals and nutrients) were filtered, *in situ,* through a 0.45 µm sterile surfactant free cellulose acetate membrane syringe filter (Minisart 16555K) into an acid-washed sample bottle provided by the analysing laboratory. Each syringe and pre-packaged filter was pre-rinsed in site water prior to sample collection. Individually packaged cellulose acetate membrane pre-filters with a pore size of 1.2 µm (Minisart 17593k) were used at more turbid sites if required, to assist in filtration. For samples which did not require filtration (TSS, total nutrients and metals, chlorophyll *a* and organics), water samples were decanted directly into the laboratory provided sample bottles.

Samples were stored on ice for transport to the analysing laboratory, with filtered nutrient samples frozen overnight in order to prolong sample holding times. In order to extend holding times for chlorophyll *a*, samples were pre-processed at VE through 0.45 µm glass fiber filters, using a manifold and vacuum pump, with the volume of water passed through the filter recorded (typically 500 ml). Filter papers were folded in aluminum foil, placed in airtight plastic bags, then frozen to extend the holding period of these samples to 28 days, in accordance with APHA method 12000H (APHA, 2005). All water samples were analysed at ALS laboratories.

Duplicate water samples for all parameters were collected at 10% of sites as per established protocols, with a field and laboratory blank also collected. Analytical laboratory quality control measures included laboratory duplicates, laboratory blanks, analysis of certified reference material and matrix spikes.

2.5 Data Management

2.5.1 Physicochemistry Loggers

Management of physicochemistry logger data was undertaken as per VE HSEQ Management System (MS) protocols, developed and peer reviewed during the three year Western Basin Dredge and Disposal Project (WBDDP), and Narrows Crossing projects (Vision Environment, 2013).

All continuous physicochemical data were manually uploaded to the VE cloud database, where it underwent SMART (Self-Monitoring Algorithm in Real Time) deconfounding. SMART was developed by VE as an initial automatic data deconfounding process in order to filter out erroneous raw real time data from multiple instruments, to provide a more accurate and instantly usable real time data set. However, SMART can also be used as an initial deconfounding tool for logged datasets.

Following the initial deconfounding, the SMART data were manually validated. In most cases, the SMART data did not need altering. However, there were some instances where data was removed from the dataset incorrectly, in which case it was inserted back into the dataset.

Erroneous data were identified using the following procedures as per VE HSEQ MS protocols:

- Turbidity
  - Continually increasing turbidity values, suggesting fouling, with no apparent environmental causes.

  - Intermittent, erratic values, either markedly higher or lower than the majority of values recorded at that time by that logger or adjacent loggers and inconsistent with previous trends.
- pH
  - pH values outside the typical lower estuarine and marine conditions (7.6 to 8.4). However, if both loggers were showing pH outside this range and environmental causes were indicated, these were considered a valid result.
  - SMART automatically moved pH data from the dataset when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).
- Conductivity
  - Conductivity values outside the typical lower estuarine and marine conditions (50 to 62 mS/cm), unless both loggers were showing conductivity outside this range and environmental causes were indicated (e.g. during a rain event).
  - If the difference between two of the loggers was 5 mS/cm or greater, the value closest to 55 mS/cm was kept, and the alternate values moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5 mS/cm difference was based on ± 10% difference between readings, which was higher than the Hydrolab DS5X sensor accuracy, which is reported at 1%.
- Dissolved oxygen
  - Oxygen values outside the typical lower estuarine and marine conditions (70 to 120% saturation), unless both loggers were showing DO outside this range and environmental causes are indicated.
  - If the difference between the loggers was 5% or greater, the value closest to 100 % saturation was kept, and the alternate values were moved by SMART and identified as erroneous. However, this was manually checked and confirmed by VE personnel. Note that the 5% difference was higher than the Hydrolab DS5X sensor accuracy, which is reported at 1% at concentrations <8 mg/L (or 100% saturation at 25ºC).
  - SMART automatically moved dissolved oxygen data from the dataset when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).
- Temperature
  - SMART automatically moved temperature data from the dataset when a logger had a conductivity result of zero (e.g. logger having been removed from the water during logger exchange).

Seasonal (Wet Season: 1 November 2016 to 30 April 2017; Dry Season: 1 July to 31 October 2016, 1 May to 30 June 2017) statistics were calculated for each site using validated data, including means, medians, standard errors and percentiles. Data were plotted in conjunction with wave heights and rainfall.

One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in water quality parameters among sites and seasons (wet season and dry season). Interactions between sites and season were also tested to determine if site patterns were consistent over seasons. Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill, 2000, Underwood, 1997). Fisher's Least Significant Difference (LSD) Post hoc tests were used to determine any differences among sites.

2.5.2 BPAR Loggers

Management of BPAR logger data was undertaken as per VE HSEQ MS protocols. All BPAR data were manually uploaded to the VE cloud database. BPAR values from each logger during the non-daylight period (according to sunrise and sunset times reported by Geoscience Australia (2016)), were zeroed. Erroneous data were removed from the dataset. Subsequent calculations were based on the mean BPAR recorded from both loggers. The mean logger readings at 15 minute intervals were summed to calculate total daily BPAR in moles per square metre per day (mol/m²/day). Once the data were deconfounded, monthly and seasonal statistics were calculated for each site, including means, medians, standard errors and ranges.

Erroneous data were identified by the two loggers differing by more than 20%. When this occurred, data from both loggers was flagged and examined. If the difference between the loggers persisted for a number of hours, or values were inconsistent with other BPAR sites, the data was considered erroneous. The 20% value was assigned assuming that a variance of ±10% is acceptable between loggers. Additionally, when the daily totals for each site were inconsistent with neighbouring sites and with previous trends, data was further investigated.

Similar to the physicochemistry loggers, seasonal statistics were calculated for each site using validated data, including means, medians, standard errors and percentiles. Benthic PAR data were plotted in conjunction with ambient PAR and rainfall. One and two-way analyses of variance ($p < 0.05$, 95% confidence intervals) were used to determine statistical differences in PAR among sites and seasons (wet season and dry season), and interactions between site and season. Data were tested for homogeneity of variance and normality. Significance levels were increased ($p < 0.01$, 99% confidence intervals) where data did not meet that criterion (O'Neill, 2000, Underwood, 1997). Fisher's LSD Post hoc tests were used to determine any differences among sites.

2.5.3 Altimeters

Altitude data were produced every 15 minutes, and the data used to examine surficial sediment deposition and erosion. Erroneous data was identified using the following procedures as per VE HSEQ MS protocols:

- Negative altitude values, indicating that insufficient echo was received from the seafloor to produce a valid reading.
- Instantaneous change value > 30 mm in 15 minutes. This data was flagged for further examination. Often only one or two variable readings were gained, indicating short-lived interference such as possible fauna activity.

Validated data were then used to calculate cumulative bed level change data (change from baseline point) at 15 minute intervals, which were then plotted. Data smoothing was carried out by calculating the daily mean cumulative change for each instrument and site, and plotting in conjunction with wave heights and rainfall. Monthly bed level change was calculated for AMB1, AMB2 and AMB4 using validated data from both deployed altimeters.

2.5.4 Depth Profiling and Water Analysis

Individual survey data were tabulated for each parameter at the sub-surface, mid-column, benthos and entire water column for each site. Data for the entire column were plotted to examine how well-mixed the water column was. The vertical light attenuation coefficient (K_d) was calculated in order to compare light attenuation through the water column at different sites and on different sampling occasions.

2.6 Water Quality Guidelines and Objectives

Water quality monitoring data from Abbot Point were compared to the Great Barrier Reef Water Quality Guidelines (GBRMPA, 2010), Queensland Water Quality Guidelines or QWQG (DERM, 2009), and Australian Water Quality Guidelines or AWQG (ANZECC/ARMCANZ, 2000). The Department of Environment and Resource Management (2009) state that the Great Barrier Reef Marine Park Authority (GBRMPA) Guidelines are applicable inside the GBR Marine Park. Where there are no GBRMPA guidelines provided for a specific indicator, then the QWQG should be applied. Likewise, the QWQG takes precedence over the AWQG, due to their localised approach.

The GBRMPA guidelines used for comparison in this study were those derived for the Open Coastal area of the Burdekin (GBRMPA, 2010). The QWQG used for comparison were those derived for the Central Coast Queensland Region (which extends from the Burnett River basin near Bundaberg to the Black River Basin near Townsville) Open Coastal area. No GBRMPA Guidelines or QWQG are available for metals. Therefore, metal concentrations were compared to the AWQG (ANZECC/ARMCANZ, 2000). Trigger levels for varying levels of ecosystem protection (99%, 95%, 90% and 80% of species) have been derived for a number of metals. These guidelines refer to dissolved metals, which are those which pass through a 0.45 µm membrane filter (APHA, 2005), as these are considered to be the potential bioavailable fraction (ANZECC/ARMCANZ, 2000). The Abbot Point coastal environment can be described as slightly-to-moderately disturbed, therefore the 95% AWQG trigger value would be considered appropriate for comparison (DSITIA, 2014).

While localised water quality objectives (WQO) for the Mackay-Whitsundays Region (EHP, 2013b) have been completed by the Department of Environment and Heritage Protection (EHP) as per the Environmental Protection (Water) Policy 2009, these do not extend north to Abbot Point. Localised WQO for the Haughton, Burdekin and Don Basins region are currently under development by EHP. When the WQO have been finalised, they will take precedence over the current GBRMPA guidelines and QWQG due to their site-specific relevance.

3. RESULTS & DISCUSSION

3.1 Metocean Conditions

3.1.1 Rainfall

Approximately 1,171 mm of rainfall was recorded at Bowen Airport station (033327) between 1 July 2016 and 30 June 2017 (Figures 7 and 8), higher than the long-term average of 893 mm as recorded from 1987 to 2015 (BOM, 2017). The majority of the rainfall (901 mm) was recorded during the Wet Season (1 November 2016 to 30 April 2017), which was also higher than the long-term average of 774 mm during the Wet Season (above the 50th percentile) as recorded from 1987 to 2015. During the Wet Season, the largest rain event was recorded in late March 2017, when Tropical Cyclone (TC) Debbie made landfall as a Category 4 system near Airlie Beach on 28 March 2017. Over 380 mm of rainfall was recorded on the 28 and 29 March at Bowen, with substantial rain reported to have fallen in the week post TC Debbie. However, the Bowen Airport Station becoming non-functional from the 30 March to 15 April 2017, and therefore rainfall totals for this period (and annually) are likely to be an underestimation of the actual rainfall received.

During the Dry Season periods (1 July to 31 October 2016 and 1 May to 30 June 2017), approximately 270 mm of rainfall was recorded at Bowen Airport station, more than double the long-term dry season average of 129 mm (BOM, 2016). Two large rainfall events were the main contributors to Dry Season rainfall: late September 2016 (~ 70 mm in one day); and mid-May 2017 (>115 mm over two days).

3.1.2 River Flow

Large rain events resulted in increases in river flow from the Don River, Elliot River and Euri Creek in the subsequent days (DNRM, 2017). Total stream discharge from 1 July 2016 to 30 June 2017 from the three waterbodies were: 248,700 ML; 61,490 ML; and 170,550 ML, respectively. Maximum daily flows from the Elliot River (31,657 ML/day), Euri Creek (57,882 ML/day) and Don River (99,549 ML/day) were recorded on 29 March, after TC Debbie made landfall.

Within the Dry Season period, the most notable river flows were recorded during the late May 2017 rain period. Maximum daily flows from the Don River (7,160 ML/day) were recorded on 18 May 2017, while maximum flows from Elliot River (5,560 ML/day) and Euri Creek (22,640 ML/day) were recorded a day later.

3.1.3 Wind

Winds were found to be predominantly south-easterly from July to September 2016, prior to becoming principally north-easterly from mid-September to mid-January 2017. Winds tended to be again predominantly south-easterly from mid-January to June 2017.

Strong winds (≥ 45 km/h) were generally found to be in a south-easterly direction, with the exception of strong south-westerly winds on 19 June (57 km/h), 3 August (46 km/h), 13 November (48 km/h), and during TC Debbie on 28 March (148 km/h). Strong winds in a north or north-easterly direction were also recorded infrequently: 27 November (50 km/h); 10 and 11 December (48 to 52 km/h); 16 February (85 km/h) and 2 March (50 km/h).

3.1.4 Waves

Mean daily significant wave heights paralleled wind conditions, and ranged from 0.1 to 2.3 m from 1 July 2016 to 30 June 2017. Highest wave heights were recorded on 28 March (1.9 m) and 29 March 2017 (2.3 m) during the advent of TC Debbie. Mean daily significant wave height across the year was 0.6 m.

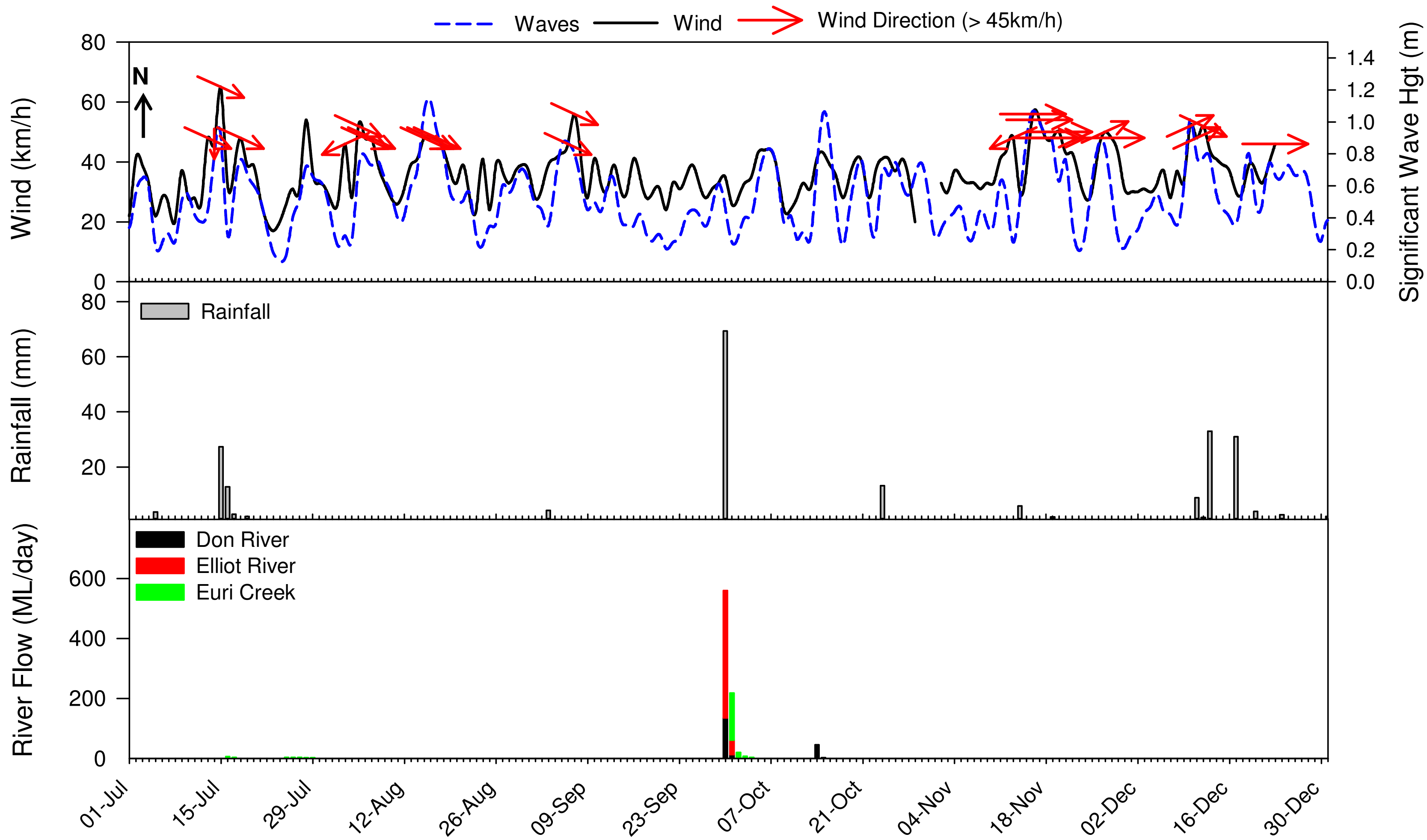

Figure 7 Port of Abbot significant wave heights, wind speed and rainfall as recorded at Bowen and river discharge from the Don River, Elliot River and Euri Creek from 1 July to 31 December 2016.
Note red arrows depict wind direction when winds > 45 km/h were recorded.

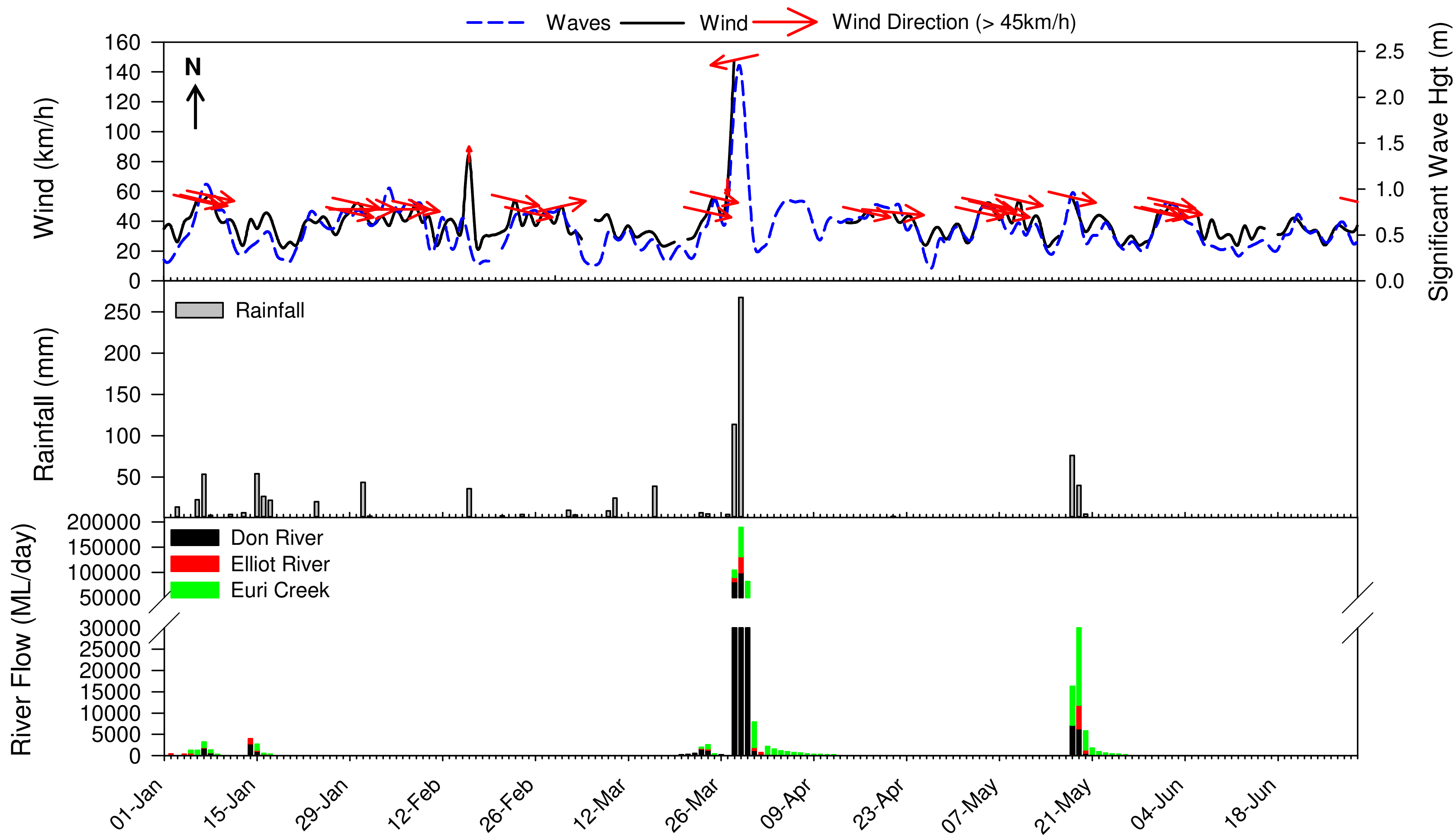

Figure 8 Port of Abbot significant wave heights, wind speed and rainfall as recorded at Bowen and river discharge from the Don River, Elliot River and Euri Creek from 1 January to 30 June 2017.
Note red arrows depict wind direction when winds > 45 km/h were recorded.

3.2 Continuous Physicochemistry Loggers

3.2.1 Turbidity

Turbidity statistics for the six sites for both the Wet and Dry Season can be found in Table 3, and turbidity plotted in Figures 9 to 16. Note that deployment periods varied across the sites, with reduced deployment periods for sites AMB1 Surface, AMB3 and AMB6, therefore seasonal statistics are not reflective of an entire season.

Overall, turbidity was significantly higher ($p < 0.05$) during the Wet Season (means: 1.5 to 5.6 NTU), than during the Dry Season (means: <1 to 4.8 NTU), similar to the 2015/2016 results (Vision Environment, 2016). Turbidity was significantly ($p < 0.05$) higher at AMB2 (mean: 5.0 NTU in both Wet and Dry Season), with AMB1 Surface, AMB1 benthic and AMB3 exhibiting significantly ($p < 0.05$) lower turbidity, similar to the 2015/2016 results (Vision Environment, 2016).

There was a significant interaction between sites and seasons, indicating that spatial patterns were not consistent across both the Wet and Dry Season. During the Wet Season, AMB2 (5.0 NTU) and AMB4 (5.6 NTU) exhibited significantly ($p < 0.05$) higher turbidity than remaining sites (1.5 to 3.4 NTU), but during the Dry Season, AMB2 (5.0 NTU) and AMB6 (5.2 NTU) exhibited significantly ($p < 0.05$) higher turbidity. The 20^{th} to 80^{th} percentile values for all sites across both seasons (<1 to 9.0 NTU) indicate that the majority of turbidity values were found within a small range.

The largest impact on turbidity during the monitoring year was the advent of TC Debbie. Where data was available extremely high turbidity was recorded during TC Debbie, in which significant wave heights reached 2.3m and winds up to 148km/h were recorded. Turbidity at AMB1 Surface reached up to 100 NTU, from typical background values of <5 NTU. Values above 50 NTU were recorded for a 24 hour period from 28 to 29 March, with relatively stable turbidity values < 10 NTU recorded by 31 March.

At AMB2 benthic, turbidity values over 100 NTU were recorded during TC Debbie from 28 to 30 March, with turbidity reaching over 250 NTU on 29 March. However, recovery was rapid with stable values < 10 NTU recorded by the 31 March. A similar response was recorded at AMB4 benthic: highest recorded turbidity was ~ 400 NTU, and stable turbidity values < 20 NTU were recorded by 1 April. No data was captured during TC Debbie for AMB1 benthic due to logger issues. Loggers deployed at AMB5 were not able to be retrieved in April 2017, therefore no data was available for the TC Debbie event for this site.

Notwithstanding TC Debbie, turbidity at each of the sites appeared to be most influenced by wave height, which was in turn influenced by wind conditions, whereas rainfall and tidal phases appeared to have little influence, similar to the 2015/2016 results (Vision Environment, 2016). Periods of higher waves tended to result in short-lived increases in turbidity, due to resuspension of benthic sediments. Previous monitoring at Abbot Point (GHD, 2009, 2010, 2012, Worley Parsons, 2014) in addition to Port of Mackay (NQBP, 2015) also found that increases in waves and wind resulted in higher turbidity.

AMB1 Surface tended to be less responsive to increased wind and waves than AMB1 benthic. High and variable benthic turbidity is most likely due to the proximity of the loggers to the benthic sediment. A similar result has been recorded in Gladstone Harbour when both surface and benthic monitoring has been undertaken (Vision Environment, 2015). The less noisy surface data has been found to be more suitable for the establishment of compliance trigger values and subsequent monitoring (Vision Environment, 2015).

Table 3 Turbidity statistics from data collected from loggers deployed during from July 2016 to June 2017.
*Note that Dry Season includes data collected from 1 July to 31 October 2016 and 1 May to 30 June 2017. Wet Season includes data collected from 1 November 2016 to 30 April 2017. *Does not include data from TC Debbie.*

Site	Deployment Period	No. validated turbidity values		Wet Season					Dry Season				
		Wet Season	Dry Season	Mean ± se	Median	Range	20th %ile	80th %ile	Mean ± se	Median	Range	20th %ile	80th %ile
AMB1 Surface	14 Feb to 30 Jun 17	5193	5856	3.4 ± 0.1	1.0	<1 - 103	<1	2.8	1.8 ± 0.0	1.7	<1 – 9.6	1.1	2.6
AMB1	1 Nov 16 to 30 Jun 17	11317	13114	1.6 ± 0.0*	1.0	<1 - 16	1.0	1.8	1.5 ± 0.0	<1	<1 - 27	<1	2.6
AMB2	1 Nov 16 to 30 Jun 17	16673	13083	5.0 ± 0.1	1.8	<1 - 255	1.0	6.1	5.0 ± 0.0	4.8	<1 - 47	<1	7.8
AMB3	1 Nov 16 to 15 Feb 17	9567	3599	1.6 ± 0.0*	1.0	<1 - 21	1.0	1.1	3.9 ± 0.1	2.2	<1 - 25	1.6	6.5
AMB4	1 Nov 16 to 30 Jun 17	14710	8310	5.6 ± 0.0	1.6	<1 - 398	1.0	6.5	<1	<1	<1 - 16	<1	1.0
AMB5	1 Nov 16 to 30 Jun 17	9730	13987	2.1 ± 0.0*	1.4	1.0 - 20	1.0	2.6	3.4 ± 0.0	2.6	<1 - 35	2.3	4.6
AMB6	1 Nov 16 to 15 Feb 17	10117	6682	1.5 ± 0.0*	1.0	1.0 - 29	1.0	1.7	5.2 ± 0.0	4.1	<1 - 20	3.2	9.0

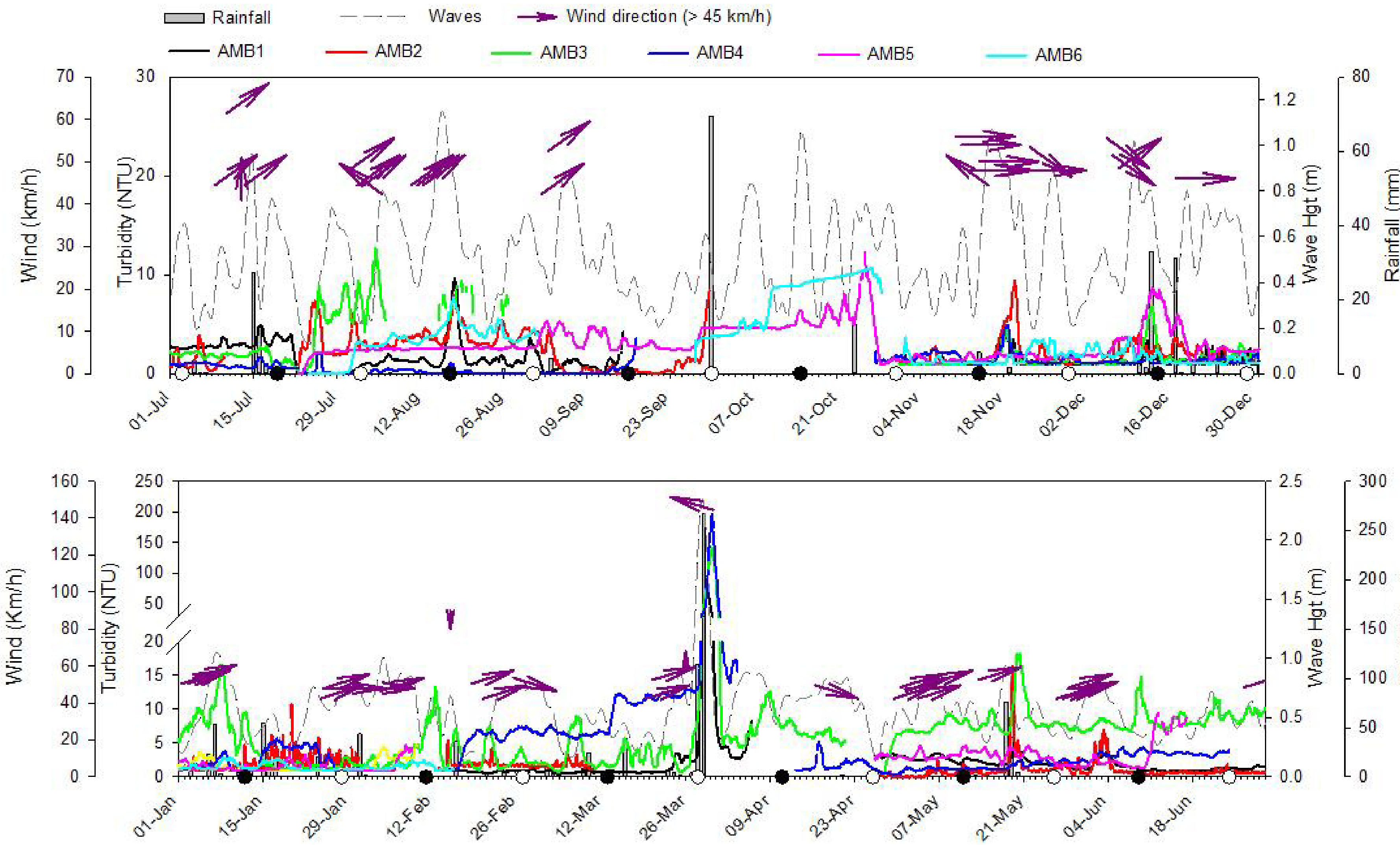

Figure 9 Turbidity 24h rolling average (RA), rainfall and wave height at AMB1 to AMB6 from July 2016 to June 2017.
Note purple arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Note the varying scales on the plots. AMB1 surface deployed from February to June 2017. AMB3 and AMB6 deployed from July 2016 to February 2017.

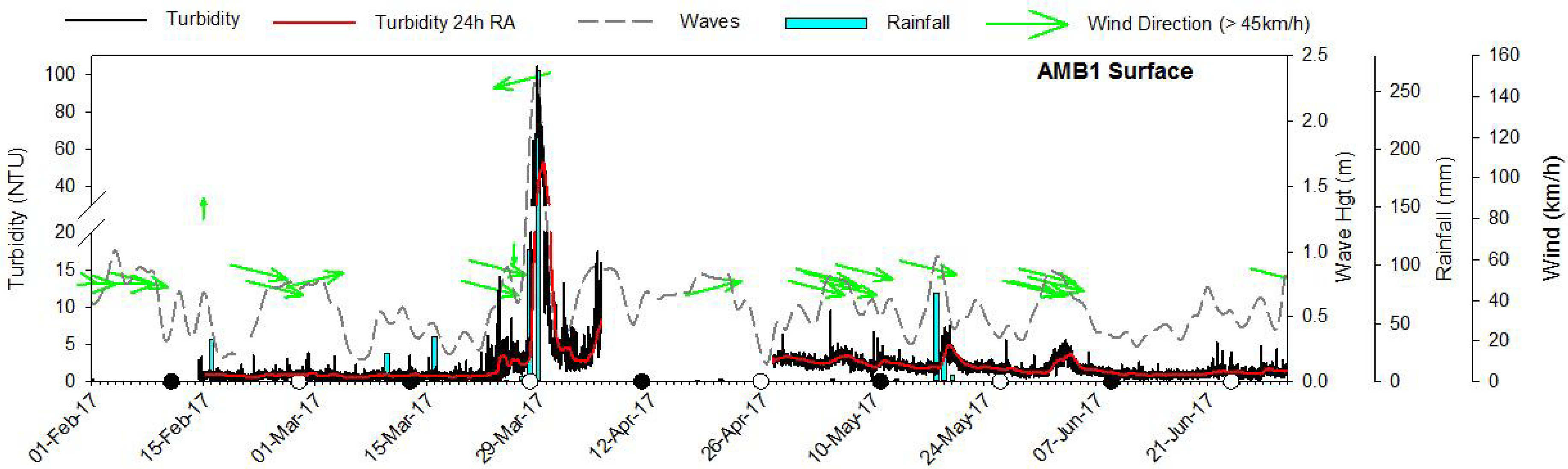

Figure 10 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB1 Surface from February to June 2017.
AMB1 Surface deployed from February 2017 onwards. Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively.

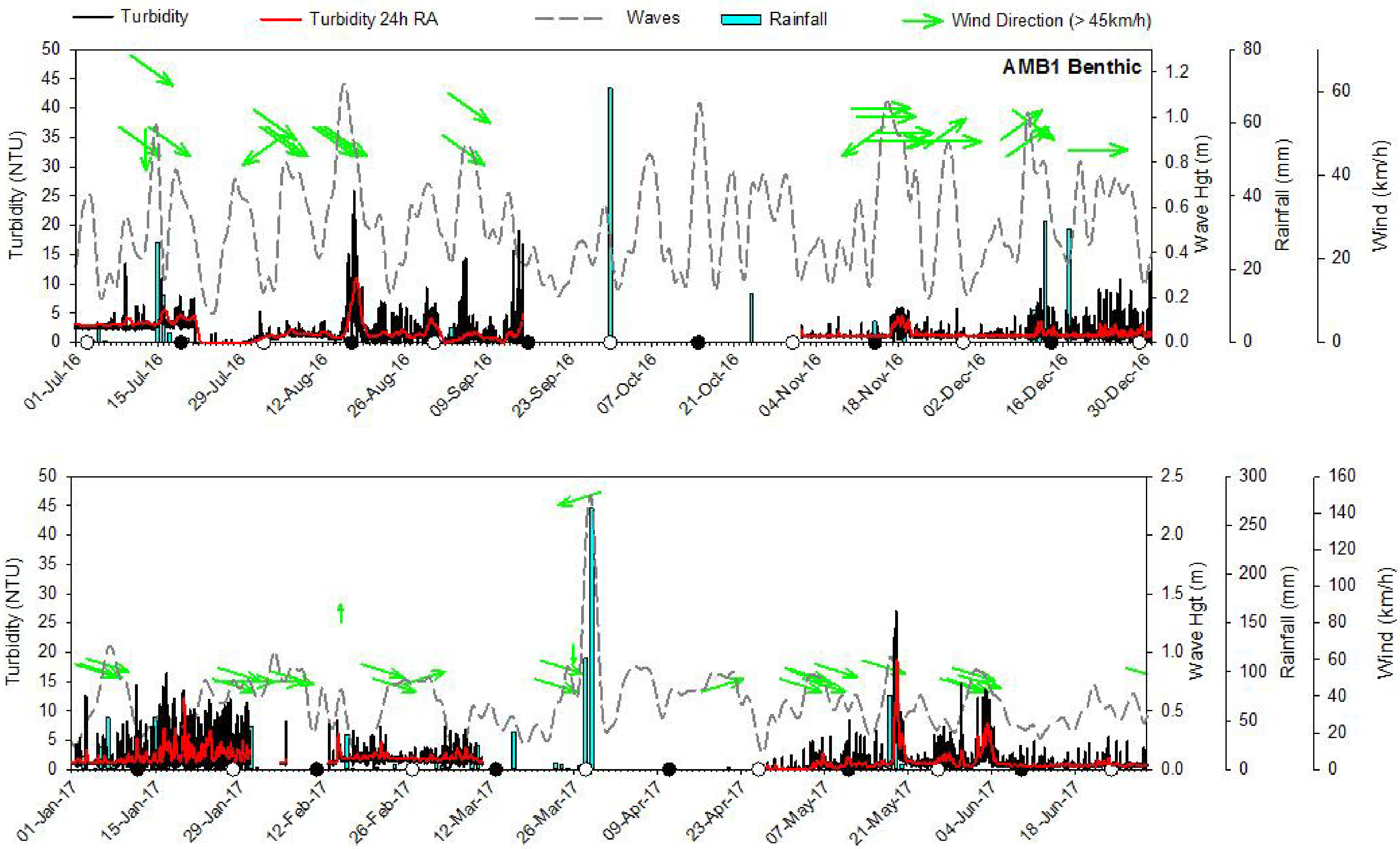

Figure 11 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB1 Benthic from July 2016 to June 2017.
Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Fouling prevented collection of valid data on September/October 2016 and March/April 2017.

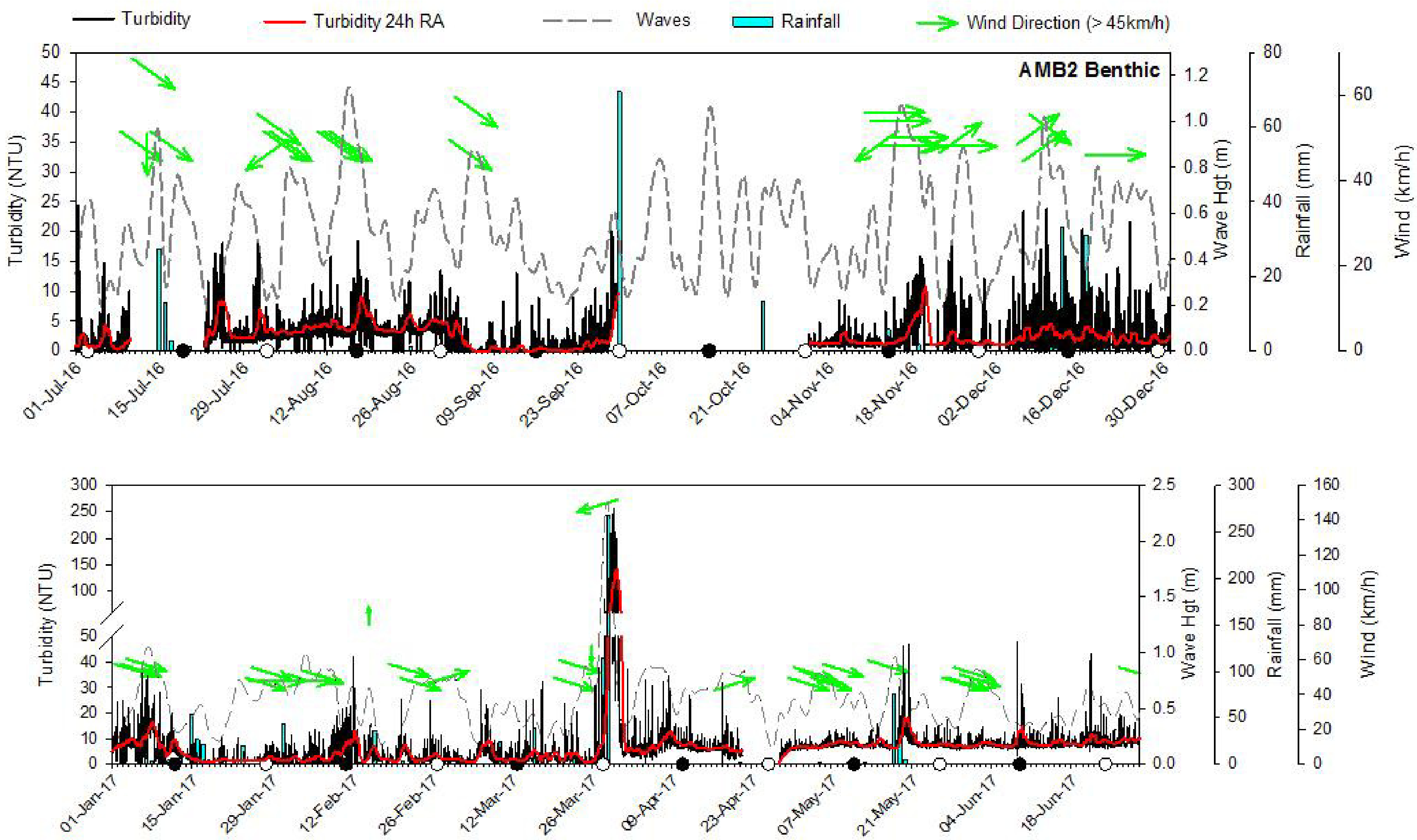

Figure 12 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB2 Benthic from July 2016 to June 2017.
Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Fouling prevented collection of valid data on September/October 2016.

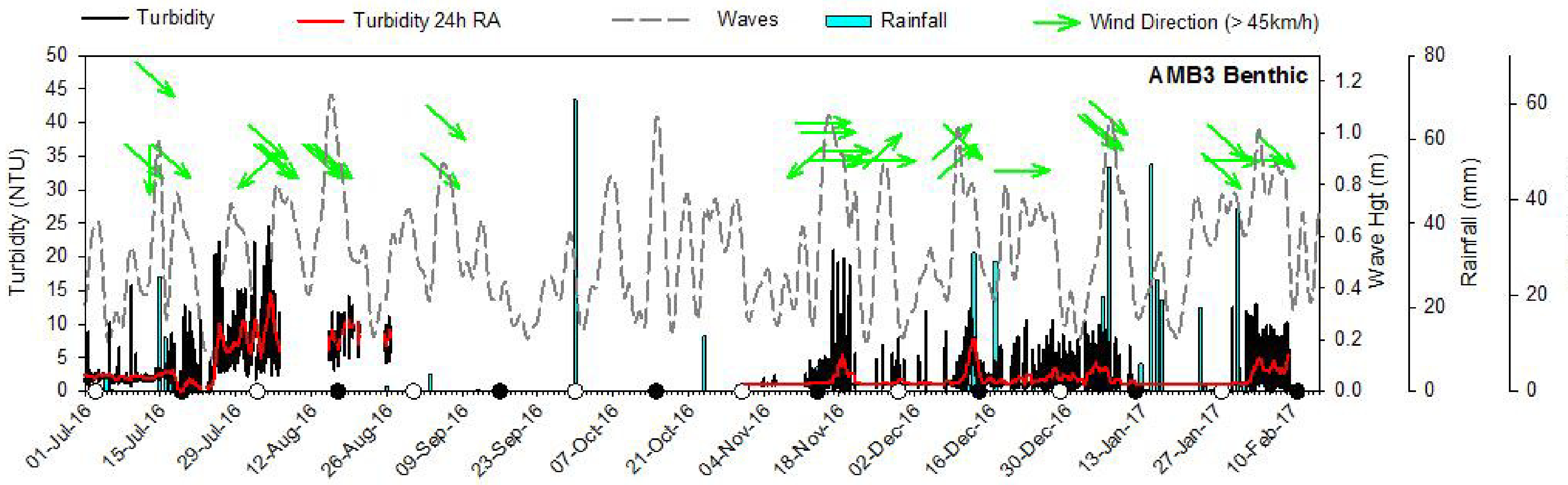

Figure 13 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB3 Benthic from July 2016 February 2017.
Continuous monitoring at AMB3 ceased in February 2017. Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Fouling prevented collection of valid data on September/October 2016.

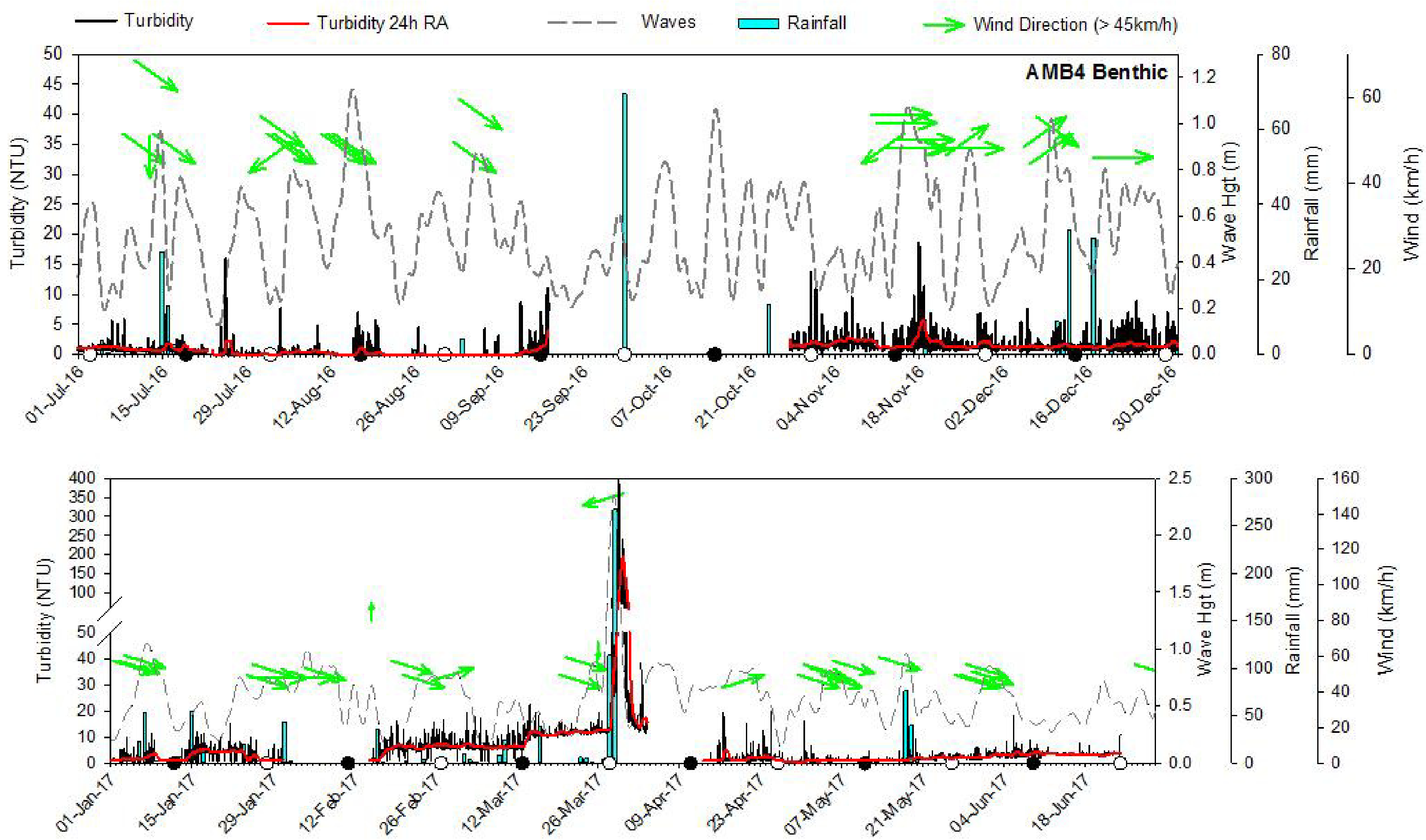

Figure 14 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB4 Benthic from July 2016 to June 2017.
Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Fouling prevented collection of valid data on September/October 2016 and January/February 2017.

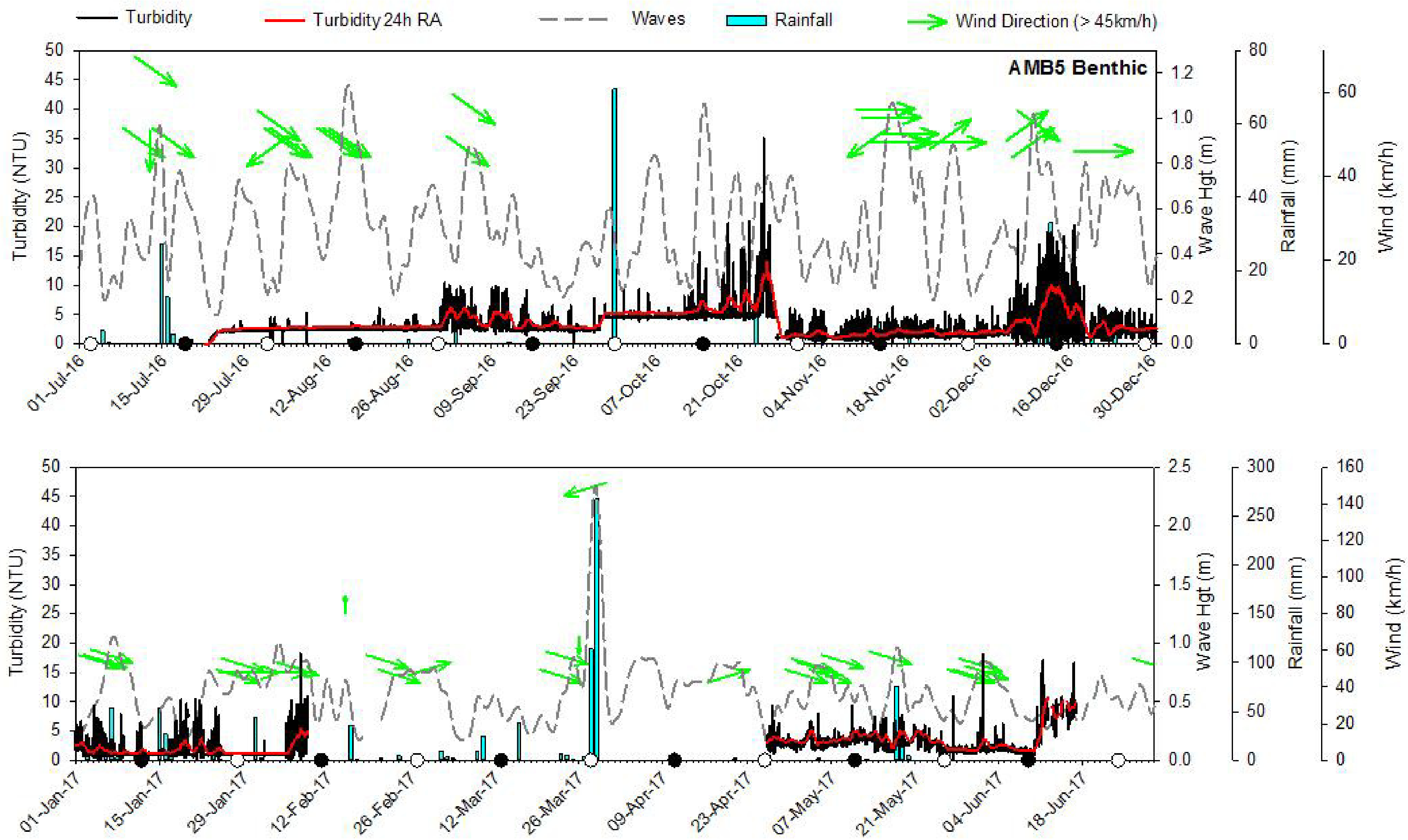

Figure 15 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB5 Benthic from July 2016 to June 2017.
Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. No data available from February to April 2017 due to logger loss after TC Debbie.

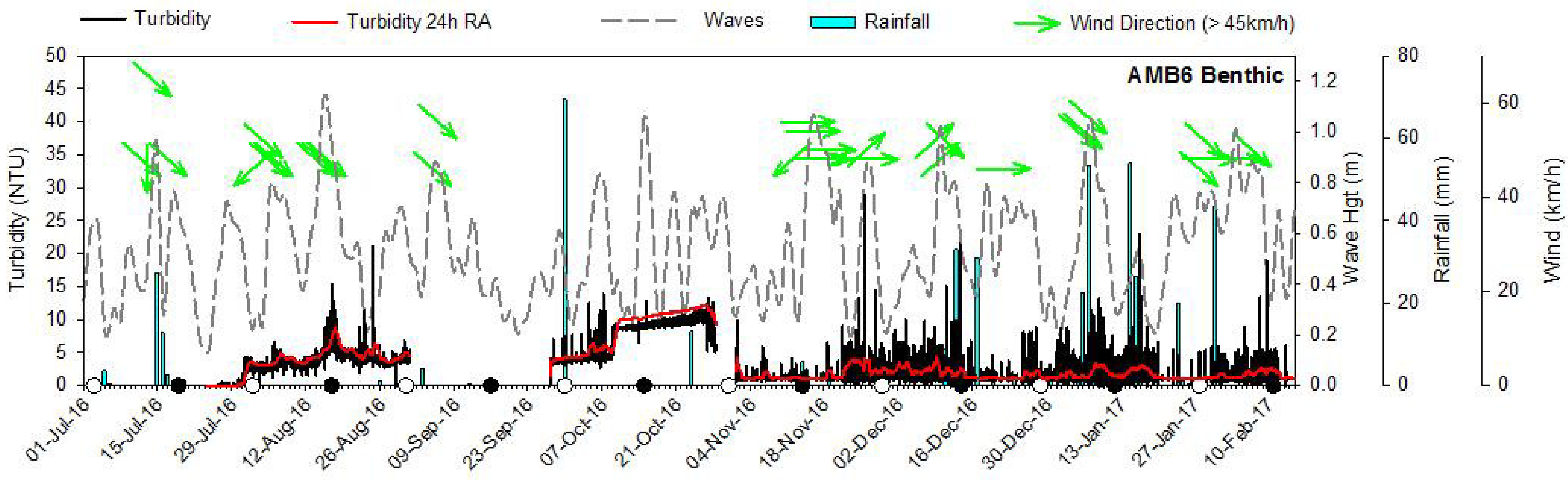

Figure 16 Mean turbidity and 24h rolling average (RA), rainfall and significant wave height at AMB6 Benthic from July 2016 to February 2017. *Continuous monitoring at AMB6 ceased in February 2017. Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods, respectively. Fouling prevented collection of valid data in July and September 2016.*

There is no GBRMPA guideline for turbidity, therefore the QWQG should be used for comparison. Mean turbidity at all six sites during both seasons (with the exception of AMB4 during the Dry Season) was higher than the QWQG of 1 NTU, as found in previous monitoring programs (GHD, 2009, 2010, 2012, Vision Environment, 2016, Worley Parsons, 2014). However, the QWQG, which apply to open coastal waters, could be considered conservative and therefore not entirely suitable for application, to the near shore Abbot Point sites, which can be influenced by adjacent river flows.

3.2.2 Temperature

Water temperatures at all sites exhibited a clear seasonal pattern, associated with ambient air temperatures. Temperatures at all sites were significantly ($p < 0.05$) higher during the Wet Season (means: 28.1 to 29.0ºC) than during the Dry Season (means: 22.6 to 24.3ºC), paralleling ambient conditions (Table 4). Little variation was evident between sites. Of note were the small decreases in temperature associated with rain events (Figure 17). Longer duration precipitation events generally resulted in more noticeable temperature declines. There appeared to be little relationship between temperature and site depth.

3.2.3 pH

The pH at the majority of sites remained reasonably stable throughout the monitoring period (Table 4, Figure 18), with most values within, or marginally lower than the QWQG of 8.1 to 8.4. No significant seasonal or spatial variation was evident. However, as found in 2015/2016 (Vision Environment, 2016), antifouling measures required for the benthic loggers often interfered with pH readings, and thus limited pH data is available for all sites except AMB1 Surface.

Of note was the diurnally fluctuating pH at AMB5 when data was able to be gained. This pattern was also evident in 2015/2016 and was attributed to the biological activity associated with the adjacent coral reef and coral associated photosynthetic organisms (Vision Environment, 2016). Fluctuations in pH are evident when biological activity is high, with lower pH at night during respiration (release of carbon dioxide) and increased pH during the day when photosynthesis is occurring (consumption of dissolved carbon dioxide) (Geoscience Australia, 2015). Large diurnal fluctuations in DO were also noted to occur concurrently (Figure 20).

3.2.4 Conductivity

With the exception of AMB1 Surface immediately after TC Debbie (~ 25 mS/cm), conductivity also tended to remain reasonably stable throughout the monitoring period, with means values ranging from 53.1 to 55.9 mS/cm across the seasons (Table 4, Figure 19).

The large volume of rain experience during TC Debbie (> 380 mm) resulted in high flow from Don River and Euri Creek (> 150, 000 ML on 29 March 2017), which would have directly impacted AMB1 Surface. Benthic conductivity was only able to be recorded at AMB2 on this occasion, and did not exhibit a notable decrease, despite being in the flowpath of the Elliot River.

During flood events, the lighter freshwater tends to remain on the surface, with the more dense seawater remaining below, resulting in vertical stratification of the water column. However, mixing of the water column within a few days of TC Debbie resulted in the removal of the salinity halocline, with conductivity levels at AMB1 Surface back to typical marine levels by early April 2017.

Table 4 Temperature, pH, conductivity and dissolved oxygen statistics from data collected from loggers deployed July 2016 to June 2017.
N = 1020 - 17692 for wet season and 1110 – 17692 for dry season.

Site	Wet Season temperature (ºC)			Dry Season temperature (ºC)		
	Mean ± se	**Median**	**Range**	**Mean ± se**	**Median**	**Range**
AMB1 Surface	28.1 ± 0.0	28.9	24.4 – 30.9	22.9 ± 0.0	23.2	20.8 – 25.0
AMB1	28.5 ± 0.0	28.9	24.5 – 30.5	23.6 ± 0.0	23.2	20.9 – 26.8
AMB2	28.6 ± 0.0	28.9	24.9 – 30.3	23.6 ± 0.0	23.2	21.2 – 26.8
AMB3	29.1 ± 0.0	29.2	26.6 – 31.4	22.6 ± 0.0	22.5	21.9 – 23.3
AMB4	29.0 ± 0.0	29.2	25.0 – 31.0	23.1 ± 0.0	22.8	20.7 – 26.7
AMB5	28.1 ± 0.0	28.2	25.8 – 30.3	24.3 ± 0.0	24.2	22.4 – 26.7
AMB6	28.6 ± 0.0	28.8	26.3 – 30.3	24.1 ± 0.0	23.9	21.5 – 26.7
	Wet Season pH			**Dry Season pH**		
	Mean ± se	**Median**	**Range**	**Mean ± se**	**Median**	**Range**
AMB1 Surface	8.2 ± 0.0	8.2	7.9 – 8.3	8.2 ± 0.0	8.2	8.0 – 8.2
AMB1	8.2 ± 0.0	8.2	8.1 – 8.3	8.2 ± 0.0	8.2	8.0 – 8.3
AMB2	8.2 ± 0.0	8.2	7.9 – 8.4	8.2 ± 0.0	8.2	8.0 – 8.3
AMB3	8.2 ± 0.0	8.2	7.9 – 8.4	8.0 ± 0.0	8.0	7.9 – 8.3
AMB4	8.2 ± 0.0	8.2	8.1 – 8.1	8.2 ± 0.0	8.2	8.0 – 8.4
AMB5	8.1 ± 0.0	8.1	7.8 – 8.3	8.2 ± 0.0	8.2	8.0 – 8.4
AMB6	8.0 ± 0.0	8.0	7.9 – 8.4	8.2 ± 0.0	8.2	8.0 – 8.4
	Wet Season conductivity (mS/cm)			**Dry Season conductivity (mS/cm)**		
	Mean ± se	**Median**	**Range**	**Mean ± se**	**Median**	**Range**
AMB1 Surface	53.1 ± 0.0	54.2	24.6 – 55.0	53.2 ± 0.0	53.1	49.8 – 54.2
AMB1	54.6 ± 0.0	54.7	47.2 – 56.3	53.7 ± 0.0	52.7	50.5 – 55.6
AMB2	55.7 ± 0.0	55.8	51.2 – 58.0	54.2 ± 0.0	53.7	48.3 – 58.5
AMB3	54.4 ± 0.0	54.8	49.1 – 56.1	53.4 ± 0.0	52.3	50.3 – 58.0
AMB4	55.9 ± 0.0	56.3	51.3 – 59.8	55.7 ± 0.0	56.9	52.0 – 58.7
AMB5	55.2 ± 0.0	55.1	50.6 – 57.9	55.3 ± 0.0	53.8	45.4 – 58.9
AMB6	55.3 ± 0.0	55.8	50.0 – 56.5	53.5 ± 0.0	53.5	50.5 – 54.9
	Wet Season dissolved oxygen (% sat.)			**Dry Season dissolved oxygen (% sat.)**		
	Mean ± se	**Median**	**Range**	**Mean ± se**	**Median**	**Range**
AMB1 Surface	93 ± 0	93	72 - 103	100 ± 0	100	94 - 106
AMB1	113 ± 0	115	75 - 133	102 ± 0	101	88 - 130
AMB2	101 ± 0	102	63 - 127	96 ± 0	95	82 - 107
AMB3	112 ± 0	112	82 - 136	103 ± 0	103	91 - 107
AMB4	107 ± 0	107	79 - 130	100 ± 0	99	91 - 116
AMB5	109 ± 0	110	80 - 130	103 ± 0	101	82 - 133
AMB6	114 ± 0	115	70 - 124	92 ± 0	93	70 - 121

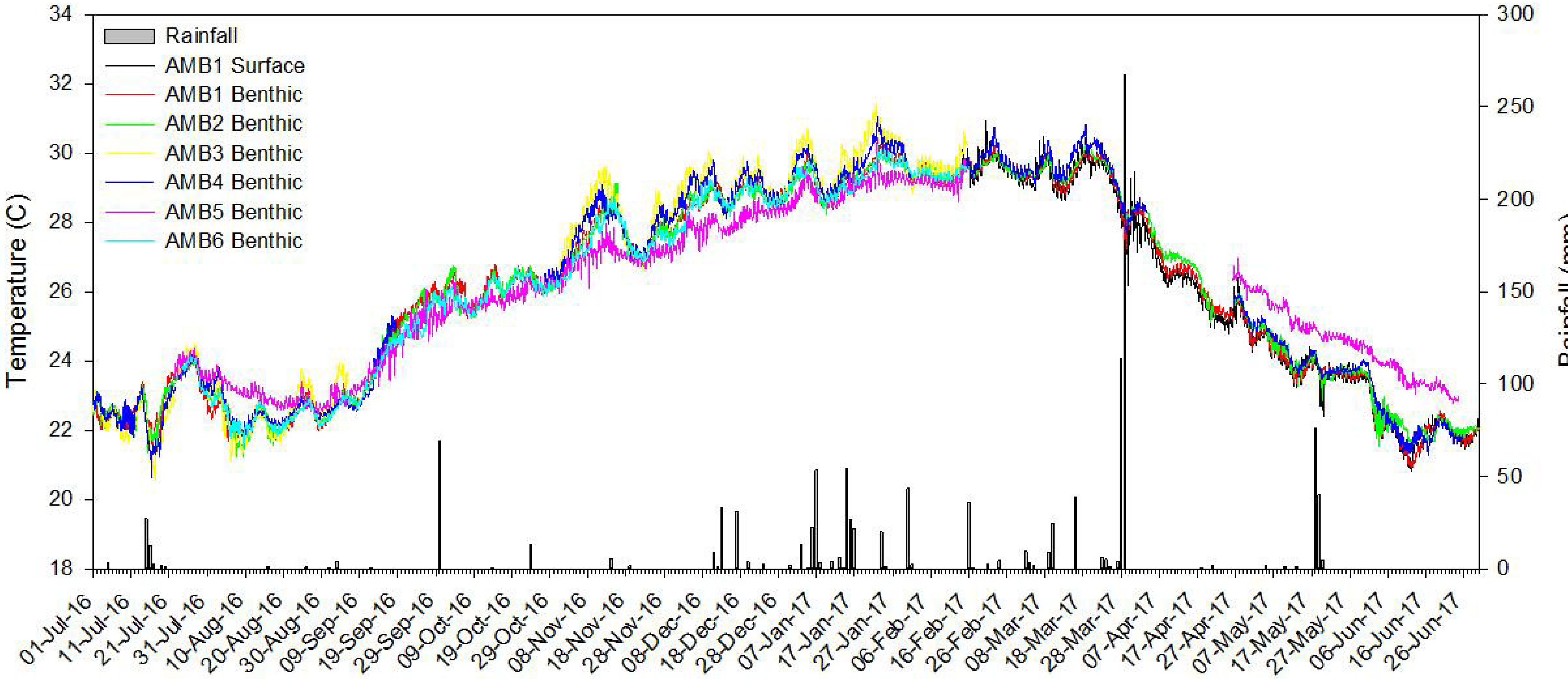

Figure 17 Temperature and rainfall at monitoring sites from July 2016 to June 2017.
AMB1 surface deployed from February to June 2017. AMB3 and AMB6 deployed from July 2016 to February 2017.

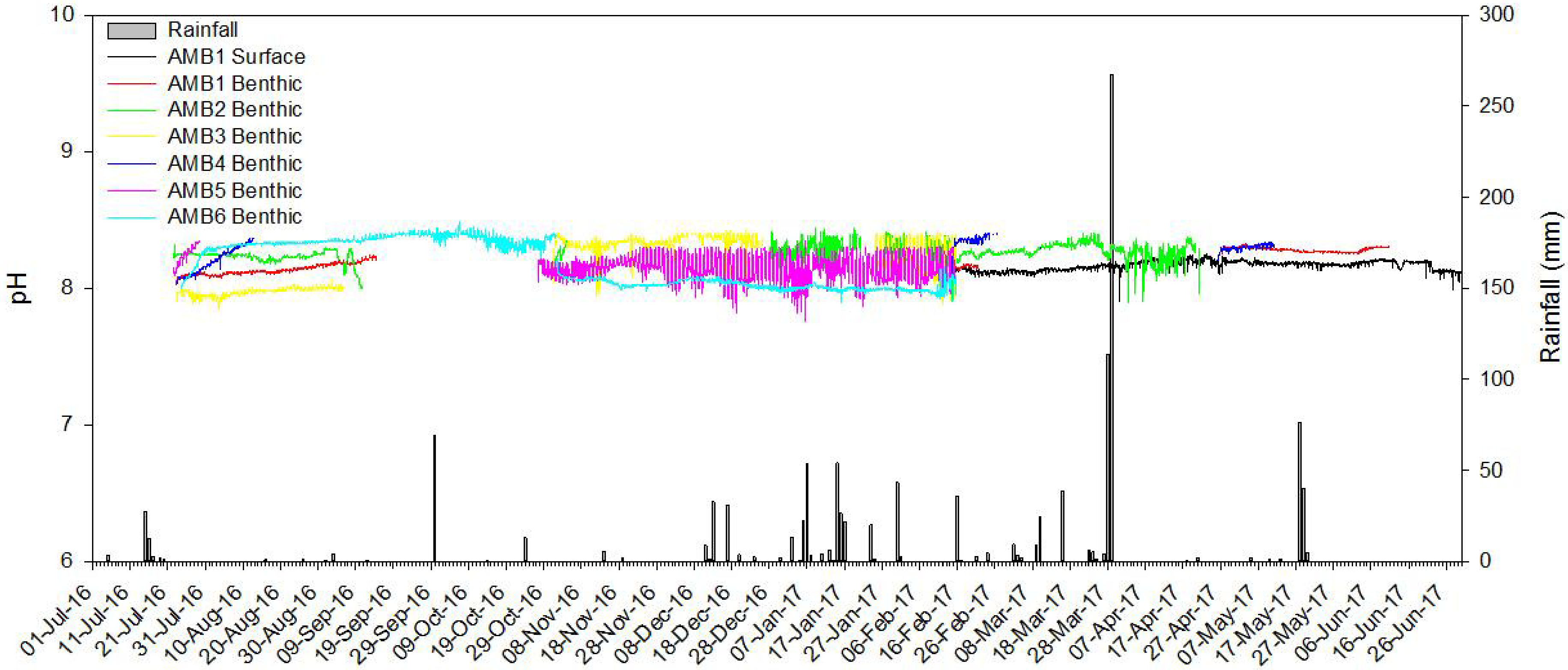

Figure 18 pH and rainfall at monitoring sites from July 2016 to June 2017.
AMB1 surface deployed from February to June 2017. AMB3 and AMB6 deployed from July 2016 to February 2017.

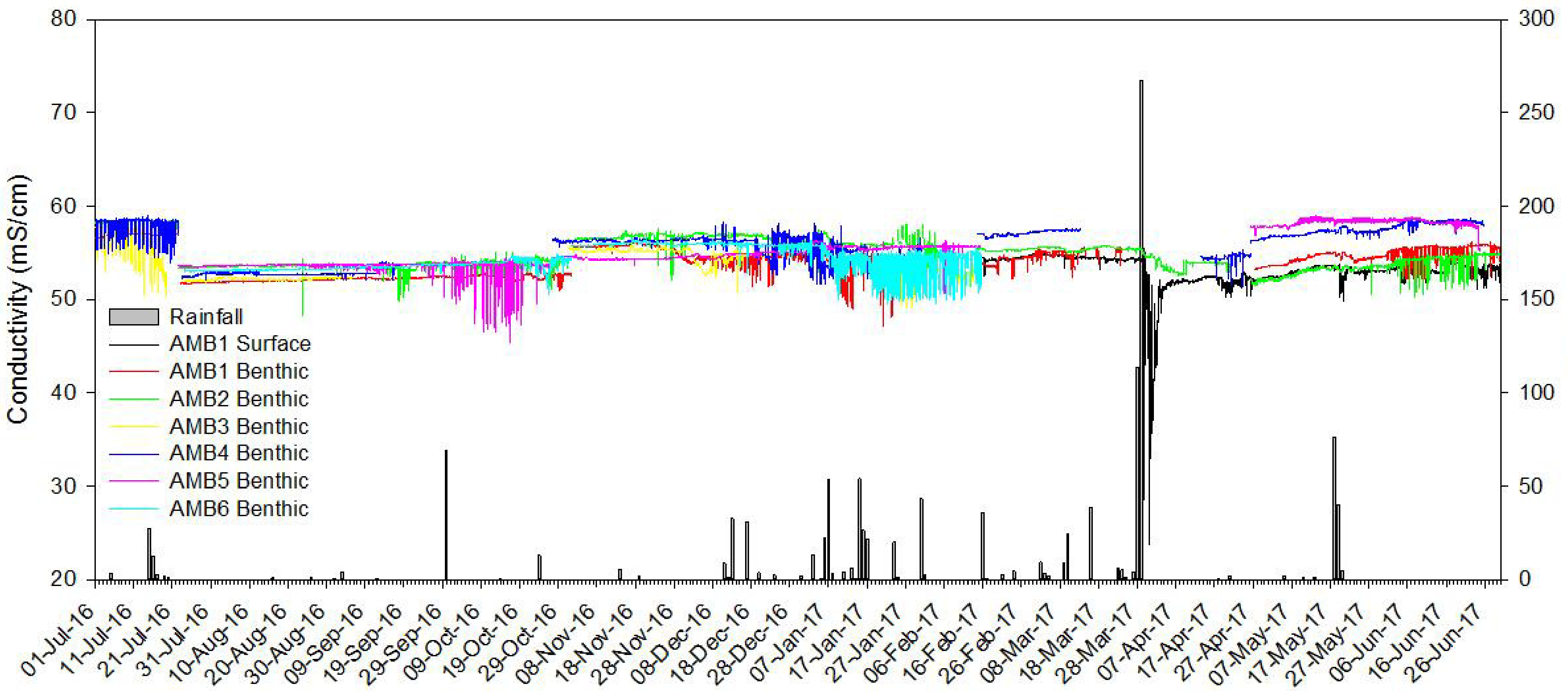

Figure 19 Conductivity and rainfall at monitoring sites from July 2016 to June 2017.
AMB1 surface deployed from February to June 2017. AMB3 and AMB6 deployed from July 2016 to February 2017.

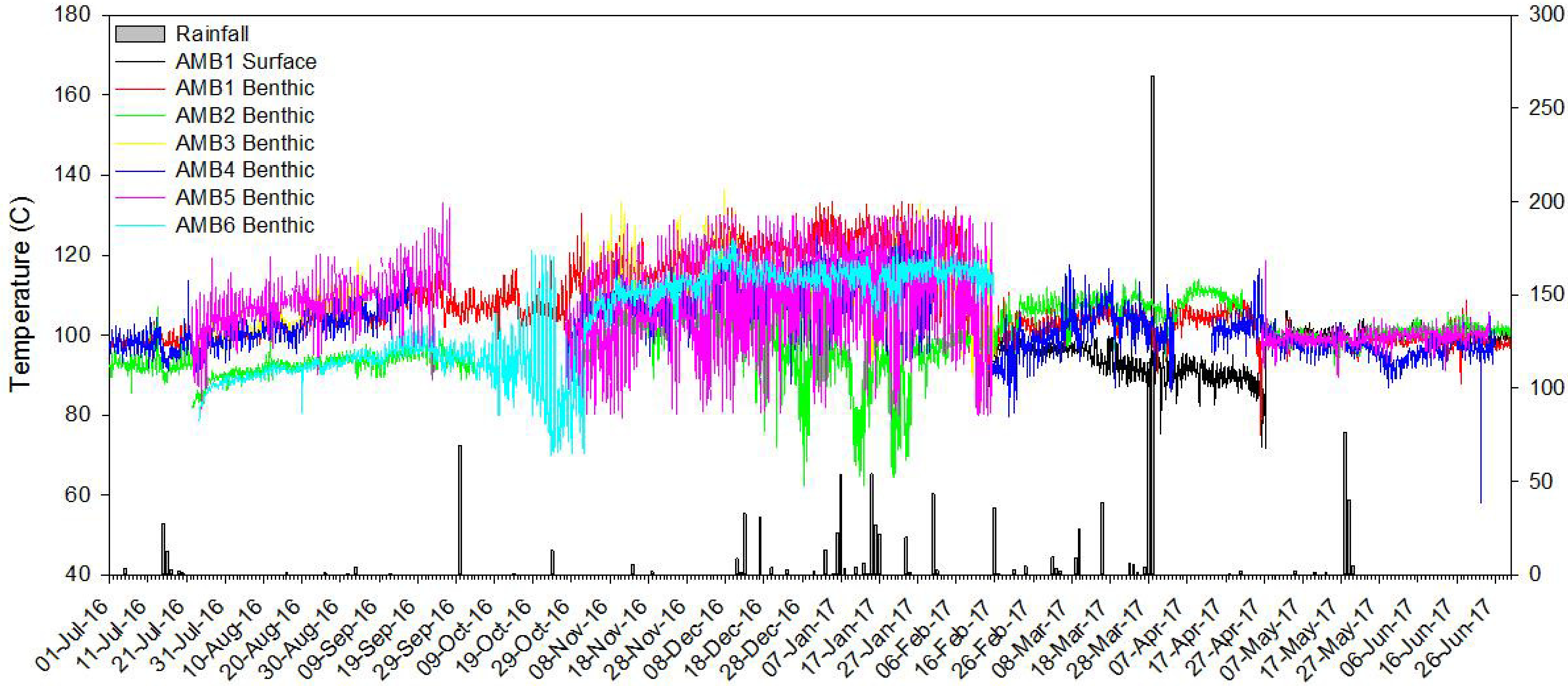

Figure 20 Dissolved oxygen and rainfall at monitoring sites from July 2016 to June 2017.
AMB1 surface deployed from February to June 2017. AMB3 and AMB6 deployed from July 2016 to February 2017.

3.2.5 Dissolved Oxygen (DO)

Dissolved oxygen exhibited periods of high fluctuation at the majority of sites, but particularly at AMB5 during the spring months (Table 4, Figure 20). Highly fluctuating DO at AMB5 can be attributed to the adjacent coral reef and activity of coral associated photosynthetic organisms, with lower DO (and pH) at night during respiration and increased DO (and pH) during the day when photosynthesis is occurring. Similar fluctuations in DO have been recorded adjacent to seagrass meadows (Hume *et al.*, 2011, Marba *et al.*, 2006)

Overall, dissolved oxygen was significantly ($p < 0.05$) higher during the Wet Season (means: 93 to 114% saturation) than during the Dry Season (means: 92 to 103% saturation). Throughout the Dry Season, mean DO values were within, or slightly below, the QWQG of 95 to 105% saturation, while highly oxygenated waters (> 105% saturation) were recorded at several sites during the Wet Season, most likely due to the longer day lengths permitting longer photosynthesis periods, and the decreased solubility of oxygen as water temperature increases.

3.3 Physicochemistry Depth Profiling

While the continuous physicochemical loggers provided information about near benthos conditions and sub-surface conditions at AMB1, physicochemical depth profiling provided information in regards to the entire water column. Statistics, including means and standard errors, for depth profiled physicochemical parameters undertaken during July and October 2016, in addition to February and April 2017 are tabulated in Tables 5 to 8. Light attenuation (K_d), or the rate at which light diminishes through the water column, was also calculated at each site and recorded. Depth profile plots comparing data across sampling events at each site are illustrated in Figures 21 to 24.

While depth profiling was undertaken at AMB1 in October/November 2016 and data logged appropriately, the data file was corrupted from the ProDSS water quality meter during data transfer, an issue that had not been experienced previously. A software update to the ProDSS has ensured that data loss has not occurred again. However, minimal depth-profiling data for AMB1 was manually recorded on the field sheet, which was available for backup and validation, and have been tabulated in this report.

As expected, clear seasonal patterns were evident for water temperature. Similar to the continuous loggers, warmest water temperatures were evident during the February 2017 survey (29.3 to 30.3 ºC), and lowest temperatures were evident during the July 2016 survey (23.2 to 24.3 ºC). Intermediate temperatures were recorded in October 2016 (26.1 to 26.8 ºC) and April 2017 (25.3 to 26.3 ºC).

All pH values during all surveys were within, or marginally below, the QWQG of 8.0 to 8.4. Previous monitoring of pH at Abbot Point has also found pH values marginally lower than the QWQG range (Vision Environment, 2016, Worley Parsons, 2014), indicating that this is a common occurrence.

Conductivity was higher during the July 2016 survey than the other surveys, most likely due to the lower amount of rainfall experienced during the Dry Season. High conductivity did not continue to the October 2016 survey likely attributable to the large rainfall experienced just prior to the survey. Despite the large rainfall event associated with TC Debbie just four weeks prior to the April 2017 sampling, conductivity in April 2017 remained similar to October 2016 and February 2017.

Table 5 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during July 2016 sampling event.
Values are means ± se (n = 3 for subsurface, mid and benthos, n = 17 to 51 for whole column). Values outside recommended QWQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	22/07/2016 16:00	Sub-surface	23.8 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	4.1 ± 0.0	0.2
		Mid	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	4.4 ± 0.0	
		Benthos	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	4.8 ± 0.1	
		Whole column	23.5 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	4.4 ± 0.0	
AMB2	22/07/2016 12:15	Sub-surface	23.5 ± 0.0	8.1 ± 0.0	61.5 ± 0.0	101 ± 0	1.4 ± 0.0	0.2
		Mid	23.3 ± 0.0	8.1 ± 0.0	61.5 ± 0.0	101 ± 0	<1	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.6 ± 0.0	100 ± 0	<1	
		Whole column	23.4 ± 0.0	8.1 ± 0.0	61.6 ± 0.0	101 ± 0	<1	
AMB3	23/07/2016 2:30	Sub-surface	23.6 ± 0.0	8.1 ± 0.0	61.3 ± 0.0	102 ± 0	5.8 ± 0.0	0.3
		Mid	23.2 ± 0.0	8.1 ± 0.0	61.3 ± 0.0	102 ± 0	5.9 ± 0.0	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	103 ± 0	5.5 ± 0.3	
		Whole column	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	5.9 ± 0.0	
AMB4	23/07/2016 10:30	Sub-surface	23.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	101 ± 0	<1	0.3
		Mid	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	<1	
		Benthos	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	101 ± 0	<1	
		Whole column	23.2 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	101 ± 0	<1	
AMB5	22/07/2016 8:00	Sub-surface	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	89 ± 0	6.6 ± 0.0	0.5
		Mid	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	89 ± 0	7.1 ± 0.4	
		Benthos	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	89 ± 0	7.5 ± 0.2	
		Whole column	23.2 ± 0.0	8.0 ± 0.0	61.5 ± 0.0	89 ± 0	7.2 ± 0.1	
AMB6	23/07/2016 16:15	Sub-surface	24.3 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	102 ± 0	1.0 ± 0.0	0.3
		Mid	23.6 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	101 ± 0	1.1 ± 0.1	
		Benthos	23.5 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	100 ± 0	1.4 ± 0.0	
		Whole column	23.8 ± 0.0	8.1 ± 0.0	61.4 ± 0.0	101 ± 0	1.1 ± 0.0	
QWQG			**-**	**8.0 – 8.4**	**-**	**95 - 105**	**1**	**-**

Table 6 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during October/November 2016 sampling event. *Values are means ± se (n = 3 for subsurface, mid and benthos, n = 17 to 31 for whole column). Values outside recommended QWQG are highlighted in blue. AMB1 subsurface values only able to be reported due to ProDSS malfunction.*

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	01/11/2016 09:15	Sub-surface	26.4	8.2	56.2	103	<1	0.2
		Mid	-	-	-	-	-	
		Benthos	-	-	-	-	-	
		Whole column	-	-	-	-	-	
AMB2	31/10/2016 13:45	Sub-surface	26.8 ± 0.0	8.1 ± 0.0	56.0 ± 0.0	103 ± 0	1.0 ± 0.0	0.2
		Mid	26.2 ± 0.0	8.2 ± 0.0	56.1 ± 0.0	102 ± 0	<1	
		Benthos	26.1 ± 0.0	8.2 ± 0.0	56.1 ± 0.0	102 ± 0	<1	
		Whole column	26.4 ± 0.1	8.1 ± 0.0	56.1 ± 0.0	102 ± 0	<1	
AMB3	27/10/2016 14:15	Sub-surface	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	104 ± 0	<1	0.4
		Mid	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	104 ± 0	<1	
		Benthos	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	104 ± 0	<1	
		Whole column	26.5 ± 0.0	8.1 ± 0.0	56.5 ± 0.0	104 ± 0	<1	
AMB4	27/10/2016 11:30	Sub-surface	26.2 ± 0.0	8.1 ± 0.0	56.2 ± 0.0	102 ± 0	1.1 ± 0.0	0.2
		Mid	26.2 ± 0.0	8.1 ± 0.0	56.3 ± 0.0	102 ± 0	1.2 ± 0.0	
		Benthos	26.2 ± 0.0	8.1 ± 0.0	56.4 ± 0.1	98 ± 2	1.1 ± 0.0	
		Whole column	26.2 ± 0.0	8.1 ± 0.0	56.3 ± 0.0	101 ± 1	1.1 ± 0.0	
AMB5	27/10/2016 07:30	Sub-surface	25.9 ± 0.0	8.1 ± 0.0	55.6 ± 0.0	97 ± 0	1.3 ± 0.0	0.2
		Mid	25.9 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	97 ± 0	1.3 ± 0.0	
		Benthos	25.9 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	97 ± 0	1.3 ± 0.0	
		Whole column	25.9 ± 0.0	8.1 ± 0.0	55.6 ± 0.0	97 ± 0	1.3 ± 0.0	
AMB6	01/11/2016 06:30	Sub-surface	26.2 ± 0.0	8.1 ± 0.0	56.0 ± 0.0	102 ± 0	<1	0.2
		Mid	26.2 ± 0.0	8.2 ± 0.0	56.0 ± 0.0	101 ± 0	<1	
		Benthos	26.3 ± 0.0	8.2 ± 0.0	56.2 ± 0.0	102 ± 0	<1	
		Whole column	26.2 ± 0.0	8.1 ± 0.0	56.1 ± 0.0	102 ± 0	<1	
QWQG			**-**	**8.0 – 8.4**	**-**	**95 - 105**	**1**	**-**

Table 7 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during February 2017 sampling event.
Values are means ± se (n = 6 for subsurface, mid and benthos, n = 30 to 39 for whole column). Values outside recommended QWQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	14/2/2017 8:00	Sub-surface	29.4 ± 0.0	8.1 ± 0.0	55.4 ± 0.0	98 ± 0	<1	0.2 ± 0.0
		Mid	29.4 ± 0.0	8.1 ± 0.0	55.4 ± 0.0	97 ± 0	<1	
		Benthos	29.4 ± 0.0	8.1 ± 0.0	55.4 ± 0.0	97 ± 0	<1	
		Whole column	29.4 ± 0.0	8.1 ± 0.0	55.4 ± 0.0	97 ± 0	<1	
AMB2	14/2/2017 11:00	Sub-surface	29.8 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	99 ± 0	<1	0.3 ± 0.0
		Mid	29.4 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	98 ± 0	<1	
		Benthos	29.3 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	97 ± 0	<1	
		Whole column	29.5 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	98 ± 0	<1	
AMB3	15/2/2017 10:00	Sub-surface	30.3 ± 0.0	8.2 ± 0.0	55.6 ± 0.0	97 ± 0	<1	0.2 ± 0.0
		Mid	30.3 ± 0.0	8.2 ± 0.0	55.7 ± 0.0	97 ± 0	<1	
		Benthos	30.3 ± 0.0	8.2 ± 0.0	55.7 ± 0.0	97 ± 0	<1	
		Whole column	30.3 ± 0.0	8.2 ± 0.0	55.7 ± 0.0	97 ± 0	<1	
AMB4	14/2/2017 13:15	Sub-surface	30.1 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	100 ± 0	<1	0.2 ± 0.0
		Mid	29.4 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	100 ± 0	<1	
		Benthos	29.3 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	100 ± 0	<1	
		Whole column	29.7 ± 0.1	8.2 ± 0.0	55.5 ± 0.0	100 ± 0	<1	
AMB5	15/2/2017 8:00	Sub-surface	29.4 ± 0.0	8.1 ± 0.0	55.5 ± 0.0	94 ± 0	<1	0.1 ± 0.1
		Mid	29.4 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	94 ± 0	<1	
		Benthos	29.4 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	93 ± 0	<1	
		Whole column	29.4 ± 0.0	8.2 ± 0.0	55.5 ± 0.0	94 ± 0	<1	
AMB6	15/2/2017 11:30	Sub-surface	29.6 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	98 ± 0	<1	0.2 ± 0.0
		Mid	29.5 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	97 ± 0	<1	
		Benthos	29.5 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	96 ± 0	<1	
		Whole column	29.5 ± 0.0	8.2 ± 0.0	55.4 ± 0.0	97 ± 0	<1	
QWQG			**-**	**8.0 – 8.4**	**-**	**95 - 105**	**1**	**-**

Table 8 Discrete physicochemical statistics from depth-profiling of the water column at AMB1 to AMB6 during April 2017 sampling event.
Note AMB6 monitoring discontinued in February 2017. Values are means ± se (n = 6 for subsurface, mid and benthos, n = 23 to 50 for whole column). Values outside recommended QWQG are highlighted in blue.

Site	Sample date/time	Depth	Temperature (ºC)	pH	Conductivity (mS/cm)	Dissolved oxygen (% saturation)	Turbidity (NTU)	K_d
AMB1	26/4/2017 15:30	Sub-surface	26.3 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	102 ± 0	6.6 ± 0.1	0.4 ± 0.0
		Mid	25.3 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	101 ± 0	5.8 ± 0.1	
		Benthos	25.3 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	100 ± 0	5.6 ± 0.1	
		Whole column	25.7 ± 0.1	8.1 ± 0.0	55.0 ± 0.0	101 ± 0	6.1 ± 0.1	
AMB2	26/4/2017 13:00	Sub-surface	26.3 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	104 ± 0	7.0 ± 0.0	0.3 ± 0.0
		Mid	25.5 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	103 ± 0	6.9 ± 0.1	
		Benthos	25.5 ± 0.0	8.1 ± 0.0	55.0 ± 0.0	102 ± 0	6.4 ± 0.2	
		Whole column	25.8 ± 0.1	8.1 ± 0.0	55.0 ± 0.0	103 ± 0	6.8 ± 0.0	
AMB3	27/4/2017 8:00	Sub-surface	25.6 ± 0.0	8.0 ± 0.0	55.2 ± 0.0	100 ± 0	6.1 ± 0.0	0.4 ± 0.1
		Mid	25.6 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	100 ± 0	6.0 ± 0.1	
		Benthos	25.6 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	100 ± 0	6.1 ± 0.1	
		Whole column	25.6 ± 0.0	8.1 ± 0.0	55.3 ± 0.0	100 ± 0	6.1 ± 0.0	
AMB4	26/4/2017 11:00	Sub-surface	25.9 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	102 ± 0	7.0 ± 0.1	0.3 ± 0.0
		Mid	25.5 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	102 ± 0	6.9 ± 0.0	
		Benthos	25.5 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	101 ± 0	6.4 ± 0.2	
		Whole column	25.6 ± 0.0	8.1 ± 0.0	55.1 ± 0.0	102 ± 0	6.9 ± 0.0	
AMB5	26/4/2017 8:30	Sub-surface	26.2 ± 0.0	8.0 ± 0.0	56.6 ± 0.0	99 ± 0	7.2 ± 0.0	0.2 ± 0.1
		Mid	26.1 ± 0.0	8.1 ± 0.0	56.6 ± 0.0	100 ± 0	7.3 ± 0.1	
		Benthos	26.1 ± 0.0	8.1 ± 0.0	56.6 ± 0.0	99 ± 0	7.3 ± 0.1	
		Whole column	26.2 ± 0.0	8.1 ± 0.0	56.6 ± 0.0	99 ± 0	7.2 ± 0.1	
QWQG			**-**	**8.0 – 8.4**	**-**	**95 - 105**	**1**	**-**

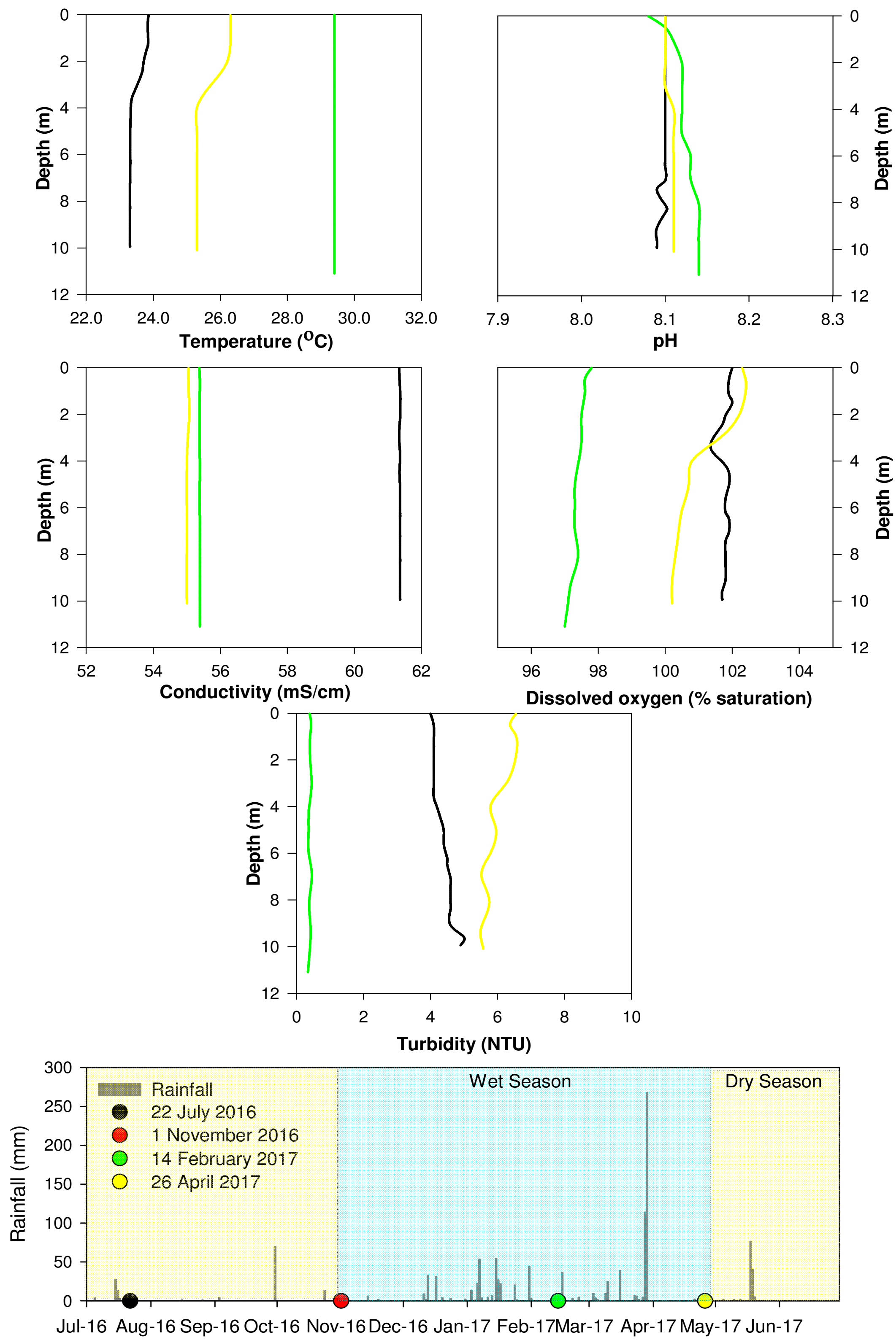

Figure 21 Depth-profiled physicochemical parameters and associated rainfall at AMB1 during July 2016, and February and April 2017.
Note no data available for October/November 2016 due to the malfunction of the ProDSS.

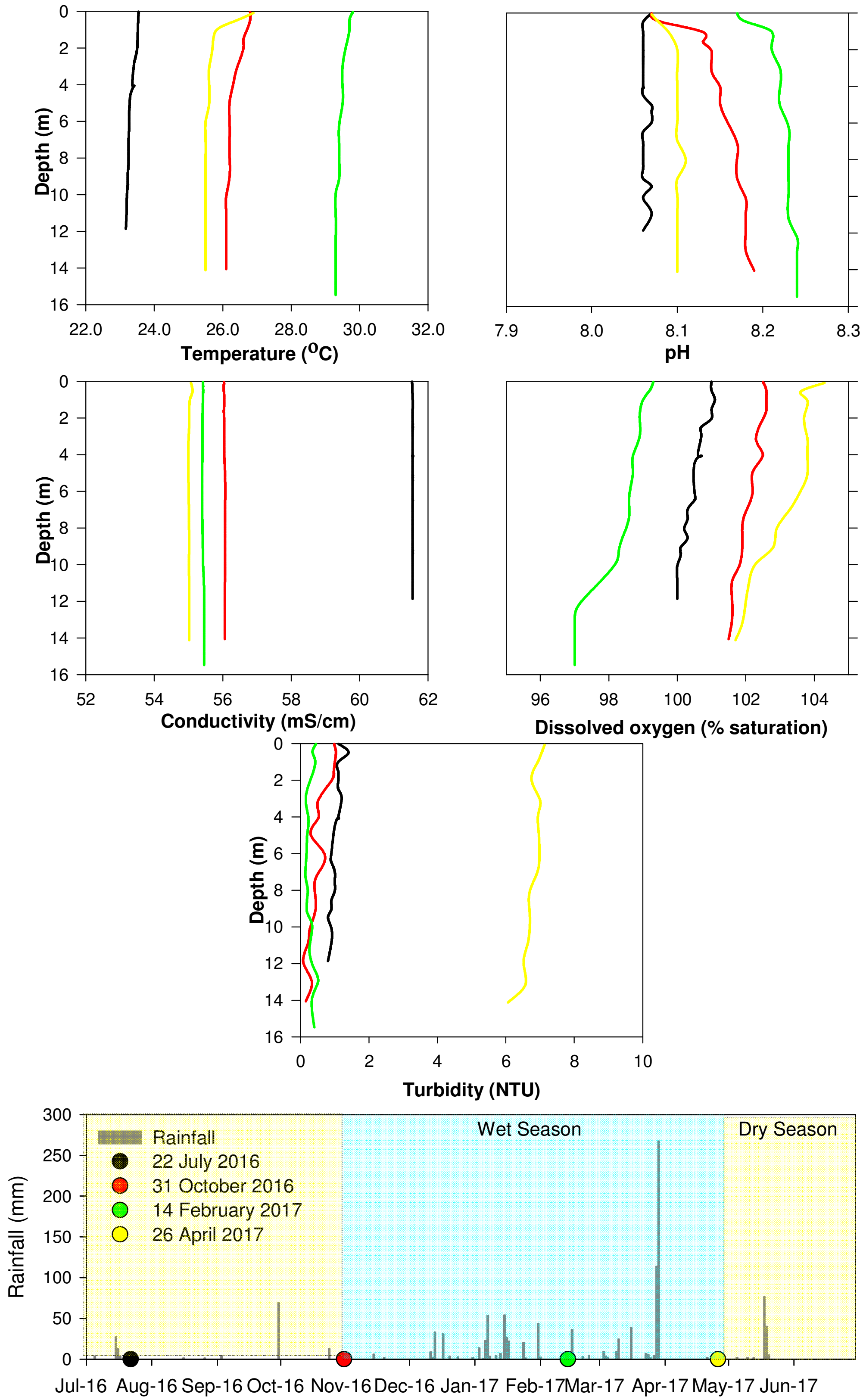

Figure 22 Depth-profiled physicochemical parameters and associated rainfall at AMB2 during July and October/November2016, and February and April 2017.

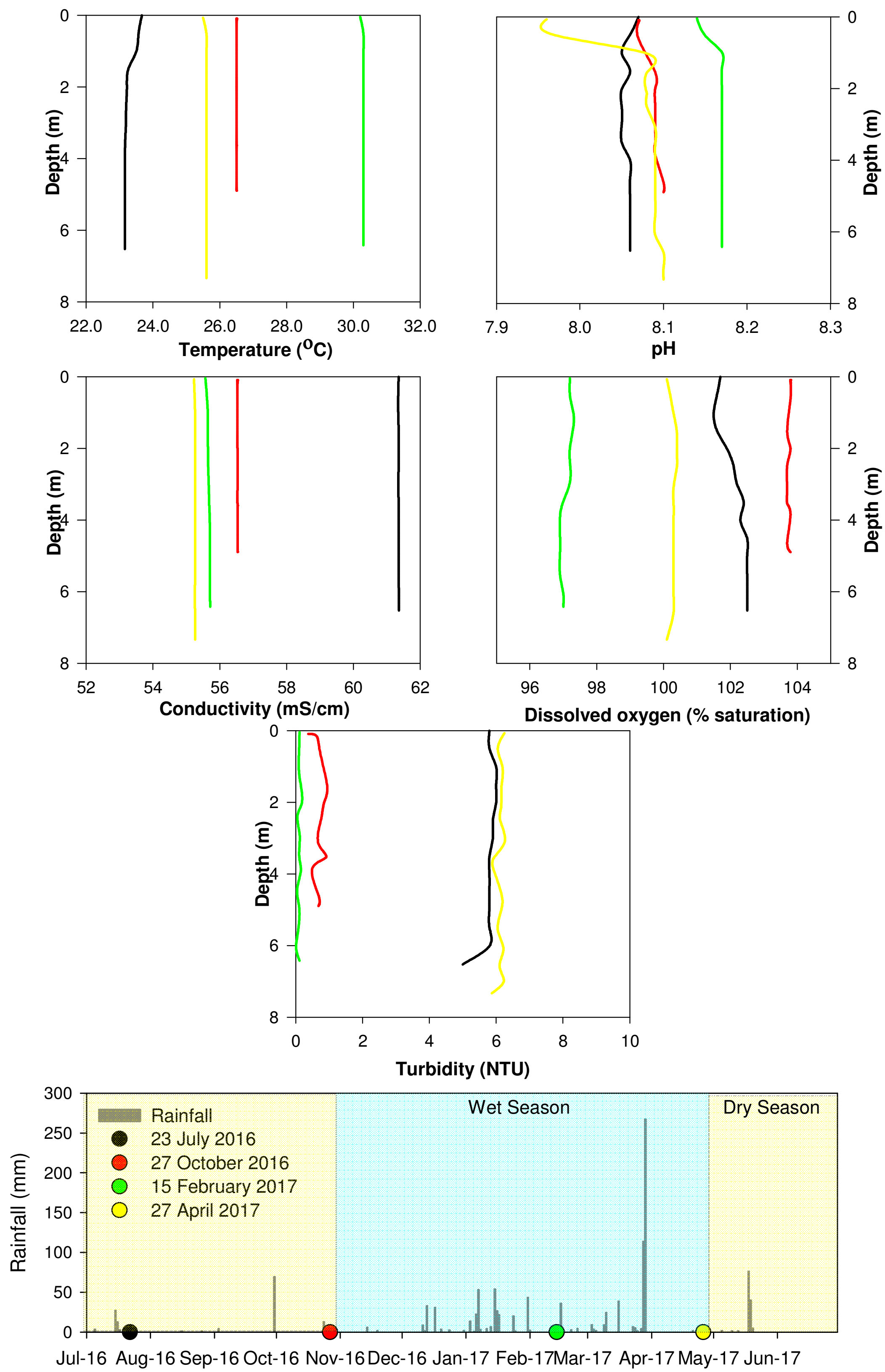

Figure 23 Depth-profiled physicochemical parameters and associated rainfall at AMB3 during July and October/November2016, and February and April 2017.

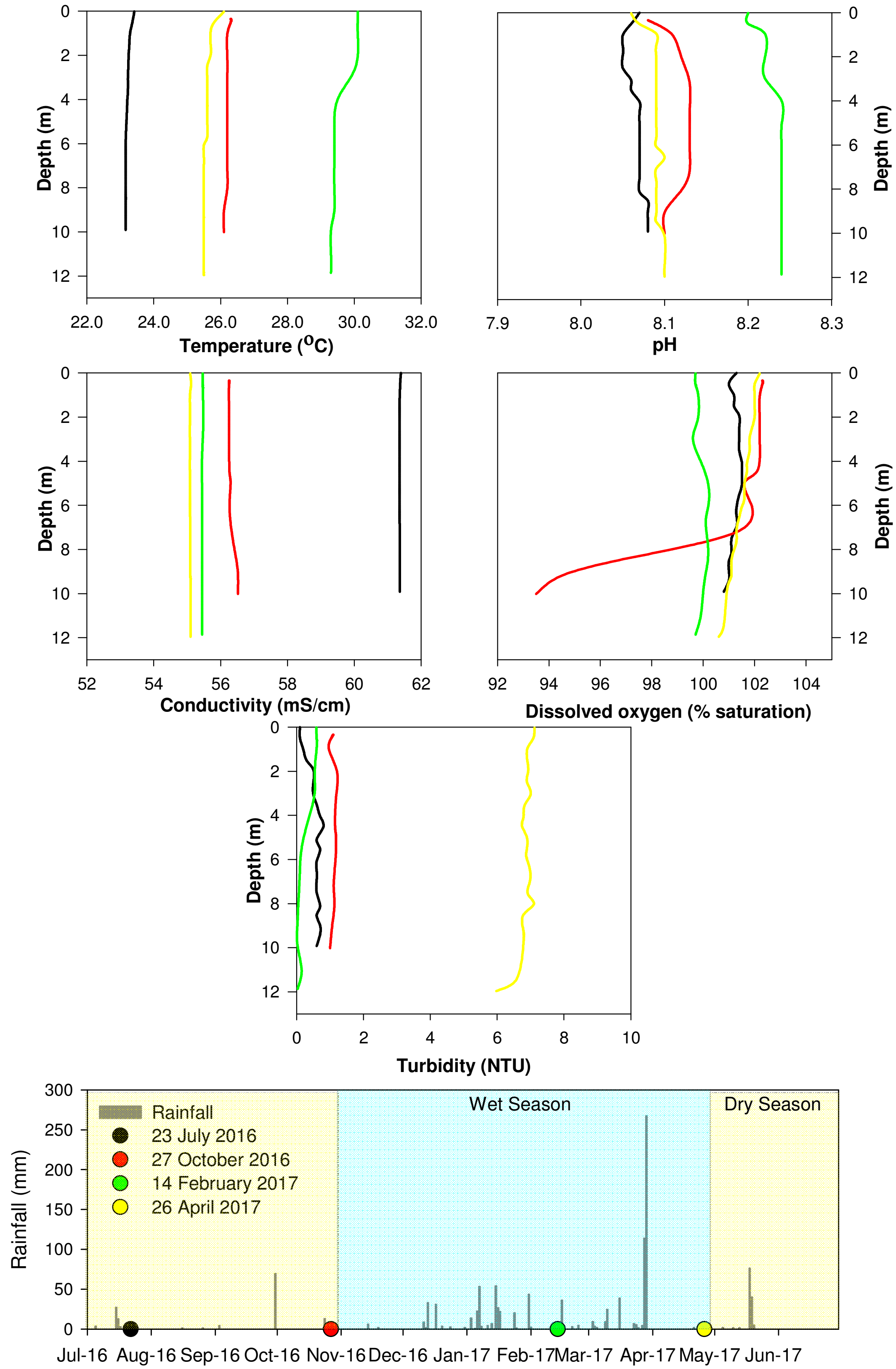

Figure 24 Depth-profiled physicochemical parameters and associated rainfall at AMB4 during July and October/November2016, and February and April 2017.

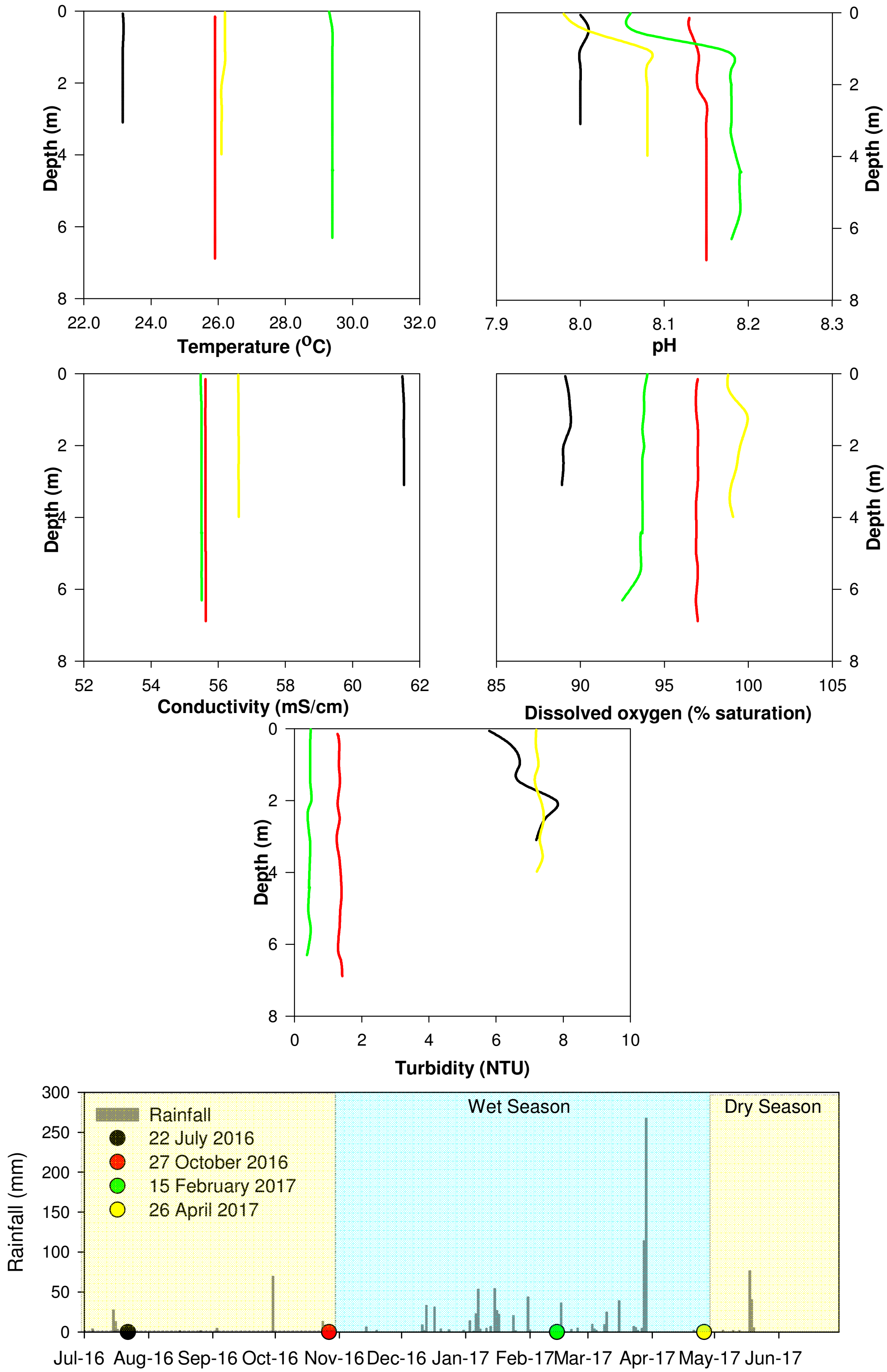

Figure 25 Depth-profiled physicochemical parameters and associated rainfall at AMB5 during July and October/November2016, and February and April 2017.

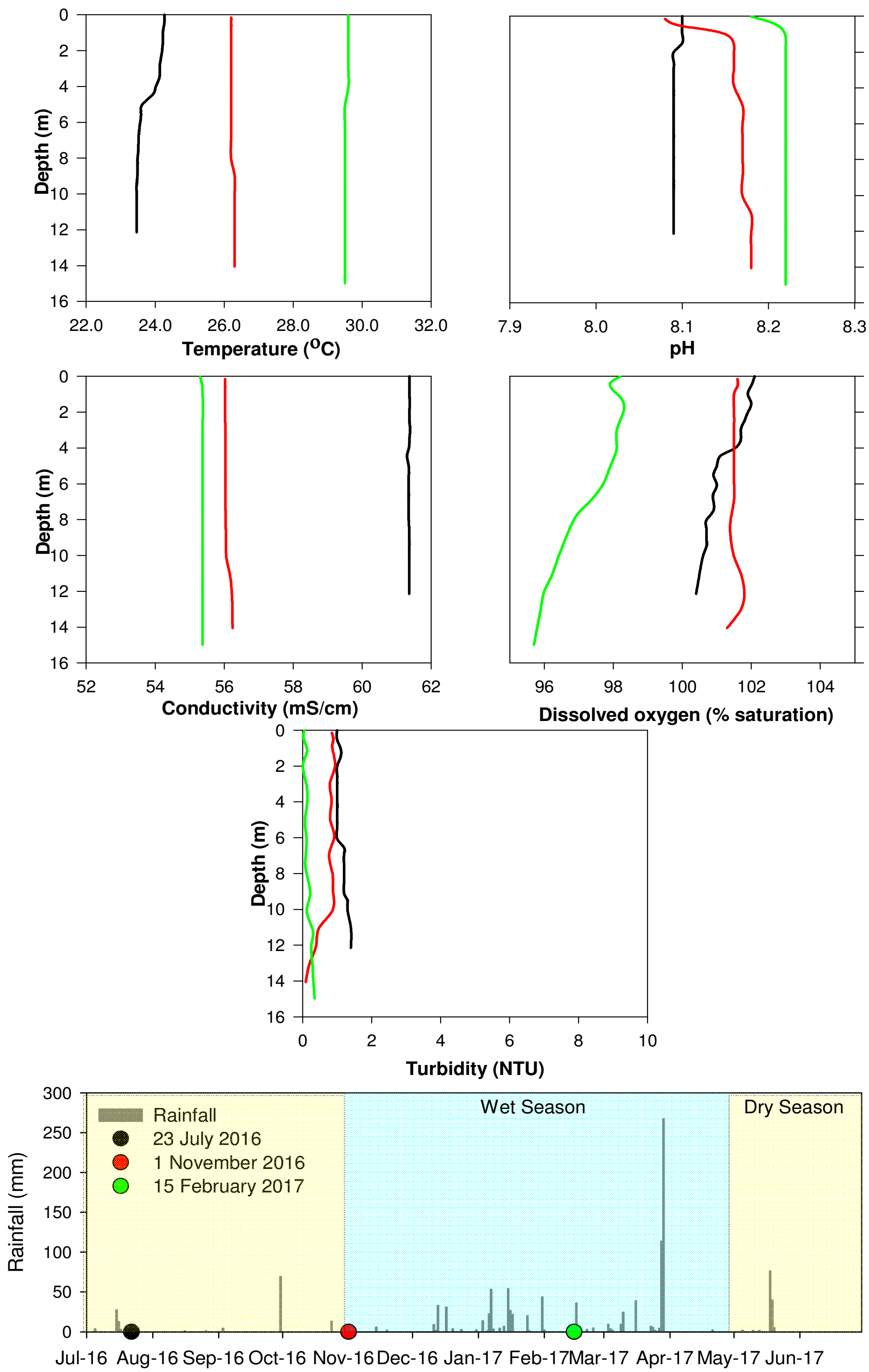

Figure 26 Depth-profiled physicochemical parameters and associated rainfall at AMB6 during July and October/November2016, and February 2017.
Note monitoring of AMB6 ceased in February 2017.

Dissolved oxygen did not exhibit a clear seasonal pattern, with the majority of values remaining within the QWQG of 95 to 100% saturation. The exception to this was the lower oxygen levels (89% saturation) at AMB5 in July 2016. However, this is likely to have been an artefact of sampling time, with sampling undertaken in the morning. This highlights the benefits of continuous loggers for which data is not biased due to sampling time. As recorded by the continuous loggers, diurnal oxygen fluctuations due to respiration and photosynthesis of marine organisms were consistently larger at AMB5. The pH during the July sampling at AMB5 (8.0) was also lower than typical (8.1 to 8.2).

For most sites, depth-profiled turbidity was highest in April 2017 (5.8 to 7.3 NTU), exceeding the QWQG of 1 NTU. The higher turbidity recorded at this time may have been a residual effect of the elevated turbidity experienced during TC Debbie a few weeks prior. However, values higher than the QWQG were experienced at several sites during both July (<1 to 7.5 NTU) and October 2016 (<1 to 1.3 NTU). The QWQG which apply to open coastal waters could be considered conservative for the near shore Abbot Point sites, which can be influenced by adjacent river flows. Long-term turbidity monitoring supports the premise that the QWQG may not be suitable for application at these sites. Light attenuation remained reasonably consistent across sites and monitoring events, generally ranging between 0.1 and 0.5.

Temperature, pH and conductivity remained consistent with water depth at all sites during all four sampling events. Some variation in pH and DO with water depth was evident at some sites during certain surveys; however no consistent pattern, nor vertical stratification, was detected. Previous monitoring programs had also found that Abbot Point coastal waters are well-mixed especially under non-flood conditions (GHD, 2009, 2010, 2012, Vision Environment, 2016, Worley Parsons, 2014).

3.4 Continuous BPAR Loggers

There are three major environmental factors that can affect BPAR: the available ambient light, water depth and water clarity. Thus all three variables are considered in the following section. Mean seasonal ambient PAR and BPAR is reported as Total Daily PAR (TDP) in Table 9 and Figures 27 to 32.

Table 9 Total Daily PAR (TDP) statistics from data collected from loggers deployed July 2016 to June 2017.
N = 105 to 179 for wet season and 79 to 183 for dry season. Note BPAR monitoring at AMB2, 3 and 6 ceased in February 2017.

Site	Depth (m)	Wet Season TDP (mol/m^2/day)			Dry Season TDP (mol/m^2/day)		
		Mean ± se	Median	Range	Mean ± se	Median	Range
Base	-	68.6 ± 1.4	74.4	3.0 - 86.0	64.6 ± 1.2	66.1	6.9 – 91.1
AMB1	9.0	2.3 ± 0.1	2.5	<0.1 – 6.5	1.8 ± 0.1	1.9	<0.1 – 6.6
AMB2	12.2	1.1 ± 0.1	0.9	0.1 – 2.9	0.6 ± 0.1	0.4	<0.1 – 2.6
AMB3	3.9	8.7 ± 0.4	8.0	1.5 – 18.4	5.7 ± 0.2	5.8	0.6 – 11.1
AMB4	8.5	2.3 ± 0.1	2.2	<0.1 - 6.1	1.9 ± 0.1	2.0	0.1 – 3.9
AMB5	6.3	8.2 ± 0.3	8.4	1.6 – 14.8	7.6 ± 0.4	7.5	0.5 – 16.9
AMB6	13.1	1.3 ± 0.1	1.3	0.1 – 4.2	1.3 ± 0.1	1.3	<0.1 – 4.3

TDP at Bowen Base was significantly ($p < 0.05$) higher in the Wet Season (68.6 mol/m^2/day) than in the Dry Season (64.6 mol/m^2/day), similar to 2015/2016 (Vision Environment, 2016). TDP was also significantly ($p < 0.05$) higher at each benthic site (except AMB6) during the Wet Season (site seasonal means ranging from 1.1 to 8.7 mol/m^2/day), than during the Dry Season (site seasonal means ranging from 0.6 to 7.6 mol/m^2/day), despite the significantly lower turbidity experienced during the latter season (see Section 3.2.1).

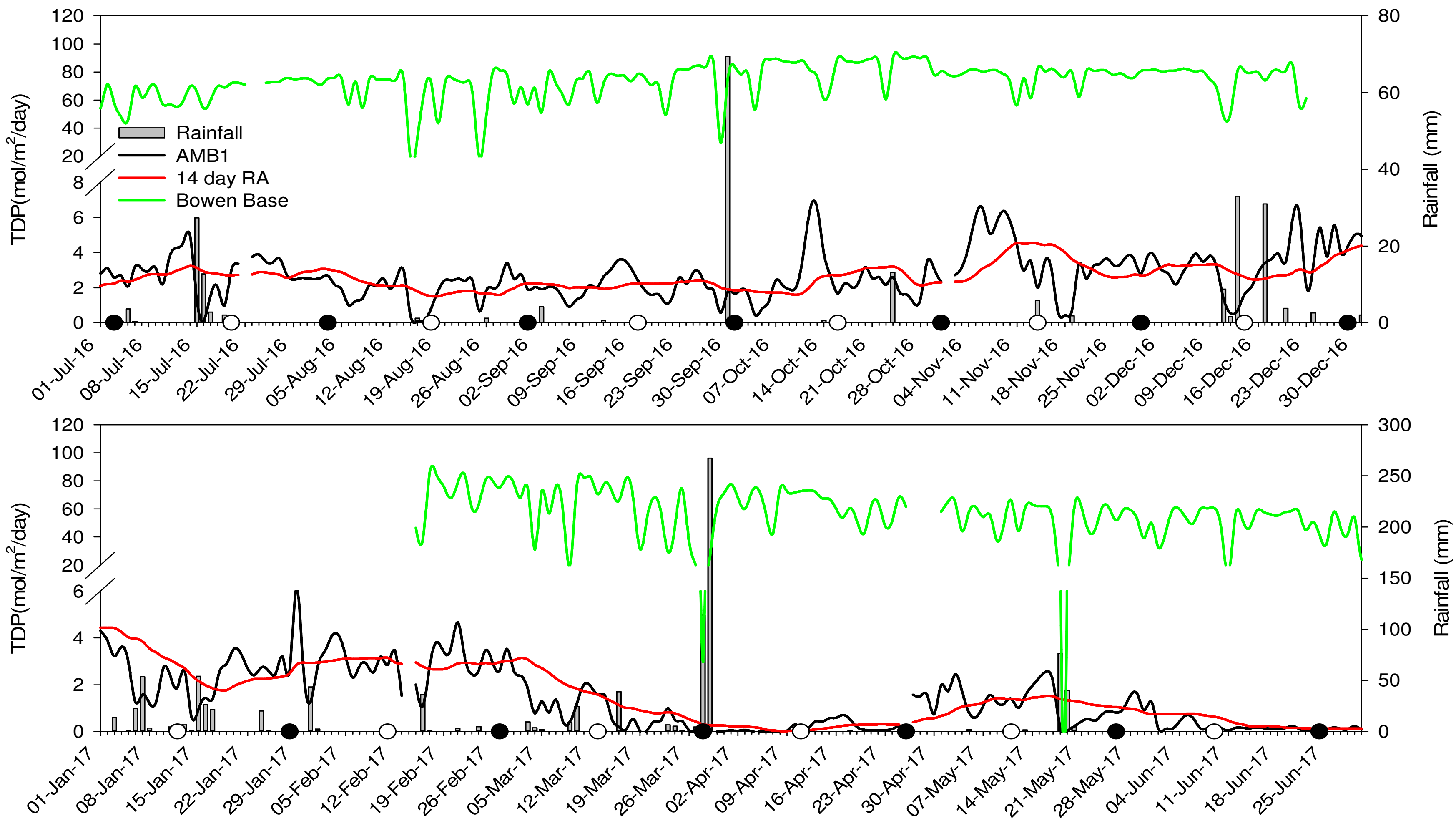

Figure 27 Benthic TDP and 14 day rolling average for BPAR at AMB1 and ambient (Bowen base) TDP from July 2016 to June 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

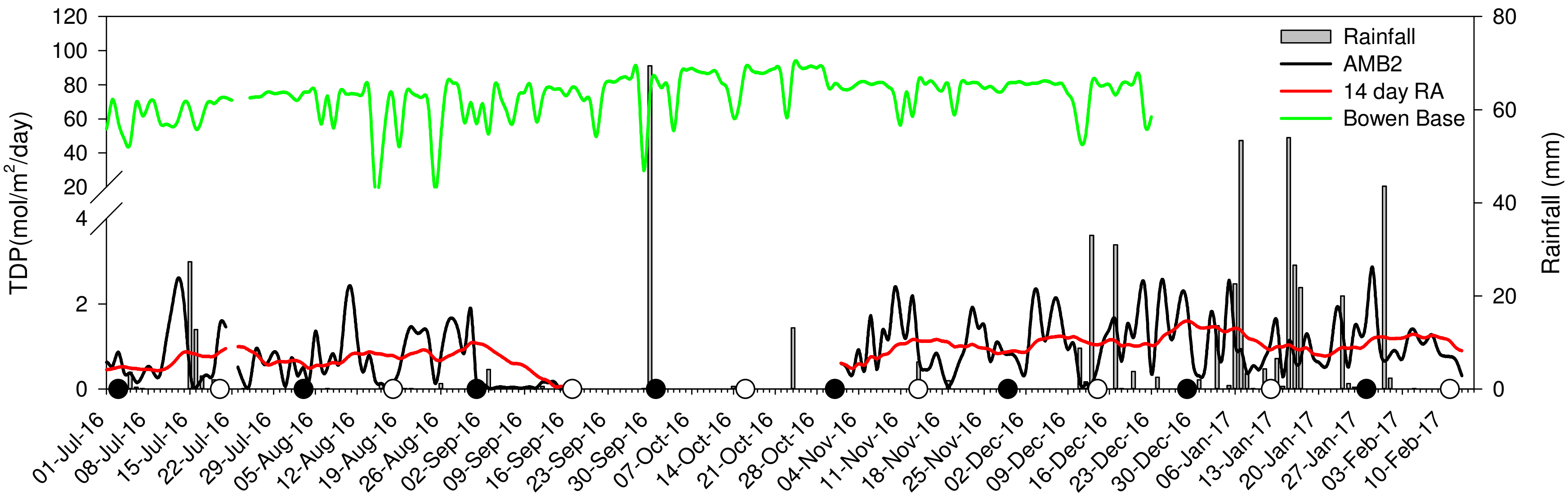

Figure 28 Benthic TDP and 14 day rolling average for BPAR at AMB2 and ambient (Bowen base) TDP from July 2016 to February 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively. Note BPAR monitoring at AMB2 ceased in February 2017.

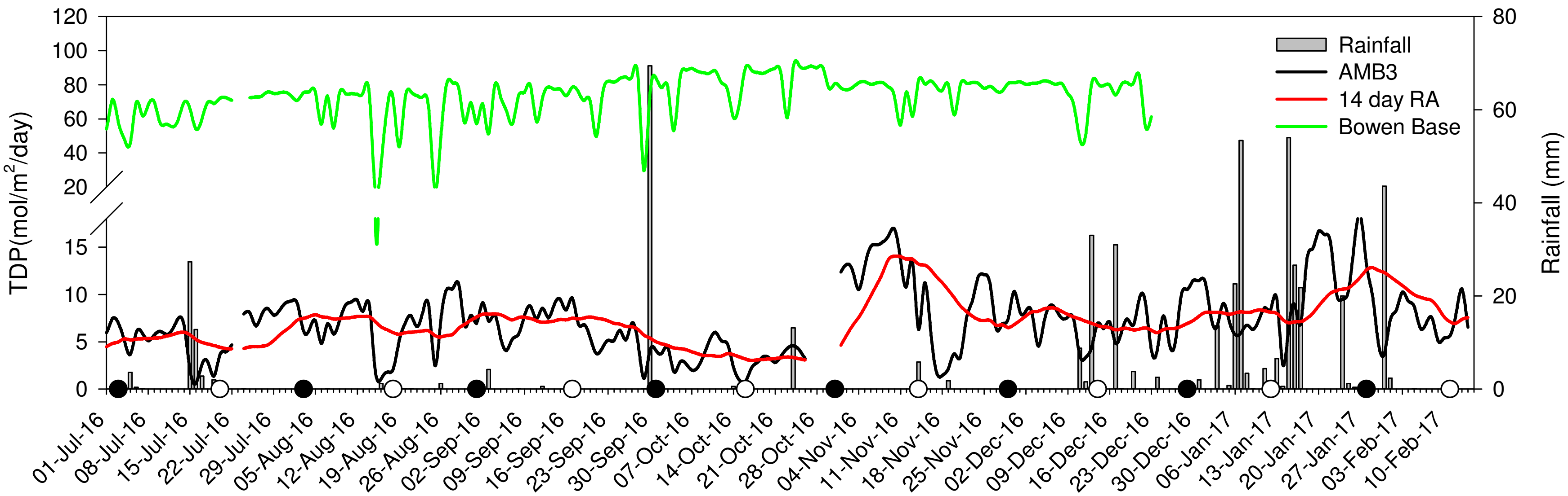

Figure 29 Benthic TDP and 14 day rolling average for BPAR at AMB3 and ambient (Bowen base) TDP from July 2016 to February 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively. Note BPAR monitoring at AMB3 ceased in February 2017.

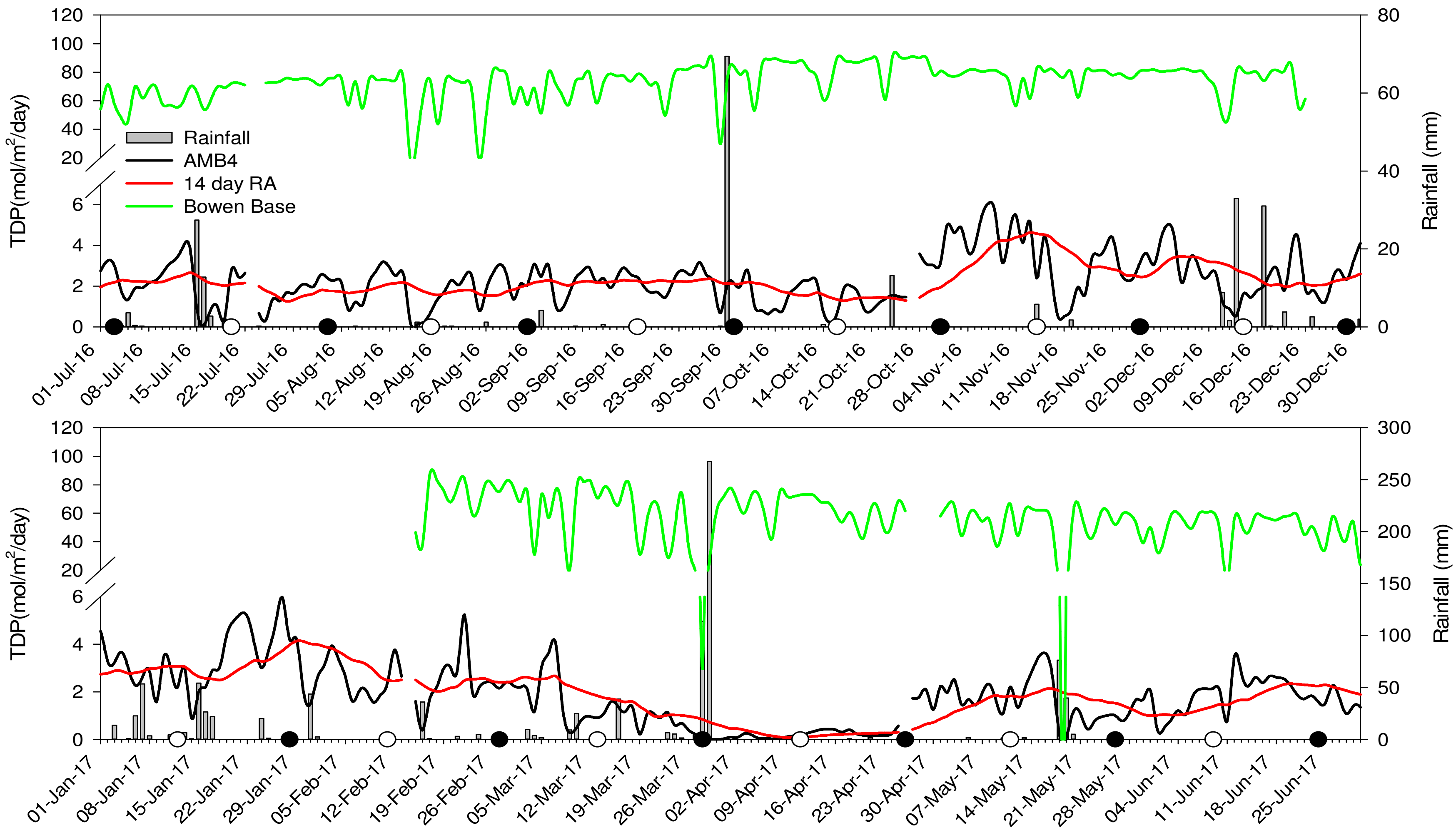

Figure 30 Benthic TDP and 14 day rolling average for BPAR at AMB4 and ambient (Bowen base) TDP from July 2016 to June 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

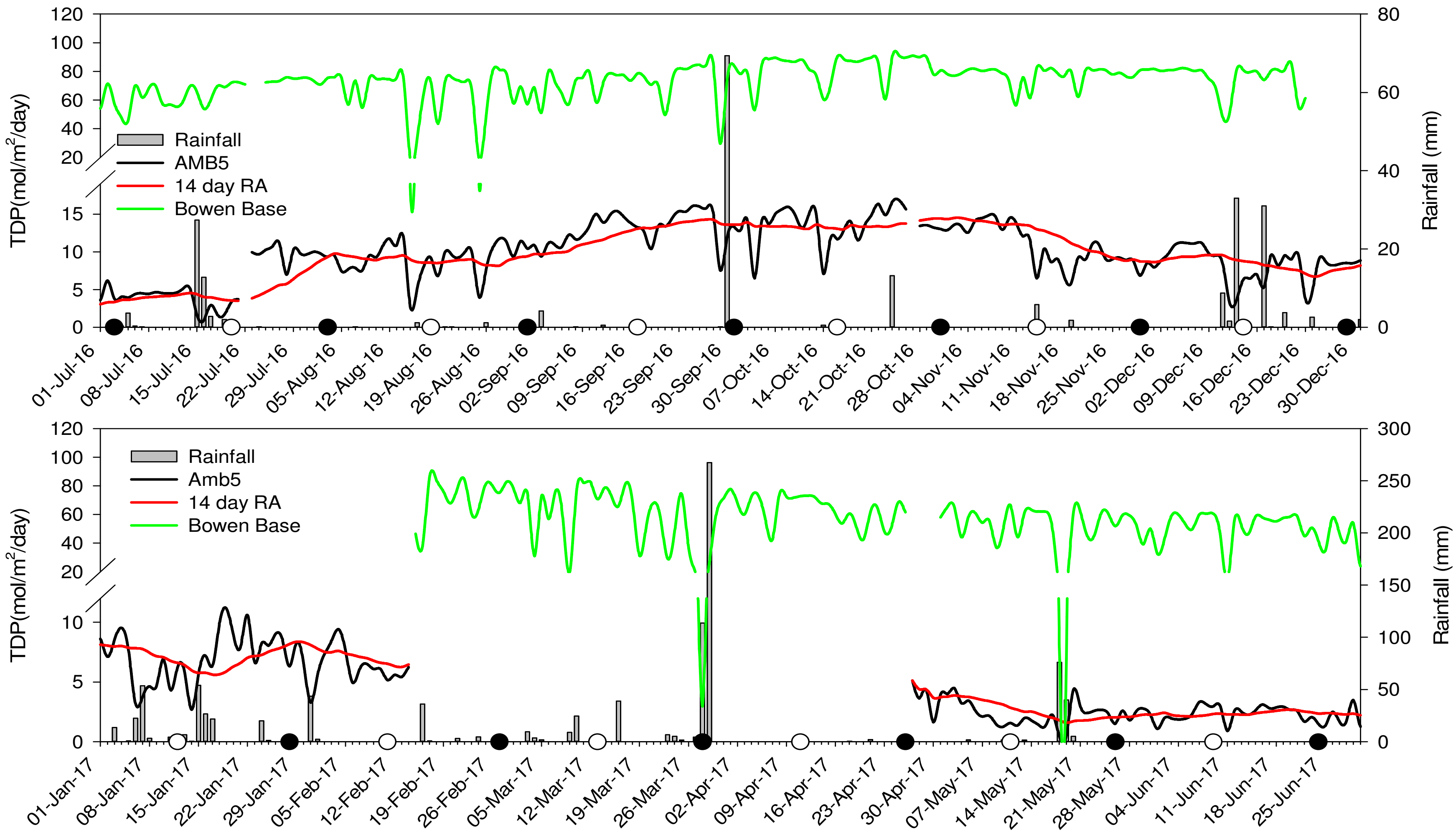

Figure 31 Benthic TDP and 14 day rolling average for BPAR at AMB5 and ambient (Bowen base) TDP from July 2016 to June 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively.

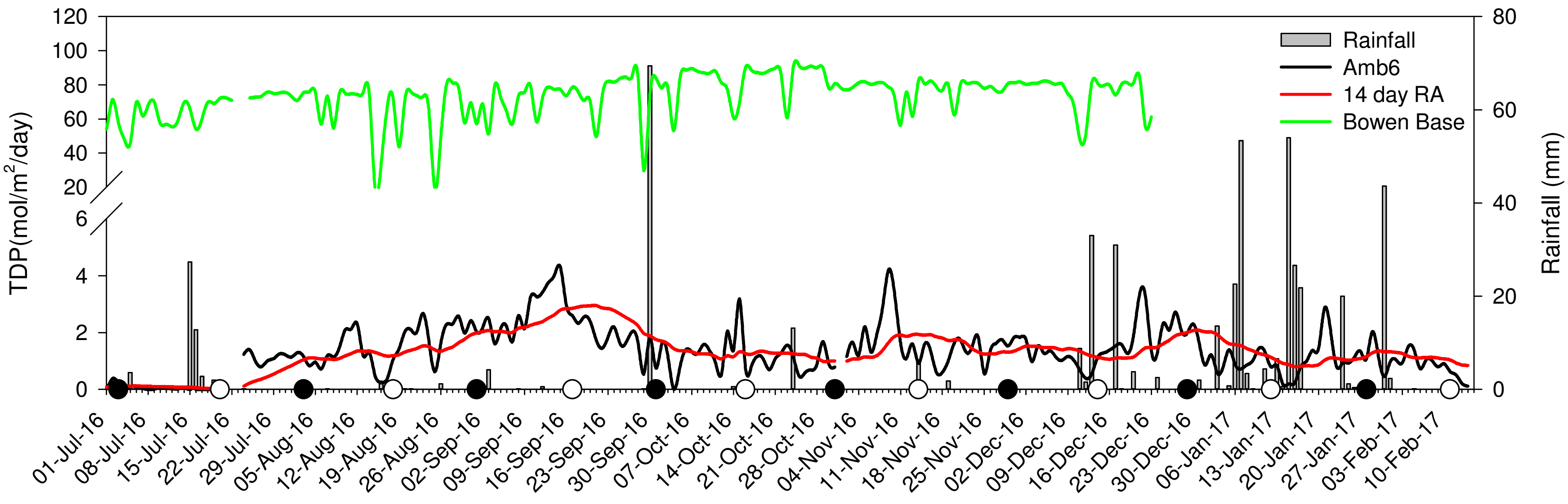

Figure 32 Benthic TDP and 14 day rolling average for BPAR at AMB6 and ambient (Bowen base) TDP from July 2016 to February 2017 compared to ambient PAR measured at Bowen Base and rainfall.
Open and closed circles indicate full and new moon periods, respectively. Note BPAR monitoring at AMB6 ceased in February 2017.

The TDP at AMB6 did not differ significantly across the Wet (1.3 mol/m^2/day) and Dry (1.3 mol/m^2/day) seasons, similar to the 2015/2016 results (Vision Environment, 2016). Ambient PAR can typically be higher in the Wet Season due to the longer day lengths. However this can often be offset by the higher number of cloudy days experienced over this period, with associated rainfall causing an increase in turbidity, thus reducing BPAR. A similar result was recorded in the previous monitoring programs (Vision Environment, 2016, Worley Parsons, 2014).

Similar to 2015/2016 (Vision Environment, 2016) the shallowest sites (AMB3 and AMB5 at 3.9 and 6.5 m depth) exhibited significantly ($p < 0.05$) higher TDP in both the Wet Season (8.2 to 8.7 mol/m^2/day) and the Dry Season (5.7 to 7.6 mol/m^2/day) than all other sites. AMB2 and AMB6 are the deepest sites (12.2 and 13.1 m) and TDP at these sites was significantly ($p <0.05$) lower than all other sites during both seasons (0.6 to 1.3 mol/m^2/day) due to light being diminished prior to reaching the benthic logger. Intermediate TDP was recorded at AMB1 and AMB4 which are located at 8.5 to 9.0 m depth. Similar seasonal and depth patterns of TDP have been recorded in previous monitoring programs (Vision Environment, 2016, Worley Parsons, 2014).

Light requirement trigger values for intertidal seagrass species (*Zostera capricorni*) were utilised in the Gladstone Western Basin Dredge and Disposal Program as an ecological trigger on which management decisions could be made to inform the dredging operations (Vision Environment, 2013). This has set a precedent for incorporating light into guidelines for future dredging and construction activities.

Although *Zostera capricorni* has been identified in Abbot Point seagrass communities, the most common and widely distributed species in the shallow areas adjacent to the coast is *Halodule uninervis* (McKenna and Rasheed, 2011). A recent review conducted as part of the Australian Government's National Environmental Science programme (NESP) Tropical Water Quality Hub has recommended acute light requirements of 12 seagrass species in the Great Barrier Reef (Collier *et al.*, 2016), including *H. uninervis.* The suggested management light threshold for *H. uninervis* is 5 mol/m^2/day over a 14 day period (Collier *et al.*, 2016). As such, sufficient light would be available at AMB3 and AMB5 to support the growth of *H. uninervis* during both the Wet and Dry Seasons. At the remaining sites, insufficient light would be available at the benthos to support the year round growth of this seagrass species. *H. uninervis* has occasionally been found in deeper areas of the port (McKenna *et al.*, 2016), indicating sufficient light was available in these areas during seagrass establishment.

For deeper areas of the port (>10m) the most common seagrass species found are *Halophila spinulosa* and *Halophila decipiens* (McKenna *et al.*, 2016).These species have a much lower light requirement with recent studies suggesting that a light threshold of 1.5 to 2 mol/m^2/day is required to maintain growth and reproduction for the deepwater Halophila (Chartrand *et al.*, 2017).

Deepwater seagrasses are highly seasonal, often being present for around half the year at many locations (York *et al.*, 2015). Under natural circumstances light may only be sufficient for their growth for relatively short times of the year and the light requirement may only need to be met for around 12 weeks during the growing season (July-December) to support the maintenance of populations to enable them to produce seed for the following years annual recruitment (Chartrand *et al.*, 2017).

While light requirements for a number of species of seagrass within the Great Barrier Reef are now established (Chartrand *et al.*, 2012, Collier *et al.*, 2016), little information exists on applicable light requirements for coral species (Alquezar *et al.*, in prep).

3.5 Sedimentation

Sedimentation was measured at AMB1 for the entire year (July 2016 to June 2017), and for part of the year at AMB2 (July 2016 to February 2017) and AMB4 (February to June 2017), using fixed deployment acoustic altimeters. Increased wave energy resulting from increased wind speeds, or stronger currents resulting from larger tidal ranges, has the potential to result in increased sediment resuspension. One of three outcomes occurs during such an event: deposition of sediment from another location, movement of sediment to another location, or resuspension with no net change. Two forms of information were provided by the altimeters:

- Instantaneous bed level change indicating the amount of sediment flux occurring at a set point in time; and
- Net cumulative change in bed level over a given period.

Due to the cessation of sedimentation monitoring at AMB2 and commencement at AMB4 mid Wet Season, meaningful seasonal statistics could not be produced. In lieu of seasonal statistics, monthly statistics have been tabulated (Table 10), which can allow direct comparison across sites. Monthly values were calculated using the last value of the previous month and subtracting from the last value of the season in question. Sediment flux (in relation to baseline bed level) calculated every 15 minutes and daily mean cumulative bed level change are illustrated in Figures 33 to 34.

Table 10 Net Bed Level Change statistics from data collected from altimeters deployed AMB1, AMB2 and AMB4 between July 2016 and June 2017
*Values are means ± se (n = 182 for wet season and 184 for dry season.) *Indicates incomplete annual dataset, so total annual sedimentation values should be treated with caution.*

Site	Dominant Wind Direction	Net bed level change (mm)		
		Amb 1	Amb 2	Amb 4
July 2016	SE	-17.0	-10.8	
August 2016	SE	-1.2	+10.0	
September 2016	SE	-4.6	No data available	
October 2016	NE	+24.8	-44.7	
November 2016	NE	+33.3	-45.3	
December 2016	NE	+8.6	-9.5	
January 2017	NE	+16.1	-4.8	
February 2017	SE	-9.5		-1.9
March 2017	SE	+92.9		+64.3
April 2017	SE	-5.5		+1.6
May 2017	SE	+4.8		+10.4
June 2017	SE	-8.1		-3.3
Total		**+134.6**	**-105.1***	**+71.3***

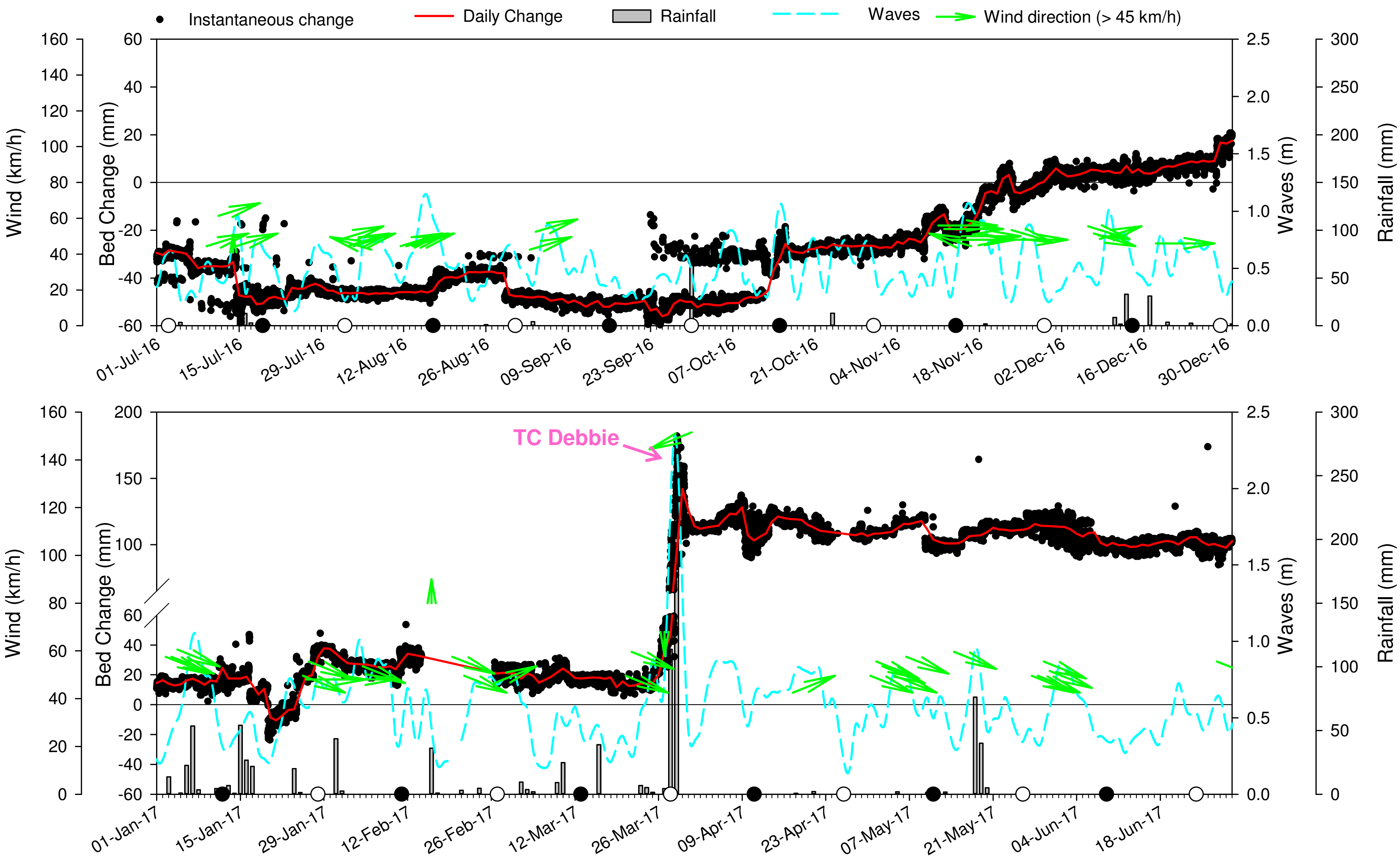

Figure 33 Mean instantaneous bed level change and daily cumulative bed level change at AMB1 from July 2016 to June 2017 compared to wave heights and rainfall. *Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods respectively.*

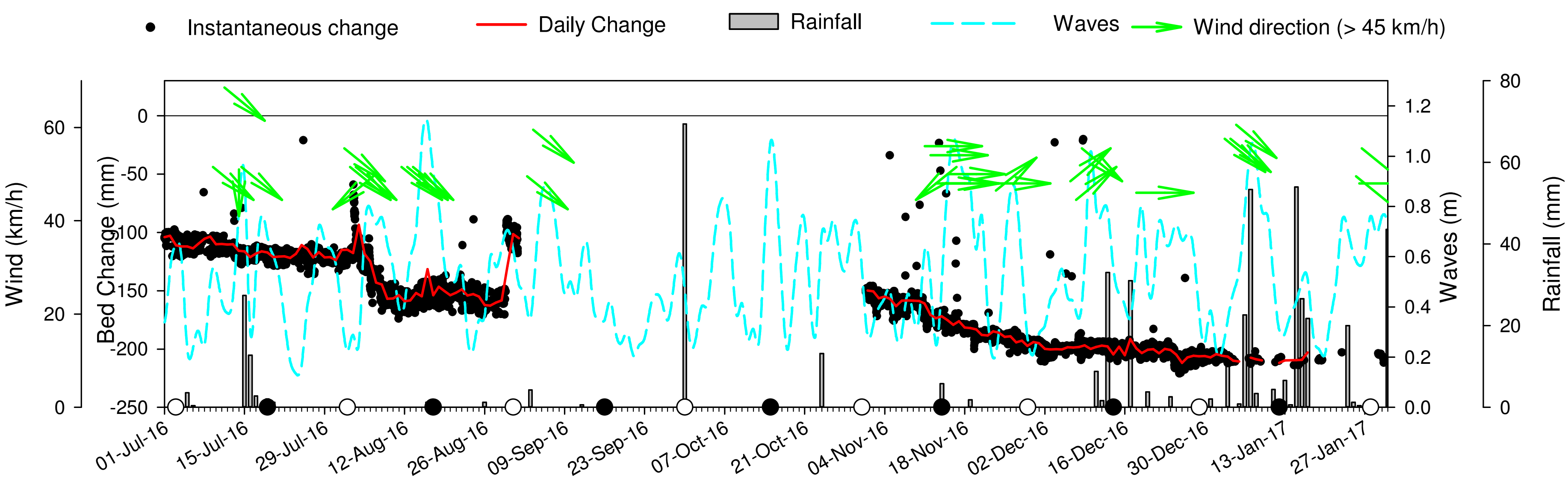

Figure 34 Mean instantaneous bed level change and daily cumulative bed level change at AMB2 from July 2016 to January 2017 compared to wave heights and rainfall. *Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods respectively. Note that no data was able to be recorded from altimeters deployed during September and October 2016.*

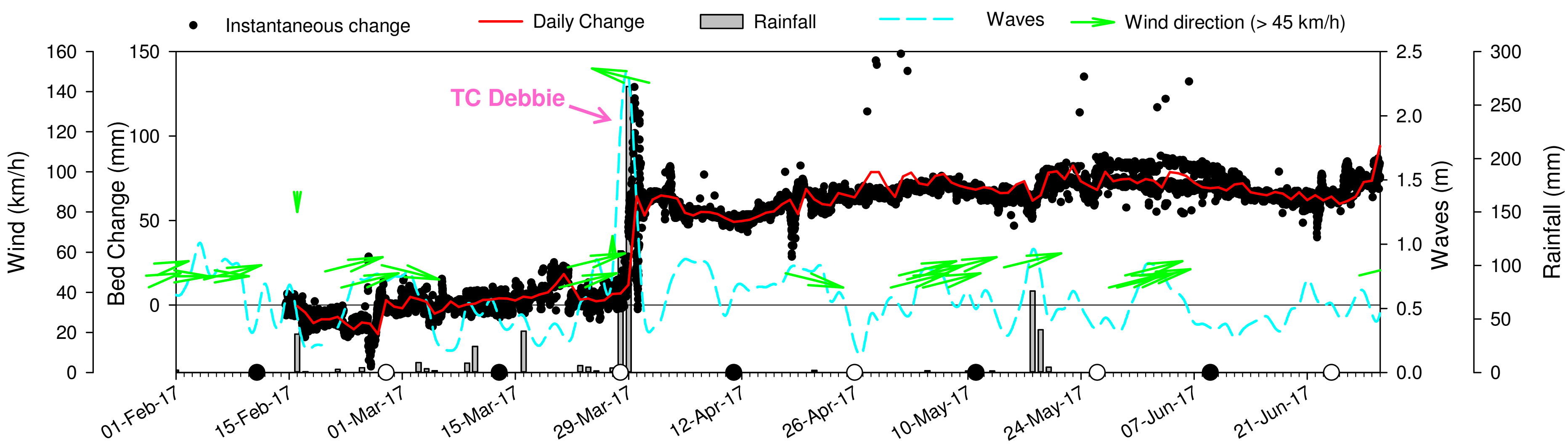

Figure 35 Mean instantaneous bed level change and daily cumulative bed level change at AMB4 from February to June 2017 compared to wave heights and rainfall. *Note green arrows depict wind direction when winds > 45 km/h were recorded. Open and closed circles indicate full and new moon periods respectively.*

Throughout the monitoring period of July 2016 to June 2017, sediment deposition of approximately 135 mm was recorded at AMB1, with the majority of deposition occurring during March 2017 (TC Debbie). From July to September 2016 when the dominant wind direction was south-easterly, a general trend of erosion was evident at AMB1, ranging from 1.2 to 17 mm monthly. However, deposition commenced with the dominant wind change to north-easterly from October to January with between 8.6 and 33 mm deposited monthly. When the south-easterly winds again dominated in February, erosion became apparent. However, the advent of TC Debbie resulted in rapid deposition of 120 mm over a four day period, followed by erosion of approximately 30 to 40 mm in the two days post-cyclone. Generally, a transition from deposition to erosion is associated with the change in wind direction which occurs during the crossing of a cyclone. Since April 2017, bed levels have remained reasonably stable, varying less than 10 mm from month to month. The relationship between deposition and erosion and dominant wind direction was also described in 2015/2016 (Vision Environment, 2016).

Sedimentation data at AMB2 was collected from July to August 2016, and then again from November 2016 to February 2017. Data gaps in September and October 2016 were due to the benthic unit being tipped over and dragged several meters from its position, most likely due to a fishing trawler, resulting in the complete loss of one altimeter. When data were able to be recorded, erosion was recorded at AMB2 even during the north-easterly winds from October 2016 to January 2017, when erosion appeared to be accelerated. Previous sedimentation data has suggested that sediment flux at AMB2 is much less volatile than at AMB1 and appears mostly unresponsive to rainfall, tidal fluctuations or wave heights (Vision Environment, 2016). AMB2 is approximately 3 to 4 m deeper than AMB1 and thus may not respond to metocean conditions as strongly as the shallower site.

Altimeters were deployed at AMB4 in mid-February 2017, and thus were also able to record sedimentation patterns during TC Debbie. Prior to TC Debbie, bed levels remained reasonably stable with values remaining within 10 mm of baseline. During TC Debbie, almost 60 mm of deposition recorded between 27 and 29 March, with bed levels remaining relatively stable. Post cyclone, bed levels remained stable once again, with monthly deposition or erosion values remaining ≤ 10 mm. Continued sedimentation monitoring will determine whether typical seasonal wind changes has a similar affect at AMB4 that it does on AMB1.

GRBMPA have provided a sedimentation guideline trigger value of a maximum mean annual value of 3 mg/cm^2/day and a daily maximum of 15 mg/cm^2/day, based on sediment traps used in experimental and field conditions (De'ath and Fabricius, 2008, GBRMPA, 2010). However, the measurement units are not easily applied to altimeter data, which is measured in mm. Overall, mean daily deposition at AMB1 during the monitoring year can be calculated as 0.37 mm/day.

3.6 Water Sampling

Water sampling was undertaken during July and October 2016, in addition to February and April 2017. TSS, nutrient and chlorophyll *a* concentrations from all surveys are listed in Table 11, and depicted in Figure 36. Note that TSS sampling changed from biannually to quarterly in 2017, and water sampling at AMB6 ceased in February 2017.

TSS were higher overall during the April 2017 survey (<1 to 8 mg/L) than the previous surveys carried out in July 2016 and February 2017 (<1 to 3 mg/L), paralleling the depth-profiled turbidity values and lower water clarity recorded post TC Debbie.

Table 11 Concentrations of nutrients, chlorophyll *a* and Total Suspended Solids at AMB1 to AMB6 during monitoring occasions from July 2016 to June 2017.
Values exceeding the QWQG are highlighted in blue. Note that AMB6 sampling was not required during February and April 2017.

Parameter	Month	Site						QWQG
		AMB1	AMB2	AMB3	AMB4	AMB5	AMB6	
Total suspended solids (mg/L)	Jul 16	<1	1	1	<1	<1	1	2
	Feb 17	3	<1	<1	1	<1	-	
	Apr 17	2	<1	8	5	2	-	
Total Phosphorus (µg/L)	Jul 16	<5	<5	<5	<5	<5	<5	20
	Oct 16	<5	<5	<5	<5	<5	<5	
	Feb 17	<5	<5	<5	<5	<5	-	
	Apr 17	33	28	31	29	28	-	
Orthophosphate (µg/L)	Jul 16	<1	<1	<1	<1	<1	<1	6
	Oct 16	<1	<1	<1	<1	<1	<1	
	Feb 17	2	<1	<1	<1	2	-	
	Apr 17	<1	<1	<1	<1	<1	-	
Total Nitrogen (µg/L)	Jul 16	90	110	80	110	100	120	140
	Oct 16	260	230	230	260	280	180	
	Feb 17	295	95	136	110	141	-	
	Apr 17	170	128	264	106	150	-	
Total Kjeldahl Nitrogen (TKN) (µg/L)	Jul 16	90	110	80	110	100	120	-
	Oct 16	260	230	220	260	270	180	
	Feb 17	295	95	136	110	137	-	
	Apr 17	170	116	252	104	132	-	
NOx (Nitrite + Nitrate) (µg/L)	Jul 16	<2	<2	<2	<2	3	<2	3
	Oct 16	4	4	8	4	10	5	
	Feb 17	<2	<2	<2	<2	4	-	
	Apr 17	<2	12	12	2	18	-	
Chlorophyll *a* (µg/L)	Jul 16	0.20	0.26	0.32	0.32	0.10	0.21	0.45
	Oct 16	0.34	0.61	0.41	0.50	0.18	0.28	
	Feb 17	0.36	0.27	0.35	0.25	0.22	-	
	Apr 17	0.12	0.08	0.07	0.13	0.08	-	

Total phosphorus concentrations remained below laboratory limits of reporting (LOR) during all surveys with the exception of April 2017, where concentrations ranged from 28 to 33 µg/L, exceeding the QWQG of 20 µg/L. The higher phosphorus within the water column may also have been a consequence of the higher TSS and turbidity at this time, with a higher concentration of phosphorus-containing particles in the water column. However, orthophosphate concentrations remained below LOR, indicating phosphorus was not in a readily bioavailable form.

In contrast, highest total nitrogen concentrations were evident during October 2016 (180 to 260 µg/L) with all sites exceeding the QWQG of 140 µg/L. During February (95 to 295 µg/L) and April (106 to 264 µg/L) 2017, exceedances of the QWQG were recorded only at selected sites. Total Kjeldahl Nitrogen (TKN) concentrations were similar to total nitrogen concentrations, indicating that nitrogen was predominantly in an organic form, thus not readily bioavailable. Nitrogen oxide (nitrate + nitrite) concentrations exhibited high concentrations during both October 2016 (4 to 10 µg/L) and April 2017 (<2 to 18 µg/L), exceeding the QWQG of 3 µg/L at a number of sites. All nitrogen forms were lowest during the July 2016 survey.

Chlorophyll *a* concentrations were highest during October 2016, with concentrations at AMB2 and AMB4 exceeding the QWQG of 0.45 µg/L. Chlorophyll *a* concentrations are generally stimulated by increased temperature, light and nutrients (Popovich and Marcovecchio, 2008), with elevated concentrations usually found in the summer months. However, all chlorophyll a concentrations remained below QWQG in February 2017 (0.22 to 0.36 µg/L), possibly due to the lower nutrient concentrations available at this time.

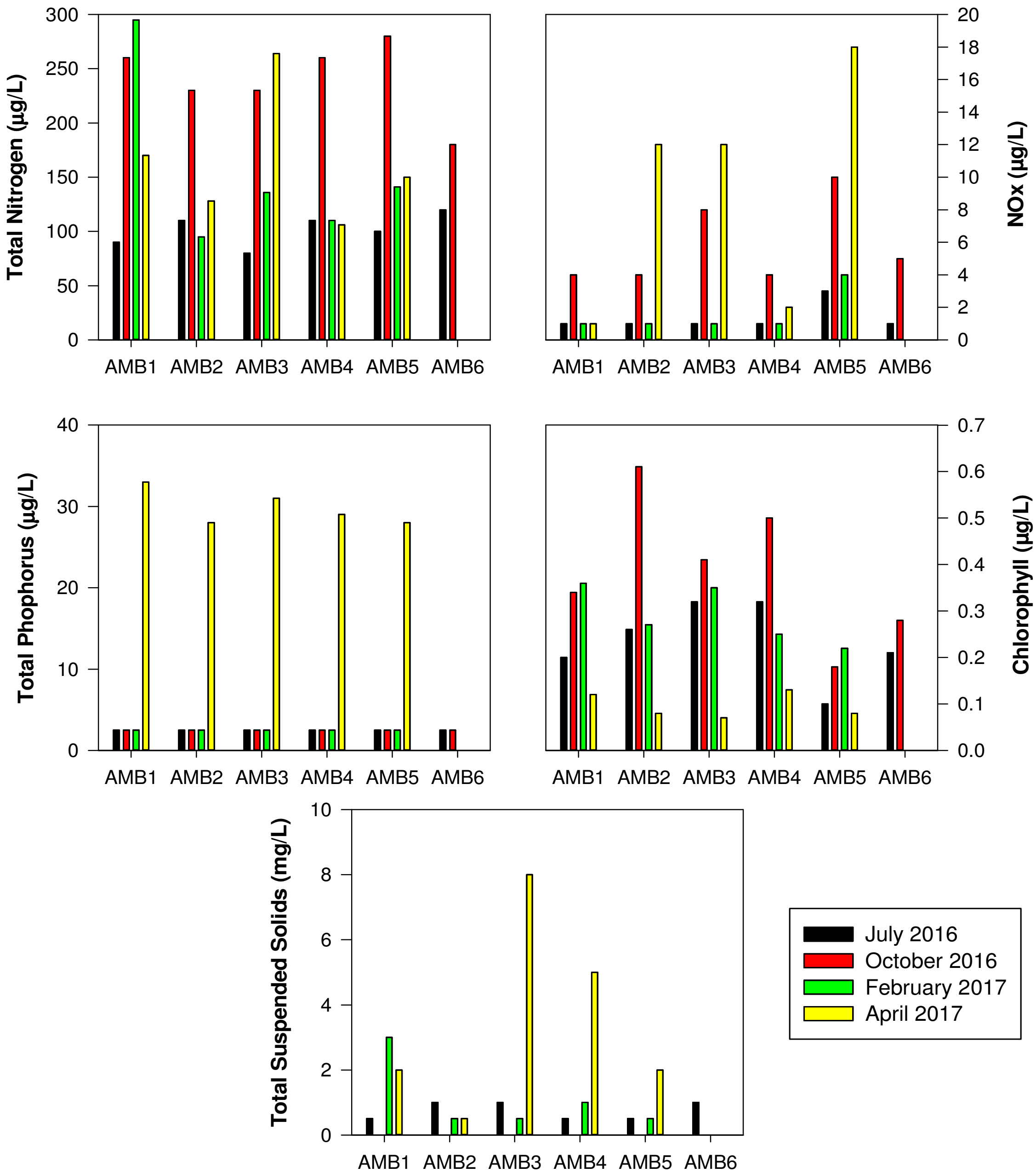

Figure 36 Concentrations of nutrients, chlorophyll *a* and Total Suspended Solids at AMB1 to AMB6 during monitoring occasions from July 2016 to June 2017.
Orthophosphate not plotted as the majority of results were < LOR. Values which were < LOR, were plotted as ½ LOR. Note that AMB6 sampling was not required during February and April 2017, while TSS sampling changed from biannual to quarterly in 2017.

Water sampling of dissolved metals and organics was undertaken during the July 2016 and February 2017 surveys, with total metals added to the analysis suite during the latter survey (Table 12). Of the dissolved and total metals, only arsenic was detected across the sites during both surveys. Concentrations (1.2 to 1.9 µg/L) were similar to previously recorded concentrations (Vision Environment, 2016, Worley Parsons, 2014), suggesting perhaps a regionally specific natural geological dominance. Total copper was detected at AMB1 during February 2017 (4 µg/L) and exceeded the 95% species protection trigger value of 1.3 µg/L. However, dissolved concentrations were <LOR, indicating low bioavailability. All other metal concentrations were below LOR, and therefore well below the 95% AWQG trigger level.

All concentrations of hydrocarbons, BTEXN and herbicides were below LOR at each site where monitored during each survey (Table 13), similar to previously recorded concentrations (Vision Environment, 2016, Worley Parsons, 2014).

Table 12 Concentrations of dissolved and total metals at AMB1 to AMB6 during sampling occasions from July 2017 to June 2017.
Values exceeding the 95% AWQG are highlighted in blue. Note that total metals sampling commenced in 2017. AMB2, AMB5 and AMB6 sampling for metals was not required in 2017.

Metal (µg/L)	Month	Site						AWQG
		AMB1	AMB2	AMB3	AMB4	AMB5	AMB6	
Dissolved Arsenic	Jul 16	1.3	1.2	1.2	1.3	1.2	1.3	-
	Feb 17	1.9	-	1.7	1.6	-	-	
Total Arsenic	Feb 17	1.9	-	1.7	1.8	-	-	
Dissolved Cadmium	Jul 16	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	5.5
	Feb 17	<0.2	-	<0.2	<0.2	-	-	
Total Cadmium	Feb 17	<0.2	-	<0.2	<0.2	-	-	
Dissolved Chromium	Jul 16	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	Cr(III) 27.4 Cr(VI) 4.4
	Feb 17	<0.5	-	<0.5	<0.5	-	-	
Total Chromium	Feb 17	<0.5	-	<0.5	<0.5	-	-	
Dissolved Copper	Jul 16	<1	<1	<1	<1	<1	<1	1.3
	Feb 17	<1	-	<1	<1	-	-	
Total Copper	Feb 17	4	-	<1	<1	-	-	
Dissolved Lead	Jul 16	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	4.4
	Feb 17	<0.2	-	<0.2	<0.2	-	-	
Total Lead	Feb 17	<0.2	-	<0.2	<0.2	-	-	
Dissolved Mercury	Jul 16	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.4
	Feb 17	<0.04	-	<0.04	<0.04	-	-	
Total Mercury	Feb 17	<0.04	-	<0.04	<0.04	-	-	
Dissolved Nickel	Jul 16	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	70
	Feb 17	<0.5	-	<0.5	<0.5	-	-	
Total Nickel	Feb 17	<0.5	-	<0.5	<0.5	-	-	
Dissolved Zinc	Jul 16	<5	<5	<5	<5	<5	<5	15
	Feb 17	<5	-	<5	<5	-	-	
Total Zinc	Feb 17	<5	-	<5	<5	-	-	

Table 13 Concentrations of hydrocarbons, BETXN and herbicides at AMB1, AMB2 and AMB4 during sampling occasions from July 2017 to June 2017.

Parameter (µg/L)	Month	Site		
		AMB1	AMB2	AMB4
Total Recoverable Hydrocarbons				
C6 - C9 Fraction	Jul 16	<20	<20	<20
	Feb 17	<20	<20	<20
C10 - C14 Fraction	Jul 16	<50	<50	<50
	Feb 17	<50	<50	<50
C15 - C28 Fraction	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
C29 - C36 Fraction	Jul 16	<50	<50	<50
	Feb 17	<50	<50	<50
C10 - C36 Fraction (sum)	Jul 16	<50	<50	<50
	Feb 17	<50	<50	<50
C6 - C10 Fraction	Jul 16	<20	<20	<20
	Feb 17	<20	<20	<20
C6 - C10 Fraction minus BTEX (F1)	Jul 16	<20	<20	<20
	Feb 17	<20	<20	<20
>C10 - C16 Fraction	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
>C16 - C34 Fraction	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
>C34 - C40 Fraction	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
>C10 - C40 Fraction (sum)	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
>C10 - C16 Fraction minus Naphthalene (F2)	Jul 16	<100	<100	<100
	Feb 17	<100	<100	<100
BETXN				
Benzene	Jul 16	<1	<1	<1
	Feb 17	<1	<1	<1
Toluene	Jul 16	<2	<2	<2
	Feb 17	<2	<2	<2
Ethylbenzene	Jul 16	<2	<2	<2
	Feb 17	<2	<2	<2
meta- & para-Xylene	Jul 16	<2	<2	<2
	Feb 17	<2	<2	<2
ortho-Xylene	Jul 16	<2	<2	<2
	Feb 17	<2	<2	<2
Total Xylenes	Jul 16	<2	<2	<2
	Feb 17	<2	<2	<2
Sum of BTEX	Jul 16	<1	<1	<1
	Feb 17	<1	<1	<1
Naphthalene	Jul 16	<5	<5	<5
	Feb 17	<5	<5	<5
Herbicides				
Hexazinone	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Metribuzin	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Diuron	Jul 16	<0.20	<0.20	<0.20

Parameter (µg/L)	Month	Site		
		AMB1	AMB2	AMB4
	Feb 17	<0.02	<0.02	<0.02
Fluometuron	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Tebuthiuron	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Bromacil	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Chlorsulfuron	Jul 16	<2.0	<2.0	<2.0
	Feb 17	<0.20	<0.20	<0.20
Ametryn	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Atrazine	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Cyanazine	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Cyromazine	Jul 16	<0.50	<0.50	<0.50
	Feb 17	<0.05	<0.05	<0.05
Prometryn	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Propazine	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Simazine	Jul 16	<0.20	<0.20	<0.20
	Feb 17	<0.02	<0.02	<0.02
Terbuthylazine	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01
Terbutryn	Jul 16	<0.10	<0.10	<0.10
	Feb 17	<0.01	<0.01	<0.01

4. References

Alquezar, R., L. E. Andersen, and K. Anderson. in prep. Light based thresholds and health indicators of two branching corals, Acropora formosa and Acropora hyacinthus, in Central Queensland, Australia: A pilot study. Ecological Indicators.

ANZECC. 1992. Australian Water Quality Guidelines for Fresh and Marine Waters. Australian and New Zealand Environment and Conservation Council, Canberra, Australia.

ANZECC. 1998. Interim Ocean Disposal Guidelines. Australian and New Zealand Environment and Conservation Council, Canberra, Australia.

ANZECC/ARMCANZ. 2000. National Water Quality Management Strategy: Australian Guidelines for Water Quality Monitoring and Reporting. Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

APHA. 2005. Standard Methods for the Examination of Water and Wastewater. 21st edition. Port City Press, Baltimore, USA.

AS/NZS. 1998a. 5667.1:1998 Water Quality - Sampling. Part 1: Guidance on the design of sampling programs, sampling techniques and the preservation and handling of samples. Joint Standards Australia/Standards New Zealand.

AS/NZS. 1998b. 5667.4:1998 Water Quality - Sampling. Part 4: Guidance on sampling from lakes, natural and man-made. Joint Standards Australia/Standards New Zealand.

AS/NZS. 1998c. 5667.6:1998 Water Quality - Sampling. Part 6: Guidance on sampling of rivers and streams. Joint Standards Australia/Standards New Zealand.

BOM. 2016. Bureau of Meteorology. Gladstone, Queensland, Department of Environment and Heritage, Canberra, Australia.

BOM. 2017. Bureau of Meteorology. Gladstone, Queensland, Department of Environment and Heritage, Canberra, Australia.

Chartrand, K. M., C. V. Bryant, A. M. Sozou, P. J. Ralph, and M. Rasheed. 2017. Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) , James Cook University, Cairns, Australia.

Chartrand, K. M., P. J. Ralph, K. Petrou, and M. A. Rasheed. 2012. Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program. DEEDI, Cairns.

Collier, C. J., K. M. Chartrand, C. Honchin, A. Fletcher, and M. Rasheed. 2016. Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. National Environmental Science Programme, Reef and Rainforest Research Centre Limited, Cairns, Australia.

De'ath, G. and K. E. Fabricius. 2008. Water quality of the Great Barrier Reef: distributions, effects on reef biota and trigger values for the protection of ecosystem health. Final Report to the Great Barrier Reef Marine Park Authority., Australian Institute of Marine Science, Townsville, Australia.

DERM. 2009. Queensland Water Quality Guidelines, Version 3. ISBN 978-0-9806986-0-2, Department of Environment and Resource Management.

DERM. 2010. Monitoring and Sampling Manual, Version 2 September 2010. Water and Corporate Services Division, Department of Environment and Resource Management, Brisbane, Australia.

DNRM. 2017. Don Basin Streamflow Data. Department of Natural Resources and Mines.

DSITIA. 2014. Report on draft aquatic ecosystem water quality guidelines for the Capricorn Curtis Coast (draft). Department of Science, Information Technology, Innovation and the Arts, Queensland

EHP. 2013a. Draft environmental values and water quality objectives for Mackay-Whitsunday region waters. Department of Environment and Heritage Protection.

EHP. 2013b. Proserpine River, Whitsunday Island and O'Connell River Basins Environmental Values and Water Quality Objectives. Department of Environment and Heritage Protection, Brisbane, Australia.

Erftemeijer, P. L. A. and R. R. R. Lewis III. 2006. Environmental impacts of dredging on seagrasses: A review. Marine Pollution Bulletin 52:1553-1572.

GBRMPA. 2010. Water quality guidelines for the Great Barrier Reef Marine Park. Revised Edition. Great Barrier Reef Marine Park Authority

Townsville.

Geoscience Australia. 2015. Coastal Issues: Algal blooms. OzCoasts - Australian Online Coastal Information.

GeoScience Australia. 2016. Compute Sunrise, Sunset & Twilight Times.

GHD. 2009. Abbot Point Environmental Monitoring - baseline water quality Assessment - final report. North Queensland Bulk Ports Ltd, Brisbane.

GHD. 2010. Report on Abbot Point multi-cargo facility - hydrodynamic and sediment transport modelling - addendum. North Queensland Bulk Ports Ltd, Brisbane.

GHD. 2012. Abbot Point Terminals 0, 2 and 3 Capital Dredging Project Public Environmental Review. North Queensland Bulk Ports Ltd, Brisbane.

Hume, A. C., P. Berg, and K. J. McGlathery. 2011. Dissolved oxygen fluxes and ecosystem metabolism in an eelgrass (Zostera marina) meadow measured with the eddy correlation technique. Limnology and Oceanography 56:86-96.

Marba, N., M. Holmer, E. Gacia, and C. Barron. 2006. Seagrass bed and coastal biogeochemistry.*in* A. W. D. Larkum, R. J. Orth, and C. M. Duarte, editors. Seagrasses:Biology, Ecology and Conservation. Springer, Netherlands.

McKenna, S. A. and M. A. Rasheed. 2011. Port of Abbot Point Long-Term Seagrass Monitoring: Interim Report 2008-2011. DEEDI Publication, Fisheries Queensland

Cairns.

McKenna, S. A., A. M. Sozou, E. L. Scott, and M. A. Rasheed. 2016. Port of Abbot Point Long-Term Seagrass Monitoring: Annual Report 2014-2015. Centre for Tropical Water & Aquatic Ecosystem Research Cairns, Australia.

NQBP. 2012. Port Handbook: Port of Abbot Point. North Queensland Bulk Ports Corporation Ltd, Mackay, Queensland.

NQBP. 2015. Your Ports Environment Report. North Queensland Bulk Ports Corporation Ltd, Mackay, Queensland.

O'Neill, M. E. 2000. Theory & Methods A Weighted Least Squares Approach to Levene's Test of Homogeneity of Variance. Australian & New Zealand Journal of Statistics 42:81-100.

Popovich, C. A. and J. E. Marcovecchio. 2008. Spatial and temporal variability of phytoplankton and environmental actors in a temperature estuary of South America (Atlantic coast, Argentina). Continental Shelf Research 28:236-244.

Underwood, A. J. 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press.

USEPA. 1997. *In vitro* Determination of Chlorophylls a, b, c1 + c2 and Pheopigments in Marine and Freshwater Algae by Visible Spectrophotometry. US EPA.

Valiela, I., J. McClelland, J. Hauxwell, P. J. Behr, D. Hersh, and K. Foreman. 1997. Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. Limnology and Oceanography 42:1105-1118.

Vision Environment. 2013. WBDDP Water Quality Monitoring - September 2013., Gladstone, Australia.

Vision Environment. 2015. EIS for Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project: Water Quality Monitoring June 2014 to June 2015. Gladstone, Australia.

Vision Environment. 2016. Abbot Point Ambient Water Quality Monitoring: October 2015 to October 2016. Gladstone, Australia.

Worley Parsons. 2014. Abbot Point Baseline Water Quality Monitoring Report. Brisbane, Australia.

York, P., A. Carter, K. M. Chartrand, T. L. Sankey, L. Wells, and M. Rasheed. 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: annual occurrence and response to a major dredging program. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) , James Cook University, Cairns, Australia.