



# Ecologically relevant targets for pollutant discharge from the drainage basins of the Fitzroy Region, Great Barrier Reef

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Prepared for the Fitzroy Basin Association by Jon Brodie, Stephen Lewis, Scott Wooldridge,  
Zoe Bainbridge, Jane Waterhouse, Carol Honchin



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## Ecologically relevant targets for pollutant discharge from the drainage basins of the Fitzroy Region, Great Barrier Reef

Jon Brodie<sup>1</sup>, Stephen Lewis<sup>1</sup>, Scott Wooldridge<sup>1,2</sup>, Zoe Bainbridge<sup>1</sup>,  
Jane Waterhouse<sup>3</sup> Carol Honchin<sup>4</sup>

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1. TropWATER, James Cook University, Townsville
2. Australian Institute of Marine Science, Townsville
3. C<sub>2</sub>O Consulting, Townsville
4. Great Barrier Reef Marine Park Authority, Townsville

### Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)

James Cook University  
Townsville

**Phone :** (07) 4781 4262

**Email:** TropWATER@jcu.edu.au

**Web:** www.jcu.edu.au/tropwater/

### Executive summary

#### *Ecologically Relevant Targets*

Ecologically relevant targets (ERTs) attempt to define the pollutant load reductions that would be required to meet the Great Barrier Reef (GBR) Water Quality Guidelines, which are set at a standard considered to be suitable to maintain ecosystem health. Thus ERTs are required to be met to achieve the overall long-term Reef Plan goal “To ensure that by 2020 the quality of water entering the reef from broadscale land use has no detrimental effect on the reef’s health and resilience”. The Reef Plan 2013 Targets (RPTs) were only set at the whole of GBR scale (hence not for individual basins) and were not set to achieve this overall goal. ERTs have been set for all the basins in the Fitzroy region where possible, for the main pollutants addressed in the Reef Plan 2013 targets. In addition RPTs have been set for the Fitzroy Region basins based on the overall GBR RPTs. Both sets of targets, Reef Plan 2013 targets for 2018 and ERTs, are shown in Table E1.

The methods for deriving the ERTs vary between the pollutants. These are summarised below, and described in detail in the body of this report.

#### *Total Suspended Sediments and particulate nitrogen and phosphorus targets*

Ecologically relevant targets for suspended sediments are derived from understanding the impacts of sedimentation and turbidity on coral communities and seagrass meadows, and the relationships between end of catchment loads and turbidity in the receiving environment. The suspended sediment of most risk to the GBR (as it is the fraction that is transported furthest in flood plumes, stays in suspension longest (Storlazzi et al. 2015) and results in the greatest degree of resuspension) is the fine fraction sometimes defined as that smaller than 15.7  $\mu\text{m}$ , i.e. below the fine silt boundary and containing the clay and fine silt fractions (Bainbridge et al. 2012, 2014, 2015; Bartley et al. 2014; Douglas et al. 2008) or of even more risk, just the clay particle size fraction <4  $\mu\text{m}$ . This is the component that contains most of the nitrogen and phosphorus content (and other contaminants), travels widely in flood plumes rather than all depositing near the river mouth (Lewis et al. 2014, 2015a, 2015b), is most effective at attenuating light when in suspension (Storlazzi et al. 2015) and drives increased turbidity on the inner-shelf of the GBR (Fabricius et al. 2013, 2014; Logan et al. 2014, in press). This increased fine sediment supply and hence increased turbidity and sedimentation can have severe impacts on GBR organisms such as reef fish (e.g. Wenger et al. 2011) through effects on juvenile recruitment and feeding; corals through sedimentation (e.g. Weber et al. 2012; Flores et al. 2012; Pollock et al. 2014; Wenger et al. 2015); decreased light for seagrass and corals (Fabricius et al. 2013, 2014; Collier et al. 2012a, 2012b); and increasing the competitive advantage of macro-algae and turf algae over corals (Gowan et al. 2014; Goatley & Bellwood 2012, 2013; Wenger et al. 2015); and seagrass (Petus et al. 2014). Suspended sediment also interacts with other stressors to increase the overall impact of multiple stressors on coral reefs (e.g. Ban et al. 2015; Risk 2014; Graham et al. 2015). Resuspension of sediment in windy conditions or strong tidal currents in shallow waters (<15 m) leads to conditions where suspended sediment concentrations are above the GBR water quality guidelines (De'ath & Fabricius 2008; Great Barrier Reef Marine Park

Authority 2010), and this threatens coral reefs and seagrass meadows through reduced light for photosynthesis (Bartley et al. 2014).

Using this knowledge of ecological relevance and factoring in the availability of data, suspended sediment targets for reduction of the  $<15.7/20\ \mu\text{m}$  fraction have been set. For the purposes of the targets, and within the margin of error of the estimates, the  $<15.7\ \mu\text{m}$  fraction can be equated to the  $<20\ \mu\text{m}$  fraction modelled by Source Catchments. The actual targets are derived from the analysis of the relationship between photic depth and river discharges in the region (Fabricius et al. 2014; Logan et al. 2014, in press). The analysis shows a linear relationship between reduced fine sediment proxied by water volume (and also particulate nitrogen (PN) and particulate phosphorus (PP) loads) and increased Secchi depth (measured as photic depth) and indicates that a 50% reduction of the fine sediment fraction will be sufficient to generally meet the Great Barrier Reef Marine Park Authority (GBRMPA) guidelines for Secchi depth (and thus Suspended Solids (SS) concentrations) for coastal waters for phototrophic benthos at the depths affected.

No total suspended solids (TSS) targets have been set for the other basins in the region as there is either no theoretical underpinning of sediment loads and coastal clarity or there is simply no data to base such an analysis on.

Targets for PN and PP are also for a 50% reduction which will be largely achieved through a 50% reduction in the  $<20\ \mu\text{m}$  fine sediment load.

### *Dissolved inorganic nitrogen targets*

The anthropogenic dissolved inorganic nitrogen (DIN) load from the Fitzroy River is estimated to be 50 tonnes — the result of a total DIN load of 1106 tonnes and a pre-development load of 1057 tonnes (Dougall et al. 2014). In making this estimate it is assumed that no anthropogenic DIN is generated from grazing lands just through the fact of having cattle present. This assumption needs further research as there are certainly some indications that grazed savannah and woodland leaks more DIN than when in an ungrazed (from cattle) state. Thus virtually all anthropogenic DIN in the Fitzroy is assumed to be from grains and cotton cropping but the load is very small, approximately 50 tonnes. Thus the RPT for DIN from the Fitzroy Basin is small i.e. about a 25 tonne reduction and it is highly likely that the ERT will be similarly small. However further effort is required to establish a biogeochemical model for the Fitzroy marine region which would allow ERTs to be more reliably estimated for a chlorophyll  $a$  (Chl- $a$ ).

### *PSII herbicides targets*

The photosystem-II inhibiting herbicides (PSII herbicides) are currently the main pesticides of concern in the GBR, and are thus the only ones specifically addressed in Reef Plan, and concentrations have been detected in some parts of the GBR that are likely to cause negative effects in the freshwater, estuarine and marine environments. A new set of ecotoxicity threshold values have recently been proposed for marine environments (Smith et al., in prep-a), which have been developed to revise and update the Australian and New Zealand Water Quality guidelines. These proposed marine threshold values are available for the PSII herbicides diuron, atrazine, ametryn, hexazinone and tebuthiuron and have been derived using the latest ecotoxicological data and



statistical techniques. It is likely that these guidelines will be adopted for the Great Barrier Reef Marine Park in place of the current GBRMPA (2010) values and are thus used in setting ERTs for these PSII herbicides for the Fitzroy Natural Resource Management (NRM) region. Furthermore, Smith et al. (in prep-b) have developed 'toxic load factors' in order to normalise the PSII herbicide loads/concentrations to a standard 'additive' concentration that can then be compared to a guideline value. Hence we apply the new ecotoxicity threshold values and these toxic load factors at the end-of-river systems across the river basins of the Fitzroy River NRM region as (1) The 99% level of protection is in accordance with the current GBRMPA (2010) guideline's recommendations; (2) The 'additive' toxic load factors have been developed using the latest science and understanding; and (3) if the guideline is met at the end of the river then this ensures that no part of the marine park is negatively affected by a particular herbicide.

While the herbicide concentrations are of most importance to gauge their risk to receiving waters, the Reef Plan targets revolve around annual load reductions. Furthermore Reef Plan targets do not consider the 'toxic load' (i.e. the herbicides are summed and reported as a 'total PSII load' and hence are considered of equal toxicity, although this is known to not be the case). Hence to develop ERTs we normalise the PSII herbicide loads to better reflect their toxic effects and then examine the reductions required to ensure that herbicide concentrations will remain below these ecologically relevant threshold concentrations. As a preliminary approach, we updated the Lewis et al. (2011) model with new monitored load data to produce the individual herbicide load estimations for the Fitzroy basins. We calculated a PSII equivalent 'toxic load' using the toxic load factors proposed by Smith et al. (in prep-b). We then used the predicted PSII normalised (to diuron) concentration and the diuron ecotoxicity value ( $0.08 \mu\text{g.L}^{-1}$ ) to examine the likely reduction required to the end-of-basin loads so that the PSII herbicide concentrations would remain below these values. This analysis suggests that all basins of the Fitzroy NRM region do not require any reduction in current PSII herbicide loads (i.e. diuron, atrazine, ametryn, hexazinone and tebuthiuron) to achieve the guideline values.

However, the increased detection of the herbicide metolachlor (a non-PSII used in broadacre cropping) in the Fitzroy River is of concern as concentrations, at times, have exceeded current 'best estimated' guideline values. Based on our current understanding (and lack of an 'approved guideline value') we suggest that reductions of metolachlor in the Fitzroy are likely in the order of 60 to 70% to achieve ERTs. However this requires more research to validate this finding and we are not including these reductions (in metolachlor) in the current Fitzroy Water Quality Improvement Plan (WQIP).

**Table E1. Summary of pollutant load reduction targets for basins in the Fitzroy region.**

River	Styx	Shoalwater	Waterpark	Fitzroy	Calliope	Boyne
<b>TSS RPT</b>	20%	20%	20%	20%	20%	20%
<b>TSS ERT<sup>1</sup></b>	Not calculable at present	Not calculable at present	Not calculable at present	50% reduction in fine fraction (< 4 µm) SS	Not calculable at present	Not calculable at present
<b>DIN RPT</b>	50%	50%	50%	50%	50%	50%
<b>DIN ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present
<b>PN RPT</b>	20%	20%	20%	20%	20%	20%
<b>PN ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	50%	Not calculable at present	Not calculable at present
<b>PP RPT</b>	20%	20%	20%	20%	20%	20%
<b>PP ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	50%	Not calculable at present	Not calculable at present
<b>DIP RPT</b>	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
<b>DIP ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present
<b>PSII RPT</b>	60%	60%	60%	60%	60%	60%
<b>PSII ERT (diuron equivalent conc.)</b>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>

The table shows two sets of targets: Reef Plan Targets (RPTs) and Ecologically Relevant Targets (ERTs) for Total Suspended Solids (TSS), Dissolved Inorganic Nitrogen (DIN), Particulate Nitrogen (PN), Dissolved Inorganic Phosphorus (DIP), Particulate Phosphorus (PP) and PSII Herbicides (PSII).

The calculations of the TSS load reductions required based on actual particle size analysis from monitored data are only available for the Fitzroy Basin. It should be noted, however, that it is only possible to measure progress towards the 20% or 50% reduction in total SS using the Source Catchments model at this time, which is based on a particle size of <20 µm not <4 µm.

It is critically important to note that all RPTs are based on **% reductions in anthropogenic loads** while ERTs for sediment and nutrients are based on **% reductions in total loads**.

In March 2015 the Reef 2050 Long-Term Sustainability Plan (LTSP)<sup>1</sup> was released. The LTSP is a joint initiative between the Australian and Queensland governments and provides an overarching strategy for management of the GBR, and contains objectives, targets and actions across several themes including: biodiversity, ecosystem health, heritage, water quality, community benefits and

<sup>1</sup> <http://www.environment.gov.au/marine/gbr/publications/reef-2050-long-term-sustainability-plan>

Accessed June 2015



governance. The plan builds on the Reef Plan targets (for 2018) as follows, with the extended LTSP targets in bold:

- at least a 50% reduction in anthropogenic end-of-catchment *dissolved inorganic nitrogen* loads in priority areas, **on the way to achieving up to an 80% reduction in nitrogen in priority areas such as the Wet Tropics and Burdekin by 2025**
- at least a 20% reduction in anthropogenic end-of-catchment loads of sediment in priority areas, **on the way to achieving up to a 50% reduction in priority areas such as the Wet Tropics and Burdekin by 2025**
- at least a 20% reduction in anthropogenic end-of-catchment loads of particulate nutrients in priority areas
- at least a 60% reduction in end-of-catchment pesticide loads in priority areas.

Note the priority areas mentioned in Reef Plan 2013 have never been clearly defined although it is commonly thought that they do apply in parts of the Fitzroy NRM region. In the case of the LTSP the Fitzroy is not specifically mentioned at all. The LTSP targets are comparable with the ERTs defined in this WQIP, however, the timeframes are more ambitious and the wording of the LTSP targets requires further interpretation to identify priority areas and the form of nitrogen under consideration and the particle size of sediment under consideration.

### *Fitzroy Basin Summary — load targets (for Fitzroy Basin) based on 2014 Source Catchments results*

#### *RPTs — by 2018/20*

1. 20% reduction in anthropogenic fine sediment by 2018–2020. Baseline total load = 1,950,000 tonnes; Anthropogenic = 1,410,000 tonnes; pre-development = 540,000 tonnes. Thus 20% reduction involves reduction of 280,000 tonnes leaving the new total load at 1,670,000 tonnes.
2. 50% reduction in anthropogenic DIN. Baseline total load = 1100 tonnes; Anthropogenic = 50 tonnes; pre-development = 1050 tonnes. Thus 50% reduction involves reduction of 25 tonnes leaving the new total load at 1075 tonnes.
3. 60% reduction in PSII. Baseline total load = 530 kg (all anthropogenic). Thus 60% reduction involves a reduction of 320 kg leaving total load of 210 kg.
4. 20% reduction in PN and PP.

### *ERTs — by 2035*

1. 50% reduction in total load i.e. 50% of 1,950,000 = 970,000 tonnes leaving total load of 970,000 tonnes. Progress towards the RPT will obviously take us some way towards the ERT.
2. DIN — no major reduction needed but management of sources where possible.
3. PSII — no reduction needed but management of sources where possible. However, better consideration of risks to freshwater systems will likely require significant management.
4. A 50% reduction in fine sediment will encompass the required reductions in PN and PP.

### 1. Introduction

Riverine pollutant loads to the GBR lagoon have increased substantially since European settlement, with published estimated increases of up to six-fold for suspended sediment, six-fold for nitrogen, and nine-fold for phosphorus (Kroon et al. 2012). The modeled average annual load of six widely used PSII herbicides (atrazine, tebuthiuron, simazine, ametryn, diuron and hexazinone) is estimated to be 17,000 kilograms; however, this is likely to underestimate the total pesticide load, as at least 34 pesticides have been detected in waterways that discharge to the GBR (Brodie et al. 2013a). More recent results from the Source Catchments (SCM) modelling program within the Paddock to Reef Monitoring and Modelling Program (Carroll et al. 2012; Dougall et al. 2014; Waters et al. 2013, 2014) have produced smaller estimates of increases above pre-European *viz* 2.8 times increase for SS, two-times for dissolved inorganic nitrogen (DIN), two-times for dissolved inorganic phosphorus (DIP), three-times for particulate phosphorus (PP) and two-times for particulate nitrogen (PN). These newer, but likely more reliable, estimates (Dougall et al. 2014; Waters et al. 2014) have been used in our process to derive targets described below. The main source of excess nutrients, fine sediments and pesticides is agricultural land use (Waterhouse et al. 2012), with increased loads of (i) fine sediment and particulate nutrients primarily derived from erosion in rangeland grazing and cropping lands; (ii) dissolved inorganic nutrients, particularly nitrogen, associated with fertiliser applications in cropping land uses such as sugarcane and broad acre cropping; and (iii) pesticides (particularly herbicides) primarily sourced from sugarcane cultivation and grazing lands (Brodie et al. 2012, 2013a).

End-of-system load targets for the major pollutants addressed in Reef Plan 2009 were set for the entire Great Barrier Reef in Reef Plan 2009 (Queensland Government 2009). The targets are shown in Table 1. In addition, load targets were set within the Reef Rescue initiative in 2008 (Brodie et al. 2012) as also shown in Table 1. The two sets of targets are loosely linked although internally inconsistent. Both sets of targets were set on the basis of what could be achieved through 'feasible' agricultural management change to 'better' management practices of the Great Barrier Reef Catchment (GBRC) (Brodie et al. 2012). End-of-system load targets for the major pollutants addressed in Reef Plan 2009 were updated in 2013 (Queensland Government 2013). Targets were not established on the basis of ecological realities for the GBR although attempts to design targets of this type have been made (e.g. Brodie et al. 2009). There is no guarantee that the Reef Plan 2009 or Reef Plan 2013 targets will lead to the overall Reef Plan objective "*To ensure that by 2020 the quality of water entering the reef from adjacent catchments has no detrimental impact on the health and resilience of the Great Barrier Reef*". Reef Plan 2013 includes water quality targets and land and catchment management targets to be achieved by 2018 as listed in Table 2.

Targets at a basin-scale were not set during Reef Plan 2009 or Reef Plan 2013. Thus there are no formal Reef Plan targets for the basins of the Fitzroy Region.

**Table 1. Reef Plan (2009) and Reef Rescue (2009) targets.**

Target	Scale (area) for reporting	Reporting frequency
50% Reduction in N load at EOC by 2013	EOC for all GBR catchments	Annual
50% Reduction in P load at EOC by 2013	EOC for all GBR catchments	Annual
Reduce the load of dissolved nutrients from agricultural lands to the GBR lagoon by 25% by 2013	EOC for all GBR catchments	Annual
Reduce the discharge of particulate nutrients from agricultural lands to the GBR lagoon by 10% by 2013	EOC for all GBR catchments	Annual
50% Reduction in pesticide load at EOC by 2013	EOC for all GBR catchments	Annual
Reduce the load of chemicals from agricultural lands to the GBR lagoon by 25% by 2013	EOC for all GBR catchments	Annual
Minimum 50% late dry season groundcover in DT grazing lands by 2013	Sub catchment for Burdekin and Fitzroy.	Annual
20% Reduction in sediment load by 2020	EOC for all GBR catchments	Annual
Reduce the discharge of sediment from agricultural lands to the GBR lagoon by 10% by 2013	EOC for all GBR catchments	Annual
No net loss or degradation of wetlands	Catchment for all GBR catchments	Years 1 and 5
Condition and extent of riparian areas improved	Catchment for all GBR catchments	Years 1 and 5
80% of landholders adopted improved practices	Sub catchment or catchment by sector	Annual
To increase the number of farmers who have adopted land management practices that will improve the quality of water reaching the reef lagoon by a further 1300 over three years	Sub catchment or catchment by sector	Annual progress; major report 2011
50% of landholders adopted improved practices (grazing)	Sub catchment or catchment	Annual

Target	Scale (area) for reporting	Reporting frequency
To increase the number of pastoralists who have improved ground cover monitoring and management in areas where runoff from grazing is contributing significantly to sediment loads and a decline in the quality of water reaching the reef lagoon by a further 1500 over three years	Sub catchment or catchment	Annual progress; major report 2011

Reef Rescue targets shaded. (Note EOC means 'end-of-catchment').

**Table 2. Reef Pan 2013 Targets**

*Reef Plan Water quality targets (2018)*

- At least a 50% reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas.
- At least a 20% reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas.
- At least a 60% reduction in end-of-catchment pesticide loads in priority areas. The PSII herbicides considered are hexazinone, ametryn, atrazine, diuron and tebuthiuron.

*Reef Plan Land and catchment management targets (2018)*

- 90 % of sugar cane, horticulture, cropping and grazing lands are managed using best management practice systems (soil, nutrient and pesticides) in priority areas.
- Minimum 70% late dry season ground cover on grazing lands.
- The extent of riparian vegetation is increased.
- There is no net loss of the extent, and an improvement in the ecological processes and environmental values, of natural wetlands.

The possibility of reaching the overall goal of Reef Plan (see above) of 'no detrimental impact' is also in question given that current 'Best Management Practices' may not be enough to achieve this outcome (Kroon 2012; Thorburn & Wilkinson 2013). Modeling land-use adoption scenarios across the entire GBR has shown that complete adoption of current best management practices in grazing and sugarcane would be sufficient to meet the Reef Plan targets for PSII herbicides, but are

uncertain for suspended sediment, nitrogen and phosphorus (Thorburn & Wilkinson 2013; Thorburn et al. 2013; Waters et al. 2013) and the desired ecological outcomes (Kroon 2012).

In March 2015 the Reef 2050 Long-Term Sustainability Plan (LTSP)<sup>2</sup> was released. The LTSP is a joint initiative between the Australian and Queensland governments and provides an overarching strategy for management of the GBR, and contains objectives, targets and actions across several themes including: biodiversity, ecosystem health, heritage, water quality, community benefits and governance. The plan builds on the Reef Plan targets (for 2018) as follows, with the extended LTSP targets in bold:

- at least a 50% reduction in anthropogenic end-of-catchment *dissolved inorganic nitrogen* loads in priority areas, **on the way to achieving up to an 80% reduction in *nitrogen* in priority areas such as the Wet Tropics and Burdekin by 2025**
- at least a 20% reduction in anthropogenic end-of-catchment loads of sediment in priority areas, **on the way to achieving up to a 50% reduction in priority areas such as the Wet Tropics and Burdekin by 2025**
- at least a 20% reduction in anthropogenic end-of-catchment loads of particulate nutrients in priority areas
- at least a 60% reduction in end-of-catchment pesticide loads in priority areas.

Note the priority areas mentioned in Reef Plan 2013 have never been clearly defined although it is commonly thought that they do apply in parts of the Fitzroy NRM region. In the case of the LTSP the Fitzroy is not specifically mentioned at all. The LTSP targets are comparable with the ERTs defined in this WQIP; however, the timeframes are more ambitious and the wording of the LTSP targets requires further interpretation to identify priority areas and the form of nitrogen under consideration and the particle size of sediment under consideration.

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<sup>2</sup> <http://www.environment.gov.au/marine/gbr/publications/reef-2050-long-term-sustainability-plan>

## 2. Changes in the targets between 2009 and 2013

Large changes in many of the targets were made in Reef Plan 2013. In particular, greatly relaxed targets were set for nitrogen and phosphorus while the sediment target remained unchanged and a small tightening of the pesticide target resulted (from 50% reduction in loads to 60% reduction). In Table 3 we have calculated the changed nitrogen and phosphorus targets resulting from the changes made between Reef Plan 2009 and Reef Plan 2013. This calculation involved using the percentages

of PN to DIN to DON in the Source Catchments estimates for the whole GBR discharge (Waters et al. 2014) and that a reasonable interpretation of the Reef Plan 2013 target of:

- At least a 50% reduction in anthropogenic end-of-catchment dissolved inorganic nitrogen loads in priority areas
- At least a 20% reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas

meant a 50% reduction in DIN, a 20% reduction in PN and no reduction in DON with 'priority areas' ignored (as they are not clearly defined in Reef Plan 2013) in favour of 'all the GBR catchment (GBRC)'.

Similarly for phosphorus we interpreted the Reef Plan 2013 targets of:

- At least a 20% reduction in anthropogenic end-of-catchment loads of sediment and particulate nutrients in priority areas.

meant no reduction in DIP, a 20% reduction in PP and no reduction in DOP across the GBRC.

From these calculations we estimate that in 2009 a 50% reduction in TN load was required whereas in 2013 we estimate a 36% reduction is all that is required. Similarly for TP, in 2009 a 50% reduction was required whereas in 2013 only a 16% reduction is required. These changes will have consequences in reporting progress towards targets, as the targets are now much 'easier'.

In Table 3 we estimate current targets for the various parameters. In each case the final target is the current load minus the reduction required under the Reef Plan targets.



**Table 3. Targets calculated for the 2009 and 2013 Reef Plans for nutrients using SCM current load estimates.**

Parameter	Pre-European (PE) loads (tonnes)	Current load (CL) (tonnes)	Anthropogenic load (AL)	Load reduction required (LR)	New target = CL – LR (tonnes)
<b>Reef Plan 2009</b>				50%	
<b>TN</b>	19,000	37,000	18,000	9,000	28,000
<b>TP</b>	2,500	6,300	3,800	1,900	4,400
<b>Reef Plan 2013</b>				20% PN, 50% DIN, 20% PP, 0% DIP	
<b>PN</b>	3,500	12,000	8,500	1,700	10,300
<b>DIN</b>	500	10,000	9,500	4,750	5,250
<b>DON</b>	14,000	14,000	0	0	14,000
<b>Thus TN</b>	19,000	37,000	18,000	6,450 (36% of Anthropogenic load)	30,550
<b>PP</b>	1,300	4,400	3,100	620	3,580
<b>DIP</b>	600	1,300	700	0	1,300
<b>DOP</b>	600	600	0	0	600
<b>Thus TP</b>	2,500	6,300	3,800	620 (16% of Anthropogenic load)	5,680

### 3. Stage One targets based on Reef Plan targets (not ecologically based) for individual GBR basins

The current Reef Plan targets apply to the total catchment area of the GBR and total discharge from this GBR Catchment (GBRC). Thus there are no targets for individual river basins or NRM regions. The different basins across the GBRC vary greatly in their degree of development and hence relative magnitude of anthropogenic loads of pollutants. The Lockhart Basin on Cape York has little development of intensive land uses and as a result, anthropogenic loads of all the pollutants are almost zero. In contrast, the Tully Basin is highly developed and anthropogenic loads of all pollutants are large. For investigation of priority reductions needed for individual basins, a first step beyond GBR-wide targets is required to develop the Reef Plan targets at the basin-scale. As a first step for WQIP purposes we have developed individual basin targets based on the 2013 set targets. We have used targets (for 2018) of a 20% overall reduction in anthropogenic suspended sediment load; a 20% reduction in anthropogenic loads of particulate nitrogen (PN) and particulate phosphorus (PP); 50% reduction in anthropogenic loads of dissolved inorganic nitrogen (DIN); zero reduction in anthropogenic loads of dissolved inorganic phosphorus (DIP) and 60% reductions of loads of PSII herbicides. The PSII herbicides considered are hexazinone, ametryn, atrazine, diuron and tebuthiuron.

The method adopted requires load reductions equal to the overall reduction target for the GBR applied to anthropogenic loads i.e. the target for DIN at the GBR scale is 50% reduction in anthropogenic load, hence the target for DIN reduction in the Fitzroy Basin is also 50% of the anthropogenic load. For basins with no anthropogenic load e.g. DIN in the Olive-Pascoe Basin the target is still 50% reduction, but 50% of zero is 0 tonnes. This method still produces confronting (in a management sense) absolute load reduction targets but does distribute the required reductions in a proportional way, in terms of the increased loads that have occurred due to development of the individual basins, across the GBR catchment.

The calculation method to get to the new target in all cases is as follows using TSS in the Fitzroy Basin as an example.

Current total TSS load = 1905 kilotonnes. Anthropogenic TSS load = 1410 kilotonnes. 20% reduction (the target) in anthropogenic load of 1410 = 280 kilotonnes to be reduced. Thus target total load = 1905 (current total) – 280 (amount to be reduced) = 1625 kilotonnes.

For the Water Quality Improvement Plan process in the Fitzroy we have chosen to use the following set of targets for the Reef Plan 2013 derived targets out of those estimated above:

- SS — 20% reduction (but see ecologically relevant Stage Two targets discussed below)
  - PN — 20% reduction (but see ecologically relevant Stage Two targets discussed below)
  - PP — 20% reduction (but see ecologically relevant Stage Two targets discussed below)
  - DIN — 50% reduction
  - PSII herbicides — 60% reduction
- There are no targets for DON, DIP or DOP.

## 4. Stage Two ecologically relevant suspended sediment targets based on particle size–nutrient content relationships

The sediment story for the Fitzroy Basin is elaborated in Lewis et al. (2015a) for the Fitzroy WQIP. In general fine sediments (<15.7  $\mu\text{m}$ ) originating from areas of (primarily) basaltic soils via surface erosion in cropping lands and sub-surface erosion in grazing lands are delivered efficiently to the river mouth and then dispersed offshore in high river discharge conditions. The delivery in high discharge periods causes high mortality to corals via low salinity stress and long-term damage to coral reefs and seagrass meadows due to extended periods of high turbidity (low clarity) and hence reduced light for photosynthesis.

Discussion of sediment particle size made in this section follow the Udden–Wentworth size classification for sand (>63  $\mu\text{m}$ ), medium and coarse silt (15.7–63  $\mu\text{m}$ ), fine silt (4–15.7  $\mu\text{m}$ ) and clay (<4  $\mu\text{m}$ ). Note the word ‘clay’ has two meanings in this discussion: (1) a particle size class, generally <4  $\mu\text{m}$  but sometimes <2  $\mu\text{m}$  (we use the <4  $\mu\text{m}$  definition here); and (2) a mineral type e.g. montmorillonite, smectite, illite, generally small particles but may be larger than 4  $\mu\text{m}$ . These size classes, although standard, are often augmented with additional class fractions to represent specific processes in fluvial or marine systems. For example, the 10  $\mu\text{m}$  threshold, or sortable silt fraction, is used in oceanography to distinguish silt sizes <10  $\mu\text{m}$  that behave differently under wave and current processes (McCave et al. 1995). Silt <10  $\mu\text{m}$  generally behaves in the same way as clay, and silt <10  $\mu\text{m}$  responds more readily to hydrodynamic processes offshore. Therefore the sortable silt fraction is often referred to in publications describing sediment transport processes in the near-shore zone (e.g. Orpin et al. 1999).

Importantly the Source Catchments Model models and transports material of nominally <20  $\mu\text{m}$  size class and we will use that size class as well at times.

Ecologically relevant targets for suspended sediments are derived from understanding the impacts of sedimentation and turbidity on coral communities and seagrass meadows, and the relationships between end-of-catchment loads and turbidity in the receiving environment. The suspended sediment of most risk to the GBR (as it is the fraction that is transported furthest in flood plumes, stays in suspension longest (Storlazzi et al. 2015) and results in the greatest degree of resuspension) is the fine fraction sometimes defined as that smaller than 15.7  $\mu\text{m}$ , i.e. below the fine silt boundary and containing the clay and fine silt fractions (Bainbridge et al. 2012, 2014, 2015; Bartley et al., 2014; Douglas et al. 2008; Waterhouse et al. 2013) or of even more risk, just the clay fraction <4  $\mu\text{m}$ . This is the component that contains most of the nitrogen and phosphorus content (and other contaminants), travels widely in flood plumes rather than all depositing near the river mouth (Lewis et al. 2014, 2015a, 2015b; Delandmeter et al. 2015), is most effective at attenuating light when in suspension (Storlazzi et al. 2015) and drives increased turbidity on the inner- and mid-shelf of the GBR (Fabricius et al. 2013, 2014; Logan et al. 2014, in press).

This increased fine sediment supply and hence increased turbidity and sedimentation can have severe impacts on GBR organisms such as reef fish (e.g. Wenger et al. 2011, 2012, 2013, 2014) through effects on juvenile recruitment and feeding; corals through sedimentation (e.g. Weber et al. 2006, 2012; Flores et al. 2012; Pollock et al. 2014); decreased light (Fabricius et al. 2013, 2014); with these effects reviewed by Risk (2014) and Jones et al. (2015); and increasing the competitive advantage of macro-algae and turf algae over corals (Gowan et al. 2014; Goatley & Bellwood 2012, 2013); and seagrass (Collier et al. 2012; Petus et al. 2014). Suspended sediment also interacts with other stressors to increase the overall impact of multiple stressors on coral reefs (Ban et al. 2015; Risk 2014; Graham et al. 2015). Resuspension of sediment in windy conditions or strong tidal currents in shallow waters (<15 m) leads to conditions where suspended sediment concentrations are above the GBR water quality guidelines (De'ath & Fabricius 2008; Great Barrier Reef Marine Park Authority 2010), and this threatens coral reefs and seagrass meadows through reduced light for photosynthesis (Bartley et al. 2014).

In addition, it is now thought (Bainbridge et al. 2015) that the mineral type of fine particles is important in driving adverse effects offshore i.e. it is the expandable clays like smectite that are most efficient at being transported in suspension in the marine environment (Smith et al. 2008) and forming the organic rich floccs (Bainbridge et al. 2012) that are most responsible for far-field resuspension causing loss of clarity (Fabricius et al. 2014; Logan et al. 2014, in press) and adverse effects on corals when sediment is deposited onto the coral surface (Weber et al. 2006, 2014).

As recently reviewed by Bartley et al. (2014 and references therein), Schaffelke et al. (2013) and Brodie et al. (2013b), some coral species can tolerate very high sedimentation rates and turbidity, and can recover from short-term or low levels of sedimentation. However, most corals reliant on autotrophy through zooxanthellae are negatively affected by smothering (sedimentation) and reduced light availability for photosynthesis due to turbidity in the water column. Other effects of turbidity on corals (and poor water quality generally) include increased susceptibility to ocean acidification (Uthicke et al 2014; Vogel et al. 2015).

### 4.1 Sedimentation

Flores et al. (2012) comprehensively reviewed the lethal and sub-lethal effects of chronic exposure of corals to fine sediments and highlighted that particulate matter settling onto the coral cause stress as the process of sediment rejection leads to down-regulation of photosynthesis and increased rates of respiration and mucous production. The level of stress is related to particle size, organic content and nutrient composition of the sediment. With increasing exposure to sediments, coral growth rates decline, symbionts are known to be expelled (bleaching), and tissue loss occurs. Sedimentation also negatively affects rates of gamete fertilisation and survival and settlement of coral larvae (Flores et al. 2012). High sedimentation rates may reduce larval recruitment, making the settlement substratum unsuitable (Dikou & van Woesik 2006; Hodgson 1990). Particle size and organic and nutrient-related sediment properties are key factors determining sedimentation stress in corals (Philipp & Fabricius 2003; Weber et al. 2006, 2012) due to microbial processes leading to reduced oxygen and the formation of toxic hydrogen sulphide. The nutrient enhanced sediments are known to form 'muddy marine snow', which can have detrimental impacts on corals within 1 hour of settling (Fabricius & Wolanski 2000). De'ath and Fabricius (2008) suggest that a daily maximum sedimentation rate of  $15 \text{ mg cm}^{-2} \text{ d}^{-1}$  or a mean annual rate of  $3 \text{ mg cm}^{-2} \text{ d}^{-1}$  as ecologically relevant values that should guard against excessive coral mortality.

Pollock et al. (2014) showed from studies during dredging on Western Australian reefs that reefs exposed to the highest number of days under a dredge sediment plume (296 to 347 days) had a two-fold higher levels of coral disease, largely driven by a 2.5-fold increase in white disease syndromes, and a six-fold increase in other signs of compromised coral health relative to reefs with little or no plume exposure (0 to 9 days). They reported:

*"The greater prevalence of other indicators of compromised coral health at high sediment plume exposure sites was largely the result of elevated levels of sediment-associated necrosis and bleaching, which were 57-fold and 9-fold higher, respectively. Increased turbidity reduces the amount of light available for photosynthesis, while sediment deposition further shades corals and taxes energy budgets through the need to allocate energy to sediment removal. Although corals are able to actively remove sediment particles through ciliary and tentacular movement, combined with polyp distension and mucus production, these mechanisms can become overwhelmed during periods of intense and/or chronic sediment deposition. When sediment stress is chronic, even low-levels can dramatically alter coral energy budgets by reducing Symbiodinium densities (i.e., bleaching) and by decreasing the photochemical efficiencies ( $F_v/F_m$ ) of the Symbiodinium that remain. If resulting energy deficits are not relieved through either metabolic depression or heterotrophic feeding, bleaching can lead to mortality of the affected coral tissue (i.e., sediment necrosis)."*

These values (a daily maximum sedimentation rate of  $15 \text{ mg cm}^{-2} \text{ d}^{-1}$  or a mean annual rate of  $3 \text{ mg cm}^{-2} \text{ d}^{-1}$ ) i.e. ecologically relevant values that should guard against excessive coral mortality equate to average suspended sediment concentrations of  $1.6 \text{ mg L}^{-1}$  in winter and  $2.4 \text{ mg L}^{-1}$  during the summer wet season and have been adopted into GBRMPA water quality guidelines (GBRMPA 2010).

### 4.2 Turbidity

Growth of adult corals, seagrass and macroalgae is inhibited through reduced light caused by reduced water clarity. Sediment resuspension in windy conditions or strong tidal currents in shallow waters (<15 m) leads to conditions where TSS concentrations are above the GBR water quality guidelines (De'ath & Fabricius 2008; GBRMPA 2010). Reduced water clarity leads to changes in the distribution of seagrasses to shallower waters (Collier et al. 2012) or when the reduced clarity is prolonged to seagrass mortality (Petus et al. 2014). For coral reef systems, reduced water clarity has been associated with increased macroalgal cover, reductions in coral biodiversity (De'ath & Fabricius 2010), increased macro-bioeroder densities (LeGrand & Fabricius 2011), shifts from communities dominated by phototrophic corals to heterotrophic filter feeders (Birkeland 1988), reduced resilience against ocean acidification (Vogel et al. 2015) and increased presence of heterotrophic soft corals compared to autotrophic types as well as loss of soft corals in more turbid waters (Fabricius & De'ath 2001a) and loss of crustose coralline algae (Fabricius & De'ath 2001b). However, some coral reefs have developed and thrived in near-shore areas with high turbidity (Browne et al. 2012; Palmer et al. 2010).

For strong ecological relevance we will choose to set targets for reduction of the <15.7  $\mu\text{m}$  particle size fraction. This fraction of the SS load forms organic rich flocs in the flood plumes (Bainbridge et al. 2012), which are transported hundreds of kilometres from the river mouth. Figures 1 and 2 show river flood plumes from the Burdekin and Burnett-Mary regions, while Figures 3, 4 and 5 show a selection of plumes from the Fitzroy region where the inner plume is dominated by coarser sediment fractions (muddy brown material near the river mouth) and the further reaches of the plume dominated by the fine sediment fractions (<15.7  $\mu\text{m}$ ) and algal blooms. Hence this finer sediment fraction (<15.7  $\mu\text{m}$ ) is considered to be the most important component of the total suspended sediment load in terms of risk to Great Barrier Reef ecosystems (Bainbridge et al. 2012).



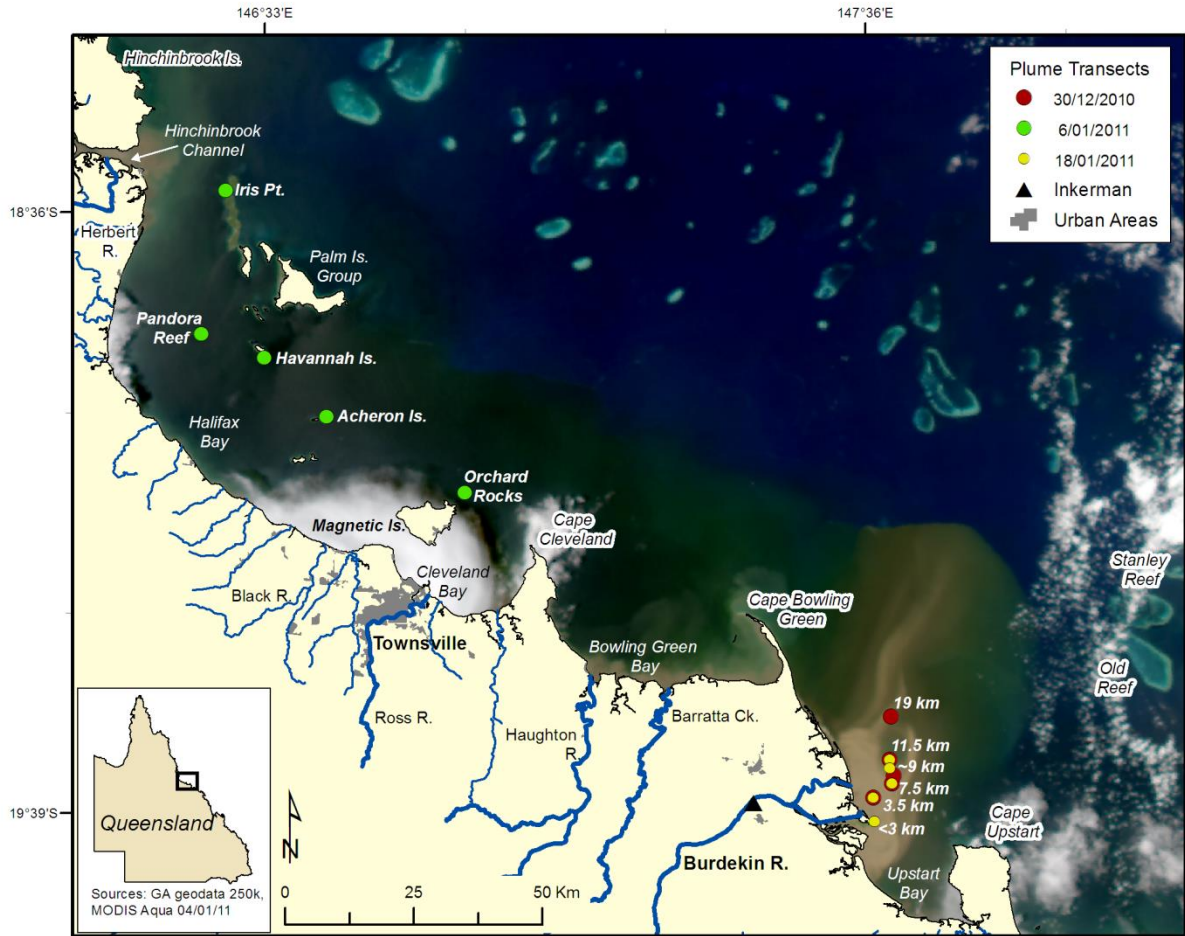


Figure 1. Burdekin River plume 2011 (from Bainbridge et al. 2012).



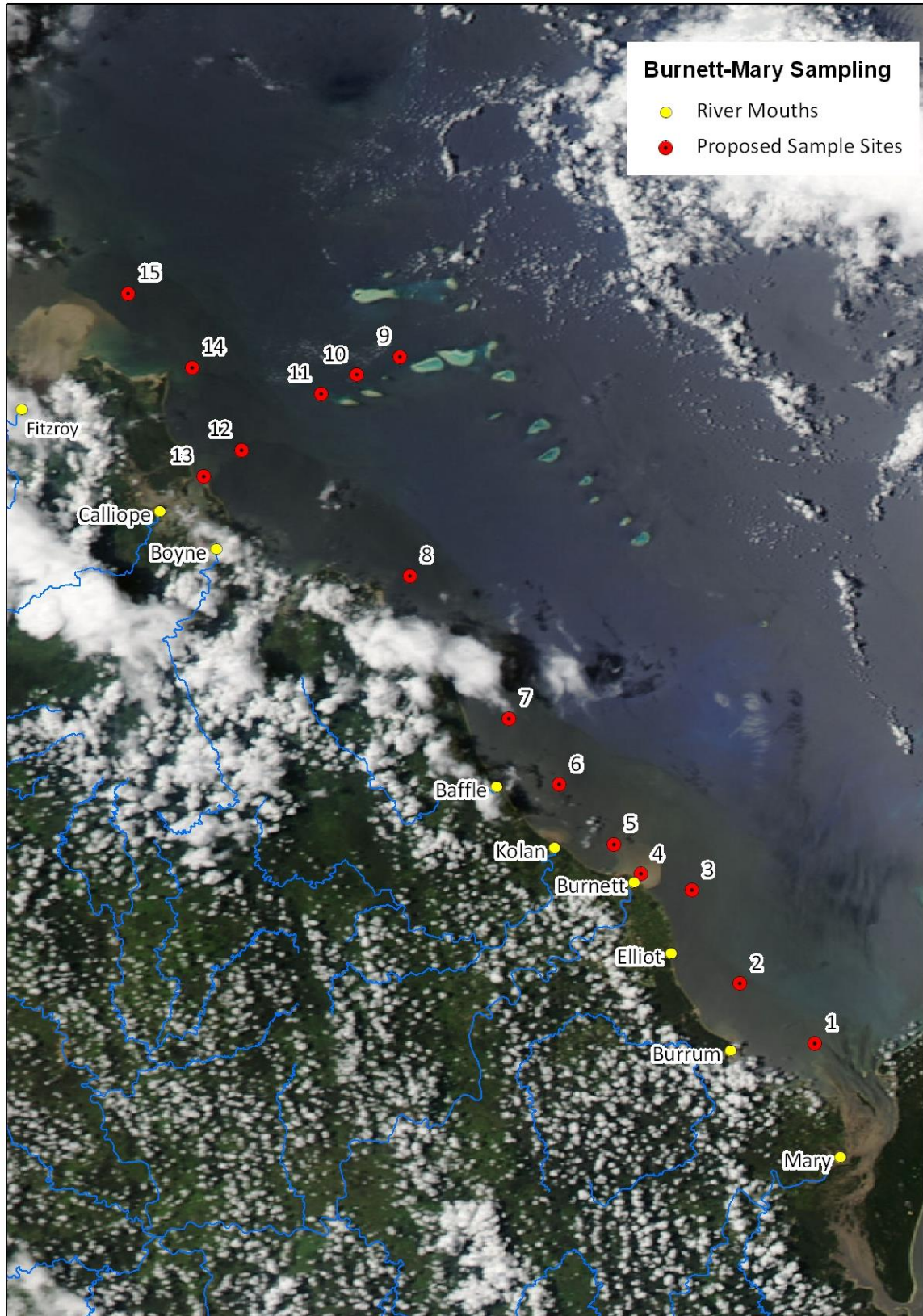


Figure 2. Burnett and Mary rivers plumes 2011



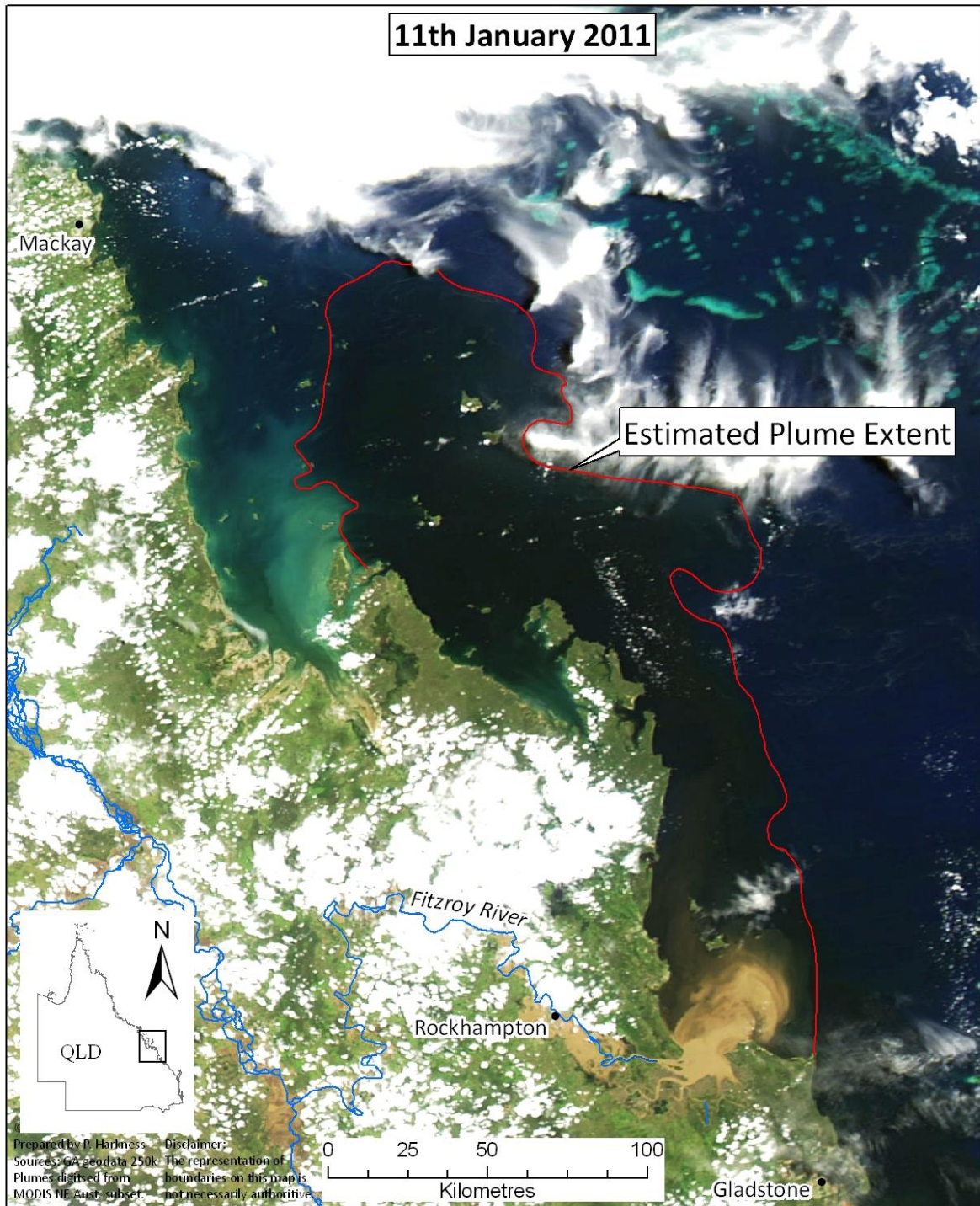


Figure 3. Plume from the Fitzroy River (2011)

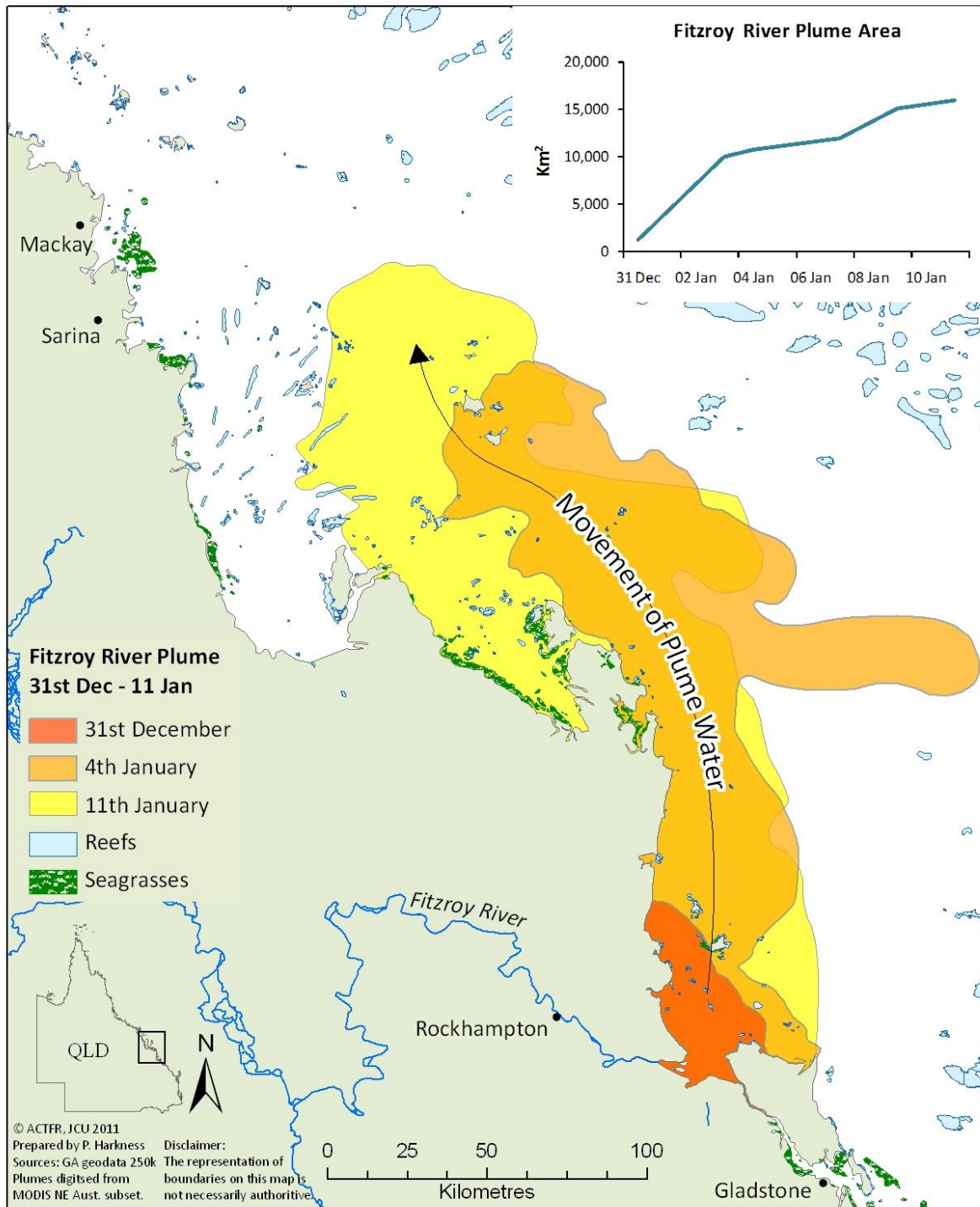


Figure 4. Plume from the Fitzroy River mapped through time (2011).





*Figure 5. Plume from the Fitzroy River (2011) showing the contrast between the phytoplankton dominated plume (green — from the river) adjacent to sediment plumes in Shoalwater Bay generated through (tidal) resuspension.*

Currently we only have particle size distribution for river discharge sediment at  $<4 \mu\text{m}$  and  $<63 \mu\text{m}$  fractions from the GBR Catchment Loads Monitoring Program (e.g. Turner et al. 2013). Hence we will have to use the  $<4 \mu\text{m}$  particle size fraction to develop our ERTs as these are the only quantifiable data that exist. We note by using the  $<4 \mu\text{m}$  particle size fraction will give a conservative estimate on the SS load reduction targets. In Table 4 we have modified Figure 7.24 from Turner et al. (2013) showing the proportions of the size classes of suspended sediment found in 11 rivers in the GBRC. Details of the methodology of the methods can be found in Turner et al. (2013).

**Table 4. Particle size fractions (%) from selected large rivers.**

Particle fraction	Normanby (up river site)	Barron	Johnstone	Tully	Herbert	Burdekin	Pioneer	Fitzroy	Burnett
Coarse sand 2000–250 µm	0.4	4	0.2	0.4	0.6	0.6	0.8	0.8	0.5
Fine sand 62– 250 µm	0.4	6	9	4	7	4	5	0.8	2
Silt 4–62 µm	47	66	75	66	70	50	70	38	53
Clay 0.24–4 µm	52	24	15	29	22	46	25	60	45

modified from Turner et al. 2013.

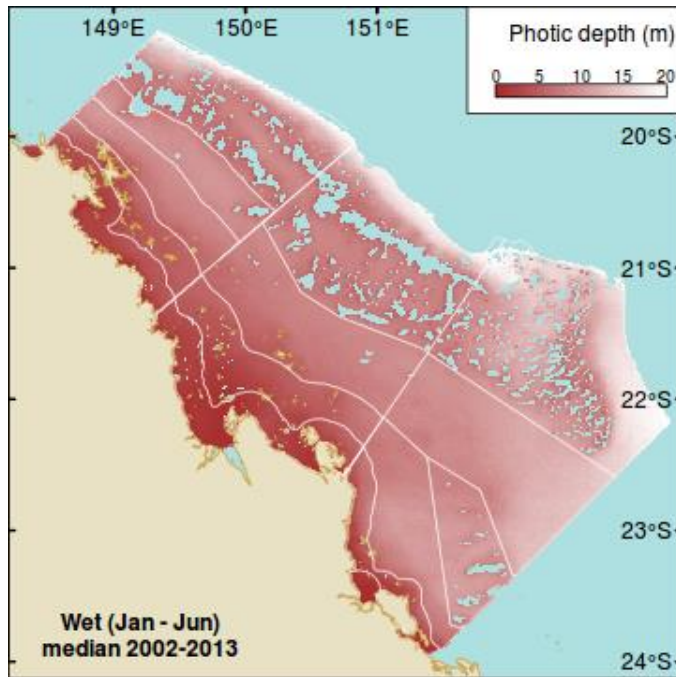
Specifically for the Fitzroy River at Rockhampton end-of-system site, particle size distributions, including a <20 µm class, over the period 2006–2011 were 64.1% at <2 µm class; 93.6% <20 µm class; 99.4% <63 µm class; and 100% <2000 µm class (Ryan Turner pers. comm.). Thus for the targetted <15.7 or <20 µm fractions 93.6% of the discharge is in this category. A reduction in 50% of the total SS load can be assumed to quite accurately reflect a 50% reduction in the <20–15.7 µm load.

The slopes of the relationship between photic depth and river discharges examined initially in the Burdekin region (Fabricius et al. 2014; Logan et al. 2013) suggests that annual mean photic depth across the shelf was reduced by 1.7% for each 1000 tonnes of TP discharged into the GBR, or by 0.47% for each 1000 tonnes of TN. River discharge was used to analyse this relationship as it serves as a good proxy (as do PP and PN) for the fine sediment fraction. River discharge of total SS (TSS) gives a much poorer correlation as TSS is not a good proxy for just the fine fraction (<15.6 µm) (Logan et al. 2013, 2014). For the Burdekin region five bands (zones) across the shelf were analysed as follows:

- *Coastal*: 0–0.1 fractional units across the GBR
- *Inshore*: 0.1–0.25 fractional units across the GBR
- *Lagoon*: 0.25–0.45 fractional units across the GBR
- *Mid-shelf*: 0.45–0.65 fractional units across the GBR
- *Outer shelf*: 0.65–1 fractional units across the GBR

For the southern GBR, which includes the Mackay-Whitsundays and Fitzroy regions, the analysis was somewhat different (Logan et al. 2014, in press). The Fitzroy region cannot be partitioned up as simple parallel bands, due to its geomorphology around to the Capricorn-Bunker Group of islands and the Swains complex, and the estuarine Keppel Bay. Consequently, the Fitzroy region was partitioned according to a combination of geomorphological regions and boundary rules (based on distances from coastlines and bioregions) to reflect the broader range of oceanographic characteristics (Figure 7). Broad Sound was analysed separately, as its high tidal range and distance

from the major Whitsundays and Fitzroy rivers make this area unrepresentative of the two Whitsundays and Fitzroy regions. The boundaries were chosen to best match those of both the Whitsundays and Fitzroy areas. The mean photic depth over an 11-year period is shown in Figure 6. In Figure 7, the temporal patterns of photic depth show the large decrease in photic depth following large river discharge events, and the signal of tropical cyclone Hamish in offshore waters in March 2009.



*Figure 6: Median photic depth for each grid point within each of the 15 southern zones averaged across all wet season days over 11 years.*

From Logan et al. 2014.

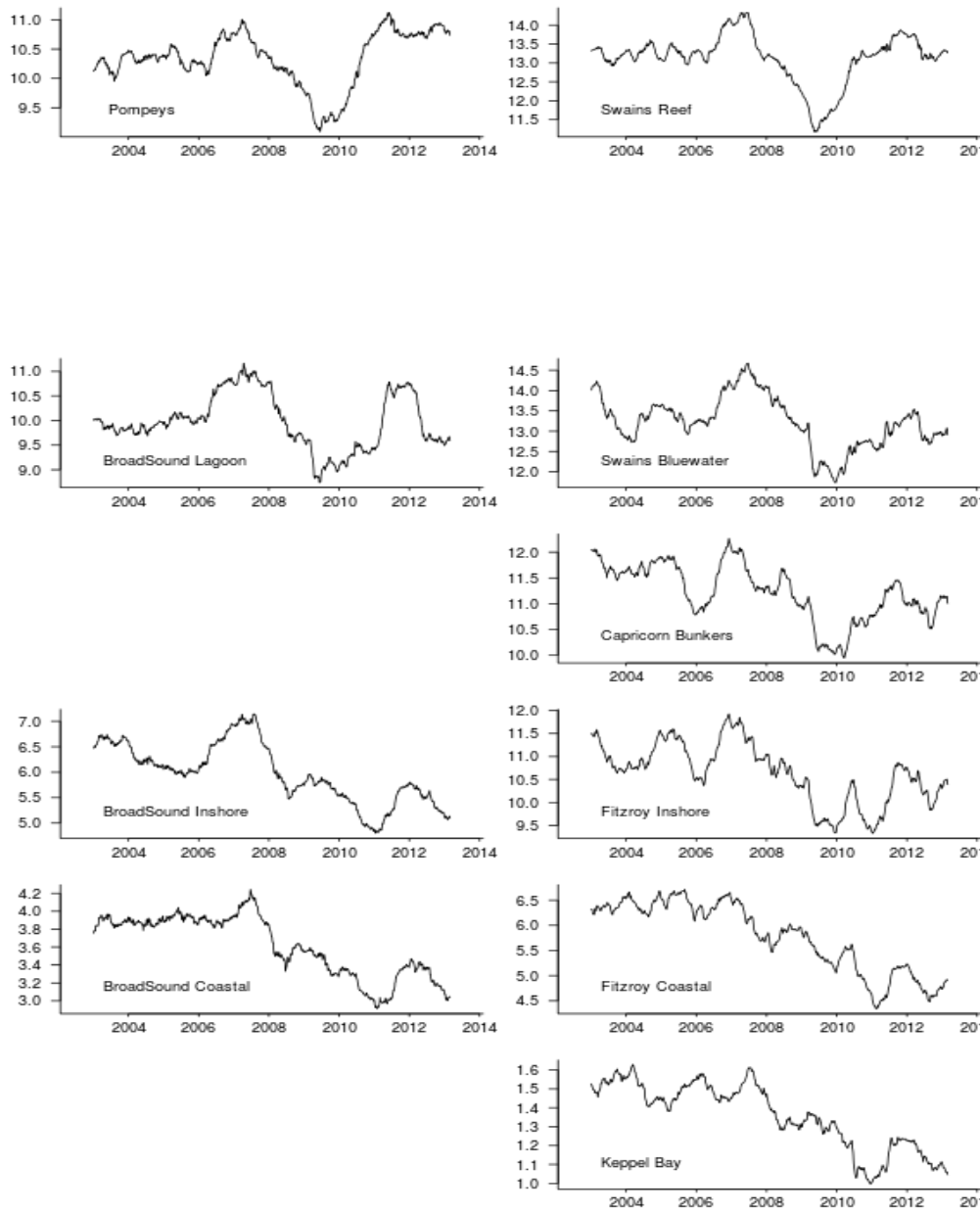


Figure 7: Eleven-year temporal trend in photic depth within each of the zones in the Broad Sound and Fitzroy regions.

Logan et al. 2014.



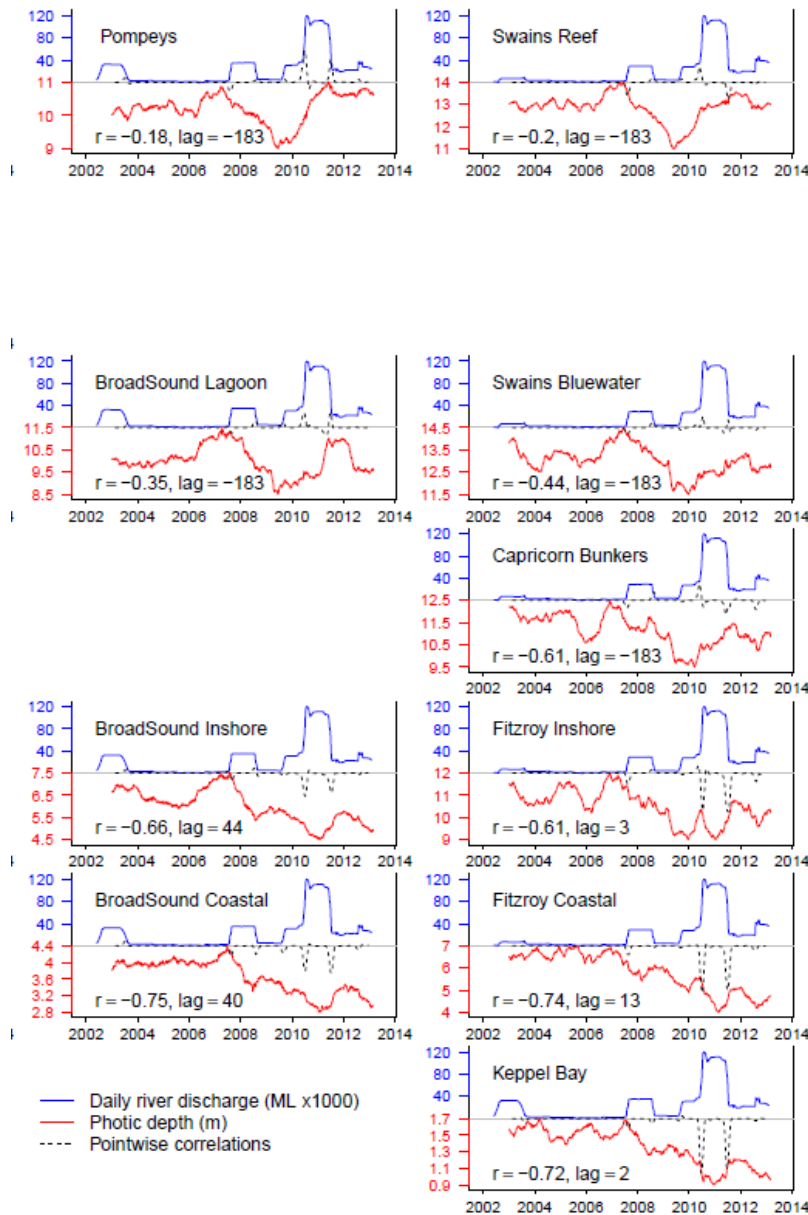
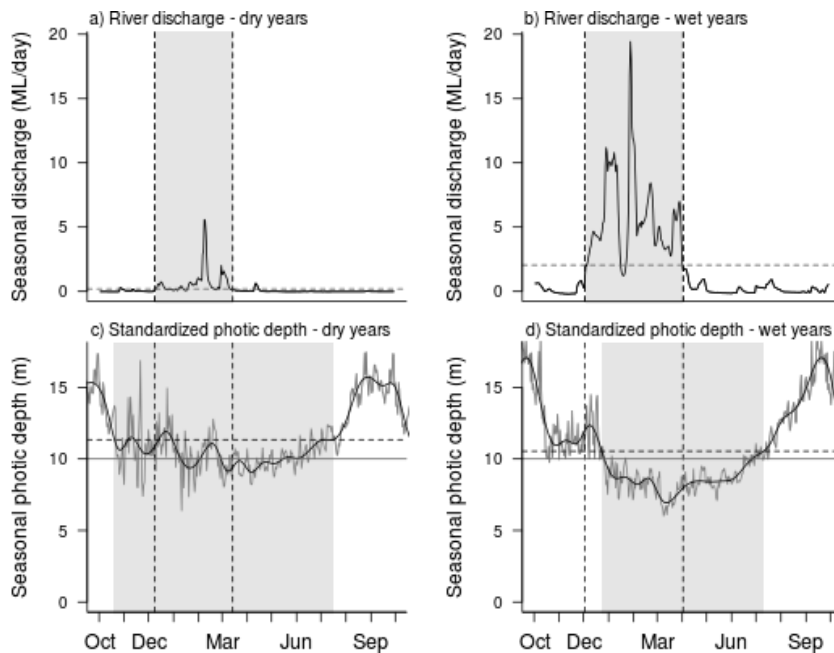


Figure 8: Eleven-year temporal trend cycle in river discharge (blue lines) and photic depth (red lines) within each of the 15 zones partitioned from the Fitzroy and Broad Sound regions of the GBR.

The correlation coefficient,  $r$ , indicates the strength of the correlations between the two trend cycles. The lags indicate the number of days in which either the photic depth trend or discharge trend would need to be shifted to maximise the correlation. Black dashed lines represent a running covariance between photic depth and discharge, highlighting moments (as spikes) when both trends show rapid shifts (negative spikes: rapid increases in discharge and reductions in photic depth) (Logan et al. 2014, in press).

Results from the correlation between photic depth and Fitzroy River discharge are shown in Figures 8 and 9.



*Figure 9: Seasonal cycles of river discharges and photic depth following decomposition of the seasonal components of the time series, separated for dry years (2002 - 2006) and wet years (2007 – 2012).*

Above example is the analysis for Fitzroy Inshore zone (Logan et al. 2014).

In the Fitzroy region, the relationship between annual loads of TSS (and all other nutrients) and annual photic depth was typically strong in the coastal and inner-shelf zones, and declined with increasing distance from the coast (Figure 8). Typically, rates of recovery of photic depth were substantially lower than rates of decline. The relationships between the river load metrics (TSS, PN, PP, DIN and DIP) were so strong that their associations between annual photic depth and annual river loads were almost identical.

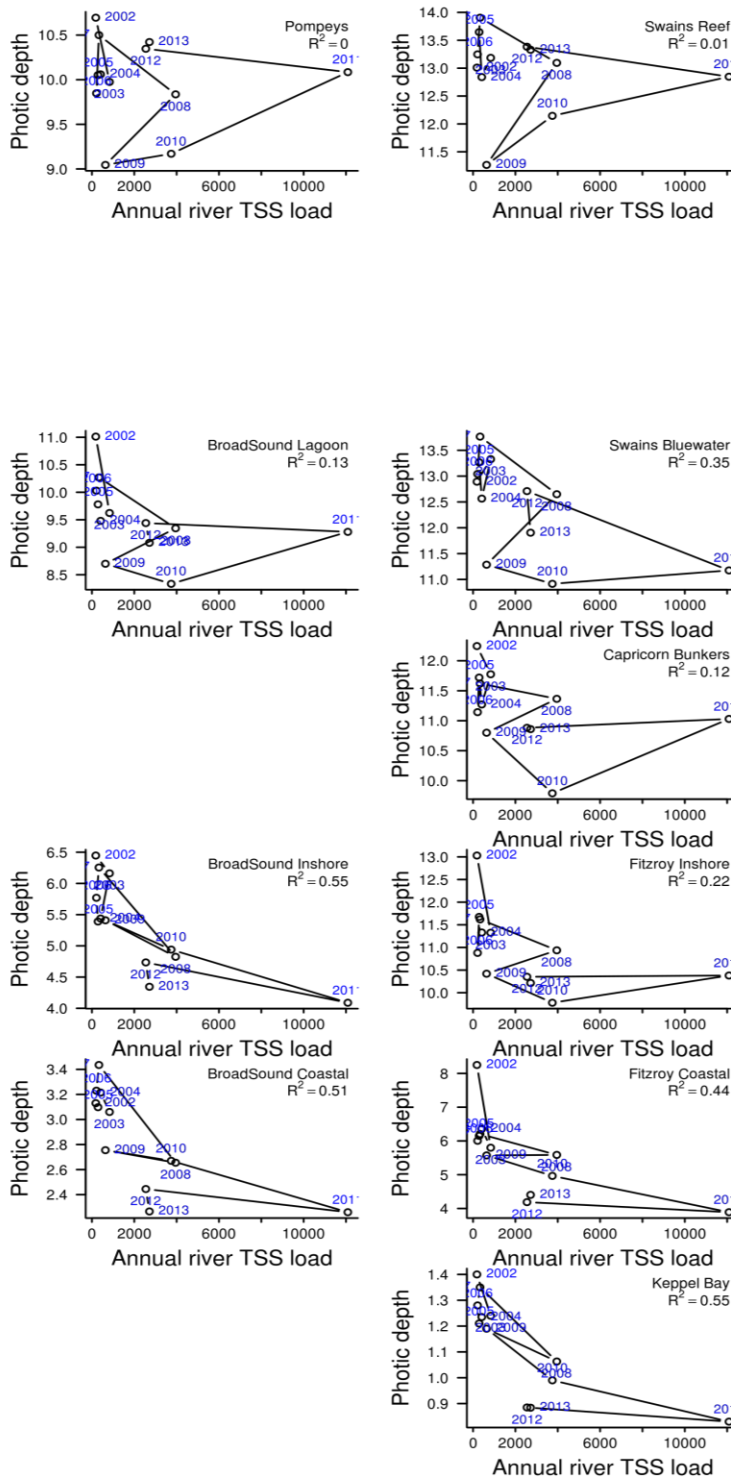


Figure 10: Relationships between annual mean photic depth and annual river loads of TSS (and/or particulate and dissolved nutrients) in individual years in the BroadSound and Fitzroy Regions). (Logan et al. 2014).

In the Fitzroy and Whitsundays regions substantial declines in photic depth occurred in many of the inner zones throughout the 11-year observation period (Figures 8 and 10). Similar systematic trends did not occur in the outer zones, where photic depth showed one relatively large drop that appeared to coincide with tropical cyclone Hamish in March 2009. This drop was lessened, yet still detectable in the mid-shelf and lagoon zones. In all southern regions, correlations between **daily** photic depth and discharges weakened steeply and systematically across the shelf. They were very pronounced close to the shore (coastal and inshore zones:  $r = -0.61$  to  $-0.79$ ) and very weak on the outer shelves ( $r = -0.18$  to  $-0.27$ ). In the Fitzroy region, the correlations were strong for the Keppel Bay, Fitzroy coastal, Fitzroy inshore and Capricorn-Bunkers zone ( $r = -0.74$  to  $-0.61$ ), and poor for the Swains Reef ( $r = -0.20$ ). The correlations in the Broad Sound to the Fitzroy River discharges were also surprisingly strong for the coastal and inshore zones ( $r = -0.75$  and  $-0.66$ ), despite their distance from the river and the high tidal ranges. The running covariance between photic depth and discharge showed that some rapid losses in photic depth were linked to rapid increases in river discharges in the Keppel Bay, Fitzroy coastal and inshore zones. These spikes were greatly attenuated in the Broad Sound coastal and inshore zones. The lags in the Keppel Bay and Fitzroy coastal and inshore zones were 0 to 13 days, indicating that their photic depth declined within <13 days after the rivers started flooding (Figure 9). For the Broad Sound coastal and inshore zones and the Whitsundays coastal zone the lags were 36 to 44 days. In all zones further away from the coast (where photic depth was more weakly correlated to the rivers), a negative half-year lag would have improved the correlations, which may be an artefact related to tropical cyclone Hamish (March 2009) causing massive resuspension events. When **annual** mean photic depth and river load data were used (Figure 11), annual correlations were typically strong in the coastal and inner-shelf zones ( $r = -0.50$  to  $-0.81$ ), and declined with increasing distance from the coast.

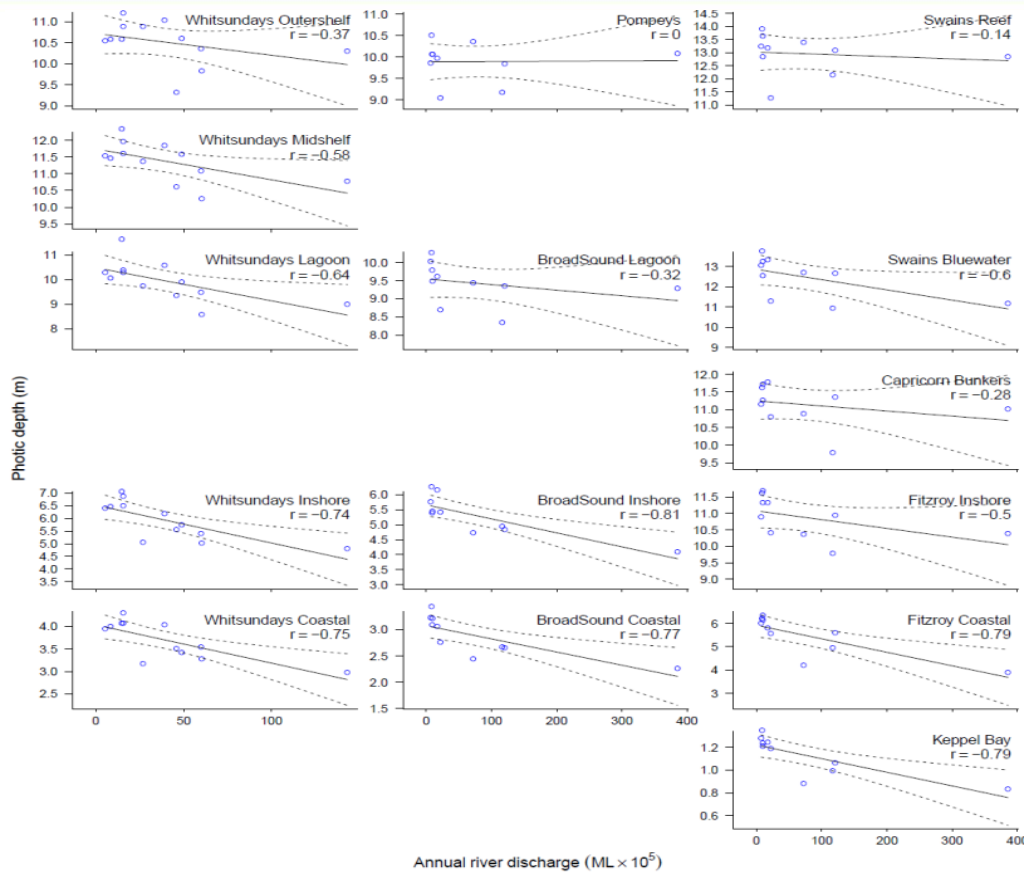


Figure 11: Relationships between annual mean photic depth and annual river discharge in the 15 southern GBR regions and zones.

Note the different scales on both x and y axes (Logan et al. 2014).

Using this knowledge of ecological relevance and factoring in the availability of data, suspended sediment targets for reduction of the <math>15.7\text{--}20\ \mu\text{m}</math> fraction have been set. For the purposes of the targets, and within the margin of error of the estimates, the <math>15.7\ \mu\text{m}</math> fraction can be equated to the <math>20\ \mu\text{m}</math> fraction modelled by Source Catchments. The actual targets are derived from the analysis of the relationship between photic depth and river discharges in the region (Fabricius et al. 2014; Logan et al. 2014, in press). The analysis shows a linear relationship between reduced fine sediment proxied by water volume (and also particulate nitrogen (PN) and particulate phosphorus (PP) loads) and increased Secchi depth (measured as photic depth) and indicates that a 50% reduction of the fine sediment fraction will be sufficient to generally meet the GBRMPA guidelines for Secchi depth (and thus SS concentrations) for coastal waters for phototrophic benthos at the depths affected.

As the influence of the other basins in the Fitzroy Region i.e. Styx, Water Park, Shoalwater, Calliope, Boyne to both total and anthropogenic fine sediment export were minor (Table 5) compared to the Fitzroy itself (Dougall et al. 2014) we have not set ERTs for these rivers. In addition we do not have photic depth correlations for the receiving waters of the Calliope and Boyne basins (basically Port Curtis).

**Table 5. Total and anthropogenic TSS loads for the Fitzroy Regions basins.**

Basin	Styx	Shoalwater	Water Park	Fitzroy	Calliope	Boyne
<b>Total TSS load (kt/y)</b>	<b>68</b>	<b>53</b>	<b>32</b>	<b>1,740</b>	<b>44</b>	<b>11</b>
<b>Anthropogenic load (kt/y)</b>	<b>36</b>	<b>25</b>	<b>2</b>	<b>1,300</b>	<b>24</b>	<b>5</b>

From Dougall et al. 2014.

Targets for PN and PP are also for a 50% reduction, which will be largely achieved through a 50% reduction in the <20 µm fine sediment load.

## 5. Ecologically relevant DIN targets

The health and ecology of coral reefs are very sensitive to enrichment from dissolved inorganic nitrogen (DIN). Field studies on the GBR indicate higher biodiversity of hard corals and phototrophic octocorals (and lower macroalgal cover) on reefs with low seawater Chl *a* concentrations (van Woesik et al. 1999; Fabricius et al. 2005; De'ath & Fabricius 2008). A threshold value of <0.45 µg/L Chl *a* has been identified as a potentially important trigger value for the maintenance of a healthy reef status (De'ath & Fabricius 2008) (Figure 12) and has been adopted as the marine trigger value in GBRMPA's water quality guidelines (GBRMPA 2010). A possible contributing factor to this biological response is the increased vulnerability of corals to thermal bleaching and mortality during summer heat stress conditions when also exposed to poor (ambient) water quality conditions, particularly nutrient-enrichment (Wooldridge 2009; Wagner et al. 2010; Vega-Thurber et al. 2014).

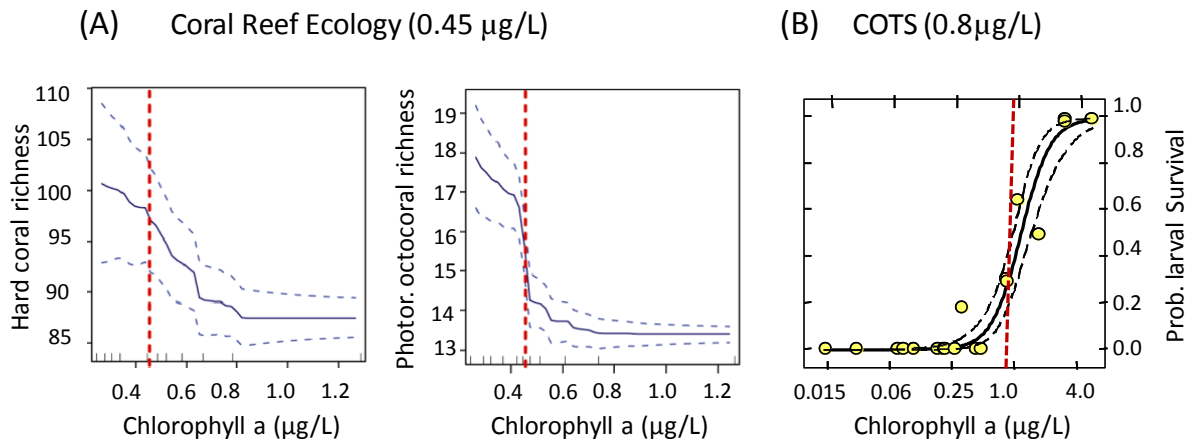


Figure 12: Impact of nutrient-enrichment (as indicated by seawater chlorophyll a concentration) on coral health status. (A) Exceedance of 0.45 µg/L triggers loss of hard coral and octocoral richness (De'ath & Fabricius 2008), (B) Exceedance of 0.8 µg/L triggers the enhanced survival of crown-of-thorns-starfish (COTS)

Brodie et al. 2005; Fabricius et al. 2010.

The anthropogenic DIN load from the Fitzroy River is estimated to be 50 tonnes — the result of a total DIN load of 1106 tonnes and a pre-development load of 1057 tonnes (Dougall et al. 2014). In making this estimate it is assumed that no anthropogenic DIN is generated from grazing lands just through the fact of having cattle present. This assumption needs further research as there are certainly some indications that grazed savannah and woodland leaks more DIN than when in an ungrazed (from cattle) state. Thus virtually all anthropogenic DIN in the Fitzroy is assumed to be from grains and cotton cropping but the load is very small, approximately 50 tonnes. Thus the RPT for DIN from the Fitzroy Basin is small i.e. about a 25 tonne reduction and it is highly likely that the ERT will be similarly small. However, further effort is required to establish a biogeochemical model for the Fitzroy marine region that would allow ERTs to be more reliably estimated for Chl-a.



### 6. Ecologically relevant pesticide targets

The photosystem II inhibiting herbicides (PSII herbicides) are currently the main pesticides of concern in the GBR (and are thus the only ones specifically addressed in Reef Plan) and concentrations have been detected in some parts of the GBR that are likely to cause negative effects in the freshwater, estuarine and marine environments (Lewis et al. 2012). Indeed, it is the concentration of a particular herbicide that provides a measure of toxicity to non-target species. A new set of ecotoxicity threshold values have recently been proposed for marine environments (Smith et al., in prep-a), which have been developed to revise and update the Australian and New Zealand Water Quality guidelines. These proposed marine threshold values are available for diuron, atrazine, ametryn, hexazinone and tebuthiuron (and the insecticide imidacloprid) (Table 6) and have been derived using the latest ecotoxicological data and statistical techniques. It is the view that these guidelines will be adopted for the Great Barrier Reef Marine Park in place of the current GBRMPA (2010) values. The most common PSII herbicides used in the Fitzroy region are atrazine (predominantly cropping) and tebuthiuron (predominantly grazing). Losses of both are highly dependent on the timing of the rainfall events following application, and the amount of ground cover retained on the paddock as residues from previous crops or residual pasture (Shaw & Silburn 2014). As conservation tillage has increased and as improved management practices take place (shifting from high-risk to low-risk management in relation to sediments) there is an increased reliance on all herbicides for weed control. This results in a trade-off between tillage, which greatly increases run-off and soil loss, and the increased use of herbicides, which results in increased potential for loss into receiving waters (Shaw et al. 2013; Thorburn et al. 2013).

We contend that the proposed 99% ecological protection values for Australian marine environments be adopted for the end-of-river systems in the Fitzroy basins as (1) The 99% level of protection is in accordance with the current GBRMPA (2010) guideline's recommendations and (2) if the guideline is met at the end of the river then this ensures that no part of the marine park is negatively affected by a particular herbicide. A new set of ecotoxicity threshold values have recently been proposed for pesticides in marine environments (Rachael Smith pers. comm.) which have been developed to revise and update the Australian and New Zealand Water Quality guidelines. These proposed marine threshold values are available for the PSII herbicides diuron, atrazine, ametryn, hexazinone and tebuthiuron (Table 6) and have been derived using the latest ecotoxicological data and statistical techniques. It is likely that these guidelines will be adopted for the Great Barrier Reef Marine Park in place of the current GBRMPA (2010) values (Carol Honchin pers. comm.) and are thus used in setting ERTs for these PSII herbicides for the Fitzroy NRM region. Poggio et al. (2013) have also developed a relative toxicity measure (to diuron), which we have used for herbicides commonly used in the Great Barrier Reef that currently have no official recognised value (Table 6). In the absence of additional data, we consider these values can be used as a first approximation guide to gauge potential effects in the Great Barrier Reef of these particular herbicides. We note that herbicide guideline values can also be derived for freshwater and estuarine environments and these are currently under development.

While the herbicide concentrations are of most importance to gauge their risk to receiving waters, the Reef Plan targets revolve around annual load reductions. Furthermore Reef Plan targets do not consider the ‘toxic load’ (i.e. the herbicides are summed and reported as a ‘total PSII load’ and hence are considered of equal toxicity, although this is known to not be the case). Hence to develop ERTs the PSII herbicide loads are normalised to better reflect their toxic effects and then the reductions required to ensure that herbicide concentrations will remain below these ecologically relevant threshold concentrations are examined. As a preliminary approach, the Lewis et al. (2011) model was updated with new monitored load data to produce the individual herbicide load estimations for the Fitzroy basins. A PSII equivalent ‘toxic load’ was calculated using the toxic load factors proposed by Smith et al. (pers. comm.). The predicted PSII normalised (to diuron) concentration and the diuron ecotoxicity value ( $0.08 \mu\text{g}\cdot\text{L}^{-1}$ ) were then used to examine the likely reduction required to the end-of-basin loads so that the PSII herbicide concentrations would remain below these values. This analysis suggests that all basins of the Fitzroy NRM region do not require any further reduction in current PSII herbicide loads (i.e. diuron, atrazine, ametryn, hexazinone and tebuthiuron) to achieve the guideline values. Therefore the recommendation is to prevent any increases of PSII herbicide concentrations in waterways in the Fitzroy region by managing contributing land uses at best management standards.

**Table 6. Previous GBRMPA (2009) guideline values compared with the new proposed 99% Australian marine guideline for a range of pesticides and a ‘derived guideline’ based on relative toxicity scores to diuron.**

Herbicide	Existing GBRMPA (2009) guideline ( $\mu\text{g}\cdot\text{L}^{-1}$ )	Proposed 99% guideline ( $\mu\text{g}\cdot\text{L}^{-1}$ )	Derived guideline ( $\mu\text{g}\cdot\text{L}^{-1}$ )	Toxic load PSII factor
Diuron	0.9	<b>0.08</b>	0.08	1.0
Ametryn	0.5	<b>0.02</b>	0.08	0.65
Atrazine	0.6	<b>2.8</b>	0.53	0.036
Hexazinone	1.2	<b>0.9</b>	0.23	0.21
Tebuthiuron	0.02	<b>4.3</b>	N/A	0.019
Imidacloprid	N/A	<b>0.03</b>	N/A	N/A
Metribuzin	N/A	N/A	0.67	N/A
S-Metolachlor	N/A	N/A	0.27	N/A
Pendimethalin	N/A	N/A	13	N/A
Glyphosate	N/A	N/A	80	N/A
2,4-D	0.8	N/A	7.3	N/A
Fluroxypyr	N/A	N/A	20	N/A

Smith et al., in prep-a; Poggio et al. 2013. The bolded values are considered our best estimates for 99% protection of marine species. Also shown are the ‘toxic load factors’ developed by Smith et al. (in prep-b).

**Table 7. Predicted annual herbicide loads for the Fitzroy basins using the updated Lewis et al. (2011) model and the PSII weighted load based on ecotoxicity threshold values.**

Basin	Flow (ML/y)	Ametryn (kg)	Atrazine (kg)	Diuron (kg)	Hexazinone (kg)	Tebuthiuron (kg)	Total 'toxic' PSII load	Toxic AMC ( $\mu\text{g.L}^{-1}$ )
Fitzroy River	4,659,346	0	586	81	27	639	119.4	0.03
Shoalwater Creek	387,422	0	1	0	0	0	1.0	0.00
Boyne River	40,307	0	1	0	0	1	0.1	0.00
Calliope River	117,034	0	0	0	0	1	0.0	0.00
Styx River	271,616	0	0	0	0	1	0.0	0.00
Water Park Creek	391,686	0	0	0	0	0	0.0	0.00

Of course, using an annual mean concentration does not account for periods when much higher herbicide concentrations can occur in a stream or river. For example, in Barratta Creek, Davis et al. (2012) shows that ~90% of the herbicide load was discharged in only 12% of the annual flow. However, given the much larger size of the Fitzroy River such a disparity between load and flow would not be as pronounced. Indeed, the current monitoring data from the Fitzroy River suggest that these PSII additive values have not yet been exceeded and hence the ecologically relevant targets should be 0% (no reductions required in current load).

However, the increased detection of the herbicide metolachlor (a non-PSII used in broadacre cropping) in the Fitzroy River is of concern as concentrations, at times, have exceeded current 'best estimated' guideline values. Based on our current understanding (and lack of an 'approved guideline value') we suggest that reductions of metolachlor in the Fitzroy are likely in the order of 60 to 70% to achieve ERT targets. However this requires more research to validate this finding and we are not including these reductions (in metolachlor) in the current Fitzroy WQIP.

## 7. Research and information gaps

In the course of estimating ERTs for the Fitzroy Region, a number of important information and research gaps constrained estimation of some targets. These include:

1. Bioavailability of PN. The bioavailability of PON discharged from rivers to the GBR is not accurately known. Although it is generally believed that most PON can become bioavailable through bacterial mineralisation in its residence time period in the GBR lagoon (Brodie et al. 2012b, 2015), no studies have examined this in detail. This is recognised as a major research gap and currently active attempts are being made to seek funding to research this issue.
2. Silt vs clay fractions in river discharge data. While the Queensland GBR River Monitoring Program does measure particle size fractions in the rivers monitored (including the Fitzroy River), analysis of silt sized fractions (4–63  $\mu\text{m}$ ) is only currently reported as total silt (Turner et al. 2013) and not the sub-categories e.g. fine silt (4–16  $\mu\text{m}$ ). This is a relatively minor issue that should be able to be easily resolved with the monitoring team.

3. Role of DIP/phosphate. While management of DIP (phosphate, orthophosphate, FRP) was missing from Reef Plan 2013, DIP is still an important parameter to consider when modelling nitrification and eutrophication of the GBR (Brodie et al. 2011). We have not included targets for DIP but that is a topic that needs further research as to its importance.
4. The other basins besides the Fitzroy. While the Fitzroy Region is dominated by the Fitzroy Basin and indeed the Fitzroy Catchment, the other basins are not unimportant. Information on the Styx, Water Park, Calliope, Boyne and Shoalwater basins is much more limited than for the Fitzroy Basin and this severely constrains our ability to set targets for these basins.
5. The Fitzroy does not have operational a running version of the ChloroSim model (Wooldridge et al. 2015). In addition, while there is a biogeochemical model designed by Barbara Robson and others it only covers the inner part of Keppel Bay and is not suitable for analysing chlorophyll dynamics at the whole-of-Fitzroy marine region scale. A new biogeochemical model is in development under the eReefs program but is not available for use at this time.
6. Estimates of the anthropogenic load of DIN from cropping lands in the Fitzroy (cotton and grains mainly but also some horticulture) is not provided in Source Catchments at the moment. In addition, an understanding of anthropogenic DIN loads from grazing lands, while modelled, is not really understood with respect to the cause(s) of the load.
7. There is far less information available for all parameters used in setting ERTs for the other five basins in the region compared to the Fitzroy Basin.

## 8. Summary

In Table 8 we summarise the Reef Plan and draft ecologically relevant total load targets for Fitzroy Region basins.

**Table 8. Summary of pollutant load reduction targets for basins in the Fitzroy region.**

River	Styx	Shoalwater	Waterpark	Fitzroy	Calliope	Boyne
<b>TSS RPT</b>	20%	20%	20%	20%	20%	20%
<b>TSS ERT<sup>1</sup></b>	Not calculable at present	Not calculable at present	Not calculable at present	50% reduction in fine fraction (< 4 µm) SS	Not calculable at present	Not calculable at present
<b>DIN RPT</b>	50%	50%	50%	50%	50%	50%
<b>DIN ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present
<b>PN RPT</b>	20%	20%	20%	20%	20%	20%
<b>PN ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	50%	Not calculable at present	Not calculable at present
<b>PP RPT</b>	20%	20%	20%	20%	20%	20%
<b>PP ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	50%	Not calculable at present	Not calculable at present
<b>DIP RPT</b>	Not specified	Not specified	Not specified	Not specified	Not specified	Not specified
<b>DIP ERT</b>	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present	Not calculable at present
<b>PSII RPT</b>	60%	60%	60%	60%	60%	60%
<b>PSII ERT (diuron equivalent conc.)</b>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>	<0.08 µg.L <sup>-1</sup>

The table shows two sets of targets: Reef Plan Targets (RPTs) and Ecologically Relevant Targets (ERTs) for Total Suspended Solids (TSS), Dissolved Inorganic Nitrogen (DIN), Particulate Nitrogen (PN), Dissolved Inorganic Phosphorus (DIP), Particulate Phosphorus (PP) and PSII Herbicides (PSII).

The calculations of the TSS load reductions required based on actual particle size analysis from monitored data are only available for the Fitzroy Basin. It should be noted, however, that it is only possible to measure progress towards the 20% or 50% reduction in total SS using the Source Catchments model at this time, which is based on a particle size of <20 µm not <4 µm.

### 8.1 Summary for the Fitzroy Basin

Fitzroy load targets (for Fitzroy Basin) — based on 2014 Source Catchments results

### *RPTs — by 2018–20*

1. 20% reduction in anthropogenic fine sediment by 2018–2020. Baseline total load = 1,950,000 tonnes; Anthropogenic = 1,410,000 tonnes; pre-development = 540,000 tonnes. Thus 20% reduction involves reduction of 280,000 tonnes, leaving the new total load at 1,670,000 tonnes.
2. 50% reduction in anthropogenic DIN. Baseline total load = 1100 tonnes; Anthropogenic = 50 tonnes; pre-development = 1050 tonnes. Thus 50% reduction involves reduction of 25 tonnes leaving the new total load at 1075 tonnes.
3. 60% reduction in PSII. Baseline total load = 530 kg (all anthropogenic). Thus 60% reduction involves a reduction of 320 kg leaving total load of 210 kg.
4. 20% reduction in PN and PP.

### *ERTs — by 2035*

1. 50% reduction in total load i.e. 50% of 1,950,000 = 970,000 tonnes leaving a total load of 970,000 tonnes. Progress towards the RPT will obviously take us some way towards the ERT.
2. DIN — no major reduction needed but management of sources where possible.
3. PSII — no reduction needed but management of sources where possible. However, better consideration of risks to freshwater systems will likely require significant management.
4. A 50% reduction in fine sediment will encompass the required reductions in PN and PP.

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**Fitzroy Basin Association Incorporated**  
PO Box 139, Rockhampton QLD 4700  
Phone: (07) 4999 2800  
Fax: (07) 4921 2860

[www.fba.org.au](http://www.fba.org.au)

