Improvements to water quality monitoring through the inclusion of ocean colour products correlated with in-situ water quality gradients for the Great Barrier Reef

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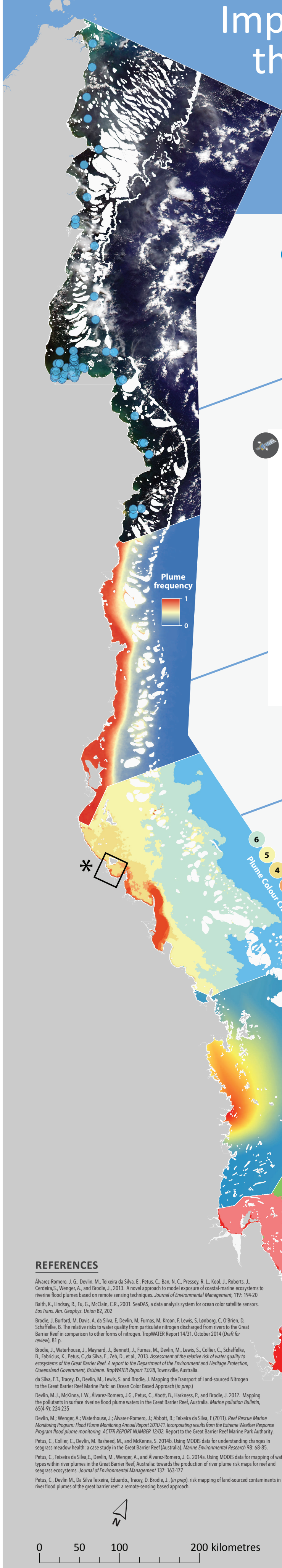


BACKGROUND

There has been a well-recognized link between declining water quality and the ecological health of coastal ecosystems for the Great Barrier Reef (GBR).

A strong driver of water quality change in the GBR is the pulsed nature of river flow into marine ecosystems driving delivery of potentially damaging pollutants through river flow.

On average, 70 km^3 of freshwater is discharged each year by rivers and streams into the GBR lagoon (Furnas 2003), and its delivered in discrete, short-lived flood events during the 5-month summer wet season, forming distinct flood plumes in the coastal zone that sometimes reach far out into the lagoon.

The Reef Rescue Marine Monitoring Program (MMP) was established in 2005 to help assess the long-term status and health of GBR ecosystems and is a critical component in the assessment of water quality as land management practices are improved across GBR catchments.

OBJECTIVES

The wet season Water Quality Program under the MMP has a particular focus on sampling and describing the extent and content of the river plumes and assessment of the acute and chronic impacts associated with the inputs from terrestrial discharge. As part of this, the program aims to map and model the spatial and temporal extent of the water quality conditions as measured by in-situ sampling and satellite imagery, particularly through the use of ocean colour products. Specifically it is aimed at:

- Identify human induced and natural changes in water quality parameters in the GBR waters by monitoring river flood plumes water.
- Developing of maps and models of the river flood plumes to summarize land-sourced pollutants transport and light levels within the GBR lagoon.
- Evaluating the susceptibility of GBR key ecosystems to the river plume/pollutants exposure.

1. COLLECTION OF WATER SAMPLES FOR WATER QUALITY ANALYSES

Wet season water quality data have been collected as part of the MMP, aiming to investigate the acute and chronic influence of terrestrial runoff on inshore GBR water quality (Johnson *et al.* 2011; Devlin *et al.* 2011).

Water samples for this work were collected along six regions of the northeastern Australian coast within the GBR including: the Normanby (14.4°S), Tully (18°S), Herbert (18.5°S), Burdekin (19.5°S), Mackay WS, (20.7°S), and Fitzroy (23.5°S) regions.

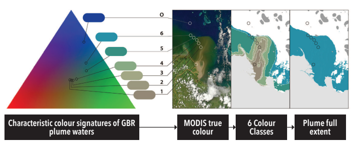
Discrete regional cross-shelf transects have been monitored within each region during the wet season (ca. December to April) from 2006 to 2013. Sampling was initiated at the onset of the wet season, targeting the period after first flush, the rise, peak and flux of high river flow conditions. Sampling parameters include dissolved and total nutrients, total suspended solids, dissolved organic matter, chlorophyll, phytoplankton community descriptors, PSII herbicides and CTD (conductivity, temperature and depth) profiles with measurements for light attenuation and dissolved oxygen.

2. REMOTE SENSING MAPPING OF FLOOD PLUMES

Prior to RS imagery availability, the extent of plumes were mapped using aerial surveys. Plumes were readily observable as brown turbid water masses contrasting with the clearer seawater. The visible edge of the plume was followed at an altitude of 1000–2000m in a light aircraft and mapped using a global positioning system (GPS).

The current flood plume mapping now utilises information available from satellite imagery. This method uses daily MODIS Level-0 data acquired from the NASA Ocean Colour website (http://oceancolour.gsfc.nasa.gov) that are processed to quasi-true color images (spatial resolution of 500 m × 500 m), using the SeaWiFS Data Analysis System (Álvarez-Romero *et al.* (2013, SeaDAS; Baith *et al.* 2001). The true-colour images are then spectrally enhanced (from red-green-blue to hue-saturation-intensity colour system) and classified to six ocean colour categories through a supervised classification using spectral signatures from plume water in the GBR. These ocean colour classes are correlated to a change in water quality gradients specific to the wet season conditions.

Color classes 1 to 3 correspond to the brownish turbid water masses with high sediment and CDOM concentrations, classes 4 and 5 to to the greener water masses with lower sediment concentrations and increased chl-a concentrations and class 6 is the transitional water mass between plume waters and marine waters.

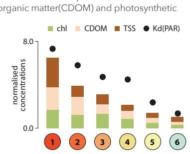


METHODS

Triangular color plot showing the characteristic colour signatures of the Great Barrier Reef river plume waters (six color classes) in the Red-Green-Blue space. A method has been developed to map the GBR river plumes and the different water masses inside the river plumes using these characteristic signatures and a supervised classification of MODIS true color data.

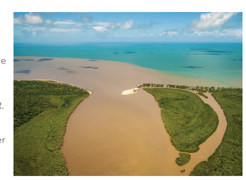
3. LINKING REMOTE SENSING IMAGES TO IN-SITU DATA

The six colour classes characterized in the plume maps are based on optical properties of the flood plume waters and reflect different concentrations of total suspended sediments (TSS), coloured dissolved organic matter(CDOM) and photosynthetic phytoplankton pigment (mainly chlorophyll a). Extending this concept, variations in these colour classes represent water masses with different WQ characteristics. This concept is tested throughmatch-ups between in-situ data and the six-colour class maps.. Several parameters were investigated and Dissolved Inorganic Nitrogen (DIN), Particulate Nitrogen (PN), , PN, TSS and PSII herbicides have shown consistent patterns of variation across the six-colour class. All these parameters present a general reduction trend from class 1 (more inshore waters) to colour class 6 (more offshore waters), providing a method that characterises the annual and multi-annual frequency of colour class mapped in plume water with different WQ characteristics.



4. MAPPING LAND-SOURCED CONTAMINANTS TRANSPORT

The frequency and extent of the influence of flood plumes containing differing concentrations of pollutants (e.g., DIN, PN and TSS) are used to provide an estimation of the extent of surface exposure of these pollutants to coral reefs and seagrass.. Pollutants plume load maps are produced by combining in-situ data collected under the MMP with, plume maps derived from MODIS imagery and monitored end-of-catchment pollutant load in each wet season (c.a., Dec. to Apr., inclusive) from 2003 to 2013 (Brodie *et al.*, 2014; da Silva *et al.*, in prep.). The river loads provide the amount of a pollutant that has been delivered along the GBR. The in-situ data provides the pollutant mass variation as a function of the river plume movement away from the river mouth. The satellite imagery provides the direction and intensity the pollutant mass is transported over the GBR lagoon. As a result, this method produces maps of pollutants dispersion in the GBR waters expressed in mass per area, which are converted to concentration maps by dividing them by the bathymetry of the GBR lagoon. Annual maps of pollutants have been produced to describe differences in GBR exposure to these pollutants.



River runoff is the principal carrier of sediment, nutrients and contaminants from the land into coastal and inshore lagoon waters of the Great Barrier Reef

5. SUSCEPTIBILITY OF KEY GBR ECOSYSTEMS

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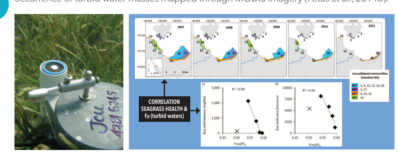
Spatial outputs of the remote sensing methods help identifying and clustering areas and ecosystems which may experience acute or chronic high exposure to river plumes (exposure assessment) and thus, help evaluating the likely adverse responses of GBR ecosystems to land-sourced contaminants (Petus *et al.*, 2014a). River plume maps produced have been used as an interpretative tool for understanding changes in seagrass meadow health in the GBR, and decline in seagrass meadow area and biomass has been positively linked to high occurrence of turbid water masses mapped through MODIS imagery (Petus *et al.*, 2014b).



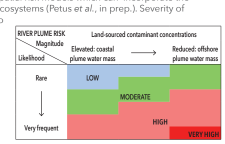
Location and spatial extent of the seagrass meadows monitored in Cleveland Bay from October 2007 to October 2011, and correlation between annual total seagrass a) biomasses and b) areas and the mean annual frequencies of Primary water type (Fp. Hu: *Halodule uninervis* (thin)-dominated communities, Cs: *Cymodocea serrulata*-dominated communities, Zm: *Zostera muelleri*-dominated communities, and Hs: *Halophila spinulosa*-dominated communities. Trendlines and determination coefficient are computed without considering the year 2009 (cross symbol).

DATA SOURCES

- Remote sensing
- In situ water quality
- Catchment loads
- Coral monitoring
- Seagrass monitoring
- Modelling

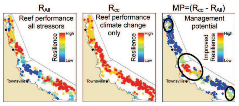
6. SPATIAL RISK MAPS

There is the need to enhance the GBR remote sensing models todevelop spatial risk models which can incorporate the combined effects of contaminants with the susceptibility of the individual ecosystems (Petus *et al.*, in prep.). Severity of individual ecosystem response to the single stressors can be combined into a single indicator of the ecosystem response. This exercise is challenging because the response of GBR ecosystems to frequency and intensity of exposure to land-sourced contaminants (respectively or combined) in plume waters are often unknown at a regional or ecosystem level (Brodie *et al.*, 2013). Time series of MODIS plume water masses maps can help by summarizing the likelihood and magnitude of the river plume risk. This can be done by spatially clustering water masses with different concentrations and proportions of land-sourced contaminants. A framework to produce river plume risk maps for seagrass and coral ecosystems based on a simplified risk matrix has been proposed in Petus *et al.* (2014a). Work is in progress to test and improve this simplified approach.



7. THE WAY FORWARD: INTEGRATION WITH MODELS

We are currently integrating our empirically derived products with hydrodynamic models. Virtual (modelled) river tracers allow us to assess the relative contribution of each watershed to observed plume characteristics. We then explore the impacts that different land management scenarios will have on plume - ecosystem interactions. For example, we are using this approach, combined with coral trajectory models, to assess the future vulnerability of reefs to both local (water quality) and global (climate change) stressors. Results will help with marine spatial planning decision making, by identifying those reefs that will most benefit from land management improvements, and which catchments should be prioritized from a cost-benefit point of view.



Initial coral trajectory model runs for the next 30 years identified reefs that are performing worse (see the blues in A) than the effects of climate change alone would suggest (B). These are the reefs that have the most local management potential via improved water quality measures (outlined in black in panel C).

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