Tropical Water Quality Hub

National **Environmental Science** Programme

MUCH MORE THAN JUST SEDIMENTS: The Importance of Sediment Composition for Great Barrier Reef Ecosystems

Stephen Lewis and Zoe Bainbridge
TropWATER, James Cook University, Townsville

Image: Tom Stevens

This report should be cited as:
Lewis, S. and Bainbridge, Z. (2021) Much more than just sediments: The importance of sediment composition for Great Barrier Reef ecosystems. Report to the National Environmental Science Program. Reef Rainforest Research Centre Limited, Cairns (20pp.).

Published by the Reef and Rainforest Research Centre on behalf of the Australian Government's National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub.

The Tropical Water Quality Hub is part of the Australian Government's National Environmental Science Program and is administered by the Reef and Rainforest Research Centre Limited (RRRC). The NESP TWQ Hub addresses water quality and coastal management in the World Heritage listed Great Barrier Reef, its catchments and other tropical waters, through the generation and transfer of world-class research and shared knowledge.

This report is available for download from the NESP Tropical Water Quality Hub website: **www.nesptropical.edu.au**

www.synthesis.nesptropical.edu.au

Introduction

The National Environmental Science Program (NESP) Tropical Water Quality (TWQ) Hub invested in research to improve understanding of the sources, transformation and influence of riverine-derived sediment and associated particulate nutrients in the Great Barrier Reef (GBR) to deliver improved methods for monitoring its influence in the GBR and prioritise catchment remediation efforts for managers. This research has taken a ‘catchment to reef’ approach to answer a series of specific questions about the most important characteristics of sediment delivered to the GBR and the potential ecological implications of these characteristics (Figure 1).

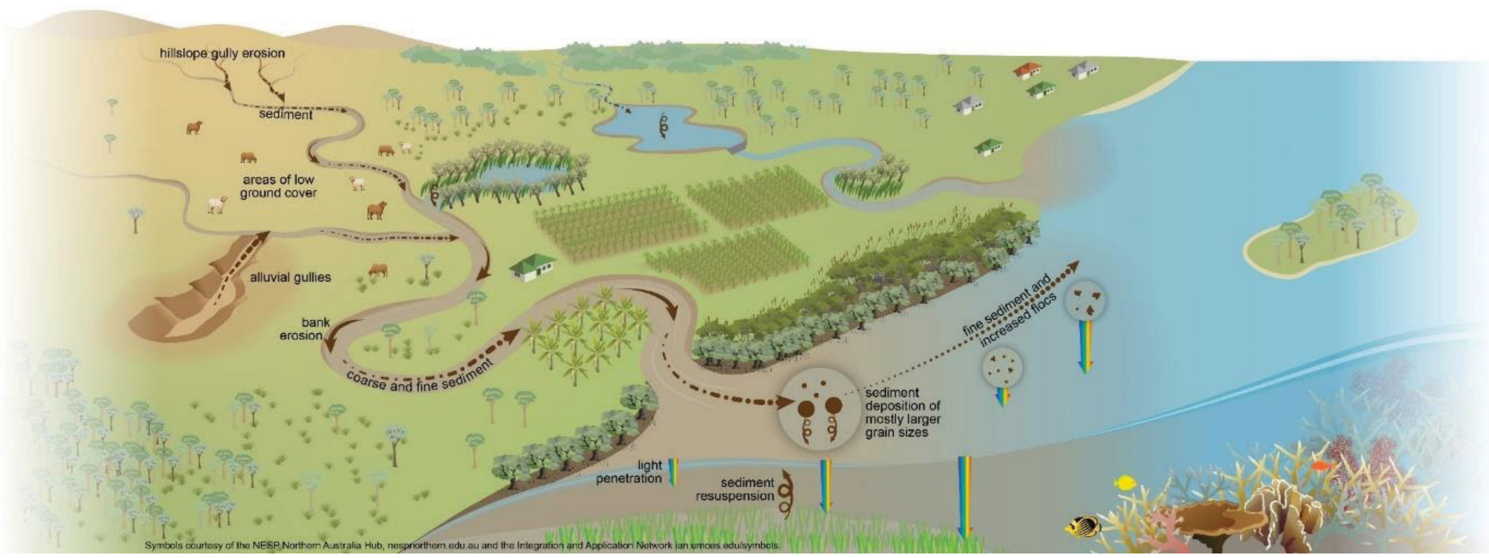

Figure 1: *Conceptual understanding of sediment sources and transport across the catchment to marine continuum.*

Hub research has enabled us to now identify the most damaging properties of sediment, associated particulate nutrients and its effects on ecological communities as it moves from catchment to reef. It is the fine grained (colloidal, clay and fine silts <20 µm), organic-rich sediment that has a critical impact on marine ecosystems through both direct effects (i.e. smothering) and increased reduction of benthic light relative to sediments produced in the marine environment.

Marine sediments are commonly lighter in colour, carbonate-rich and mostly (but not always) coarser compared with land-sourced sediments. An improved understanding of the influence (including potential impacts) of sediment on GBR ecosystems and the ‘sea to source’ connections and interactions is required to guide management responses that reduce sediment delivery to the GBR.

Several NESP TWQ Hub projects built on this knowledge to extend the ability of managers to improve management of sediment discharged from the GBR catchments:

- Project 2.1.5 and Project 5.8 What's really damaging the reef? Tracing the origin and fate of the environmentally detrimental sediment and associated bioavailable nutrients. Stephen Lewis[1], Zoe Bainbridge[1], Thomas Stevens[1], Cassandra James[1], Scott Smithers[1], Joanne Burton[2], Alexandra Garzon-Garcia[2], Jon Olley[3], Chengrong Chen[3], Mohammad Bahadori[3], Mehran Rezaei Rashti[3].

- Project 3.3 Light thresholds for seagrasses of the GBRWHA: a synthesis and guiding document. Catherine Collier[1], Katie Chartrand[1], Carol Honchin[7], Adam Fletcher[8], Michael Rasheed[1].

- Project 5.4 Deriving ecologically relevant targets to meet desired ecosystem condition for the Great Barrier Reef: a case study for seagrass meadows in the Burdekin region. Catherine Collier[1], Alex Carter[1], Megan Saunders[4], Vikki Lambert[4], Matthew Adams[4], Kate O'Brien[4], Mark Baird[5], Michael Rasheed[1], Len McKenzie[1], Rob Coles[1]

- Project 2.1.9 Risk assessing dredging activities. Ross Jones[6], Rebecca Fisher[6], David Francis[9], Wojciech Klonowski[10], Heidi Luter[6], Andrew Negri[6], Mari-Carmen Pineda[6], Gerard Ricardo[6], Matt Slivkoff[10], James Whinney[1]

- Project 2.3.1 and Project 5.3 Benthic light as ecologically-validated GBR-wide indicator for water quality drivers, thresholds and cumulative risks. Barbara Robson[6], Marites Canto[1,6], Catherine Collier[1], Stephanie di Perna[1,6], Murray Logan[6], Patricia Menendez[6], Lachlan McKinna[11], Sam Noonan[6], Katharina Fabricius[6]

Author affiliations: [1]James Cook University, [2]Department of Environment and Science,[3]Griffith University, [4]University of Queensland, [5]CSIRO, [6]AIMS, [7]GBRMPA, [8]Ports North, [9]Deakin University, [10]In situ Marine Optics, [11]Go2Q.

Specific questions about this product should be directed to:

Dr Stephen Lewis, TropWATER, James Cook University
Stephen.lewis@jcu.edu.au

Dr Zoe Bainbridge, TropWATER, James Cook University
Zoe.bainbridge@jcu.edu.au

Abbreviations

DIN	Dissolved inorganic nitrogen
GBR	Great Barrier Reef
NESP	National Environmental Science Program
RMS	Relative mean square
SPM	Suspended particulate matter
SSC	Suspended sediment concentration
TWQ	Tropical Water Quality

Background

The influence of anthropogenic sediment and associated particulate nutrients delivered to the GBR lagoon on water clarity has been disputed over the past few decades. Much of this debate is centred on the contribution and influence of the 'newly delivered sediment' derived from flood plumes compared with the 'existing sediment' that is regularly disturbed from the seabed by wave action (termed 'sediment resuspension'). Over the past decade, we have improved our knowledge on the transport, transformation, exposure, impact and fate of land-based runoff of sediment and its associated particulate nutrients in the GBR which has been important to guide management efforts.

Prior to 2016 (commencement of the NESP TWQ Hub), the following key principles were established:

- For the larger rivers that deliver the highest sediment loads to the GBR (e.g. Burdekin and Fitzroy), most (> 80%) of the sediment is deposited near the river mouth and retained, i.e. this deposited fine sediment is not subsequently reworked and transported northwards via longshore drift; hence it is the suspended particulate matter (SPM) carried in flood plumes that contribute the 'newly delivered sediment' in the GBR (Lewis et al. 2014, 2015; Delandmeter et al. 2015).
- Fine sediment (clay and fine silt fractions) present within organic-rich large sediment flocs[1] is the SPM most likely to travel the furthest in flood plumes in the GBR (Bainbridge et al. 2012).
- A correlation between seasons of elevated river discharge (and related sediment/nutrient loads) and reduced water clarity/photic depth in the subsequent months has been established for many parts of the GBR lagoon (Fabricius et al. 2013, 2014, 2016).
- Distinct water quality and environmental gradients extending offshore from river mouths have been demonstrated that highlight the variability of terrestrial riverine influence (Fabricius et al. 2005; Udy et al. 2005; Cooper et al. 2007; Lewis et al. 2012).
- Examination of sediment dynamics including (i) changing sedimentation rates and associated reduced light availability on coral reefs resulting from riverine flood and storm events (Wolanski et al. 2005, 2008), and (ii) the impact of increased sediment loads within algal turfs on herbivory rates on coral reefs (Goatley and Bellwood, 2012, 2013; Goatley et al. 2016; Gordon et al. 2016).
- A link between elevated river discharge (and related sediment/nutrient loads), light reductions and seagrass meadow area has been established (Collier et al. 2012; Petus et al. 2014).
- Light thresholds have been developed for specific seagrass species (Collier et al. 2014).
- Empirical and modelled data have been used to set 'ecologically relevant targets' for sediment loads based on relationships between sediment load and light to meet the established thresholds (Brodie et al. 2017).

[1] Sediment flocs are mineral particles bound with plankton and other sticky organic matter

This NESP TWQ Hub research has direct relevance to managing sediments in the Great Barrier Reef and sought to understand:

1. What is the influence of newly-delivered sediment (i.e. from river plumes) on turbidity regimes at inshore GBR coral reef and seagrass locations?
    - If no influence of the newly delivered sediment can be found on turbidity regimes then reducing the loads of sediment delivered from the rivers become less of a priority. Examining this also allowed for a better appreciation of the specific ecosystems and spatial areas that are likely influenced by the delivery of new sediment.

2. What are the main characteristics of the suspended particulate matter that influence light and turbidity regimes and how do these change in flood plumes as salinity increases with (sediment) transport away from the river mouth?
    - Better identifying the 'most damaging' sediment in the Great Barrier Reef (i.e. the suspended sediment that travels furthest) so that it can be traced back to a catchment source(s).

3. Can particulate nitrogen from catchment sources be transformed during delivery to the marine environment to become bioavailable, and why does this matter?
    - The potential additional nutrient contribution of suspended sediments which places additional value on managed reductions of suspended sediment sources (i.e. gain both sediment and nutrient reductions)

4. What is the contribution and influence of the anthropogenic component of this sediment on GBR turbidity regimes?

Key Findings

1. What is the influence of newly-delivered sediment (i.e. from river plumes) on turbidity regimes at inshore GBR coral reef and seagrass locations?

The spatial and temporal influence of newly delivered riverine sediment on turbidity (and benthic light) on the prevailing marine sediment resuspension regime has been debated for at least three decades. The complexity of this issue hinges on our ability to quantify and separate the contribution of the suspended sediment discharged from rivers (and its resuspension in subsequent months) from those produced by wave-driven resuspension of the existing compacted seafloor. Furthermore, the influence of the newly delivered sediment was quantified spatially across the inshore GBR so that the key ecosystems that are influenced can be identified.

Turbidity and light loggers and sediment traps were installed from June 2016 to March 2020 along a longitudinal gradient offshore from the Burdekin River mouth (Figure 2) in the Dry Tropics region (Lewis et al. 2020). Loggers and traps were also deployed at Dunk Island off the mouth of the Tully River from June 2016 to March 2019.

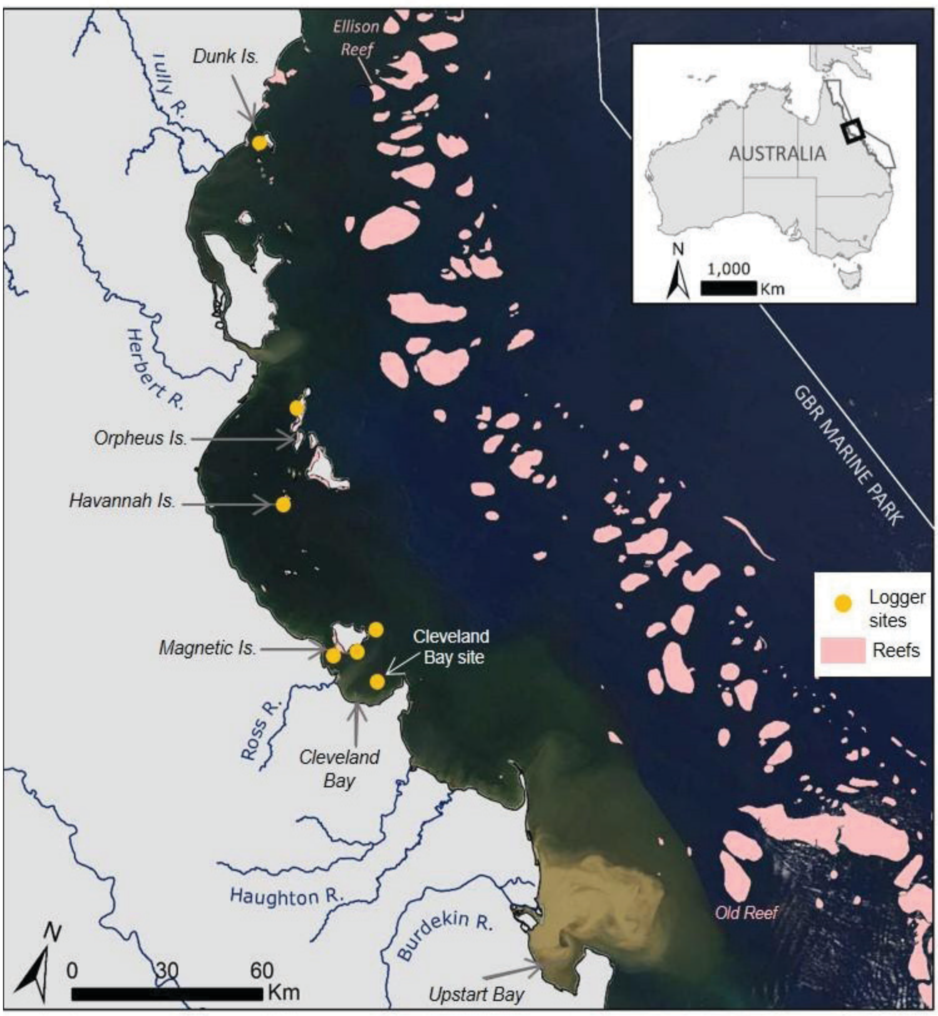

Figure 2: *Map of the turbidity and light logger and sediment trap sites positioned to capture the influence of the Burdekin River. An additional site at Dunk Island was deployed to capture the influence of the Tully River. The base MODIS (Aqua true-colour) satellite image was captured on the 12th February 2019 following peak discharge at the Burdekin River mouth, highlighting a visible turbid sediment plume ('primary water type' defined by ocean colour class) and less turbid secondary waters moving northwards along the Queensland coastline (image adapted from Bainbridge et al. 2021). Reefs shown as pink polygons.*

The loggers (‘nephelometers’) were deployed ~ 50 cm above the seafloor (Figure 3) over 2 to 3 month periods and captured continuous 10 min measurements of turbidity, light and the relative mean square (RMS) variability in pressure (a measure of wave energy) while the sediment traps capture the total sediment mass over each deployment period.

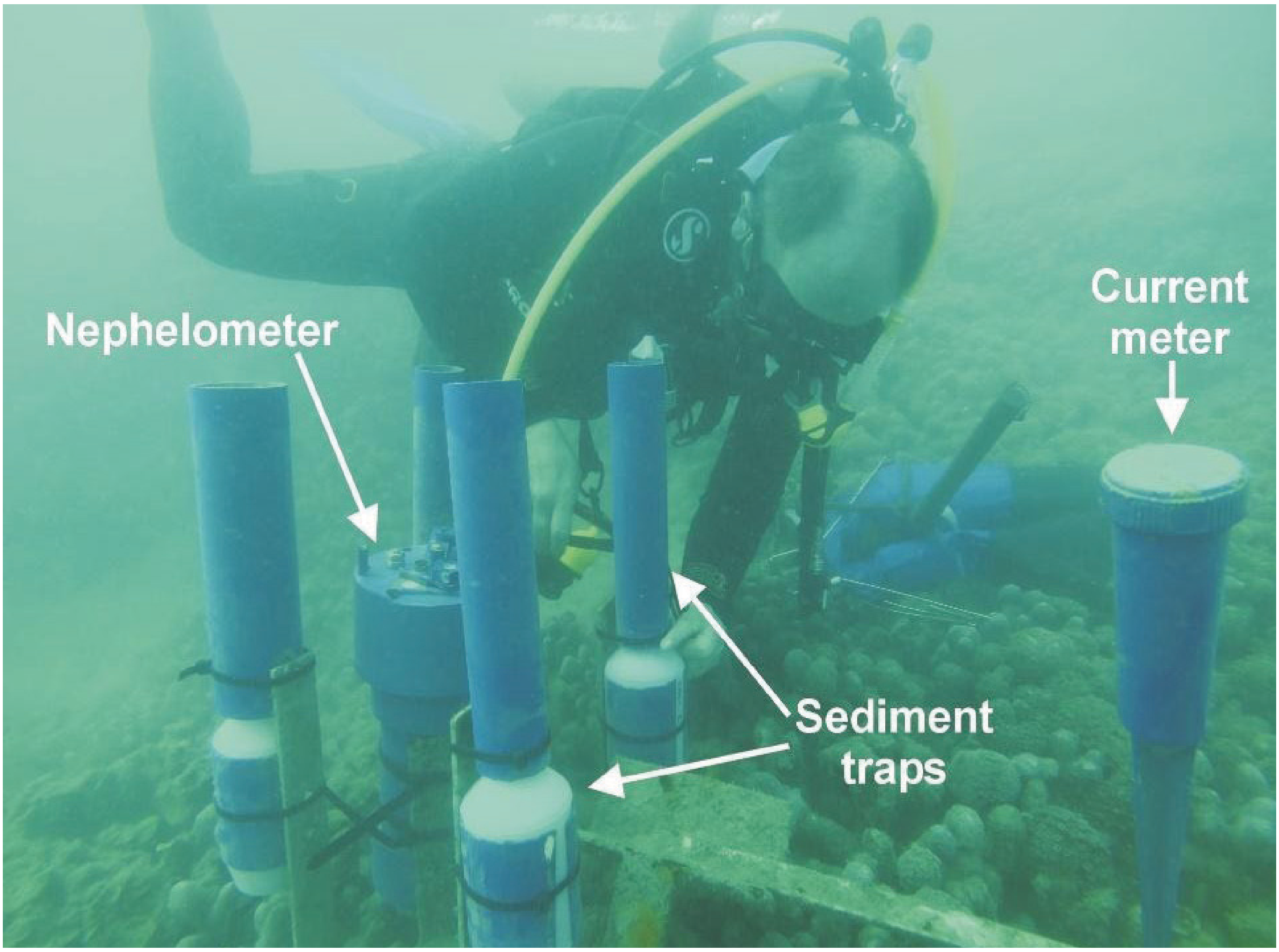

Figure 3: *Typical instrument set up at the seven sites with nephelometer (turbidity, light and RMS pressure sensors), current meter and four replicated sediment traps (Image: Ian McLeod).*

The collected data showed a clear influence of newly delivered flood plume sediment on both the initial SPM concentration (measured as suspended sediment concentration (SSC) converted from turbidity measurements) and the resultant light regime, during the plume event and, at some sites, in the resuspension events over the few months following the flood event (Figure 4). Specifically, the 2019 flood event (which was > 3 times the median discharge for the Black, Ross, Haughton and Burdekin Basins) resulted in the highest SPM concentration measured in the turbidity loggers and/or the highest accumulation rates (and highest total nutrient concentrations) in sediment traps of the data collected over the 4-year monitoring period (2016-2020). These data build on and independently support the previous research findings of Fabricius et al. (2014, 2016) who highlighted the influence of river discharge and associated loads on satellite measured photic depth[2], particularly across the inshore and mid shelf sections of the GBR. The temporal influence of the newly delivered sediment on turbidity regimes can range from the period of exposure of the plume (i.e. days to 1-2 weeks) to several months following the flood event due to the repeated resuspension of this newly delivered (and deposited) sediment. The particulate nutrients associated with this newly delivered SPM also likely favour the proliferation of macroalgae growth at coral reef sites (Lewis et al. 2020).

[2] Photic depth refers to the depth in the water column where only 1% of the surface irradiance remains

The impact of the newly delivered sediment and associated particulate nutrients in the inshore GBR show:

A) Increased suppression of light in shallow (~ 5 m) turbid water environments over the duration of the flood plume and during the months afterwards, depriving benthic habitats of growth light requirements;

B) Pulsed delivery and deposition of flood plume sediment and associated nutrients to inshore coral reef sites can support an increase in macroalgae cover and corresponding decrease in live coral cover in the months following impact, and;

C) Development of persistent turbidity (and reduced photic depth) resulting from wave and current disturbance driving resuspension of the seafloor or from newly delivered sediment.

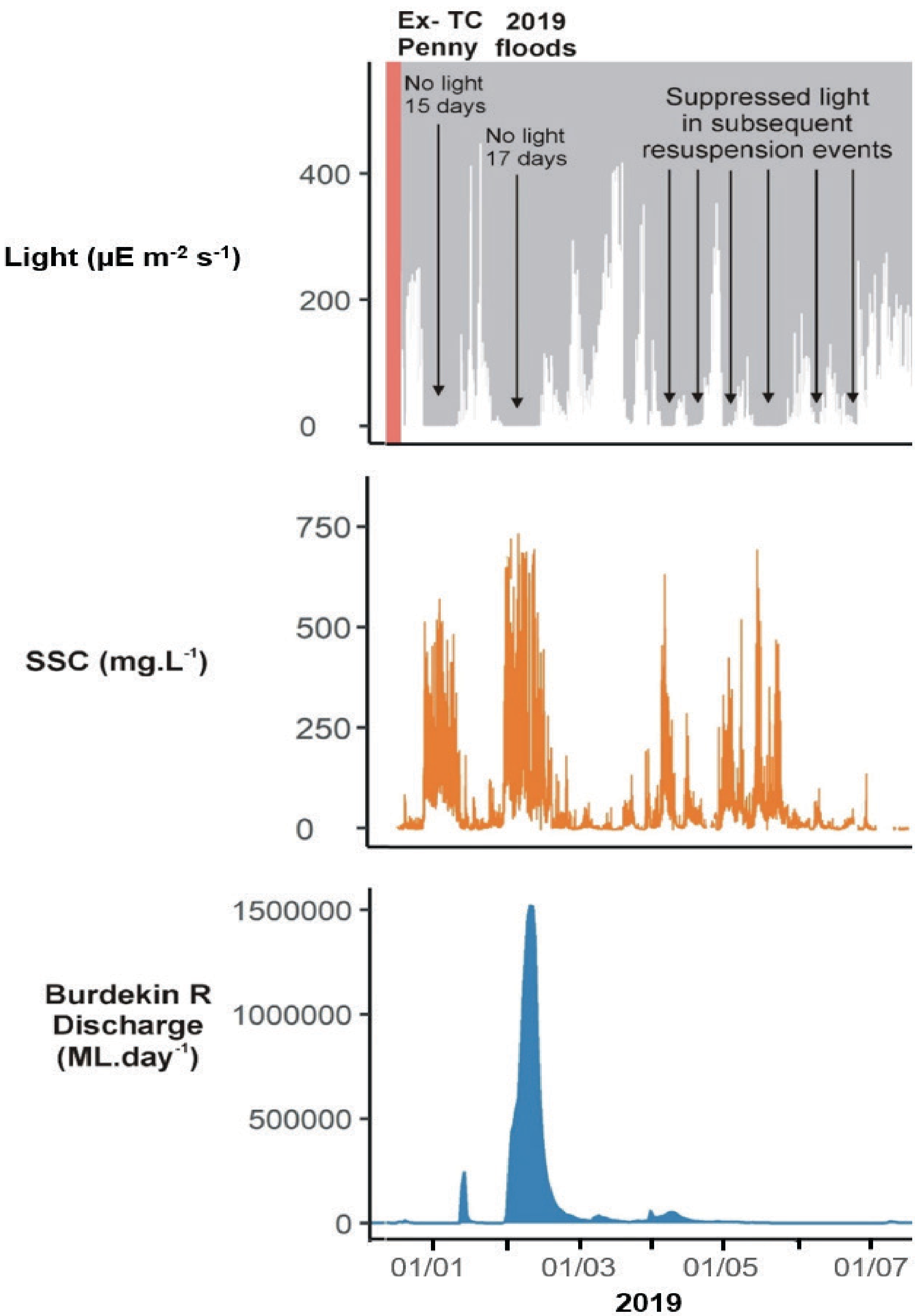

Figure 4: *Logger data from Cleveland Bay demonstrate the relatively high suspended sediment concentrations (SSC) and corresponding low light conditions in the water column from the large resuspension event triggered by Ex-Tropical Cyclone Penny and the 2019 floods. In addition to local river discharge entering Cleveland Bay, the Burdekin River discharged 14.5 million ML during the three week period 30/01-19/02; an event of this size has an approximate 1 in 5 return interval. Importantly, the subsequent resuspension events in the months following the 2019 flood (lighter wind/wave conditions) also produced suppressed light conditions beyond what would be expected in the absence of a flood (Lewis et al. 2020).*

A) Suppression of light during and after a flood plume:

Logger data collected from the Cleveland Bay site (~ 5 m water depth) demonstrated the influence of two considerable events in the 2018/19 wet season (Figure 4). The first event was triggered by Ex-Tropical Cyclone Penny in 2019 which produced a large wave-driven resuspension event, while the second event was associated with 2019 flood events (Burdekin and local rivers). Elevated SSCs (> 50 mg L^{-1}) measured by the logger coincided with both events and the light sensor showed that light did not reach the seafloor for periods of weeks during each of these events (Figure 4). Importantly, the resuspension events in the months following the 2019 flood event showed suppressed light conditions with SSC concentrations above what would be expected under the wind and wave regime in absence of the recent flood. This highlights one of the influences of newly delivered sediment to the GBR, indicating that benthic ecosystems that rely on surface light (e.g. coral and seagrass) and that are exposed to such conditions could potentially receive suppressed light for long periods both during and in the months after the event (e.g. Fabricius et al. 2016; Strahl et al. 2019; Lewis et al. 2020). Strong linkages have also been found between reduced seagrass condition/extent and the occurrence of single (2019 flood) and consecutive large flood events from the Burdekin River relating to these suppressed light conditions (Collier et al. 2012; Petus et al. 2014; Lambert et al. 2021; McKenna et al. 2020; McKenzie et al. 2020).

B) Pulsed delivery and deposition:

Large stands of macroalgae were observed at the Havannah Island inshore fringing reef (Figure 2) during site visits following the 2019 floods. This was the first and only time this growth was observed over the four-year monitoring program (Lewis et al. 2020). Based on this evidence, it was postulated that the newly delivered sediment and associated particulate nutrients were deposited at the site during the flood event which then fostered the proliferation of macroalgae. This increase in macroalgae abundance is clearly related to a disturbance event (i.e. likely the 2019 flood), although the key mechanism that drives such overgrowth on coral reefs is less understood (e.g. see McCook, 1999; McCook et al. 2001). This site is known to undergo shifts to macroalgae dominance following similar large acute disturbance events such as bleaching and storms (e.g. Cheal et al. 2010). At coral reef sites exposed to occasional large flood plume events, the newly delivered sediment likely becomes trapped and retained within either the coral reef framework (acting as a baffle) or within algal turfs (Tebbett et al. 2018) and is less likely to be resuspended.

C) Elevated and persistent turbidity:

NESP TWQ Hub research highlights relatively small changes in water column SPM/turbidity concentration (i.e. an increase by ~ 1 mg L^{-1} or ~ 1 NTU) can reduce water clarity by over half (Lewis et al. 2020). Elevated SPM concentrations not only reduce light available to reach the seafloor but also the quality of the light spectra – or 'photosynthetically usable light' by corals and seagrasses (see Jones et al. 2020a). These new findings can help guide improved monitoring and characterisation of SPM and its influence on water column light in the marine environment. As the total suspended solid method is unlikely to have the precision required to document small changes (i.e. 1 mg L^{-1}), a more suitable approach to capture potential SPM and associated light changes in marine settings would be the direct measurements of benthic light, Secchi disk depth and turbidity. Hub research on dredging influence has also shown that direct measurements of seabed light availability provides a more ecologically relevant measurement than assessment of the water clarity (Jones et al. 2020a).

2. What are the main characteristics of the suspended particulate matter that influence light and turbidity regimes and how do these change in flood plumes as salinity increases with transport away from the river mouth?

NESP TWQ Hub research highlights the transformation of SPM across the catchment to the marine environment. Terrestrial mineral particles become finer (colloidal, clay and fine silt grains <20 µm), more organically rich, and form larger floc aggregates (mineral particles bound with plankton and other sticky organic matter) as they move further offshore in river flood plumes (Bainbridge et al. 2018, 2021; Figure 5).

Figure 5 presents a satellite image of the Burdekin plume that highlights the different colours of the flood waters in the GBR. The flood water colours can be classified into three distinct plume types termed primary (brown water), secondary (green water) and tertiary (blue-green water), which are characterised by different concentrations of optically active components (SPM, colour dissolved organic matter and chlorophyll a), which determine the colour of the water and influence the light attenuation (Petus et al. 2019). The figure highlights the changing concentration and composition of the SPM across these water types in an offshore transect from the river mouth. Despite distinct compositional differences of the SPM in the end of river discharge from GBR ‘wet’ (Tully River) and ‘dry’ (Burdekin River) tropical rivers, secondary water types of these two river plumes were characterised by similar SPM concentrations (<5 mg L^{-1}) and relatively high organic contents. Large floc aggregates, commonly 100-200 µm in size, were routinely observed in secondary waters both inshore, and as far out as the GBR mid-shelf e.g. Ellison Reef (Tully transect) and Old Reef (Burdekin transect) (Bainbridge et al. 2021). These organic-rich floc aggregates strongly influence light attenuation and are easily resuspended due to their lower density compared to older, consolidated seafloor sediments. At these distal locations, flocculated particles were found to remain in suspension throughout the water column in the weeks following peak discharge. Large floc aggregates were also captured in inshore sediment trap deployments coinciding with these river flood plume periods.

Additional NESP TWQ Hub field and laboratory research by Jones et al. (2019, 2020a, 2020b) highlights that sediment type (i.e. mineral vs marine carbonate) will strongly influence ecosystem effect thresholds, and disproportionately affect the extent of benthic light reductions (see also Storlazzi et al. 2015). For instance, organic-rich mineral clays suspended in the water column, which are consistent with the sediment type typically observed in flood plumes, were identified to have the greatest impact on coral reproduction compared to other sediment types that were examined (Ricardo et al. 2018). Emphasising the significance of this finding, there is growing evidence of the impact of reduced light conditions associated with increased sediment concentration on the physiology of more sensitive species of coral and crustose coralline algae, (Bessell-Browne et al. 2017; DiPerna et al. 2018; Strahl et al. 2019), sponges (Pineda et al. 2016) and various seagrass communities (Collier et al. 2016; Chartrand et al. 2018).

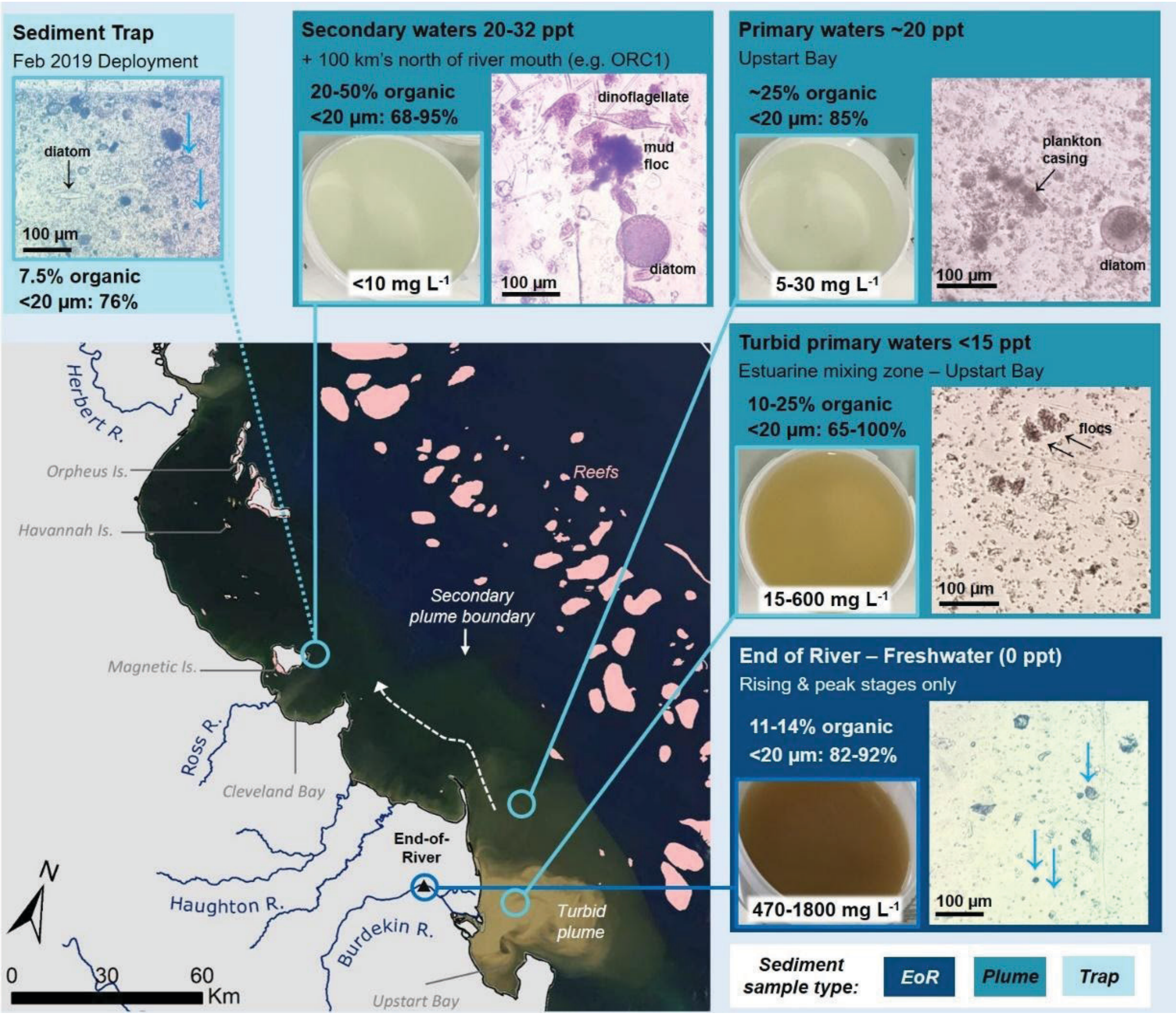

Figure 5: *Conceptual diagram of the changing characteristics of Burdekin River and flood plume sediment with samples collected along a salinity gradient from the river mouth, during three distinct river discharge events (2017–2019) from Bainbridge et al. (2021). End-of-river (freshwater), primary and secondary flood plumes and a sediment trap site that captured these flood plume events are all presented, anticlockwise from bottom right (refer to legend). Each box summarises the ranges of salinity, particulate organic content, proportion of fine sediment (<20 µm) and SPM concentration (mg L*$^{-1}$*) measured for all samples collected within each of these water types over the three events. Each box also contains a typical image of a collected 'grab' sample, and microscope imagery of a representative water sample highlighting the mineral grains of various sizes, and an increasing presence of plankton and floc aggregates as the plume water is transported away from the river mouth.*

3. Can particulate nitrogen from catchment sources be transformed during delivery to the marine environment to to become bioavailable, and why does this matter?

NESP TWQ Hub research describes the transformation of the organic matter across the catchment to reef continuum and the role of different microbial communities that influence these transitions. In particular, analysis of the various forms of carbon functional groups within organic matter in the Johnstone and Burdekin catchments show that the more bioavailable groups of carbon reduce as the organics are transported from the soil (i.e. most bioavailable) to freshwater and finally, to the marine environment (i.e. least bioavailable) (Lewis et al. 2020). This reduction of the bioavailable carbon groups is facilitated largely by different bacterial microbial communities which appear to be associated with different parts of the environment (i.e. *Proteobacteria*, *Actinobacteria* and *Acidobacteria*, the predominant groups in soil and freshwater plume sediments; and *Protobacteria* and *Bacteroidetes* dominantly associated within the estuarine flood plume and trap sediments – this highlights the key microbial communities that process carbon across the catchment to reef continuum). The processing of organic matter by these bacterial communities in riverine flood plumes results in the conversion of particulate nitrogen to a more bioavailable form (i.e. dissolved inorganic nitrogen: DIN; Figure 6).

Fine sediment draining from rivers into the GBR can fuel algal primary production by generating bioavailable nutrients (e.g. DIN). The magnitude of DIN generation from sediment depends on the sediment source soil type, the source of erosion (surface versus subsurface), sediment particle size and composition of the organics (Garzon-Garcia et al. 2018). The amount of DIN produced in flood plumes by desorption of particulate inorganic nitrogen or by microbial processing of particulate and dissolved organic nitrogen has been quantified for the Burdekin and Tully Rivers with quite different results (Garzon-Garcia et al. 2021). It was found that the sediment and associated particulate nitrogen have the potential to continue to produce DIN once it is transported and deposited on the marine floor and/or resuspended.

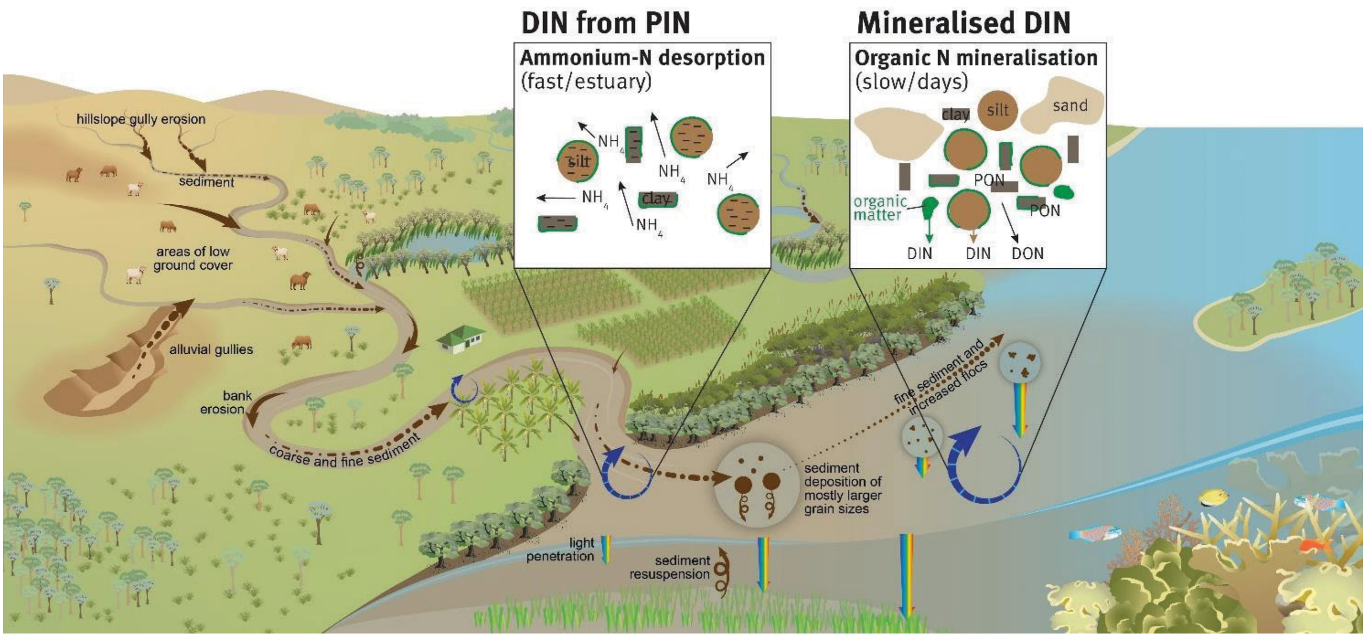

Figure 6: *Conceptual diagram of the key processes that release dissolved inorganic nitrogen (DIN) from particulate nitrogen in the river flood plume (Garzon-Garcia et al., 2018; 2021; in prep). Ammonium-N desorption: the ammonium (NH_4+-N) adsorbed to the negatively charged silt and clay particles becomes soluble through cation exchange processes (e.g. exchange of ammonium with sodium or magnesium) in water. This process would tend to occur when terrestrial sediment first mixes with saline water in the estuaries. Organic N mineralisation: the organic fraction of nitrogen associated with the eroded sediment is mineralised to DIN during sediment transport in suspension by the action of micro-organisms (bacteria and fungi). This process would continue to occur slowly in sediment plumes as they enter the estuarine and marine environment.*

4. What is the contribution and influence of the anthropogenic component of this sediment on the GBR turbidity regimes?

With the determination that there is an influence of the newly delivered sediment on the inshore GBR, the anthropogenic contribution (i.e. the additional sediment and particulate nutrient loads from rivers above natural levels) need to be considered for management intervention(s). The development and refinement of the eReefs model platform including the incorporation of a 'fluffy layer' or 'dust'-sized particles into the model (Margvelashvili et al. 2018) has greatly improved our ability to evaluate the influence of anthropogenic sediments throughout much of the GBR (Baird et al. 2021). The latest eReefs modelling quantifies the influence of the anthropogenic sediment component on TSS concentrations, Secchi disc depth and bottom photosynthetically active radiation (Bottom PAR) across the GBR lagoon (Baird et al. 2021). Independent examination using preliminary calculations (calculating the 'sediment load' held within flood plumes and knowledge of the anthropogenic sediment load) suggest that approximately 2 mg L^{-1} of the SPM transported in secondary Burdekin River plume waters could be considered anthropogenic (Lewis et al. 2020). A change of this magnitude could have considerable consequences for water clarity and benthic light levels in the GBR (Jones et al. 2020a; Lewis et al. 2020). Empirical data-based modelling have linked Burdekin River discharge and sediment loads with seagrass meadow area and condition in Cleveland Bay (Lambert et al. 2021). This research provides additional evidence that reductions in sediment loads from the Burdekin catchment likely translate to improved ecological outcomes and highlights the link between the 'additional sediment' and seagrass health.

Conclusions

NESP TWQ Hub research has greatly advanced our understanding of the transport, transformations, influence and impact of newly delivered sediment and associated particulate nutrients in the Great Barrier Reef.

- Fine sediments (<20 µm) are of greatest concern to marine ecosystems as they remain in suspension and can be transported in flood plumes and currents over long distances. These finer sediments have greater potential impact on benthic light transmission, due to their higher surface area per unit volume, lower settling rates and their potential to transform into organic-rich flocs which adhere to marine organisms (i.e. coral tissue, seagrass leaves) as well as being more easily resuspended following initial settling.
- Fine sediments also produce an additional DIN contribution to the GBR lagoon where desorption of ammonium from the sediment particles occurs when the freshwaters first mix with seawater and through bacterial microbial processing of the organic matter in the outer sections of the flood plume.
- *In situ* logger data show the influence of the newly delivered sediment at inshore sites, where the highest suspended sediment concentrations coincide with the period of the flood plume. At some sites, these sediment concentrations are elevated in resuspension events for several months following the initial flood plume which suppress light conditions.
- Other sites, including inshore coral reefs, showed enhanced macroalgae growth can occur following large flood plume events; this is potentially related to the influx of newly delivered sediment and associated particulate nutrients to the site. Relatively small changes (1 mg L^{-1}) in the concentrations of SPM can produce large reductions in water clarity in the marine environment and managing anthropogenic sediment exported to the GBR is a critical component to improve water quality.

Acknowledgements

This research is funded by the Australian Government's National Environmental Science Program (NESP) through the Tropical Water Quality (TWQ) Hub, with additional funding from the Queensland Department of Environment and Science's Reef Water Quality Science Program and in-kind support from the Chemistry Centre, Landscape Sciences, Department of Environment and Science (DES).

We acknowledge the NESP TWQ Hub Project 5.8 team and research outcomes which form the basis of this synthesis. We are grateful to Jane Waterhouse, Catherine Collier, David Haynes, Alex Garzon-Garcia and Joanne Burton for providing review of this document.

Further Reading

Bainbridge, ZT., Wolanski, E., Alvarez-Romero, JG., Lewis, SE. and 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.

Bainbridge, Z., Lewis, S., Bartley, R., Fabricius, K., Collier, C., Waterhouse, J., Garzon-Garcia, A., Robson, B., Burton, J., Wenger, A., Brodie, J., 2018. Fine sediment and particulate organic matter: a review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. Marine Pollution Bulletin 135, 1205-20.

Bainbridge, Z., Lewis, S., Stevens, T., Petus, C., Lazarus, E., Gorman, J., Smithers, S. (2021). Measuring sediment grain size across the catchment to reef continuum: Improved methods and environmental insights. Marine Pollution Bulletin 168, 112339.

Baird, M.E. Mongin, M. Skerratt, J. Margvelashvili, N. Tickell, S. Steven, A.D.L. Robillot, C. Ellis, R. Waters, D. Kaniewska, P. Brodie, J. In press. Impact of catchment-derived nutrients and sediments on marine water quality on the Great Barrier Reef: An application of the eReefs marine modelling system. Marine Pollution Bulletin.

Bessell-Browne, P., Negri, A. P., Fisher, R., Clode, P. L., & Jones, R. 2017. Impacts of light limitation on corals and crustose coralline algae. Scientific Reports 7(1), 11553.

Brodie, J.E. Lewis, S. Wooldridge, S. Bainbridge, Z.T. Waterhouse, J. Honchin, C. Holmes, G. Fabricius, K. Collier, C. Rasheed, M. 2017. Setting ecologically relevant targets for river pollutant loads to meet marine water quality requirements for the Great Barrier Reef, Australia: A preliminary methodology and analysis. Ocean and Coastal Management 143, 136-147.

Chartrand, K.M., Szabó, M., Sinutok, S., Rasheed, M.A. & Ralph, P.J. 2018. Living at the margins–The response of deep-water seagrasses to light and temperature renders them susceptible to acute impacts. Marine Environmental Research 136, 126-138.

Cheal, A.J., MacNeil, M.A., Cripps, E., Emslie, M.J., Jonker, M., Schaffelke, B. & Sweatman, H. 2010. Coral–macroalgal phase shifts or reef resilience: links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs 29(4), 1005-1015.

Collier, C. J., M. Waycott, and L. J. McKenzie. 2012. Light thresholds derived from seagrass loss in the coastal zone of the northern Great Barrier Reef, Australia. Ecological Indicators 23, 211-219.

Collier, C., Devlin, M., Langlois, L., Petus, C., McKenzie, L. Petus, C, Texeira da Silva, E., McMahon, K, Adams, M, O'Brien, K., Statton, J. and Waycott, M. 2014. Thresholds and indicators of declining water quality as tools for tropical seagrass management. Report to the National Environmental Research Program. Reef and Rainforest Research Centre Limited, Cairns (46pp.)

Collier, C. J., Chartrand, K., Honchin, C., Fletcher, A., & Rasheed, M. 2016. Light thresholds for seagrasses of the GBR: a synthesis and guiding document. Including knowledge gaps and future priorities. Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Ltd, Cairns.

Cooper, T.F., Uthicke, S., Humphrey, C. and Fabricius, K.E. 2007. Gradients in water column nutrients, sediment parameters, irradiance and coral reef development in the Whitsunday Region, central Great Barrier Reef. Estuarine, Coastal and Shelf Science 74(3), 458-470.

Delandmeter, P. Lewis, S. Lambrechts, J. Deleernsijder, E. Legat, V. Wolanski, E. 2015. 3D modelling of the transport and fate of riverine fine sediment exported to a semi-enclosed system. Estuarine, Coastal and Shelf Science 167, 336-346.

DiPerna, S., Hoogenboom, M., Noonan, S. and Fabricius, K. 2018. Effects of variability in daily light integrals on the photophysiology of the corals Pachyseris speciosa and Acropora millepora. PloS one 13(9), 0203882.

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

Fabricius, KE., Logan, M., Weeks, S., Brodie, J., 2014. The effects of river run-off on water clarity across the central Great Barrier Reef. Marine Pollution Bulletin 84(1-2), 191-200.

Fabricius, KE., Logan, M., Weeks, SJ., Lewis, SE. and Brodie, J. 2016. Changes in water clarity in response to river discharges on the Great Barrier Reef continental shelf: 2002-2013. Estuarine, Coastal and Shelf Science 173, A1-A15.

Garzon-Garcia, A., Burton, J., Ellis, R., Askildsen, M., Finn, L., Moody, P., DeHayr, R. 2018. Sediment particle size and contribution of eroded soils to dissolved inorganic nitrogen export in Great Barrier Reef catchments. Brisbane: Department of Environment and Science, Queensland Government.

Garzon-Garcia, A., Burton, J.M., Lewis, S., Bainbridge, Z., De Hayr, R., Moody, P., Brodie, J. 2021. The bioavailability of nitrogen associated with sediment in riverine plumes Marine Pollution Bulletin 173, 112910

Garzon-Garcia, A., Burton, J., Ellis, R., Askildsen, M., Moody, P., DeHayr, R. In preparation. The bioavailability of particulate nitrogen in sediment: catchment sources and processes.

Goatley, C. H. R., and D. R. Bellwood. 2012. Sediment suppresses herbivory across a coral reef depth gradient. Biology Letters 8, 1016-1018.

Goatley, C. H. R., and D. R. Bellwood. 2013. Ecological consequences of sediment on high-energy coral reefs. PLoS ONE 8, e77737.

Goatley, C. H. R., R. M. Bonaldo, R. J. Fox, and D. R. Bellwood. 2016. Sediments and herbivory as sensitive indicators of coral reef degradation. Ecology and Society 21(1), 29.

Gordon, S. E., C. H. R. Goatley, and D. R. Bellwood. 2016. Low quality sediments deter grazing by the parrotfish Scarus rivulatus on inner-shelf reefs. Coral Reefs 35, 285-291.

Jones, R., Fisher, R., & Bessell-Browne, P. 2019. Sediment deposition and coral smothering. PLoS ONE 14(6), 0216248.

Jones, R., Fisher, R., Francis, D., Klonowski, W., Luter, H., Negri, A., Pineda, MC., Ricardo, G., Slivkoff, M. and Whinney, J. 2020a. Risk Assessing Dredging Activities in Shallow-Water Mesophotic Reefs. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (78 pp).

Jones, R., Giofre, N., Luter, H.M., Neoh, T.L., Fisher, R. & Duckworth, A. 2020b. Responses of corals to chronic turbidity. Scientific Reports 10(1), 1-13.

Humanes, A., Ricardo, G.F., Willis, B.L., Fabricius, K.E. & Negri, A.P. 2017. Cumulative effects of suspended sediments, organic nutrients and temperature stress on early life history stages of the coral Acropora tenuis. Scientific Reports 7(1), 1-11.

Lambert, V. Bainbridge, Z.T. Collier, C. Lewis, S.E. Adams, M.P. Carter, A. Saunders, M.I. Brodie, J. Turner, R.D.R. Rasheed, M.A. O'Brien, K.R. 2021. Connecting targets for catchment sediment loads to ecological outcomes for seagrass using multiple lines of evidence. Marine Pollution Bulletin 169, 112494.

Lewis, S.E., Brodie, J.E., McCulloch, M.T., Mallela, J., Jupiter, S.D., Williams, H.S., Lough, J.M., Matson, E.G. 2012. An assessment of an environmental gradient using coral geochemical records, Whitsunday Islands, Great Barrier Reef, Australia. Marine Pollution Bulletin 65(4-9), 306-319.

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.

Lewis S., Packett, R. Dougall, C. Brodie, J. Bartley R., Silburn, M. 2015. Fitzroy sediment story. Report No. 15/74 for the Fitzroy Basin Association, Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Townsville, 38 pp.

Lewis, S., Bainbridge, Z. Stevens, T., Garzon-Garcia, A., Chen, C., Bahadori, M., Burton, J., Rezaei Rashti, M., James, C., Smithers, S. and Olley, J. 2020. What's really damaging the Reef?: Tracing the origin and fate of the ecologically detrimental sediment and associated bioavailable nutrients. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (254 pp.).

Luter, H.M., Pineda, M.C., Ricardo, G., Francis, D.S., Fisher, R. and Jones, R., 2021. Assessing the risk of light reduction from natural sediment resuspension events and dredging activities in an inshore turbid reef environment. Marine Pollution Bulletin, 170, p.112536.

Magno-Canto, M.M., McKinna, L.I., Robson, B.J. and Fabricius, K.E. 2019. Model for deriving benthic irradiance in the Great Barrier Reef from MODIS satellite imagery. Optics Express 27(20), A1350-A1371.

Margvelashvili, N., Andrewartha, J., Baird, M., Herzfeld, M., Jones, E., Mongin, M., Rizwi, F., Robson, B.J., Skerratt, J., Wild-Allen, K. and Steven, A., 2018. Simulated fate of catchment-derived sediment on the Great Barrier Reef shelf. Marine Pollution Bulletin 135, 954-962.

McCook, L.J. 1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs, 18, 357-367.

McCook, L.J. Jompa, J. Diaz-Pulido, G. 2001. Competition between corals and algae on coral reefs: a review of evidence and mechanisms. Coral Reefs, 19, 400-417.

McKenna, S., K. Chartrand, C. Van De Wetering, J. N. Wells, A. B. Carter, and M. Rasheed. 2020. Port of Townsville Seagrass Monitoring Program: 2019. Cairns.

McKenzie, L. J., C. J. Collier, L. A. Langlois, R. L. Yoshida, J. Uusitalo, N. Smith, and M. Waycott. 2020. Marine Monitoring Program: Annual Report for inshore seagrass monitoring 2018-2019. Great Barrier Reef Marine Park Authority, Townsville.

Petus, C., Collier, C., Devlin, M., Rasheed, M. & McKenna, S. 2014. Using MODIS data for understanding changes in seagrass meadow health: a case study in the Great Barrier Reef (Australia). Marine Environmental Research 98, 68-85.

Petus, C., Waterhouse, J., Lewis, S., Vacher, M., Tracey, D., Devlin, M., 2019. A flood of information: Using Sentinel-3 water colour products to assure continuity in the monitoring of water quality trends in the Great Barrier Reef (Australia). Journal of Environmental Management 248, 109255.

Pineda, M.C., Strehlow, B., Duckworth, A., Doyle, J., Jones, R. & Webster, N.S. 2016. Effects of light attenuation on the sponge holobiont-implications for dredging management. Scientific Reports 6(1), 1-13.

Pineda, M.C. and Waterhouse, J. 2021. Reducing end of catchment fine sediment loads and ecosystem impacts: A synthesis of NESP Tropical Water Quality Hub research. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (68pp.).

Robson, B.J., Canto, M.M., McKinna, L.I., Logan, M., Lewis, S. and Fabricius, K.E. 2021. Benthic light as ecologically-validated GBR-wide indicator for water quality: Drivers, thresholds and cumulative risks. Report to the National Environmental Science Program. Reef and Rainforest Research Centre Limited, Cairns (110pp.).

Ricardo, G.F., Jones, R.J., Clode, P.L., Humanes, A., Giofre, N. & Negri, A.P. 2018. Sediment characteristics influence the fertilisation success of the corals Acropora tenuis and Acropora millepora. Marine Pollution Bulletin 135, 941-953.

Strahl, J., Rocker, M.M. & Fabricius, K.E. 2019. Contrasting responses of the coral Acropora tenuis to moderate and strong light limitation in coastal waters. Marine Environmental Research, 147, pp.80-89.

Storlazzi, C.D., Norris, B.K. & Rosenberger, K.J. 2015. The influence of grain size, grain color, and suspended-sediment concentration on light attenuation: Why fine-grained terrestrial sediment is bad for coral reef ecosystems. Coral Reefs 34(3), 967-975.

Tebbett, S.B., Goatley, C.H. & Bellwood, D.R., 2018. Algal turf sediments across the Great Barrier Reef: Putting coastal reefs in perspective. Marine Pollution Bulletin 137, 518-525.

Udy, J., Gall, M., Longstaff, B., Moore, K., Roelfsema, C., Spooner, D.R. and Albert, S. 2005. Water quality monitoring: a combined approach to investigate gradients of change in the Great Barrier Reef, Australia. Marine Pollution Bulletin 51(1-4), 224-238.

Wolanski, E., Fabricius, K., Spagnol, S. and Brinkman, R. 2005. Fine sediment budget on an inner-shelf coral-fringed island, Great Barrier Reef of Australia. Estuarine, Coastal and Shelf Science 65, 153-158.

Wolanski, E., Fabricius, K.E., Cooper, T.F. and Humphrey, C. 2008. Wet season fine sediment dynamics on the inner shelf of the Great Barrier Reef. Estuarine, Coastal and Shelf Science 77, 755-762.

Image: Tom Stevens

This project is supported through funding from the Australian Government's National Environmental Science Program

www.nesptropical.edu.au