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Catchment to Reef: Water quality issues in the Great Barrier Reef Region—An overview of papers

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1. Background

Information and data collected over the last 20 years has highlighted the seriousness of declines in water quality in inshore regions of coral reefs worldwide (Wilkinson, 2002). This decline is consistently associated with land clearing for agricultural and urban development and expansion. Water quality adjacent to the world's largest coral ecosystem, the Great Barrier Reef, Australia, is no exception to this world-wide trend. However, several factors differentiate situation on the Great Barrier Reef from that in other parts of the world. Firstly, relevant scientific information on water quality impacts in the Great Barrier Reef has been collected and synthesised (Hutchings and Haynes, 2000; Haynes et al., 2001; Williams, 2001; Baker, 2003); secondly, Australia is willing and able to spend significant resources on environmental protection; and thirdly, a comprehensive political solution funding practical solutions has been put forward by Government: the Reef Water Quality Protection Plan (Brodie et al., 2001; RWQPP, 2003).

The Great Barrier Reef World Heritage Area is jointly managed by the Australian Federal Government, through the Great Barrier Reef Marine Park Authority, and the Queensland State Government, through the Environment Protection Agency (Queensland Parks and Wildlife Service). In addition, the Queensland State Government Department of Natural Resources, Mines and Energy has responsibility for land management in catchment areas adjacent to the reef, which are the major source of pollutants to the Marine Park. In 2002, the Federal and State Governments signed a Memorandum of Understanding, outlining a joint reef water quality strategy and leading the subsequent release of the Reef Water Quality Protection Plan in 2003 (RWQPP, 2003).

This Special Edition of the Marine Pollution Bulletin aims to provide a benchmark of current information on a broad range of aspects of the water quality issue for the Great Barrier Reef, and to provide a forum for publication of relevant data gathered by management agencies but not previously published. The Special Edition includes many of the papers presented at the Catchment to Reef: Water Quality Issues in the Great Barrier Reef Region Conference, which was held in Townsville in March 2004. Much of the science presented at this conference was crucial to the development of the Reef Water Quality Protection Plan, and this volume thus provides a valuable and up-to-date compilation of knowledge as the foundation for the implementation of that plan. The conference focused on the great variety of components and issues that must be addressed in order to improve water quality in Queensland catchments and the inshore areas of the Great Barrier Reef; a subsequent conference is focussing on measures to apply and implement the lessons derived from the research reported here. This paper aims to provide a concise overview of the content of the papers in this Special Edition.

2. Catchment aspects

One distinctive and critical aspect of runoff in the GBR catchment, as with many tropical regions, is the highly seasonal and variable flows, with a most flow

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occurring in relatively brief but extreme flood events during the wet season (austral summer), interspersed by much lower flows during the dry seasons. Rainfall patterns are highly variable between years and catchments, so that floods are not annual events for all catchments, nor uniform along the coast. Over 20 rivers flow into the Great Barrier Reef (GBR) lagoon, including relatively small catchments in the Wet Tropics, with regular wet season flows, and several large, dry tropical rivers that drain extensive areas. The two largest catchments are those of the dry tropical Fitzroy and Burdekin Rivers, together comprising almost 2/3 of the total GBR catchment (of 423 000 km^2). For much of the year these rivers discharge little, if any, freshwater into coastal waters, and major floods may only occur every five to ten years. These episodic rainfall and river flow patterns have very significant consequences for land managers, because they generate much more severe erosion potential during intense rainfall, and for scientists attempting to measure flows and associated fluxes of terrestrially derived pollutants, because most flows, and highest concentrations, occur over periods of a few days, days during which it may be very difficult and dangerous to obtain measurements.

Major flooding is often associated with cyclonic weather activity and this in itself poses massive logistical problems in monitoring these events due to flooded roads and strong winds (Devlin and Brodie, 2005). However, information about these major flood events is vital as they transport vast amounts of freshwater, sediments, fertilisers and herbicides down the rivers and out into the Great Barrier Reef lagoon (Davies and Eyre, 2005; Mitchell et al., 2005). Ford et al. (2005) examine the variability in both particulate and dissolved organic carbon concentrations during high and low flood events in the Fitzroy estuary. A significant aspect of recent work, such as the studies presented here, is the broadening focus to integrate different scales, ranging from detailed studies on a particular river to those which attempt to address the same issues at a regional scale (McKergow et al., 2005a,b). Importantly, water and pollutant flows are not limited to surface (river) flows however, Rasiah et al. (2005) suggest that considerable nutrient runoff may occur into or through groundwater, and Stieglitz (2005) identifies several forms of direct discharge of groundwaters into the Great Barrier Reef lagoon.

While rivers draining into the GBR lagoon have always experienced irregular and often massive flows defined by monsoonal rainfalls, it is the substantial increase in sediment loads and associated pollutants over the last 50–150 years that has caused recent problems. This is a consequence of the loss of vegetation in Great Barrier Reef catchments resulting from agricultural expansion (principally dryland cattle grazing and sugarcane cropping) since European settlement. In North Queensland, land clearing for agriculture became prevalent after the settlement of Europeans in the mid 1800s. European settlers arrived primarily by boat, and moved inland along the rivers, clearing much of the vegetation for dryland cattle grazing. Following this, coastal wetlands were cleared for sugarcane and other crops. Approximately 40% of the GBR catchment area has been cleared (Furnas, 2003). Until recently, it has been difficult to quantify the effects on river flows and pollutant transport of these historic changes in land-use. However, recent work by McCulloch et al. (2003), using coral cores drilled from massive *Porites* colonies, many hundreds of years old, has been able to document and quantify the major flood impacts on the studied coral colonies, indicating increased sediment exposure since European settlement. Cox et al. (2005) discuss the results of long-term water quality monitoring in north Queensland waterways. This study suggests that although water quality was relatively good at many study sites, the sites adjacent to agricultural land-use or a point source of sewage were moderate to poor, respectively, in water quality.

It is encouraging that several studies addressing the effects of catchment land management on runoff to waterways, provide indications that appropriate management can have real impacts on that runoff. O'Reagain et al. (2005) present a study, carried out in collaboration with landowners, examining the effectiveness of different management practises aimed at lowering rates of sediment and nutrient loss from dryland grazing savannahs. The results indicate that careful management of stocking rates appropriate to rainfall, slope and soil types can reduce sediment losses, with benefits to both landholders and downstream ecosystems. Another study, by Faithful and Finlayson (2005), utilised the assistance of local community members to measure water quality and describes how this collaboration helps encourage sustainable agricultural practises. A case study by Perna and Burrows (2005) describes the improvement of oxygen levels in flood plain lagoons of the Burdekin and subsequent increases in diversity of native fish populations, following the removal of exotic weed mats. This result has widespread applicability to large river systems with extensive flood plains and well-developed lagoon systems, especially because properly functioning lagoons can retain significant amounts of floodwaters, reducing the discharge into the GBR lagoon.

Another threat to marine water quality comes from the disturbance and exposure of acidic soil, primarily by coastal agriculture, aquaculture and urbanisation, resulting in acidification of adjacent marine environments. Acid sulphate soils (ASS) are relatively common along the Queensland coast. Powell and Martens (2005) discuss the essential ASS management components that need to be addressed.

3. Impacts of runoff on inshore marine ecosystems

In order to address the goals of the Reef Water Quality Protection Plan in the most effective manner, it is important to have the best possible understanding of the impacts of increased sediments, nutrients and pesticide inputs on the threatened ecosystems and species of the Great Barrier Reef. Several papers consider the impact that this increased runoff has had on inshore coral reef communities (Fabricius et al., 2005; Schaffelke et al., 2005). Birrell et al. (2005) addresses the impact of sedimentation on coral recruitment, a process critical to reef resilience. Hutchings et al. (2005) studied the impact of terrestrial runoff on rates and agents of bioerosion across a latitudinal gradient from the coast out into the Coral Sea, and found significant impacts on inshore sites heavily influenced by flood plumes from the Daintree River. Smith et al. (2005) present evidence for recruitment failure in inshore reef corals, which may be linked to declines in water quality, and propose alternative and more relevant ways of assessing this type of impact. The herbicide diuron has also been shown to impact on photosynthesis of crustose coralline algae (Harrington et al., 2005), especially when associated with sediment. In addition, Negri et al. (2005) found that diuron affects the early life stages of corals.

Increased inputs of nutrients to reef waters often lead to large phytoplankton blooms (Furnas et al., 2005). Brodie et al. (2005) used risk assessment modelling to suggest that there are strong links between such blooms and outbreaks of crown-of-thorns starfish (COTS) on the Great Barrier Reef. While the link between terrestrial runoff and outbreaks of COTS has been suggested before, it is has been largely circumstantial and this is the first study to show such strong correlations between the two events. Increased nutrient concentrations have also been linked to blooms of the toxic cyanobacterium *Lyngbya majuscula* (Albert et al., 2005).

The threats to the inshore Great Barrier Reef are not just to coral reefs, however: seagrass beds and mangrove ecosystems, habitats critical to fisheries, are also affected by eutrophication and pesticide pollution. Waycott et al. (2005) discuss how water quality influences the dynamics of Queensland seagrass beds. Mellors et al. (2005) specifically consider the variation in geochemical parameters affecting intertidal seagrasses along the central Great Barrier Reef. Seagrass beds are also vulnerable to the blooms of toxic *Lyngbya majuscula* caused by agriculturally derived nutrients (Albert et al., 2005). Bengtson-Nash et al. (2005) and McMahon et al. (2005) consider the impacts of the herbicide diuron on growth rates of seagrasses. These studies provide new insights, since most previous work in the Great Barrier Reef has focussed on mapping the distribution of seagrass beds, rather than assessing their quality. Diuron has also been strongly implicated in the extensive dieback of mangroves in the Mackay region of the Great Barrier Reef (Duke and Bell, 2005), and is thought to have a detrimental impact on mangrove seedling recruitment (Bell and Duke, 2005). This is especially significant, since mangrove degradation has major potential to exacerbate erosion of river banks and wetland areas.

Haynes et al. (2005) examine heavy metal and organochlorine concentrations in dugong (blubber and liver tissue). The findings suggest that, although both heavy metals and organochlorine chemicals, such as dieldrin, DDT and DDE are present in many of the dugong studied, the concentrations are relatively low compared to other marine mammals in other parts of the world. Jones et al. (2005) carried out a risk assessment of heavy metal contaminants in Port Curtis, near Gladstone. They found that biota, water and sediments all had elevated levels of tributyltin. Although dissolved metal concentrations were considered of low risk to humans, the level of mercury found in barramundi did pose a potential risk to human health. Another emerging water quality issue for coastal ecosystems is the discharge of antibiotics from sewage treatment works (Costanzo, Murby, Bates, et al., 2005). Further work needs to be done to investigate the effects such compounds have on coral reef and other tropical ecosystems.

To properly understand the effects of terrestrial runoff on marine ecosystems, it is important to understand the biogeochemical processing of nutrients in estuarine and marine environments. New contributions to this understanding include the model developed by Webster et al. (2005) to calculate nutrient budgets in estuaries with episodic flow, and Alongi and McKinnon's (2005) discussion of the important role of microbes in nitrogen cycling in the coastal zone, thereby reducing the amount of nitrogen that is transported to the offshore reefs. Coastal habitats, such as mangrove and intertidal zones, also provide significant protection for offshore coral reefs by trapping, transforming and storing sediments and organic matter.

4. Improvements to water quality monitoring technologies

The implementation of the Reef Water Quality Protection Plan will require assessment of its overall effectiveness, in turn requiring cost effective monitoring of water quality, and several papers in this Special Edition provide useful technical direction. Costanzo, Udy, Longstaff, et al. (2005) describe the use of stable nitrogen isotopes to measure the effectiveness of sewage treatment upgrades. Hodge et al. (2005) provide an overview of an integrated water quality monitoring system, which measures water quality parameters from a moving vessel. Phinn et al. (2005) have developed new techniques to map the quality of coastal waters using remote sens-

ing techniques, and they have resolved some of the issues critical to interpreting the optically complex waters. Other teams have developed new sensors for monitoring water quality (Udy et al., 2005; Thomas and Ridd, 2005). These innovative methods will facilitate broad-scale monitoring at a reasonable cost.

5. The way forward

Importantly, this Special Edition also includes several papers addressing technical aspects of policy and guidelines for implementation of the Reef Water Quality Protection Plan. Moss et al. (2005) address the need for a specific set of Great Barrier Reef World Heritage Area water quality guidelines in order to improve water quality management decisions, Cox et al. (2005) provide recommendations for improved water quality sampling and Powell and Martens (2005) discuss the management of acid sulphate soils. Greiner et al. (2005) provide an integrated assessment of environmental, economic and social dimensions of catchments, which supported the development of the Plan, and Bennett et al. (2005) apply the principles of adaptive management to the Plan. Emerging lessons from numerous discussions at the conference included in particular, the need for robust and coordinated, long-term monitoring of water quality and ecosystem health, and the critical importance of collaboration between the various government departments, industries and the community at large.

Although this Special Edition has concentrated on water quality science associated with the Great Barrier Reef World Heritage Area, it is likely to be relevant to many other parts of Australia, and to tropical coasts elsewhere, with heavily cleared catchments subject to episodic, high intensity rainfall. The strategy of cooperative, prioritised catchment action developed in the Reef Water Quality Protection Plan could be also adapted to other ecosystems. Natural resource managers are hoping that within 10 years significant improvements in inshore water quality can be achieved. This will necessitate major changes in the way in which agriculture is practised, along with significant restoration of riparian and dryland savannah vegetation to reduce runoff during peak flood conditions. It will also require significant reduction in fertiliser and pesticide usage in the catchment and a reduction in stock levels during drought years. Importantly, all these changes benefit agricultural and pastoral industries as well as significantly improve water quality flowing into the Great Barrier Reef.

Finally, while the Reef Water Quality Protection Plan is critical to the long-term 'health' of the reef, it is only one of many management tools being implemented by the Great Barrier Reef Marine Park Authority to protect the Reef. Other recent management initiatives include the rezoning of the reef (through the Representative Areas Program), which increased the area of no-take zones from 4.6% to 33% within the GBR Marine Park from 1 July 2004 (Day et al., 2002; GBRMPA, 2004), the restructuring of fisheries within the Great Barrier Reef, again a collaboration with the Queensland State Government, and increasing policing and enforcement effort in reef waters. In combination, these initiatives play an important role in improving the reef's resilience to potential threats such as climate change, thus enhancing the survival and long-term health of Great Barrier Reef ecosystems into the future.

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