Marine Pollution Bulletin 133 (2018) 30–43

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Contribution of individual rivers to Great Barrier Reef nitrogen exposure with implications for management prioritization

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ARTICLE INFO

Keywords:
Water quality
River pollution
Nutrients
Coral health
Decision support
Prioritization

ABSTRACT

Dissolved inorganic nitrogen (DIN) runoff from Great Barrier Reef (GBR) catchments is a threat to coral reef health. Several initiatives address this threat, including the Australian Government's Reef 2050 Plan. However, environmental decision makers face an unsolved prioritization challenge: determining the exposure of reefs to DIN from individual rivers. Here, we use virtual river tracers embedded within a GBR-wide hydrodynamic model to resolve the spatial and temporal dynamics of 16 individual river plumes during three wet seasons (2011 – 2013). We then used in-situ DIN observations to calibrate tracer values, allowing us to estimate the contribution of each river to reef-scale DIN exposure during each season. Results indicate that the Burdekin, Fitzroy, Tully and Daintree rivers pose the greatest DIN exposure risk to coral reefs during the three seasons examined. Results were used to demonstrate a decision support framework that combines reef exposure risk with river dominance (threat diversity).

1. Introduction

The Great Barrier Reef (GBR) is exposed to a suite of environmental pressures, including ocean warming, ocean acidification, storms and degraded water quality (Fabricius, 2005; De'ath et al., 2012; Albright et al., 2016; Hughes et al., 2017). While climate change is a growing threat to coral reefs including the GBR, efforts to address water quality are the focus of management and policy initiatives (Commonwealth of Australia, 2015; Kroon et al., 2016). There are several reasons for this focus. Firstly, after the 2004 rezoning of GBR Marine Park (McCook et al., 2010), improving water quality remained one of the key opportunities to increase ecosystem recovery and resilience (Wooldridge and Done, 2009; Hughes et al., 2010; Graham et al., 2013). Secondly, the bleaching event of 2016 is a reminder that climate change is a growing threat, but the capacity of regional and local managers to mitigate this threat is limited (Hughes et al., 2017). Further, it was primarily concern over the impacts of local stressors, particularly deteriorating water quality, that precipitated UNESCO's 2011 deliberation over whether to include the GBR World Heritage Area on the "in danger" list (Douvere and Badman, 2012). In response, Australia has recently released a long-term sustainability plan (Reef 2050 Plan) for the GBR (Commonwealth of Australia, 2015). A central tenet of Reef 2050 is the expectation that increased water quality will enhance ecosystem resilience, enable near-term ecosystem recovery and confer enhanced long-term adaptation to climate change. The primary instrument for meeting these ambitious goals is the Reef Water Quality Protection Plan (Reef Plan), a bilateral policy initiative of the Australian and Queensland Governments that began in 2003 with updates in 2009 and 2013.

A key component of the Reef 2050 Plan, is the rapid and dramatic reduction of anthropogenic DIN delivery to GBR waters. Specifically, the Plan aims for a minimum of 50% reduction of baseline (2009) loads by 2018, extending to 80% reduction by 2025. These targets have been informed by scientific syntheses and consensus statements (Brodie et al., 2012; Brodie et al., 2013), which in turn have been informed by multiple individual studies (see Brodie et al. (2012) for a review). It is well established that coral reefs are sensitive to nutrient enrichment (Fabricius, 2005). Adverse impacts include enhanced growth of macroalgae (McCook et al., 2001), a key competitor of coral that can lead to reductions in substrate complexity and coral cover which can precipitate cascading effects on the abundance and diversity of associated

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https://doi.org/10.1016/j.marpolbul.2018.04.069
Received 15 December 2017; Received in revised form 10 April 2018; Accepted 28 April 2018

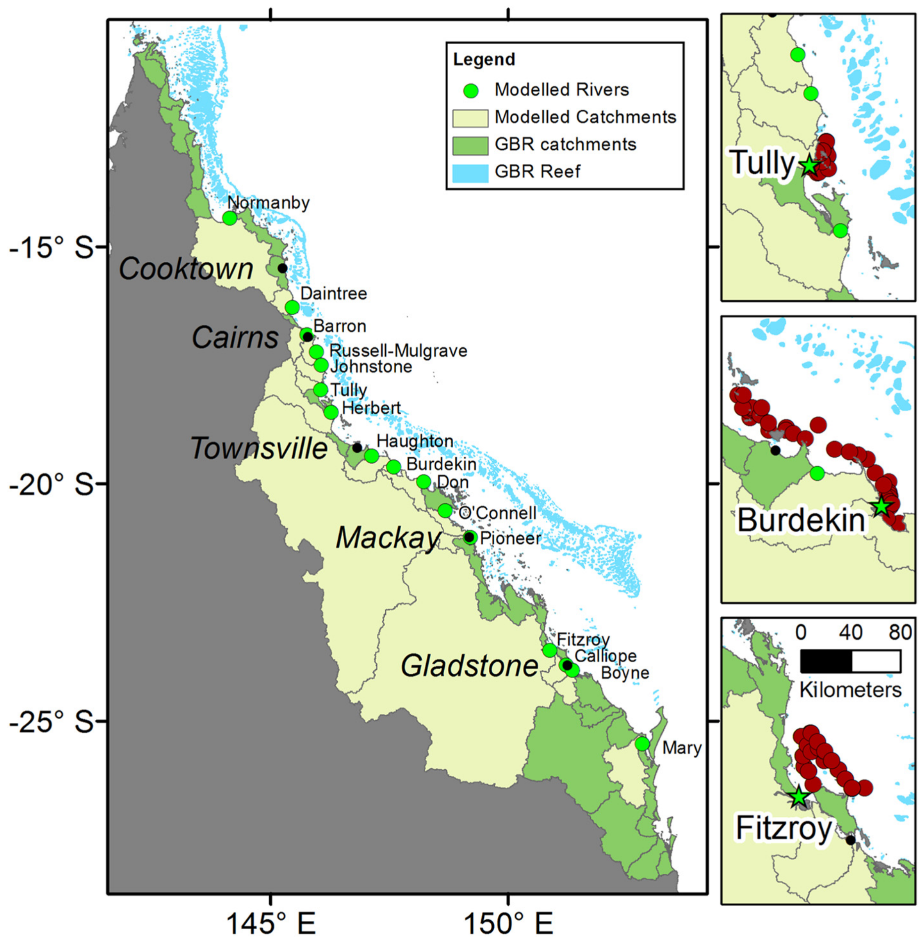

Fig. 1. GBR catchments with modelled flood plume tracer catchments shown in yellow with associated primary river mouths labelled. In-situ sample sites for the three rivers used for model calibration are shown in adjacent insets and drawn at the same scale (1:5,000,000). See Supplemental information for examples of sample site distribution within different plume waters. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fauna (Fabricius et al., 2005; Rogers et al., 2014). Importantly, reefs subjected to poor water quality have lower diversity and abundance of herbivorous fish (Cheal et al., 2010), which can reduce reef resilience (Hughes et al., 2007; Cheal et al., 2010; Mumby et al., 2016).

Most of the documented impacts of land-based pollutants are primarily restricted to inshore reefs (Fabricius et al., 2005; Roff et al., 2012). However, correlative evidence for a link between nutrient enrichment, phytoplankton blooms, larval survival and GBR-wide outbreaks of crown-of-thorns starfish (*Acanthaster planci*, COTS (Fabricius et al., 2010)) has provided a basis for establishing the 50–80% targets for nutrients (Brodie et al., 2013; Kroon et al., 2016). Experimental and modelling work has helped establish chlorophyll (chl-a) thresholds for COTS larval survival (Fabricius et al., 2010), which in turn have been used to determine the magnitude of DIN reductions needed to lower outbreak risk (Brodie et al., 2014; Wooldridge et al., 2015). A second indirect mechanism, linking DIN with greater thermal stress sensitivity (bleaching) through complex physiological processes (Wiedenmann et al., 2013; Wooldridge, 2013), suggests a 50–80% DIN reduction is necessary (Wooldridge et al., 2015). Inshore reefs often exposed to elevated DIN appear to bleach at temperatures > 2 °C lower than reefs exposed to lower concentrations of DIN (Wooldridge, 2009).

To date, the Australian and Queensland Governments have spent over AUD$375 million on Reef Plan implementation with and additional AUD$575 million expected through 2020 (Beher et al., 2016). Moving forward, it appears that targeted, strategic, and perhaps, regulatory prioritization of catchment practices will be necessary (Kroon et al., 2016). Recent work offers an economic framework for prioritizing within catchment management projects (Beher et al., 2016), but this needs to be complemented by informed prioritization of catchments themselves. Rather than spreading investments thinly across multiple catchments, targets may be more quickly reached through more intense, focused investments on a few catchments. Regardless of which prioritization criteria are used, an essential aspect for any such effort will be an understanding of the specific impacts each catchment has on downstream GBR habitats. While a combination of monitoring and modelling provides catchment-specific data on overall riverine pollutant discharge into the GBR (Waterhouse et al., 2012), the fate of specific plumes and the habitats they encroach has been much more difficult to assess (Devlin et al., 2015b). Most efforts in this regard have relied on remotely-sensed data. Although invaluable for mapping the spatial and temporal exposure of the GBR to aggregate plumes (Devlin et al., 2012; Petus et al., 2016), delineating and attributing ocean colour data to specific rivers when multiple plumes merge or when ocean sediment is resuspended, is challenging (Álvarez-Romero et al., 2013; Devlin et al., 2015b).

Here we present a new method for assessing exposure of marine habitats to land-based pollutants from individual catchments. Although our method can be applied more broadly, we focus on coral reef exposure to DIN enrichment. Our approach incorporates virtual river tracers released in simulations from 16 GBR rivers and embedded within a highly resolved circulation model. In-situ DIN observations from river plumes were used to calibrate tracer data, enabling us to quantify the relative exposure of coral reefs to DIN sourced from each of the 16 rivers. Temporal and spatial patterns were compared across