From coral to cows – using ecosystem processes to inform catchment management of the Great Barrier Reef

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Key Points

- In this paper we propose a framework that can be used for linking ecological impacts on the Great Barrier Reef to management processes in the catchments.
- This approach establishes the chain of causality between marine impact and management response.
- We demonstrate this approach for sediment in the Burdekin catchment, and propose that it could be used elsewhere and for other constituents and chemicals of concern.

Abstract

In this paper we propose a framework that can be used for designing management responses that are effective in improving the condition of Great Barrier Reef (GBR) ecosystems. The approach starts by defining the ecological process that is threatened and quantifies the properties of the constituent that is causing the impact. The framework then allows the use of a range of scientific approaches to work back up into the catchment from the coast to look at the dominant sub-catchment sources, the key processes generating the constituent, and the potential management options for reducing delivery of the constituent. We demonstrate this approach for sediment in the Burdekin catchment, however, it could be used for other constituents and chemicals of concern (e.g. nitrate). The results suggest that there is excess sediment (above pre-European) levels reaching coral reefs. The dominant source of this sediment is the Bowen and Upper Burdekin sub-catchments, and sub-surface (rill, scald and gully) erosion is dominating sediment loads. Further work on the various rehabilitation options and time frames for reducing sediment from these sources is required.

Keywords

Great Barrier Reef, Burdekin, grazing, sediment delivery, erosion, decision support

Introduction

Over the last decade, the Australian and Queensland Governments have spent >$400 million implementing on-ground rehabilitation in catchments draining to the Great Barrier Reef (GBR) in an effort to reduce the amount of sediments and nutrients reaching the GBR (Reef Water Quality Protection Plan Secretariat, 2013). Unfortunately, there is evidence that the ecological health of the GBR is continuing to decline (De'ath et al., 2012) and the 2013 Reef Water Quality Report Card suggests that despite the large investment there has been <8% reduction in sediment/nutrient yields to the GBR (based on modelled estimates; Waters et al., 2013). Existing frameworks are useful for linking agricultural practice to water quality benefits in streams (Thorburn and Wilkinson, 2013) and linking nested modeling products together (Carroll et al., 2012). However, we argue that the links between management actions being implemented in the catchments, and the ecological processes we are trying to protect on the GBR, have not been fully established or thoroughly verified within a single framework.

In this paper we propose a framework that can be used for linking ecological impacts to catchment management processes (**Figure 1**). This approach starts by defining the ecological condition, process or function that is threatened and quantifies the source and management factors of the constituent that is causing the impact. It then allows the use of a range of approaches to work back up into the catchment from the coast, to identify the dominant sub-catchment sources, the key processes generating the constituent, and the potential management options for reducing the

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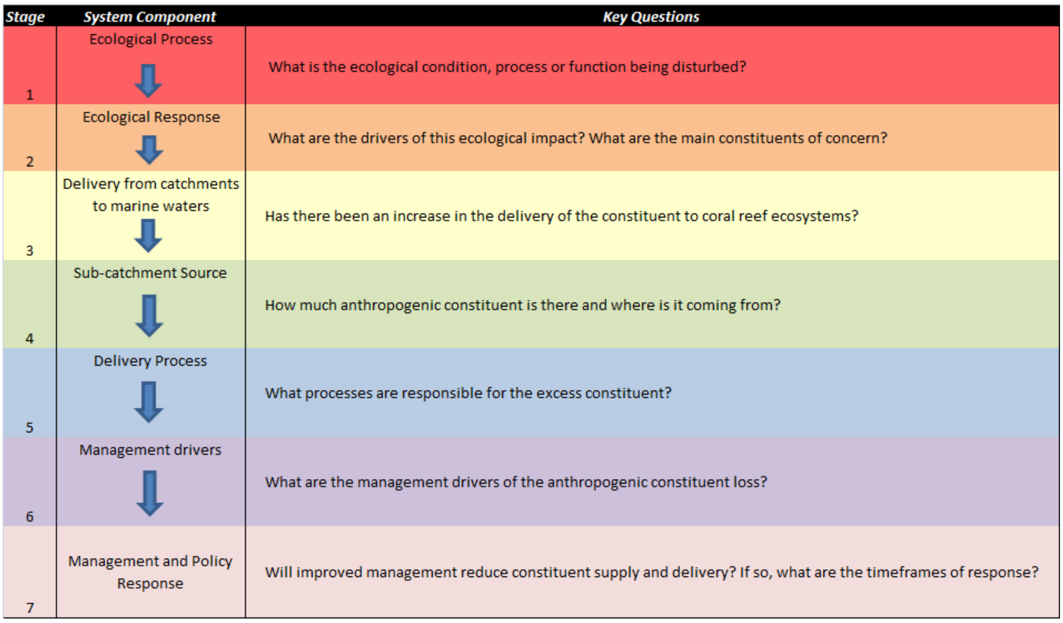
constituent. In this paper we demonstrate the approach for sediment in the Burdekin catchment; however, the same framework could be used for particulate and dissolved nutrients (Nitrogen, Phosphorus, Carbon and Silica), herbicides or pesticides. The approach could also be used for differentiating between different stressors (e.g. catchment pollution versus marine dredging) or for the impact of multiple pollutants (particulate N and dissolved N). This paper is a synthesis of the work presented in Bartley et al., (2014a).



Stage	*System Component*	*Key Questions*
1	Ecological Process ⇩	What is the ecological condition, process or function being disturbed?
2	Ecological Response ⇩	What are the drivers of this ecological impact? What are the main constituents of concern?
3	Delivery from catchments to marine waters ⇩	Has there been an increase in the delivery of the constituent to coral reef ecosystems?
4	Sub-catchment Source ⇩	How much anthropogenic constituent is there and where is it coming from?
5	Delivery Process ⇩	What processes are responsible for the excess constituent?
6	Management drivers ⇩	What are the management drivers of the anthropogenic constituent loss?
7	Management and Policy Response	Will improved management reduce constituent supply and delivery? If so, what are the timeframes of response?

Figure 1: Schematic diagram outlining the research framework for linking ecological impact to management response

Case study: The Burdekin Catchment

The Burdekin catchment is ~130,000 km^2 and drains into the Great Barrier Reef Lagoon south of Townsville on the east coast of Australia (**Figure 2**). It has an annual average rainfall of 727 mm and the largest mean annual runoff of any of the GBR catchments at 10.29 ×10^6 ML (Furnas, 2003). The Burdekin catchment is composed of 6 sub-catchment areas including the Upper Burdekin (~29% of the total area), Cape River (~15%), Belyando (~27%) and Suttor sub-catchments (~13%) all above the Burdekin Falls Dam (BFD). The Bowen sub-catchment (~8%) and Bogie and lower East Burdekin (~8%) are below the BFD (**Figure 2**). The Burdekin catchment is dominated by cattle grazing (~91%) which occurs largely on native pastures within open woodland communities (DSITIA, 2012). There are also small areas of dryland cropping in the Belyando-Suttor region (~70,000 ha), and sugar cane dominates the lower floodplain (occupying <1% of the catchment). Cattle numbers have increased in the Burdekin from ~0.05 million in 1860 to ~1.4 million in 2010-11 (see Bartley et al., 2014a).

What is the ecological process or function being disturbed?

There has been a major decline in coral cover in areas offshore from agricultural development, including the Burdekin catchment (De'ath et al., 2012; Fabricius et al., 2005). High sedimentation rates on corals can cause reduced light for photosynthesis which may, in turn, reduce larval recruitment, increase coral disease and mortality, and cause a shift to macroalgal dominance (see references within Bartley et al., 2014a). Nutrient enhanced sediment has also been linked to crown-of-thorns starfish outbreaks (Brodie et al., 2005). Other habitats, such as seagrass beds, are also vulnerable to excess sediment delivery from adjacent catchments (Waycott et al., 2005). The marine zone influenced by periodic runoff from the Burdekin catchments has been estimated at ~ 47,000 km^2 (Devlin et al., 2012), which includes ~ 246 coral reefs and 73 seagrass beds (Devlin et al., 2011).

What are the ecological impacts of anthropogenic sediment on the Great Barrier Reef?

The influence of sediment on the growth and distribution of corals was recognised ~ 100 years ago using field observations and laboratory experiments (e.g. Vaughan, 1919). More recently, it has been determined that the sediment of most concern to coral reef ecosystems is the nutrient/organic rich silt and clay sized (<63 µm) fractions (Weber et al., 2006). Trigger sediment concentrations required to minimise ecological impact on coastal waters of the GBR are 1.6 mg L^{-1} in winter and 2.4 mg L^{-1} during the summer wet season (De'ath and Fabricius, 2008). Re-suspension of sediment in windy conditions or strong tidal currents in shallow waters (<10 m) leads to conditions where total suspended sediment (TSS) concentrations are above the GBR water quality guidelines (De'ath and Fabricius, 2008; Great Barrier Reef Marine Park Authority, 2009).

Has there been an increase in terrestrial sediment delivery to coral reef systems?

Many physical factors control the delivery of terrestrial sediment from the end-of-river to marine systems, including tides, wind and wave direction and energy, land position and distance from terrestrial inputs (Lewis et al., 2014; Woolfe and Larcombe, 1998). The fate of the sediment in marine waters also depends on its particle size, mineralogy and attached materials (e.g. organic matter, nutrients, chemicals). In many cases, it is not necessarily the plume itself but rather the continual reworking of the sediment delivered by the plume that has an impact on the marine ecosystem (Storlazzi et al., 2009). In the GBR, trace element to calcium ratios in coral cores identified that the amount of fine sediment (silt and clay) leaving the Burdekin River has increased at least 5 times over the last 150 years (Lewis et al., 2007; McCulloch et al., 2003). This increase is linked to changes in animal numbers and vegetation, with the highest sediment fluxes occurring during the drought-breaking floods (when ground cover is low). Interestingly, ~80-90% of the contemporary sediment from the Burdekin River has been captured (or stored) in the Burdekin delta (Fielding et al., 2006). Only sediment <4 µm (clay) is transported more than 5 km offshore, and sediment <16 µm is transported <3km from the river mouth (Bainbridge et al., 2012). However, all fine sediment fractions (<63 µm) can be transported to the river mouth where it can be re-suspended (Fabricius et al., 2013). In summary, only the clay fractions will reach coral reef areas, however, larger sediment fractions may impact on other marine ecosystems (e.g. seagrass beds).

How much anthropogenic sediment is there and where is it coming from?

Determining the dominant (sub-catchment) source and delivery of sediment in a basin requires a combination of techniques including direct sediment flux monitoring, sediment provenance tracing and catchment modelling (Walling et al., 2011). A range of techniques have been used over the last 30 years in the Burdekin catchment to estimate end of catchment sediment yields including simple empirical models (e.g. Neil et al., 2002), catchment sediment budget modelling (e.g. McKergow et al., 2005), measured sediment loads (e.g. Joo et al., 2012) and integrated modelling and monitoring data (Kroon et al., 2012; Waters et al., 2013). The most recent research using 24 years of monitoring data at the end of the Burdekin River estimates that an average of ~3,930 Kt/yr of fine sediment reaches the estuary (Kuhnert et al., 2012). This estimate has accounted for trapping in the Burdekin Falls Dam that has been shown to trap more than 50% of the mean-annual fine sediment between 0.5 and 30 µm (Lewis et al., 2013).

Geochemical tracing (Furuichi et al., 2014) and sub-catchment monitoring (Bainbridge et al., In Review) have been used to identify the spatial sources of this sediment. The results suggest that the Upper Burdekin, Bowen and Lower Burdekin/Bogie sub-catchments dominate basin fine sediment delivery (Bainbridge et al., In Review).

Recently, Terrestrial Cosmogenic Nuclides (TCNs) have been used in the Burdekin catchment to benchmark short-term (~5 year) measurements of contemporary sediment yield against the natural geological erosion rates. Such techniques are increasingly being used to quantify the contribution of human activity against the natural variability of landscape sediment yields (Hewawasam et al., 2003). The results identify two of the five major sub-catchments in the Burdekin (Bowen and Upper Burdekin) as having accelerated erosion rates well above the long term natural geological erosion rates (Bartley et al., In Prep; Croke et al., In Review). Without an understanding of the natural susceptibility of a catchment to erosion, remediation resources may be incorrectly allocated to areas that appear to be producing high sediment yields, when in fact they have landscape attributes that generate large volumes of sediment even in the absence of disturbance by human activities.

What processes are responsible for the excess sediment?

Following the identification of the major geographic sources of sediment, it is important to determine which erosion process is predominantly responsible for the sediment loss so that appropriate restoration strategies can be implemented. Tracing of clay and fine silt sediment sources in the Bowen and Upper Burdekin sub-catchments demonstrated that sub-surface erosion is the dominant process contributing to fine sediment yields (Wilkinson et al., 2013), and further research is pending for other sub-catchments (Wilkinson et al., In Prep). Importantly, recent tracing using ^{7}Be has shown that sub-surface hillslope soils (below A horizon) is a contributor to this fine sediment loss, with rilled, scalded and badland areas on hillslopes being sources of comparable importance to vertical channel banks (Hancock et al., 2013). Sub-surface erosion can generate a larger proportion of fine sediment, due to the fine texture of B-horizons of the duplex soils that dominate many areas of the Burdekin. These erosion processes also supply coarser sand and gravel sediment fractions which impact freshwater ecosystems, but do not appreciably affect coastal turbidity.

What are the drivers of the anthropogenic sediment loss?

Critical to reducing all forms of soil erosion is reducing runoff. High rates of runoff fuel hillslope and channel erosion, and increase the risk of (the ecologically threatening) sediment (<16 µm) reaching the GBR. To reduce runoff, ground cover needs to be maintained at or above ~75% to enable infiltration during high intensity events (Roth, 2004). High vegetation cover levels also protect the soil surface from rainsplash. Heavy or severe grazing is likely to have the greatest impact on vegetation and soil condition (Orr and O'Reagain, 2011). Disturbance of native vegetation is the most likely cause of gully erosion (Shellberg et al., 2012), and adequate ground cover on both hillslopes and riparian zones is needed to reduce the potential for further gully formation.

Will improved land management reduce sediment supply and delivery?

For management to be effective, and reduce the delivery of the ecologically threatening sediment, it must be effective at influencing the primary erosion processes. It is likely that increasing native pasture cover levels across the whole catchment will help improve soil health which will reduce runoff and rates of hillslope and channel erosion. This will likely require significant reductions in grazing pressure for the foreseeable future. Once gullies are well established, specific remediation measures may also be required to assist recovery (Buckhouse, 1987). We need to better understand the eco-hydrological consequences of land use change, and the methods required to mitigate and manage these changes. It is also likely that eco-hydrological recovery may not be possible under current management in some areas, particularly if they have crossed natural ecosystem thresholds or tipping points (e.g. complete loss of A and B soil horizons). In such cases, alternative and bold policy responses may be required (see review and reccommendations inKroon et al., 2014).

Due to the costs and challenges associated with achieving substantial land use change and monitoring its effects in the long term, there are very few studies globally that have demonstrated a reduction in runoff and fine sediment delivery to coral reefs following improved land management (Kroon et al., 2014). Even at the hillslope scale, there are very few studies that have measured changes to sediment yields following improved land management in the GBR (O'Reagain et al., 2005) and published results suggest more than 10 years will be required to restore healthy eco-hydrological function to previously degraded rangelands (Bartley et al., 2014b). Even longer timescales will be needed to measure these changes at sub-catchment scales (Darnell et al., 2012). Despite these difficulties, International studies suggest that change is possible (Kroon et al., 2014), and the approach outlined in this paper provides a framework that will help facilitate that change.

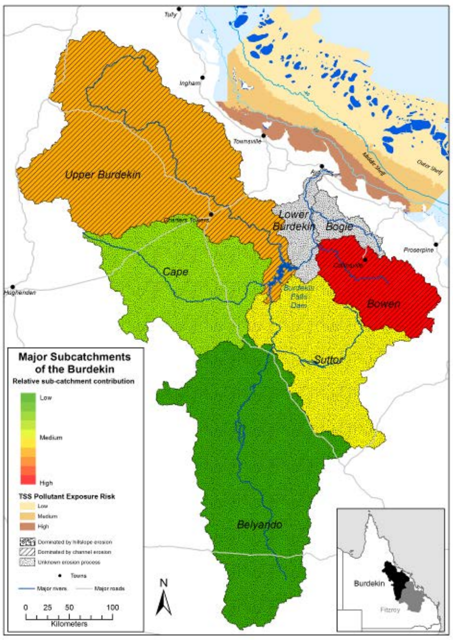


Figure 2. Map of the major sub-catchments of the Burdekin River showing the relative sub-catchment contribution and erosion process responsible for sediment delivery to the GBR (based on multiple lines of evidence). The marine total suspended sediment (TSS) pollutant exposure risk data is derived from Devlin et al., (2012).

Conclusions and areas of further research

By working outwards and upwards from the ecosystem impacts of the constituent, rather than starting with any one management lever, the approach presented in this paper should better ensure a direct connection between the ecological process we are trying to protect (e.g. coral health on the GBR) with the source of anthropogenic sediment (e.g. Bowen and Upper Burdekin sub-catchments) and management changes proposed and implemented. In the face of proposed dumping of 3 million m^3 of spoil at Abbot Point (Brodie, 2014) and the proposal to offset this spoil dumping through catchment management works in the Burdekin catchment, the need for the approach described here is even more crucial so that the optimal catchment remediation areas are chosen. Such an approach will help direct finite resources to the points of influence that can be effective in maintaining and enhancing the health of the Great Barrier Reef.

It is possible that a similar approach could be used for other constituents (e.g. dissolved inorganic nitrogen, DIN) to help direct and refine required research (e.g. is the dominant source of DIN delivered from surface runoff or groundwater or dissociation from fine sediment?). It is also imperative that modeling approaches that are being used to estimate constituent loads and evaluate progress towards water quality targets are regularly updated using the most recent process understanding. Recent advances in data-model-fusion approaches can be used to help identify where the models work well, where more data is needed, and also provide estimates of model uncertainty (e.g. Pagendam et al., 2014).

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