Extreme weather conditions in the Great Barrier Reef: Drivers of change?

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Abstract. There has been a well-recognized link between declining water quality and the ecological health of coastal ecosystems. A strong driver of water quality change in the Great Barrier Reef (hereafter GBR) is the pulsed or intermittent nature of terrestrial inputs into marine ecosystems, particularly close to the coast. Delivery of potentially detrimental terrestrial inputs (freshwater, sediments, nutrients and toxicants, typically via flood plumes) will be exacerbated under modelled climate change scenarios and presents an on-going risk to the resilience and survival of inshore GBR ecosystems. This paper presents an overview of flow and water quality associated with extreme weather conditions experienced in the GBR over the 2010 – 2011 wet season. Water quality data collected during this period within the Reef Rescue Marine Monitoring Program is presented, including the spatial and temporal extent of the water quality conditions measured by in-situ sampling and satellite imagery. The consequence of the long wet season has had profound impacts on the people living and working within the Queensland coastal area, but may also be the driver of large scale reported decline in the many inshore seagrass systems and coral reefs and species that rely on these habitats, with concerns for the recovery potential of these impacted ecosystems.

Key words: Extreme weather, GBR, flood plumes, impact

Introduction

Water quality delivered to the Great Barrier Reef (GBR) is influenced by an array of factors including land-based runoff and river flow, point source pollution, and extreme weather conditions (Brodie et al. 2011; Waterhouse et al. 2011). River discharge in wet and dry tropics river systems is dominated by large flood events associated with tropical cyclones and monsoonal rainfall (Devlin and Schaffelke 2009) Flow rates of rivers are characterised by high inter-annual, seasonal and event-coupled variability of flow (Waterhouse et al. 2011). Most rivers of the Wet Tropics drain small catchments with low inter-annual variability of rainfall and are characterised by multiple short-duration flow events each year. In contrast, discharge from the two largest Dry Tropics Rivers, the Burdekin and Fitzroy, typically occurs as one or two small annual flows, but occasionally as a very large flood event which may last for several weeks and greatly exceeds discharge from other regional rivers. The 2010-11 wet season was characterised by extreme events in the GBR region, driven by a very strong La Niña in mid 2010, which brought extraordinary rainfall, both intense and prolonged, across eastern Queensland. Three tropical cyclones (TC) crossed the North Queensland coast in this period, including TC Tasha, which crossed near Innisfail in December 2010 and eventually went south, causing severe flooding from the Brisbane, Burnett, Fitzroy and Burdekin Rivers. TC Tasha was followed by TC Anthony, a category 2 cyclone that crossed near Whitsundays in February 2011. This travelled inland and traversed south creating flooding conditions in the southern states of Australia. The third, TC Yasi (Category 5), crossed the coast between Cairns and Townsville in February 2011 causing extensive physical damage to reefs and seagrass beds (GBRMPA 2011) across the central GBR The large size of TC Yasi drove further flooding conditions north of the Whitsundays.

This paper details flow conditions and a brief overview of the water quality data collected in the associated flood plume as part of the Reef Rescue Marine Monitoring Program (Johnson et al. 2011).Plume water quality is monitored through in situ water quality measurements at peak- and post-flow conditions within targeted areas throughout the wet season(Devlin et al. 2012). Given the large size of the GBR Marine Park (350,000 km^2), river plume extent, frequency and duration is measured and mapped through the use of remote sensing and GIS analysis (Brodie et al. 2010; Schroeder et al. 2012).

Material and Methods

Measurement of flow

The frequency and spatial extent of flood plumes is mainly driven by the size of flow and the frequency at which the rivers achieve high-flow conditions. Flow data was sourced from the Department of Environment and Resource Management (Queensland, http://watermonitoring.derm.qld.gov.au/host.htm)

Flood plume mapping

The extent of the flood plume was mapped following Devlin et al. (2012) using true colour satellite imagery derived from the Moderate Resolution Imaging Spectroradiometer (MODIS). Satellite images cover the high-flow period between 1st January and 30th April 2011. The number of images available during high-flow periods was constrained to dates associated with low cloud cover (the maximum number of MODIS scenes processed for any given area was 32). True colour images and Level-2 products (chlorophyll concentration (Chl-a), coloured dissolved and detrital matter absorption coefficient (CDOM))were derived from MODIS Level-0 data using SeaWiFS Data Analysis System (SeaDASversion 6.2). A combined near infrared to short wave infrared (NIR-SWIR) correction scheme (Wang and Shi 2007) was applied to Level-1 products to overcome the atmospheric correction issues above turbid waters, commonly found in the nearshore regions of the GBR.

Water quality sampling

Flood plume waters generally move into the GBR as buoyant freshwater masses and are usually constrained in the top surface layer until dissipated or eventually mixed into the water column (Devlin and Schaffelke, 2009). Sampling sites are indicated in Figure 1, and all samples were analysed for salinity, TSS, Chl-*a*, nutrients, CDOM and water temperature.

Results

The combined extreme events produced record flows in nearly all GBR rivers, especially in the southern half of the GBR. The total flow for all GBR rivers (Fig. 2) was 2.6 times the long term median flow, with all rivers exceeding the long term median flow by 2 or more times, except for the Tully River (1.5).

The wet season started comparatively early, with high flows in the Wet Tropics during November and December 2010, extending into April 2011. Extended

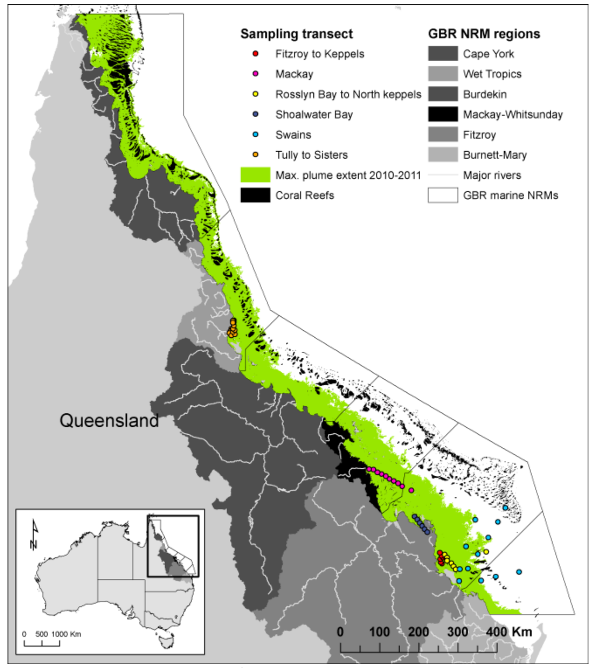

Figure 1: Overall extent of river plume water in the GBR (2010 – 2011). Note plumes were not contemporaneous but occurred from Dec 2010 to April 2011.

flows were heavily influenced by formation and passage of the three tropical cyclones (Fig. 3). Overall, flooding occurred in one or more GBR rivers for a period of 4 months.

In the Burdekin (Fig. 3b), water flowed over the spillway of the Burdekin Falls Dam for more than 300 days and the discharge at the mouth was the third highest in the instrumental record (approximately 35 million ML). This followed above average flows (mean approximately 8 million ML) in the Burdekin River in both 2008 (26 million ML) and 2009 (30 million ML). To the south, the Fitzroy River (Fig. 3a) had its largest flow in the instrumental record (approximately 38 million ML) following large flows in 2008 and 2009, while the Burnett River had its first substantial flow (8 million ML) for 20 years and about eight times the mean. The Mary River had its largest flow for 10 years. In all cases, except for the Burnett River, the instrumental record extends back about 80 years. Rivers in the Wet Tropics had above

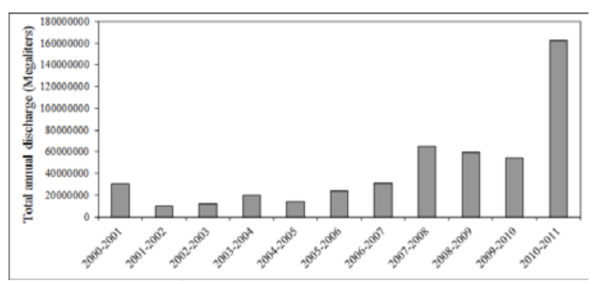

Figure 2: Annual freshwater input into the GBR (2000 – 2011) from North Queensland Rivers. Data source: Dept. of Environment and Resource Management..

average flows by factors of times 2-3 but not record flows (Fig. 3c, 3d).

Plume mapping

The combination of mapped plume images identifies the full extent of surface flood plume waters through the 2010-11 wet season. The cumulative area for plume waters discharging from Burdekin, Fitzroy and all the Wet Tropics rivers is shown in Figure 3, and represents a maximum area of approximately 135,797 km^2(i.e., ~39% of the GBR Marine Park extent).

Water quality results

High concentrations of dissolved and total nutrients, TSS, Chl-a and CDOM were measured at all sites, with salinity measuring between 15 – 32ppt. The geographical influence of high TSS, Chl-a, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorous (DIP) and salinity is shown only for the Fitzroy regions in Figure 4. Concentrations of selected water quality parameters are highly variable over time and flow, illustrating the distribution of increased particulate and dissolved parameters through the movement of flood plume waters.

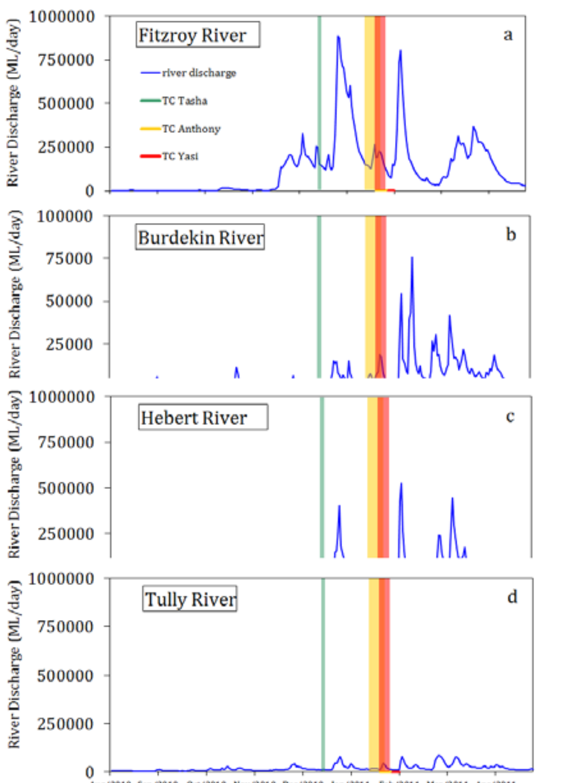

Figure 3: Extended flow periods (2010 – 2011) associated with the passage of three cyclones between December and February 2011 for (a) Fitzroy River, (b) Burdekin River, (c) Herbert River and (d) Tully River.

Variability through the plume will also be affected by the influence of multiple plumes merging in one continuous body of water through the movement of plumes in a generally northerly direction such as Herbert and Burdekin influencing the Tully region and the Mary-Burnett plumes influencing the Fitzroy region.The influence of the Fitzroy River plumes on GBR water quality was evident in sites around Mackay, which are 350km northwest from the Fitzroy River mouth and 150km offshore (see Fig. 4). The offshore edge of the plume was characterised by elevated levels of CDOM, however the characteristics of the northern moving plume waters measured near Mackay (~350km) were characterised by elevated Chl-a, CDOM and TSS concentrations. Water quality concentrations are influenced by the size and timing of the events, as well as the prevailing weather conditions and distance from river mouth (Devlin and Schaffelke 2009).

Documented impacts

The varying elevated concentrations can influence short-term ecological processes over time (weeks to months) and space (10 to 100km's), particularly for the very large dry tropic rivers such as the Fitzroy. Extensive physical damage to coral and seagrass occurred in a 300 km wide band right across the

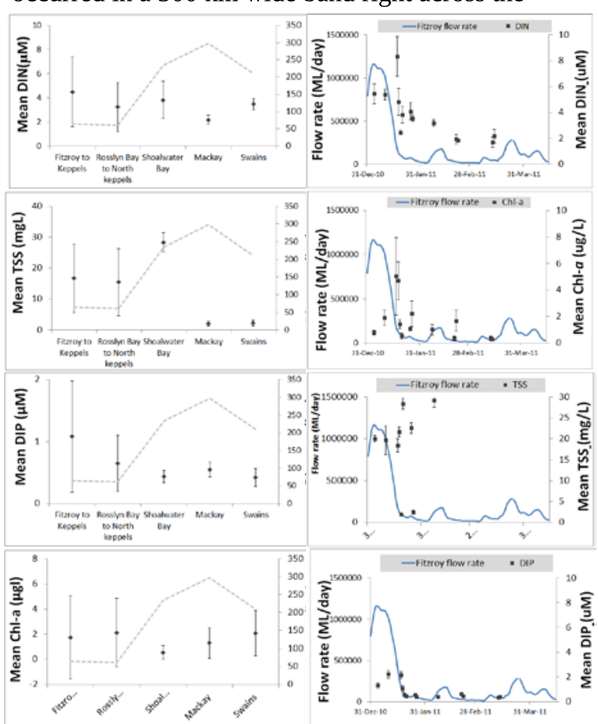

Figure 4: Mean concentrations of DIN, TSS, DIP and, Chl-*a* over each transect (left panels; with mean distance in dotted line) and from date of initial sampling (right panels). Distance graphs show mean water quality value and the mean distance of each transect (dotted line) and time graphs show daily flow (ML/day) over the sampling period.

continental shelf following TC Yasi(GBRMPA2011). Coral damage was reported within an area of approximately 89,090 km^2 of the GBR Marine Park (about 26% of the total). In total, approximately 15% of the total reef area in the Marine Park sustained some coral damage and 6% was severely damaged. It can be estimated that TC Yasi by itself accounted for a 2% loss in coral cover across the GBR (GBRMPA 2011). It was estimated that approximately 98% of the intertidal seagrass area was lost within the affected area as a consequence of TC Yasi destructive winds, and only a few isolated shoots remained in coastal and reef habitats (McKenzie et al 2012).

The combined effects of a long period of low salinity, high contaminant concentration water (e.g. Devlin and Brodie 2005; Devlin et al.2012) and physical damage from TC Yasi caused severe coral loss (GBRMPA 2011) and loss of seagrass (McKenzie et al. 2012) along the GBR coast from Hervey Bay to Cairns. Importantly these impacts come on top of declining seagrass health reported since 2009throughout the GBR south of Cairns (McKenzie et al. 2012).

Results from the monitoring program (Johnson et al. 2011; Thompson et al. 2012; McKenzie et al. 2012) show increased juvenile coral mortality and impacts on seagrass communities including increased mortality and decreased areal coverage prior to the 2011 events. These impacts were further exacerbated by the long periods of low salinity waters and reduced light associated with the extreme weather conditions (McKenzie et al. 2012). Complete seagrass recovery is expected to take several years, but will depend on habitat (estuary coast, deep-water or reefs) and the level of physical disturbance experienced. For example, estuary seagrass habitats have recovered, 2-3 years after 100% loss (Campbell and McKenzie 2004); coastal habitats have recovered in 2-3 years from remnant plants (McKenzie et al. 2012; deepwater habitats have taken 1-3 years to recover (McKenzie and Campbell 2003) and reef habitats have recovered 8-10 years after 100% loss.

Discussion

The elevated concentrations of dissolved and particulate materials carried in flood plumes have been detailed in previous plume studies (Devlin and Schaffelke 2009; Bainbridge et al. 2012; Devlin et al. 2012). Concentrations of water quality parameters measured in flood plumes are 2 to 100 fold higher than ambient conditions outside of the wet season (Schaffelke et al. 2011; Furnas et al. 2011; Devlin et al. 2012).

Large acute events may also impact on the severity of the chronic pressures and on conditions required for recovery and increased resilience. Potential stressors from flood plumes on marine ecosystems include prolonged freshwater exposure, decreased light availability and smothering by high sedimentation during flood events or due to resuspension of terrigeneous fine sediments by currents, wind generated waves and tides in the period after the flood (Fabricius et al. 2011). Large scale mortality events associated with low salinity and higher temperature waters through flood conditions have been documented for coral reefs (Berklemans 2009) and seagrasses (Waycott et al. 2005; McKenzie et al. 2010). The recent events have now shown acute stress can result in increased mortality of dugongs and sea turtles in the GBR (McKenzie et al. 2012).

Coral reefs respond to stress in complex ways especially in the presence of both acute and chronic stress (Kinsey 1988).Chronic exposure of corals to increased levels of nutrients, sedimentation and turbidity over longer periods of time will affect species that are sensitive or vulnerable to changes in environmental conditions. This can lead to medium and long-term impacts such as reduced densities of juvenile corals, subsequent changes in community composition, decreased species richness and shifts to communities that are dominated by more resilient coral species and macroalgae (Hughes et al. 2011; DeVantier et al. 2006). Recent work has linked increased turbidity from the export and availability of finer sediment out of the large Dry Tropic regions (Fabricius et al, 2011). Other long-term ecological impacts can be seen in the proliferation of Crown of Thorns Starfish (COTS) in areas which are regularly influenced by anthropogenic nutrient loads (Fabricius et al. 2010).

For the GBR the acute stresses as experienced in 2010-11 caused physical damage by cyclones and physiological damage to corals and seagrass through large discharges of fresh water, sediment and nutrient rich water input and increasing numbers of COTS outbreaks (Brodie and Waterhouse 2011). These are combined with the chronic stresses of reduced water quality from high loads of sediment, nutrient and pesticide discharge and ocean acidification. These acute and chronic stressors are driving the GBR to a degraded condition evidenced in low coral cover (Hughes et al. 2011) and poor condition of seagrass, dugongs and turtles (Bell and Ariel 2011; Brodie and Waterhouse 2012).

The combination of these acute impacts from extreme weather years with the chronic stresses of poor water quality and climate change factors such as increasing temperature may tip these systems over the thresholds for a complete phase shift (Elmhirst et al. 2009). While it is impossible to definitely attribute the extreme events in Australia (and the rest of the world but see, for example, Lough and Hobday 2011) over the last few years to a changing climate, they do give us potential understanding of the future pressures in the sense that more frequent intense cyclones and correlated rainfall and runoff events are predicted by the climate change forecasting (Trenberth 2011). The extreme weather events of 2010-11 allowed us to see this combined stress response working in 'real time'. The likelihood of increased frequency of extreme runoff events associated with climate change combined with continued chronic stresses makes the management of GBR a challenging task.

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