Department of Science, Information Technology and Innovation

Erosion processes and sources in the Burdekin Dry Tropics catchment (RP65G)

Synthesis Report

Chemistry Centre, Landscape Sciences

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Background

The declining health of the Great Barrier Reef (GBR) is considered to be the result of a combination of factors including over-fishing, coral disease, climate change and poor water quality resulting from agricultural land use (Brodie et al., 2012). Fine sediment is one of the key water quality parameters of concern to the health of the GBR (Fabricius, 2005; De'ath and Fabricius, 2010; Brodie et al., 2013). Catchment scale modelling indicates that the Burdekin catchment, which is dominated by grazing (95%), is the largest source of sediment to the GBR, exporting approximately 4M tonnes per year, or at least 25% of the average annual load from all GBR rivers (Kroon et al., 2012). Recent work by Bainbridge et al. (2012) showed that suspended sediment exported from the Burdekin River during flood events is dominated by the clay and silt size fractions.

In order to reduce the delivery of this fine sediment to the GBR, management practices which target the sources of this sediment must be put in place. To achieve this we first need an understanding of the erosion processes and spatial sources of the fine sediment. Where erosion occurs within a catchment (i.e. spatial sources and erosion processes), and the delivery of eroded sediment is influenced by a range of factors including climate, geology, topography, landuse and land management. Sediments may originate from the erosion of surface soils (hillslope erosion) and from subsurface erosion (the erosion of hillslope scalds, river beds and banks, and gullies and river banks) (Wilkinson et al. 2013). The management of these two erosion types differs. For example, sub-surface erosion along channels is best managed by a combination of interventions within the erosion features themselves to prevent stock access and also protect and restore riparian vegetation (Lovett and Price, 1999). Managing gullies is best achieved by protecting and restoring vegetation cover, and managing the surrounding land to reduce upslope runoff (Thorburn and Wilkinson, 2013; Thorburn et al., 2013b). Surface erosion is best managed by promoting groundcover, maintaining soil structure, and promoting deposition of eroded sediment before it reaches the stream (Thorburn et al., 2013). Therefore an awareness of the dominant erosion process is essential as it enables targeted and effective management strategies to be put in place. Similarly understanding the spatial sources of sediment enables prioritisation of management investment into those areas delivering greater quantities of sediment.

The Burdekin River catchment

Physiography

The Burdekin River catchment is located in the middle coastal region of Queensland and has an area of about 130,000 km^2 (Figure 1). The catchment can be split into seven sub-catchments, namely Upper Burdekin, Cape, Belyando, Suttor, Bowen and Bogie, and Lower Burdekin. Due to the physiographic and climatic similarity, the Belyando and Suttor and the Bowen and Bogie sub-catchments are combined and called the Belyando-Suttor sub-catchment and the Bowen-Bogie sub-catchment, respectively, in this study. Coastal sub-catchments of the Upper Burdekin and Bowen-Bogie contain steeper slopes compared to the inland sub-catchments of the Cape and Belyando-Suttor which are flatter.

Geology

Geology in the Burdekin River catchment is complex but the coastal hilly/mountainous region is characterised as having volcanic, plutonic and metamorphic rocks, while sedimentary rocks occur extensively in the inland flatter region.

Rainfall

Rainfall patterns in the Burdekin catchment display a contrast between the coastal and inland regions. Long-term annual mean rainfall (1890-2011) indicates that the Upper Burdekin and Bowen-Bogie sub-catchments generally receive 600-1000 mm/yr, whereas only 400-600 mm/yr fall in the Cape and Belyando-Suttor sub-catchments. Some parts of the Upper Burdekin and Bowen-Bogie receive around 2000 mm/yr. In the water year of this study (2011/12) the annual rainfall over the total Burdekin catchment was 1.4 times more than the long-term annual mean. The inland regions received 700-1000 mm which is nearly double the annual mean.

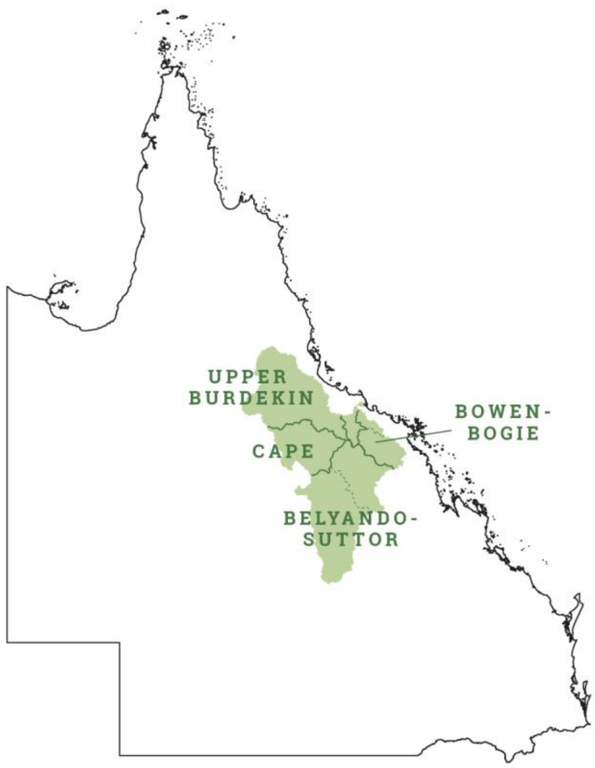

Figure 1: The Burdekin River catchment is located in the middle coastal region of Queensland and has an area of about 130,000 km^2.

Project objectives and knowledge gaps

The objectives of the Reef Water Quality science project RP65G 'Identifying erosion processes and sources in the Burdekin Dry Tropics catchment' were:

- to identify the dominant erosion processes (both contemporary and historical) within the Burdekin Dry Tropics catchment delivering sediment to the Great Barrier Reef (GBR) Lagoon
- to identify the spatial distribution of the sediment sources across the catchment delivering sediment to the GBR Lagoon
- to provide target areas for rehabilitation aimed at reducing sediment export to the GBR.

To achieve these objectives we investigated three key knowledge gaps (KG):

(KG 1) The dominant erosion processes (both contemporary and historical) within the Burdekin River catchment delivering sediment to the GBR Lagoon.

(KG 2) Spatial sources of sediment deposited in the GBR Lagoon from the Burdekin River catchment in 2011/12.

(KG 3) The temporal changes in the sources of sediment deposited in the GBR Lagoon from the Burdekin catchment.

Some information on the fate of the fine sediment was also obtained and is provided in this report.

This report synthesises the key findings of the three knowledge gaps outlined above. Full details are provided in the technical reports and publications listed below:

KG1:

Wilkinson SN, Olley J, Furuichi T, Burton J. 2014. Identifying erosion processes and sources in the Burdekin dry tropics catchment – Technical Report: Knowledge Gap 1 – Erosion process tracing. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Wilkinson SN, Olley JM, Furuichi T, Burton J, Kinsey-Henderson AE (In review): Sediment source tracing with stratified sampling and weightings based on spatial gradients in soil erosion. Journal of Soils and Sediments.

KG2:

Furuichi T, Olley J, Lewis S, Wilkinson SN, Burton J. 2015. Identifying erosion processes and sources in the Burdekin dry tropics catchment – Technical Report: Knowledge Gap 2 – Spatial source tracing. Department of Science, Information Technology and Innovation, Brisbane.

Furuichi et al. (In prep.) Comparison between geochemical tracing and sediment load monitoring for identifying spatial sources of fine suspended sediment in the Burdekin River catchment, northeastern Australia.

KG3:

Lewis S, Furuichi T, Olley J, Wilkinson S, Sharma A, Burton J. 2014. Identifying erosion processes and sources in the Burdekin dry tropics catchment –Technical Report: Knowledge Gap 3 – Temporal changes in sediment accumulation rates and sources. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Lewis, S.E. Olley, J. Furuichi, T. Sharma, A. Burton, J. 2014. Complex sediment deposition history on a wide continental shelf: implications for the calculation of accumulation rates on the Great Barrier Reef. *Earth and Planetary Science Letters* 393, 146-158.

Furuichi et al. (In prep). Temporal changes in provenances geochemically recorded in sediment on a continental shelf offshore the Burdekin River catchment, northeastern Australia.

KG 1 Dominant Erosion Process

Prior Knowledge

Catchment scale modelling of the Burdekin basin has indicated that hillslope soil erosion (including hillslope scalds) is the largest contributor to sediment exports, with gully and bank erosion together supplying less than 40% of export (Prosser *et al.*, 2002; Kinsey-Henderson *et al.*, 2007). In contrast a field-based sediment budget of a small sub-catchment suggested that surface erosion from hillslopes (not including hillslope scalds or gullies) could be a only minor contributor (Bartley *et al.*, 2007). This latter finding is consistent with a number of field based studies in Northern Australian catchments including: the Ord River scheme (Wasson *et al.*, 2002), the Fitzroy catchment (Hughes *et al.*, 2009), the Daly River (Wasson *et al.*, 2010; Caitcheon *et al.*, 2012), the Mitchell River catchment (Brooks *et al.*, 2009; Caitcheon *et al.*, 2012), the Herbert catchment (Bartley *et al.*, 2004; Tims *et al.*, 2010), the Normanby River (Olley et al., 2013), and the Upper Burdekin and Bowen catchments within the Burdekin (Wilkinson *et al.*, 2013). Prior to this current study the primary erosion processes generating the sediment delivered to the GBR from elsewhere in the Burdekin basin were yet to be assessed.

Approach

This study applied fallout radionuclide sediment source tracing methods to estimate the contribution of sediment from surface sheetwash, and sub-surface erosion from scalds, rills, gullies and channels, to fine river sediment (<10 μm fraction) delivered to the GBR Lagoon from the Burdekin River basin.

Key Findings

In 2011/12, between 86±1% and 96±1% of fine river sediment delivered to the GBR lagoon from all the catchments in the Burdekin River Basin was derived from the erosion of sub-surface soil (i.e. areas of severe rilling and scalding on hillslopes, gully erosion and channel erosion) (Figure 2). This study did not discriminate between the different sources of sub-surface soil.

At the outlets of the sub-catchments (e.g. Bowen River, Upper Burdekin River) surface soil contributions to fine river sediment were: Belyando River 0±1%; Suttor River 2±1%; Bowen River 7±1%; Upper Burdekin River 13±1%; and Cape River 14±1%. The catchment differences in surface soil contribution quantified here can be partly attributed to the occurrence of gully erosion across the basin, which is highest in the Bowen, Suttor and Upper Burdekin catchments (Gilad *et al.*, 2012). The catchment differences may also be partly attributed to variations in the rates of hillslope erosion (which has previously been modelled to be higher in the steeper and wetter Upper Burdekin for example).

The study followed 4–6 years of above-average rainfall, in some parts of the catchment. Somewhat higher proportions of sediment supply from sheetwash erosion may be expected during periods of prolonged drought when levels of vegetation ground cover are lower. However, a previous study in the Bowen River and Upper Burdekin River catchments, which occurred after 4–5 years of below-average rainfall, found surface soil contributions of 17±6%. It is therefore concluded that the fine sediment delivered to the GBR Lagoon from the Burdekin River Basin has been dominated by sub-surface sediment sources over recent decades.

Relative to the sole previous study of sediment source tracing of erosion processes in the Burdekin River catchment (Wilkinson et al., 2013), this study has extended the technique to all catchments in the basin and made methodological advances that reduced the confidence intervals around the estimate (e.g. greater number of soils samples to represent data and optimised statistical representations).

See Wilkinson et al. 2014 for the full technical report for KG1.

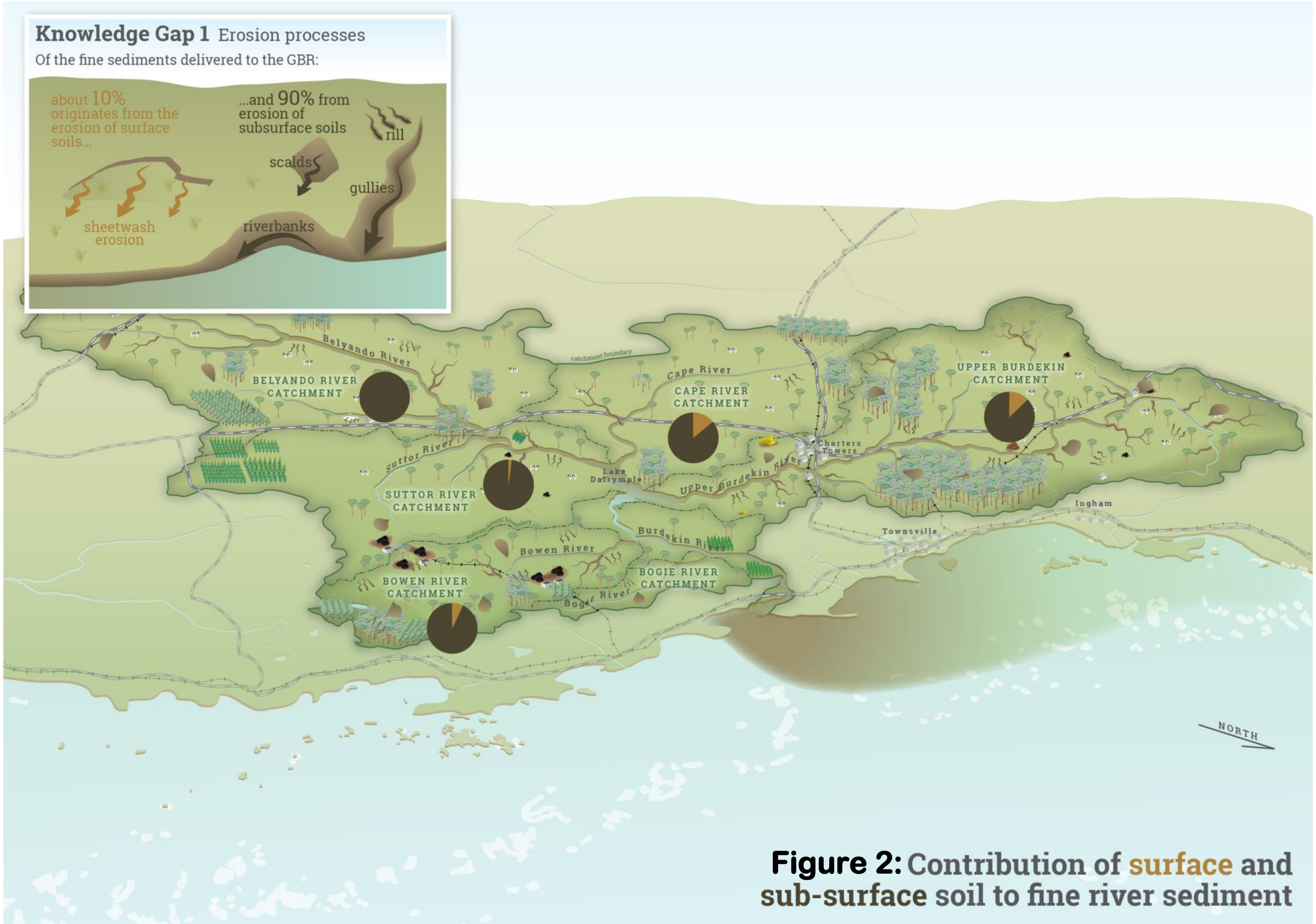

Figure 2: Contribution of surface and sub-surface soil to fine river sediment

KG2 Spatial Sources of Fine Sediment in 2011/12

Prior Knowledge

Previous information on spatial sources of fine sediment in the Burdekin River catchment has been derived from the results of programs involving monitoring (Bartley et al., 2007; Bainbridge et al.,2008; Lewis et al. 2013; Turner et al., 2012, 2013; Bainbridge et al., in review;) and catchment sediment budget modelling (Prosser et al., 2002; Bartley et al., 2004; Fentie et al., 2006; Post et al., 2006; Kinsey-Henderson et al., 2007; Dougall et al., in press). The results of these studies have indicated that the Upper Burdekin and Bowen-Bogie sub catchments contribute the largest quantities of sediment to the GBR Lagoon. A geochemical sediment source tracing study conducted by Wilkinson et al. (2013) in the Bowen River sub-catchment demonstrated that the method was useful for quantifying the relative contributions of geologically distinct sub-catchments to downstream river sediment loads. This Project extended geochemical sediment source tracing to the whole of the Burdekin catchment, focusing on the <10 µm fine sediment fraction, to provide a third line of evidence of sub-catchment sediment contributions for the water year 2011/12 and to demonstrate the ability of the method to measure spatial sources of fine sediment at multiple scales.

Approach

This study applied geochemical tracing techniques at river confluences to determine the spatial distribution of the sources within the Burdekin catchment delivering fine (<10 µm) sediment to the GBR Lagoon in the water year 2011/12.

Key Findings

Geochemical sediment tracing showed that the largest contributor of the fine sediments delivered to the GBR Lagoon in 2011/12 was the Bowen-Bogie (38%), followed by the Upper Burdekin (34%) and the Belyando-Suttor (27%) sub-catchments (Figure 3). Tracing results indicate that the Cape sub-catchment contributed <1% of the sediment to the GBR Lagoon in 2011/12. The identification of the Bowen-Bogie catchment as the largest source of fine sediment in the Burdekin River catchments is consistent with previous studies involving sediment load monitoring and catchment monitoring. It should be noted however that the proportion of fine sediment we found delivered from the Belyando-Suttor in 2011/12 is higher than that expected based on previous studies. This may be attributed to rainfall in the Belyando-Suttor sub-catchment being higher than average, and relatively higher than in other catchments in 2011/12. Further investigations are required to improve our understanding of the processes occurring in this sub-catchment. Contributions from the Belyando and Suttor sub-catchments to the St Anns confluence were 73% and 27% respectively. Finer scale sediment sourcing information was obtained for the Upper Burdekin sub-catchment and for contributions to Lake Dalrymple and can be found in Furuichi et al., 2014.

This study illustrates the benefits of sediment tracing and monitoring paired analysis. It demonstrates insights into sediment trapping in impoundments that can be determined using geochemical tracing, including particle size fractionation and differential trapping of sediment from multiple upstream source tributaries. It also demonstrates that tracing results can be used for refining sediment load estimates in circumstances where load monitoring data is uncertain due to sampling difficulties. Further details can be found in Furuichi et al., 2014.

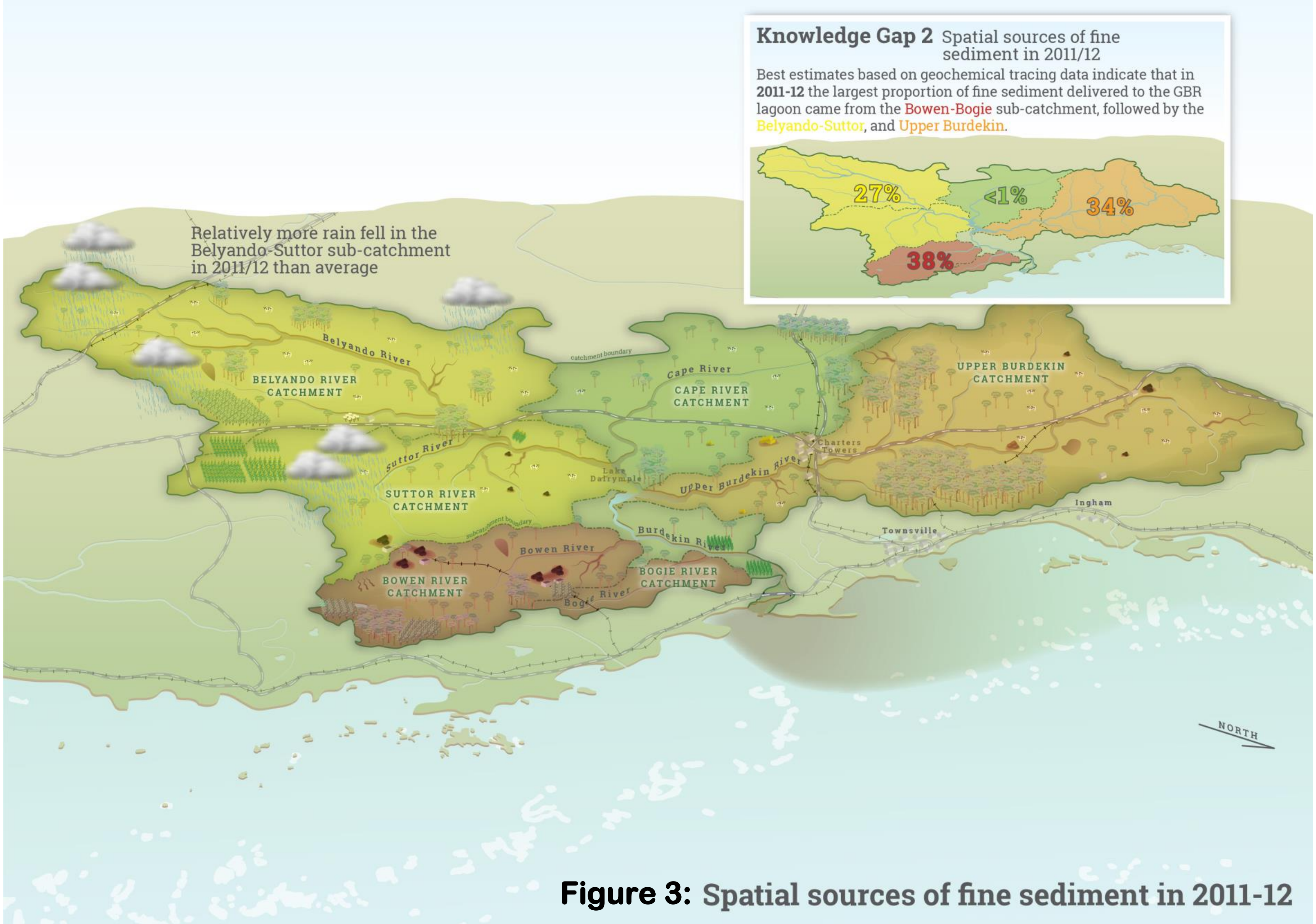

Figure 3: Spatial sources of fine sediment in 2011-12

KG3 Temporal changes in the sources of sediment

Prior Knowledge

Catchment scale modeling (Kroon et al., 2012) and coral records (McCulloch et al., 2003) indicate that the sediment load delivered to the GBR Lagoon from the Burdekin River has increased 8 to 10 fold since European settlement. It is thought that this additional terrestrial loading has negatively impacted on the receiving waters (due to increased turbidity) of the Burdekin River through a decline in seagrass habitat (Devlin et al., 2013), coral biodiversity (Fabricius and De'ath, 2001; De'ath and Fabricius, 2010; Fabricius et al., 2013) and the apparent local collapse of some species of coral (Roff et al., 2012). However, other studies suggest that terrestrial sediment delivered from the Burdekin River is largely captured in the north-facing embayments including Upstart, Bowling Green and Cleveland Bays, and therefore very little reaches the inshore reefs (Woolfe and Larcombe, 1998; Orpin et al., 2004). Indeed, the sedimentologists argue that the volume of the 'old' sediment available for resuspension on the sea floor far outweighs the volume of 'new' sediment delivered from the rivers (Woolfe and Larcombe, 1998; Larcombe and Woolfe, 1999; Orpin and Ridd, 2012). Turbidity generated by wind-driven resuspension events at inshore coral reefs greatly exceeds levels measured in river flood plumes at the same location (Woolfe and Larcombe, 1998; Larcombe and Woolfe, 1999; Orpin and Ridd, 2012). Research on some other estuaries also suggests that much of the sediment is retained close to the river mouths (Bostock et al. 2007; Bryce et al., 1998; Webster and Ford, 2010; Bainbridge et al., 2012).

The scientific debate has more recently been refined in light of new data that suggest turbidity levels in the GBR are much higher in the months following considerable river input compared to the end of the dry season (corrected for wind speed and direction) (Fabricius et al., 2013). This finding implies that the delivery of 'new' sediment does in fact play an important role in water clarity in the inshore reefs influenced by discharge from the Burdekin River. Modelling has also highlighted the importance of new sediment and the role of Tropical Cyclones to winnow-out the accumulated terrigenous sediment from the embayments (Lambrechts et al., 2010). Hence it is critical to better quantify the amount and fate of recently delivered sediments that reach the inshore reefs of the GBR and their influence on turbidity regimes. Furthermore it is important to examine the changes in sediment accumulation and sources over time and, in particular, if the extra sediment delivered from the Burdekin River comes from a specific location in the catchment. This understanding will provide improved knowledge of sediment sources and quantities over time which will support a targeted approach to sediment management.

Approach

In this study, sediment cores collected from key locations offshore from the Burdekin River were examined using optically stimulated luminescence and radiocarbon dating techniques to determine the fate of and accumulation rates of sediments delivered to the GBR. We also examined the geochemistry of two key sediment cores that lie in the current depositional area of the Burdekin River to determine if sources of sediment have changed over time.

Key Findings

Dating of cores taken from outer Bowling Green Bay showed an approximate ten-fold increase in sediment accumulation rates since European settlement (Figure 4). This is consistent with the changes in sediment load estimated from the catchment modeling (Kroon et al., 2012) and with data from coral records (McCulloch et al., 2003).

This Project also improved knowledge on the fate of sediment delivered to the GBR Lagoon from the Burdekin catchment. We found that the sediment delivered from the Burdekin River is retained within 50 km of the mouth with little sediment reaching the north-facing embayments of Bowling Green and Cleveland Bays, as previously thought. We also refined the previous hypothesis on sediment resuspension in the GBR to show that very fine sediment (< 4 um) is carried further in the marine environment and becomes available for resuspension. It appears that the sediment delivered from the Burdekin River that reaches inshore coral reefs is composed of organic-rich material.

The geochemistry of the cores revealed that sources of fine sediment to the GBR Lagoon have changed over time (Figure 4). Slightly different proportions and patterns are seen in the Upstart Bay core (period of time approximately 1871 – present) compared to the outer Bowling Green Bay core (period of time approximately 1400 or 1500 to present). These differences are currently being investigated and possible explanations include: particle size and transportability differences among the catchments and differences in flood size on the geochemical signature of sediments in Upstart Bay. The pattern of spatial sources over time is illustrated in Figure 4. In general, the results indicate that the Upper Burdekin and Bowen have always been the largest sources while the contribution from the Belyando-Suttor has declined over time. The variability of sediment source also increased post Dam. The Cape sub-catchment has consistently contributed the lowest proportion of fine sediment. It was found that the Upper Burdekin Catchment tends to contribute the largest proportion of fine sediment during major flooding events.

See Lewis et al., 2014 for the full technical report for KG3.

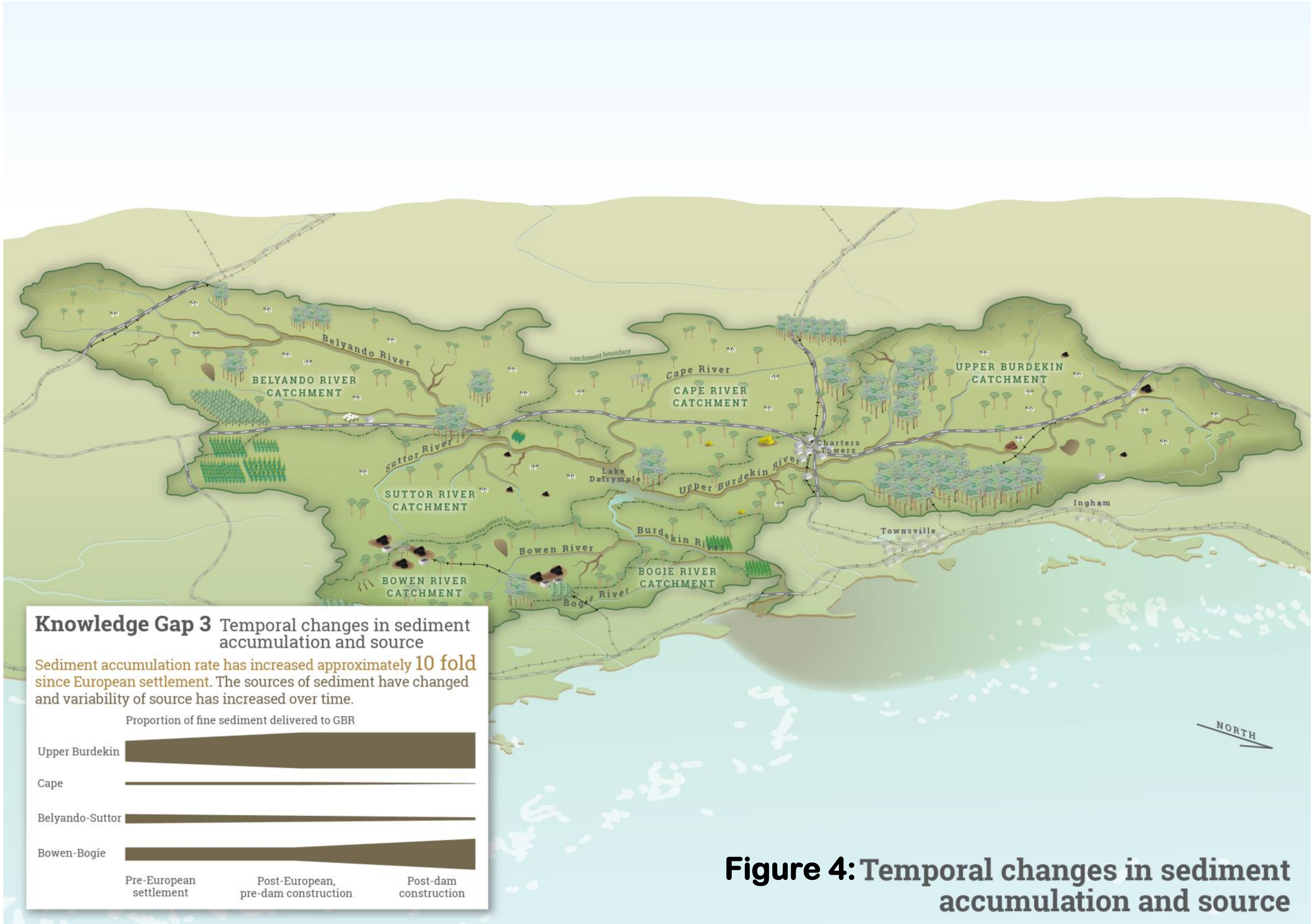

Figure 4: Temporal changes in sediment accumulation and source

Management and Policy Implications

The new knowledge provided in this project through the use of geochemical, fallout radionuclide tracing and sediment dating methods provides additional lines of evidence to support prioritisation of management. The results of this work indicate that to reduce fine sediment exports from the Burdekin River to the GBR, land management practices should focus on improving vegetation cover on sub-surface soil erosion features including gullies, channel banks and hillslope scalds and on managing grazing pressure in those areas to minimise runoff into these erosion features. Some focus should also be placed on preventative management (e.g. maintaining cover and appropriate stocking regimes) to reduce the occurrence of these features in the landscape. Spatially, the results indicate that the Bowen Bogie and the Upper Burdekin sub-catchments are the largest contemporary sources of the sediment delivered to the GBR Lagoon. In addition, results from this study will be used to evaluate and improve the accuracy of catchment models used by the Paddock to Reef monitoring, modelling and reporting program.

The output from subproject KG2 is useful for testing of models and demonstrates the capability of the spatial tracing method to measure sediment sources at multiple scales and the benefits of applying sediment tracing in conjunction with sediment load monitoring. This data should not be used on its own for prioritisation of management as it is only one year of data. In comparison the output from subproject KG3 represents long term behaviour of the catchment. When combined with previous work in the Burdekin catchment the subproject KG1 output may also be taken to represent long term behaviour, however it should be noted that earlier work which represents sources post periods of low rainfall is based on limited samples in the Upper Burdekin and Bowen Bogie catchment only. Further work during low rainfall periods and at finer spatial scales (particularly in the Upper Burdekin catchment) may be required to verify the conclusions.

User Guide

Conceptual diagrams

The conceptual diagrams displayed in this synthesis report summarise the key findings of RP65G and can be used for both policy and extension. We envisage they can be used in presentations and print material to simply and clearly communicate the key messages around spatial sources and erosion processes in the Burdekin River catchment. An additional diagram summarising all key findings is also available but has not been included in this report. All diagrams are available as jpeg files.

Datasets

All datasets will be made available to the Paddock to Reef modelling team for testing of model outputs. The datasets and associated metadata have been placed in an internal DSITI database.

Further work

While there continues to be significant advances in the knowledge to inform our understanding of the location and type of management practices that will reduce sediment loads delivered to the GBR, there are still significant gaps remaining. Here we detail some of the key knowledge gaps.

Process understanding to inform targeting and prioritisation of management

1. Improved mapping of gully erosion extent, particularly in gullied areas, within the Burdekin, Fitzroy and other gullied catchments (e.g., Burnett-Mary) (Kroon et al., 2013).
2. The sources, fate and ecosystem significance of particulate nutrient load (Kroon et al., 2013).
3. Reconstructing the erosion and sedimentation histories of river basins through sediment tracing and dating techniques (Kroon et al., 2013), to help inform the baseline for water quality improvement.
4. Continued application of geochemical sediment tracing techniques across GBR catchments not yet studied, and across a range of climatic conditions (Kroon et al., 2013; Thorburn et al., 2013b). This technique helps to validate spatial patterns of sediment generation for catchment modelling and practice change evaluation, in conjunction with or as a substitute for catchment load monitoring. This and previous studies have found that spatial patterns of sediment generation are more variable than the contributing erosion processes.
5. Assessing the trajectory of priority river systems across the GBR to determine if catchment modifications have resulted in a geomorphic threshold change to help inform water quality improvement targets and management investment.

Evaluation of management effectiveness

1. Synthesis of knowledge and new field experiments on the effectiveness of locally reducing or removing grazing pressure, and revegetation, on gully and riverbank erosion rates, in different environmental zones of GBR catchments.

2. Ongoing “experiments which quantify the short and long-term responses of erosion rates and surface runoff volumes to reduced forage utilisation” (Thorburn et al., 2013b). Transferability will be enhanced by monitoring that includes process attributes such as vegetation cover and composition, soil properties, biological activity. There have been many more studies of grazing land degradation than of land condition improvement, and yet the latter is a key objective for reducing sediment losses.

3. Field measurements to quantify the soil erosion impact or benefit of pasture renovation and improvement involving native and exotic pasture species, relative to managed utilisation of native pastures.

4. Methods to estimate annual stocking rates by property which are broadly accessible and able to be used by graziers.

5. Integration of the above investigations with the Reef Plan Report Card evaluation program, including structured assessments of information quality.

References

Bainbridge, Z. Lewis, S. Davis, A. Brodie, J. 2008. Event-based community water quality monitoring in the Burdekin Dry Tropics region: 2007/08 wet season update. ACTFR Report No. 08/19 for the Burdekin Dry Tropics NRM. Australian Centre for Tropical Freshwater Research, James Cook University, Townsville.

Bainbridge, Z.T. Lewis, S.E. Smithers, S.G., Kuhnert, P.M. Henderson, B. Brodie, J.E. In review. Suspended sediment sources, transport and export from a large, seasonally-dry tropical catchment: Burdekin River catchment, Queensland, Australia. Water Rescources Research.

Bainbridge ZT, Wolanski E, Ã• lvarez-Romero JG, Lewis SE, Brodie JE. 2012. Fine sediment and nutrient dynamics related to particle size and floc formation in a Burdekin River flood plume, Australia. Marine Pollution Bulletin, **65**: 236-248. 10.1016/j.marpolbul.2012.01.043.

Bartley R, Hawdon A, Post DA, Roth CH. 2007. A sediment budget for a grazed semi-arid catchment in the Burdekin Basin, Australia. Geomorphology, **87**: 302-321. 10.1016/j.geomorph.2006.10.001.

Bartley R, Olley J, Henderson A. 2004. A sediment budget for the Herbert river catchment, north Queensland, Australia. In: Sediment Transfer through the Fluvial System, Int Assoc Hydrological Sciences, pp: 147-154.

Bostock, H.C., Brooke, B.P., Ryan, D.A., Hancock, G., Pietsch, T., Packett, R., Harle, K., 2007. Holocene and modern sediment storage in the subtropical macrotidal Fitzroy River estuary, Southeast Queensland, Australia. Sediment. Geol. 201, 321-340.

Brodie, J.E., Kroon, F.J., Schaffelke, B., Wolanski, E.C., Lewis, S.E., Devlin, M., Bainbridge, Z.T., Waterhouse, J. and Davis, A.M., 2012. Terrestrial pollutant runoff to the Great Barrier Reef: an update of issues, priorities and management responses. Marine Pollution Bulletin 65, 81-100.

Brodie J, Waterhouse J, Schaffelke B, Kroon F, Thorburn P, Rolfe J, Johnson J, Fabricius K, Lewis S, Devlin M, Warne M, McKenzie L. 2013. Land use impacts on Great Barrier Reef water quality and ecosystem condition. 2013 Scientific Consensus Statement. http://reefplan.qld.gov.au/about/assets/scientific-consensus-statement-2013.pdf.

Bryce, S., Larcombe, P., Ridd, P.V., 1998. The relative importance of landward-directed tidal sediment transport versus freshwater flood events in the Normanby River estuary, Cape York Peninsula, Australia. Mar. Geol. 149, 55-78.

Caitcheon G, Olley JM, Pantus F, Hancock GJ, Leslie C. 2012. The dominant erosion processes supplying fine sediment to three major rivers in tropical Australia, the Daly (NT), Mitchell (Qld) and Flinders (Qld) Rivers. Geomorphology, 151–152: 188-195. 10.1016/j.geomorph.2012.02.001.

De'ath G, Fabricius K. 2010. Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. Ecol. Appl., 20: 840-850.

Devlin, M., Petus, C., Collier, C., Zeh, D., McKenzie, L., 2013. Chapter 6: Seagrass and water quality impacts including a case study linking annual measurements of seagrass change against satellite water clarity data (Cleveland Bay). in: Assessment of the relative risk of water quality to ecosystems of the Great Barrier Reef: Supporting Studies. A report to the Department of the

Environment and Heritage Protection, Queensland Government, Brisbane. TropWATER Report 13/30, Townsville, Australia.

Fabricius KE. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Marine Pollution Bulletin, 50: 125-146. http://dx.doi.org/10.1016/j.marpolbul.2004.11.028

Fabricius, K., De'ath, G., 2001. Biodiversity on the Great Barrier Reef: Large-scale patterns and turbidity related local loss of soft coral taxa. In: Wolanski, E. (Ed), Oceanographic Processes on Coral Reefs. CRC Press, Boca Raton, pp. 127-143.

Fabricius, K.E., De'ath, G., Humphrey, C., Zagorskis, I., Schaffelke, B., 2013. Intra-annual variation in turbidity in response to terrestrial runoff on near-shore coral reefs of the Great Barrier Reef. Estuar. Coast. Shelf Sci. 116, 57-65.

Fentie B, Duncan I, Sherman BS, Read A, Chen Y, Brodie J, Cogle AL. 2006. Sediment and nutrient modelling in the Burdekin NRM region. Volume 3. In: The use of SedNet and ANNEX models to guide GBR catchment sediment and nutrient target setting., Cogle AL, Carroll C, Sherman B (eds.) Queensland Department of Natural Resources, Mines and Water. QNRM06138, pp: 218 pp.

Furuichi T, Olley J, Lewis S, Wilkinson SN, Burton J. 2014. Identifying erosion processes and sources in the Burdekin dry tropics catchment – Technical Report: Knowledge Gap 2 – Spatial source tracing. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Hughes AO, Olley JM, Croke JC, McKergow LA. 2009. Sediment source changes over the last 250 years in a dry-tropical catchment, central Queensland, Australia. Geomorphology, 104: 262-275. http://dx.doi.org/10.1016/j.geomorph.2008.09.003.

Kinsey-Henderson A, Sherman B, Bartley R. 2007. Improved SedNet Modelling of Grazing Lands in the Burdekin Catchment. CSIRO Land and Water.

Kroon F, Turner R, Smith R, Warne M, Hunter H, Bartley R, Wilkinson S, Lewis S, Waters D, Carroll C. 2013. Sources of sediment, nutrients, pesticides and other pollutants in the Great Barrier Reef catchment, Chapter 4. In: Land use impacts on Great Barrier Reef water quality and ecosystem condition: 2013 Scientific Consensus Statement, Brodie J, Waterhouse J, Schaffelke B, Kroon F, Thorburn P, Rolfe J, Johnson J, Fabricius K, Lewis S, Devlin M, Warne M, McKenzie L (eds.) The State of Queensland, pp: 35.

Kroon FJ, Kuhnert PM, Henderson BL, Wilkinson SN, Kinsey-Henderson A, Abbott B, Brodie JE, Turner DR. 2012. River loads of suspended solids, nitrogen, phosphorus and herbicides to the Great Barrier Reef lagoon. Marine Pollution Bulletin, 65: 167–181. http://dx.doi.org/10.1016/j.marpolbul.2011.10.018.

Larcombe, P., Woolfe, K.J., 1999. Increased sediment supply to the Great Barrier Reef will not increase sediment accumulation at most coral reefs. Coral Reefs 18, 163-169.

Lewis SE, Bainbridge ZT, Sherman BS, Kuhnert P, Henderson B, Cooper M, Brodie JE. 2013. Calculating sediment trapping efficiencies for reservoirs in tropical settings: a case study from the Burdekin Falls Dam, NE Australia. Water Resources Research, 49: 1017-1029. 10.1002/wrcr.20117.

Lewis S, Olley J, Furuichi T, Sharma A, Burton J. 2014. Complex sediment deposition history on a wide continental shelf:Implications for the calculation of accumulation rates on the Great Barrier Reef. Earth and Planetary Science Letters, 393: 146-158.

Lewis S, Furuichi T, Olley J, Wilkinson S, Sharma A, Burton J. 2014. Identifying erosion processes and sources in the Burdekin dry tropics catchment – Technical Report: Knowledge Gap 3 – The temporal changes in the sources of sediment deposited in the GBR Lagoon. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Orpin, A.R., Ridd, P.V., 2012. Exposure of inshore corals to suspended sediments due to wave-resuspension and rive plumes in the central Great Barrier Reef: A reappraisal. Cont. Shelf Res. 47, 55-67.

Orpin, A.R., Brunskill, G.J., Zagorskis, I., Woolfe, K.J., 2004. Patterns of mixed siliciclastic-carbonate sedimentation adjacent to a large dry-tropics river on the central Great Barrier Reef shelf, Australia. Aust. J Earth Sci. 51, 665-683.

Lambrechts, J., Humphrey, C., McKinna, L., Gourge, O., Fabricius, K.E., Mehta, A.J., Lewis, S., Wolanski, E., 2010. Importance of wave-induced bed liquefaction in the fine sediment budget of Cleveland Bay, Great Barrier Reef. Estuar. Coast. Shelf Sci. 89, 154-162.

Lovett S, Price Pe. 1999. Riparian land management technical guidelines Vol 1/2. LWRRDC.

McCulloch, M., Fallon, S., Wyndham, T., Hendy, E., Lough, J. and Barnes, D., 2003. Coral record of increased sediment flux to the inner Great Barrier Reef since European Settlement. Nature, 421: 727-730.

Olley J, Brooks A, Spencer J, Pietsch T, Borombovits D. 2013. Subsoil erosion dominates the supply of fine sediment to rivers draining into Princess Charlotte Bay, Australia. Journal of Environmental Radioactivity, 124: 121-129. http://dx.doi.org/10.1016/j.jenvrad.2013.04.010.

Gilad U, Denham R, Tindall D. 2012. Gullies, Google Earth and the Great Barrier Reef: A remote sensing methodology for mapping gullies over extensive areas. In: XXII ISPRS Congress, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B8.

Post D, Bartley B, Corfield J, Nelson B, Kinsey-Henderson A, Hawdon A, Gordon I, Abbott B, Berthelsen S, Hodgen M, Keen R, Kemei J, Vleeshouwer J, MacLeod N, Webb M. 2006. Sustainable grazing for a healthy Burdekin catchment. CSIRO Land and Water.

Prosser IP, Moran C, Lu H, Scott A, Rustomji P, Stevenson J, Priestley C, Roth CH, Post D. 2002. Regional patterns of erosion and sediment transport in the Burdekin River catchment. CSIRO Land and Water Technical Report 5/02, pp: 44 pp.

Roff, G., Clark, T.R., Reymond, C.E., Zhao, J-x., Feng, Y., McCook, L.J., Done, T.J., Pandolfi, J.M., 2012. Palaeoecological evidence of a historical collapse of corals at Pelorus Island, inshore Great Barrier Reef, following European settlement. Proc. R Soc. B. 20122100. http://dx.doi.org/10.1098/rspb.2012.2100

Thorburn P, Rolfe J, Wilkinson S, Silburn M, Blake J, Gongora M, Windle J, VanderGragt M, Wegscheidl C, Ronan M, Carroll C. 2013a. The water quality and economic benefits of agricultural management practices, Chapter 5. In: Land use impacts on Great Barrier Reef water quality and ecosystem condition: 2013 Scientific Consensus Statement, Brodie J, Waterhouse J, Schaffelke B, Kroon F, Thorburn P, Rolfe J, Johnson J, Fabricius K, Lewis S, Devlin M, Warne M, McKenzie L (eds.) The State of Queensland, pp: 45.

Thorburn PJ, Wilkinson SN. 2013. Conceptual frameworks for estimating the water quality benefits of improved land management practices in large catchments Agriculture Ecosystems & Environment, 180: 192-209. http://dx.doi.org/10.1016/j.agee.2011.12.021.

Thorburn PJ, Wilkinson SN, Silburn DM. 2013b. Water quality in agricultural lands draining to the Great Barrier Reef: Causes, management and priorities Agriculture Ecosystems & Environment, 180: 4-20. http://dx.doi.org/10.1016/j.agee.2013.07.006

Turner. R, Huggins. R, Wallace. R, Smith. R, Vardy. S, Warne. M St. J. 2012, Sediment, Nutrient and Pesticide Loads: Great Barrier Reef Catchment Loads Monitoring 2009-2010, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Turner, R., Huggins, R., Wallace, R., Smith, R., Vardy, S., Warne, M.St.J., 2013. Loads of sediment, nutrients and pesticides discharged from high priority Queensland rivers in 2010-2011. Great Barrier Reef Catchment Loads Monitoring Program, Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Tims SG, Everett SE, Fifield LK, Hancock GJ, Bartley R. 2010. Plutonium as a tracer of soil and sediment movement in the Herbert River, Australia. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 268: 1150-1154.

Wasson RJ, Caitcheon G, Murray AS, McCulloch M, Quade J. 2002. Sourcing Sediment Using Multiple Tracers in the Catchment of Lake Argyle, Northwestern Australia. Environmental Management, 29: 634–646, DOI: 610.1007/s00267-00001-00049-00264.

Wasson RJ, Furlonger L, Parry D, Pietsch T, Valentine E, Williams D. 2010. Sediment sources and channel dynamics, Daly River, Northern Australia. Geomorphology, 114: 161-174. 10.1016/j.geomorph.2009.06.022.

Webster, I.T., Ford, P.W., 2010. Delivery, deposition and redistribution of fine sediment within macrotidal Fitzroy Estuary/Keppel Bay: southern Great Barrier Reef, Australia. Cont. Shelf Res. 30, 793-805.

Wilkinson SN, Hancock GJ, Bartley B, Hawdon AA, Keen RJ. 2013. Using sediment tracing to assess processes and spatial patterns of erosion in grazed rangelands, Burdekin River basin, Australia. Agriculture Ecosystems & Environment, 180: 90-102. http://dx.doi.org/10.1016/j.agee.2012.02.002.

Wilkinson SN, Olley J, Furuichi T, Burton J. 2014. Identifying erosion processes and sources in the Burdekin dry tropics catchment – Technical Report: Knowledge Gap 1 – Erosion process tracing. Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Woolfe, K.J., Larcombe, P., 1998. Terrigenous sediment accumulation as a regional control on the distribution of reef carbonates. In: Camoin, G.F., Davies P.J., (Eds.) Reefs and Carbonate Platforms in the Pacific and Indian Oceans Special Publication International Association of Sedimentologists 25, pp. 295-310.