

Nutrient management zones in the Great Barrier Reef catchment: a decision system for zone selection

Nutrient management zones (NMZ) technical report

Report No. 06/07

Compiled by J. Brodie

**This technical report was prepared following the Nutrient Management
Zone Workshop held 5 December 2005 at Townsville**



Australian Government



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Glossary

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|--------------------|--|
| ACTFR | Australian Centre for Tropical Freshwater Research |
| ANNEX | Annual Nutrient Export model |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DEW | Department of the Environment and Water Resources (Australian Government) formerly |
| DIN | Dissolved inorganic nitrogen |
| DIP | Dissolved inorganic phosphorus |
| DPIF | Department of Primary Industries and Fisheries (Queensland) |
| DON | Dissolved inorganic nitrogen |
| ERI | Ecosystem risk index |
| Fertiliser | For the purposes for this Report, considered as a material added to crops containing nitrogen (N) and/or phosphorus (P) |
| FIFA | Fertiliser Industry Federation of Australia |
| GBR | Great Barrier Reef |
| GBRMPA | Great Barrier Reef Marine Park Authority |
| NMZ | Nutrient management zone |
| NRM | Natural resource management |
| NRW | Department of Natural Resources and Water (Queensland) formerly Department of Natural Resources, Mines and Water |
| NSZ | Nutrient sensitive zones, used in Reef Plan. Nutrient management zone (NMZ) has been adopted to replace NSZ in this technical report |
| PN | Particulate nitrogen |
| QLUMP | Queensland Land-use Mapping Program |
| Reef Plan | Reef Water Quality Protection Plan |
| SedNet | Sediment River Network model |
| STM Project | Short-term Modelling Projec |

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Executive summary

Scope

The Department of the Environment and Water Resources (DEW) and the Great Barrier Reef Marine Park Authority (GBRMPA) commissioned this technical report to progress Reef Water Quality Protection Plan Action D8 which is to:

Identify and establish nutrient...[management] zones within which extension services, property resource management planning and NRM funding will be focused to minimise impact of nutrients on the Reef; and investigate further land use planning, regulatory, market and voluntary mechanisms that could be applied in these zones.

The Reef Water Quality Protection Plan (Reef Plan) is aimed at addressing diffuse pollution from broadscale land use. Urban diffuse sources and point sources of pollution such as sewage, waste from ore processing as part of mining and agriculture are dealt with separately under a range of legislation, regulations and strategies and are not dealt with through this Reef Plan action.

This technical report establishes criteria to define nutrient management zones (NMZs). The technical report does not consider mechanisms to be employed to reduce nutrient runoff in NMZs. Rather, a separate process is under way to develop policy mechanisms that will apply in these zones. The Queensland Government, principally the Department of Primary Industries and Fisheries (DPIF), is leading this process in collaboration with the Australian Government and relevant industry groups.

Work to date on policy mechanisms recognises improved nutrient management practices already in place or in train. The overall objective of the policy mechanisms is to optimise nutrient use for profitable agriculture whilst minimising the risk of movement of nutrients off-site.

NMZs will be priority geographic areas for implementation of this approach including prioritisation of government, industry and regional natural resource management (NRM) body co-investment.

A policy discussion paper is in development and is likely to be released for public consultation in March 2007.

Identification of criteria to define nutrient management zones

In November 2005, the DEW and GBRMPA commissioned the Australian Centre for Tropical Freshwater Research (ACTFR) to develop a decision system with criteria for identifying NMZs, which was outlined in an earlier draft of this technical report. A meeting of experts was then reconvened in Townsville on 5 December

2005 to discuss, and where possible agree, criteria for identifying NMZs. This final revised technical report outlines the criteria agreed at the workshop and then shows the relative importance of areas when the criteria are applied to different fertilised agricultural land uses in the Great Barrier Reef (GBR) catchment.

To classify NMZs, the GBR catchment was divided into areas of significant fertiliser use (based on land use). NMZs relate to the transport of nutrients from diffuse sources of pollution within the GBR catchment out to the GBR lagoon. Ten basically discontinuous fertilised areas were identified: Inland Normanby, Wet Tropics Coastal, Atherton and Evelyn Tablelands, Burdekin Coastal, Inland Burdekin, Bowen, Mackay–Whitsunday Coastal, Fitzroy, Inland Burnett and Burnett Coastal (see Figure 14). The Mary catchment was excluded, as its area of major influence, Hervey Bay, is outside the GBR World Heritage Area.

At the 5 December 2005 workshop, experts agreed to use a number of criteria to compare fertilised agricultural lands in the GBR catchment. The criteria relate to the application of fertiliser, the potential for loss of nitrogen and phosphorus, the likelihood that the nutrients would reach the coast, how far the nutrients are likely to spread, their effect on sensitive marine ecosystems (coral and seagrasses) and other potential adverse marine impacts.

ACTFR (Jon Brodie) revised the earlier draft of this technical report to incorporate the outcomes of the 5 December 2005 Nutrient Management Zone Workshop. This second draft was released for comment from agricultural industry representatives and scientific experts. In September 2006, DEW commissioned Professor Barry Hart, Professor Rodger Grayson, Dr Tony Church and Gary Ham to independently review the technical report. The review found the framework outlined in the report to be scientifically credible and robust, but recommended some modifications. To incorporate the recommendations of the review, the criteria agreed at the workshop were revised by (1) setting aside the final criterion (other potential adverse marine impacts) and (2) withdrawing seagrass from the sensitive marine ecosystems criterion. The resultant five criteria for identifying and prioritising fertiliser-using areas are:

1. Presence of significant areas of fertiliser-applying land uses (this was used to identify the 10 areas; the following criteria prioritise the areas)
2. Potential for nitrogen and phosphorus losses
3. Likelihood of reaching the coast (i.e. mouth of river)
4. Extent of transport of exported nutrients in the GBR lagoon (hence influence area)
5. Number and proximity to the coast of coral reefs within the influence area.

Applying these criteria to the 10 discontinuous fertilised areas leads to a priority list of regions for action on fertiliser management (Table 13). The Wet Tropics Coastal and Mackay–Whitsunday Coastal fertilising areas, followed by the Burdekin Coastal area are the highest ranked. While all 10 fertilised areas carry some level of risk and therefore should be considered nutrient management zones, the prioritised hazard assessment from this analysis can be used to inform future investment, and management programs should be targeted on the basis of this priority listing. Further prioritisation of sub-regions within the 10 NMZs may be possible on the basis of biophysical characteristics of the landscape and more complete information on fertiliser practices, but this should be pursued at the time nutrient management programs are implemented.

As precise data on fertiliser application rates, nutrient losses and nutrient fate are not known for every land use or region, the identification of NMZs has relied, by necessity, on expert determinations based on hazard levels. In the absence of complete information, an adaptable approach is also being taken to the identification of NMZs, so that as additional information becomes known the zones may be further refined. This will allow for inclusion of new areas and land uses that involve significant fertiliser use and that are likely to result in nutrient export to sensitive ecosystems of the GBR.

1. Introduction

1.1. What are nutrient management zones?

The Reef Water Quality Protection Plan (Reef Plan) is a joint initiative of the Australian and Queensland governments aimed at improving the quality of water entering the Great Barrier Reef (GBR). Diffuse sources, particularly cattle grazing and crop production, are the most significant contributors to pollutant discharges in the GBR lagoon (Productivity Commission 2003).

Action D8 of the Reef Plan requires the following:

Identify and establish nutrient...[management] zones¹ within which extension services, property resource management planning and NRM funding will be focused to minimise the impact of nutrients on the Reef; and investigate further land use planning, regulatory market and voluntary mechanisms that could be applied in these zones.

The Reef Plan defines nutrient management zones (NMZs) as ‘...areas of land that contribute significant quantities of nutrients to waterways entering the Reef and that can influence sensitive marine ecosystems’. The Reef Plan also states (p. 20) that the identification of NMZs will provide a focus for the fertiliser industry.

1.2. Scope of this technical report and related policy development

As the Reef Plan is aimed at addressing diffuse pollution from broadscale land use, urban diffuse sources and point sources of pollution are not dealt with through this Reef Plan action. These pollution sources such as sewage, waste from ore processing as part of mining and agriculture are dealt with separately under a range of legislation, regulations and strategies.

This technical report establishes criteria to define NMZs. The report does not consider mechanisms to be employed to reduce nutrient runoff in NMZs. Rather, a separate process is under way to develop policy mechanisms that will apply in these zones. The Queensland Government, principally the Department of Primary Industries and Fisheries (DPIF), is leading this process in collaboration with the Australian Government and relevant industry groups.

1 The Reef Plan used the term ‘nutrient sensitive zones’ (NSZ), rather than nutrient management zones. As the term NSZ is likely to be assumed to be a zone which is sensitive to the delivery of nutrients such as a wetland or near-shore coastal zone, rather than the application of further nutrients, as intended, the term nutrient management zone (NMZ) has been adopted to replace NSZ.

In considering policy mechanisms the overall objective has been to optimise nutrient use for profitable agriculture whilst minimising the risk of movement of nutrients off-site.

Investigations of a range of options for management within NMZs have established that an industry-specific approach is required. A phased approach has also been favoured to assist growers in overcoming impediments to good practice, with emphasis in the initial stages on industry-led voluntary approaches. Where this is ineffectual in meeting agreed targets for nutrient management, different measures will be considered by government.

NMZs will be priority geographic areas for implementation of this approach including prioritisation of government, industry and regional natural resource management (NRM) body co-investment.

A policy discussion paper is in development and is likely to be released for public consultation in March 2007.

1.3. Process of identifying nutrient management zones

A working group of officers from DPIF, the Department of Natural Resources and Water (NRW), the Great Barrier Reef Marine Park Authority (GBRMPA) and the Department of the Environment and Water Resources (DEW) has been involved in the management of Action D8. By agreement, DEW and GBRMPA have taken lead responsibility for identifying NMZs, and DPIF and NRW are leading the investigation of mechanisms to be applied in the NMZs.

Working group meetings established that **the identification of NMZs would focus on intensive agricultural areas in which nutrients are applied** (including mill mud, boiler ash and sewage sludges). This decision was based on the Reef Plan's statement that the identification of NMZs will provide a focus for the fertiliser industry and on the need to target areas with the most concentrated inputs of nutrients to the GBR. It is estimated that around 21 per cent of the nitrogen load entering the GBR is derived from around 1.1 per cent of the GBR catchment, primarily from cropping lands (Moss *et al.* 1993).

Nutrient loss from grazing is largely incidental, occurring as a result of sediment loss rather than nutrient application. A number of Reef Plan actions address sediment loss, including Action H4, which requires the identification of sub-catchment hotspots that deliver disproportionate quantities of sediment, nutrients and pesticides.

Work on Action H4 has focused on developing and using improved versions of the SedNet (Sediment River Network) model and the related ANNEX (Annual Nutrient Export) model to inform prioritisation of sub-regions in the GBR catchment. The results of this work (known as the Short-term Modelling Project) which helped

address Action H4 are discussed below. Work on H4 has focused on sediments, nutrients and pesticides, and did not contain adequate detailed information to identify NMZs as required by Action D8. Future modelling work conducted under H4 will be used to inform, and where appropriate modify, the NMZs as identified in this technical report.

In May 2005, DEW and GBRMPA, in consultation with the working group, prepared a method for identifying NMZs based on the ANNEX model. A meeting was held in June 2005 to consult regionally based scientific experts on the development of the NMZ model. This meeting concluded that at that time ANNEX was not a useful basis for identifying NMZs as it was based on limited data. Specifically, nutrient export values nominated for land uses were not regionalised and could result in unjustified discrimination between catchments (see McKergow *et al.* 2005). The meeting also identified the need for further expert input in identifying NMZs and cautioned against delineating areas at too fine a scale (sub-catchment) where datasets were not sufficiently accurate to support this.

The Short-term Modelling Project (Cogle *et al.* 2006), which uses improved versions of ANNEX, may inform prioritisation of sub-regions in the future. In this project, 57 land use and land management scenarios were analysed to evaluate the impact and average annual fate of sediments and nutrients in the GBR catchment. These catchment scenarios were developed in consultation with five regional NRM bodies in the GBR catchment—Far North Queensland, Mackay–Whitsunday, Burdekin, Fitzroy and Burnett–Mary—and were modelled using SedNet/ANNEX. The results from the modelling project show that the overwhelming majority of sediments and nutrients supplied to the GBR originate within 80–90 km of the coast.

Based upon the modelling results, total phosphorus loads were dominated by particulate phosphorus in all five regions, while total nitrogen loads more evenly comprised both particulate and dissolved forms (dissolved nitrogen dominated in Far North Queensland and the Mackay–Whitsunday region, while the Burdekin, Fitzroy and Burnett–Mary regions were dominated by particulate nitrogen). The region with the highest predicted exports of dissolved inorganic nitrogen was Far North Queensland (9100 tonnes) attributed to significant losses from applied fertiliser combined with high rainfall, in comparison to the other, lower rainfall, regions, Mackay–Whitsunday (2500 tonnes), Burdekin (2277 tonnes), Fitzroy (992 tonnes) and Burnett–Mary (434 tonnes).

Far North Queensland is also predicted to have the highest export of dissolved inorganic phosphorus (400 tonnes) compared to the other regions, Burdekin (228 tonnes), Mackay–Whitsunday (80 tonnes), Fitzroy (119 tonnes) and Burnett–Mary (40 tonnes). This may be partially linked to phosphorus fertiliser use, but many other factors not related to fertiliser use will contribute to these differences for phosphorus. Thus the results of the Short-term Modelling Project support the priority ranking

for NMZs outlined in this technical report with highest priority given to the Wet Tropics Coastal (Far North Queensland region) and Mackay–Whitsunday Coastal.

A more detailed comparison of the Short-term Modelling Project results and the results of the decision system described in this report is provided at Appendix A.

A meeting of experts was reconvened in Townsville on 5 December 2005. The list of experts attending is at Appendix B. The workshop was held to discuss, and where possible agree, the criteria for identifying NMZs. The DEW and GBRMPA had commissioned the Australian Centre for Tropical Freshwater Research to prepare a decision system with criteria for identifying NMZs, which was outlined in an earlier draft of this technical report and formed the basis for discussion at the workshop.

At the workshop, experts agreed to use a number of criteria to compare fertilised agricultural lands in the GBR catchment. The criteria relate to the application of fertiliser, the potential for loss of nitrogen and phosphorus, the likelihood that the nutrients would reach the coast, the extent of transport of nutrients, sensitive marine ecosystems (coral and seagrasses) and other potential adverse marine impacts. Each criterion has a list of desirable attributes against which it can be judged. At the workshop, experts agreed that data for many of the attributes are not currently available, and that the initial identification of zones will need to rely on attributes that have sufficient data to delineate between fertilised areas.

ACTFR (Jon Brodie) revised the earlier draft of this technical report to incorporate the outcomes of the 5 December 2005 workshop. This second draft was released for comment from agricultural industry representatives and scientific experts. In September 2006, DEW commissioned Professor Barry Hart (Water Science Pty Ltd), Professor Rodger Grayson (University of Melbourne), Dr Tony Church (Sinclair Knight Merz) and Gary Ham (agricultural consultant) to independently review the technical report. The review found the framework outlined in the report to be scientifically credible and robust, but recommended some modifications. To incorporate the recommendations of the review, the criteria agreed at the workshop were revised by (1) setting aside the final criterion (other potential adverse marine impacts) and (2) withdrawing seagrass from the sensitive marine ecosystems criterion.

The final criterion ('other potential adverse marine impacts', which accounted for crown-of-thorns starfish concentrations) was set aside as the criterion added little additional discrimination and data were limited. The withdrawal of seagrasses from the 'sensitive marine ecosystems' criterion was based on two grounds. The first is that the mapping data for seagrass are relatively old. The second is that the effect of increased nutrients on tropical seagrasses is not clearly established. This is discussed in Section 5.

This technical report outlines the agreed criteria for prioritising NMZs and then applies the criteria to rank fertilised agricultural land uses in the GBR catchment.

As precise information on fertiliser application rates, nutrient losses and fate are not known for every land use or region, the identification of NMZs relies, by necessity, on expert determinations based on hazard. In the absence of complete information, an adaptable approach is being taken to the identification of NMZs, so that as additional information arises the zones may be further refined in the future. This will also allow for the recognition and inclusion of new areas and land uses that involve significant fertiliser use and that are likely to result in nutrient export to sensitive ecosystems of the GBR, such as coral reefs. An adaptable management framework has been developed to illustrate the process for managing nutrients within the GBR catchment into the future (Figure 1). The framework can be adapted as new data become available and management options are evaluated.

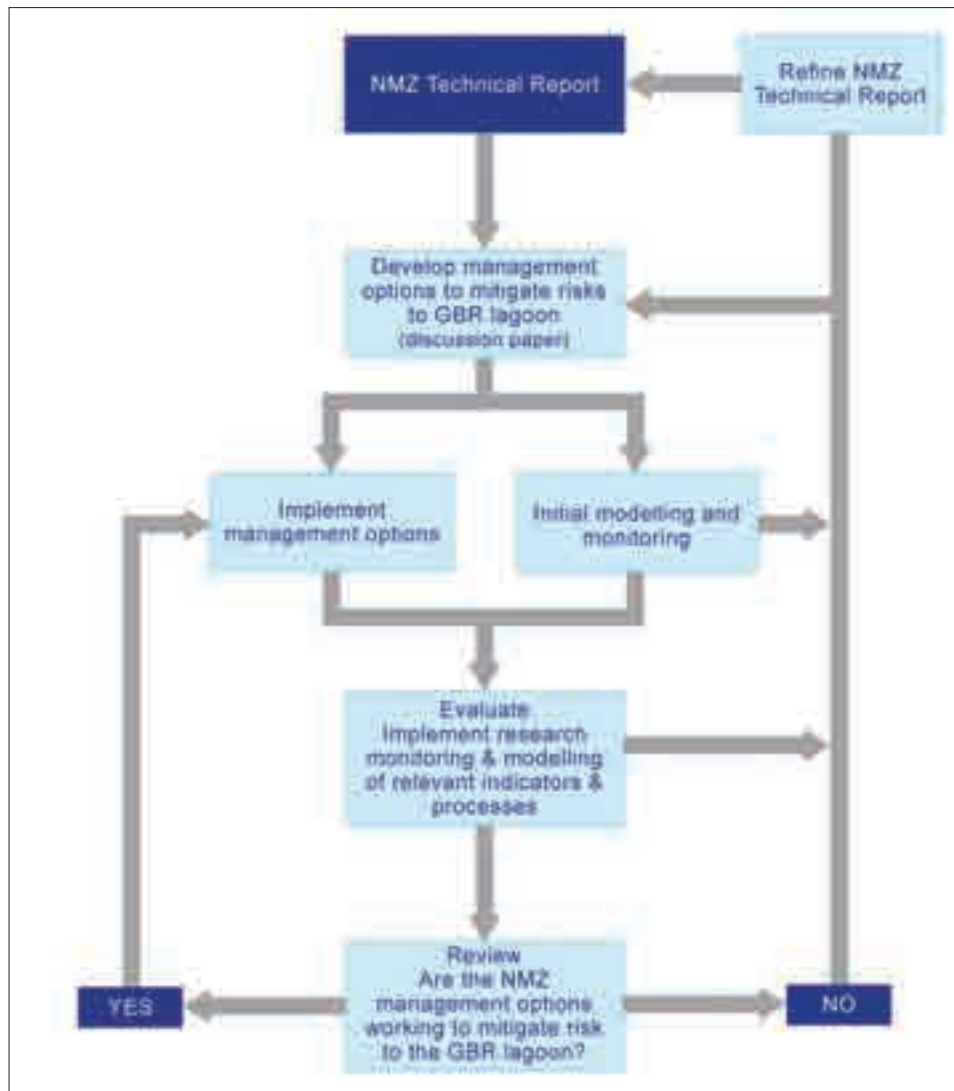


Figure 1: Adaptive management framework for nutrient management in the GBR

2. The Great Barrier Reef catchment

The Great Barrier Reef (GBR) extends along the north-east Australian continental shelf for 2000 km between 9oS and 24oS (Figure 2). The Great Barrier Reef World Heritage Area is the world's largest marine protected area and is bordered by a catchment of 423 000 km² (collectively, the 'GBR catchment', Figure 2). Grazing (predominantly beef) on native or improved pastures is the major land use (77 per cent) with cropping (3 per cent comprising sugar, horticulture, grains and cotton) and urban/residential land uses (1 per cent) occurring in smaller areas; the remainder of the catchment includes significant areas of national park and forest reserve (Gilbert and Brodie 2001). Large areas of savannah woodland and forest (approximately 200 000 km²) have been cleared or thinned to support grazing and cropping (Barson *et al.* 2000) and significant areas of freshwater and coastal wetlands have been lost or degraded (Johnson *et al.* 1997). Approximately one million people live within the GBR catchment.



Figure 2: GBR and its catchment area

3. Great Barrier Reef nutrient inputs

Sources of nutrients for the GBR include nutrient-poor Coral Sea surface water; upwelling Coral Sea deep water (nutrient rich); atmospheric inputs, including nitrogen fixation by cyanobacteria (Furnas *et al.* 1995); and land runoff. A variety of evidence clearly shows that agricultural land use has led to increased nutrient loss from the GBR catchment. In particular, river exports of nitrogen and phosphorus have increased several-fold as catchments have been converted from natural vegetation to intensive grazing and cropping systems. Estimated increases in land nutrient loading from the GBR catchment range from two to five times for nitrogen and four to 10 times for phosphorus over the last 150 years (Moss *et al.* 1993; Neil *et al.* 2002; Brodie *et al.* 2003; Furnas 2003; McKergow *et al.* 2005).

A number of long-term datasets are available for individual catchments to demonstrate changes in nutrient exports over time. For example, significant increases (4–6 per cent per annum) in particulate nitrogen concentrations were observed in the lower Tully River (Wet Tropics) over a 10-year period (1990–2000) (Mitchell *et al.* 2001). The beginning of this upward trend (ca. 1990) coincides with the start of significant land use change in the Tully River catchment as wet tropical pastures (grass) were converted to more intensively cultivated and fertilised sugarcane and banana paddocks (Mitchell *et al.* 2001).

In studies in the Douglas Shire that examine nitrogen losses from paired comparisons under different fertiliser rates (95 kg ha⁻¹ yr⁻¹ versus 190 kg ha⁻¹ yr⁻¹), 28 kg ha⁻¹ of nitrogen was lost over 14 months from the high rate compared to 15 kg ha⁻¹ from the low rate (Bartley *et al.* 2005). Of the 28 kg ha⁻¹ of nitrogen, 12 kg was lost as surface runoff and 16 kg as sub-surface loss.

While natural sources of nitrate in groundwater do exist, nitrate concentrations greater than 1 mg L⁻¹ NO₃—N in groundwater are generally a sign of fertiliser or sewage effluent contamination. Brodie *et al.* (1984) found widespread high nitrate concentrations in the Burdekin delta area in 1976–1977. More recent sampling has confirmed the persistence of these elevated levels (Keating *et al.* 1996; Biggs *et al.* 2001). Additional work by CSIRO suggests that these nitrate levels, though elevated, appear to have a correlation with iron concentrations in the groundwater, and nitrate concentrations are significantly lower with iron in the groundwater. This mechanism may be promoting the reduction of nitrate and assisting in denitrification (Thayalakumaran *et al.* 2004).

Biggs *et al.* (2001) note that although groundwater nitrate concentrations in the Mackay and Burdekin regions discussed in their study are generally high, mostly greater than 20 mg L⁻¹ NO₃ (i.e. > 4.5 mg L⁻¹ NO₃—N), their trend analysis shows that concentrations do not appear to have generally increased over the period 1997–2000. They also point out that nitrate concentrations are so high in many of the bores used for irrigation in the Mackay and Burdekin regions that the water, given the

irrigation volumes used, is a significant source of 'fertiliser' nitrogen. They calculate that a water application of 15 ML ha⁻¹ with groundwater nitrate concentrations of 50 mg L⁻¹ NO₃ (a common concentration) represents an input of N equivalent to 170 kg ha⁻¹. This is in fact close to the total Calcino (1994) recommendation for N fertiliser for ratoon sugarcane (210–250 kg⁻¹ ha⁻¹yr⁻¹) and greater than the Calcino (1994) recommendation for plant sugarcane (135–150 kg⁻¹ ha⁻¹yr⁻¹). Work by Rasiah *et al.* (2001, 2003a, b) shows that the potential contribution from fertiliser nitrogen to groundwater nitrate levels and subsequent catchment water quality can be high. It should be noted that elevated nitrate levels in groundwater can vary markedly on both spatial and temporal scales. For this reason, the incorporation of groundwater nitrogen into a nutrient management system applicable at the enterprise scale can be problematic (A. West, DPIF 2006, pers. comm.).

4. Nutrient impacts and the Great Barrier Reef

Increased loads of nutrients are reaching and influencing inner shelf reef and benthic ecosystems of the GBR, especially those of the central and southern GBR (see discussion in Section 5, Extent of hazard). Effects of nutrient inputs are now evident on inshore reefs, seagrasses and marine animals (van Woesik *et al.* 1999; Udy *et al.* 1999; Fabricius and De'ath 2004; Fabricius *et al.* 2005). The changed inputs have resulted in measurable increased phytoplankton biomass in affected areas of the GBR lagoon (Haynes *et al.* 2001; Brodie *et al.* in press; GBRMPA 2005) and reef degradation in areas adjacent to coastal agriculture (van Woesik *et al.* 1999; Fabricius and De'ath 2004; Fabricius *et al.* 2005). Changes in seagrass ecosystems at Green Island off Cairns have also been attributed to changed land nutrient inputs (Udy *et al.* 1999). Increased phytoplankton biomass and possibly changed phytoplankton species composition, associated with changed nutrient inputs, is believed to be responsible for higher trophic level changes, specifically population outbreaks of the coral-eating crown-of-thorns starfish (*Acanthaster planci*) (Brodie *et al.* 2005). Where runoff by itself does not degrade coastal reefs, it may exacerbate the effects of other stresses or threats such as freshwater inundation, cyclones and high water temperatures to cause deleterious changes.

Increased understanding of nutrient dynamics in the GBR World Heritage Area is providing insight to the importance of nutrient speciation (i.e. the form of the nutrient) in runoff and may therefore assist in improving land management practices. The form of nitrogen discharged from the GBR catchment has substantially changed from dominance by dissolved organic nitrogen (DON) in the pre-development period to dominance by dissolved inorganic nitrogen (DIN, mostly nitrate) and particulate nitrogen (PN) in recent times (Figure 3) (Brodie *et al.* 2003; Brodie and Mitchell 2006a and b). The completely bioavailable forms of nitrogen and phosphorus (nitrate, ammonium, orthophosphate) now discharged into coastal waters are easily transported over large areas of the GBR lagoon (Devlin *et al.* 2003; Devlin and Brodie 2005; Rohde *et al.* 2006), where they become active in causing long-term nutrient enrichment. While the dissolved inorganic nutrient forms are not stored in the system as such, their products are stored in the form of benthic plants, phytoplankton (measurable as chlorophyll), bacteria and dissolved organic nutrients (Furnas *et al.* 2005). The residence time of these materials in the GBR lagoon is an important factor determining the effect they may have on ecosystems. However, evidence of residence times of water in the GBR lagoon is highly uncertain. One recent estimate claims residence times of between 20 to 300 days (Luick *et al.* 2005). Such estimates are in need of further substantiation.

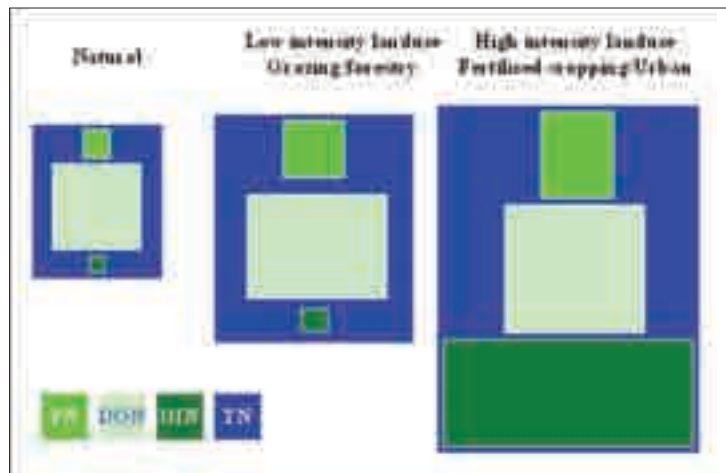


Figure 3: Land use change and impact on nitrogen species and quantity in waterways (from Brodie and Mitchell 2006a). PN= particulate nitrogen; DON= dissolved organic nitrogen; DIN= dissolved inorganic nitrogen; TN= total nitrogen. The size of each box is proportional to the quantity of each species found in waterways.

5. Extent of hazard

The extent of reefs and seagrass beds in the GBR World Heritage Area is shown in Figure 4. The coral reefs of the GBR consist of two main types: the fringing reefs (approximately 760 reefs) which occur inshore on the coast and around the high islands and are most susceptible to land-based impacts, and those of the main reef (approximately 2200 reefs) which occupy a band on the outer part of the continental shelf and are rarely influenced by land-based impacts.

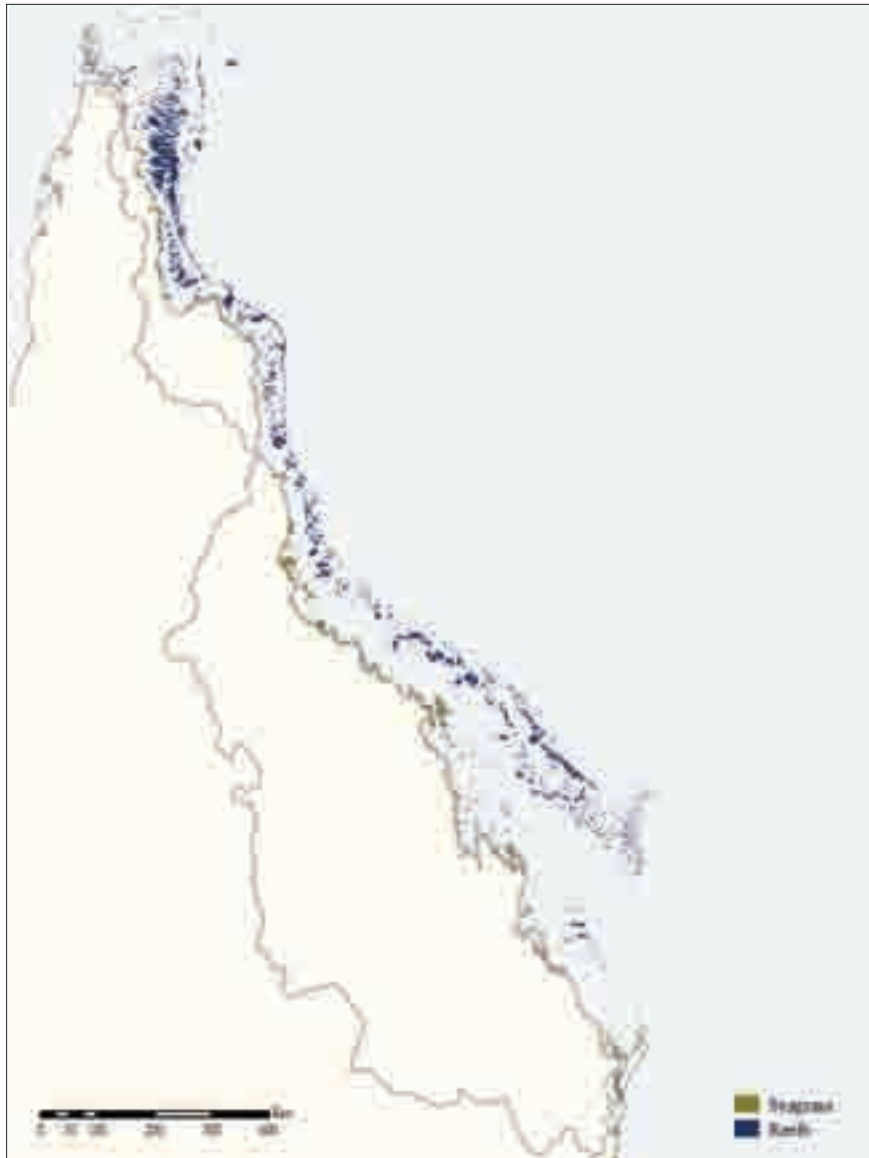


Figure 4: Areas of coral reef and seagrass in the GBR. Source of seagrass data: CSIRO 1995 (derived from Lee Long et al. 1993)

Two recent studies have attempted to determine the extent of the risk land runoff poses to the GBR. Greiner *et al.* (2003, 2005) assessed the risk of the GBR catchments to the downstream GBR waters using a variety of criteria, including estimates of sediments and nutrients discharged to the GBR, potential impacts of this discharge on adjacent ecosystems, and socio-economic criteria. Two catchments in particular, the Burdekin and Fitzroy, rated 'high' against all four aspects of risk in this assessment. This assessment was used as a basis for the catchment risk profiles included in the Reef Plan. There are several limitations to this approach, such as the accuracy of inputs (including the estimates of sediment load, catchment aquatic system condition, area of seagrass) and assumptions relating to risk to marine industries and the capacity of land managers to effect change.

Another model estimated exposure of GBR inner shelf reefs to land runoff using ratings of volume and frequency of discharge from major rivers, the predominant distribution of river plumes in GBR waters, loads of riverine pollutants, and distance of reefs from river mouths (Devlin *et al.* 2003; Figure 5). Coastal and island areas at high risk of exposure to land runoff were identified adjacent to the Wet Tropics region, from Tully to north of Cairns, and in the Whitsunday region. The nearshore zone identified as most at risk contains 438 coral reefs, 462 km² of seagrass beds, and dugong habitats. It supports important fisheries and contains significant tourism destinations. Mid and outer shelf reefs were found to be at lower risk from increased land runoff. This model has a number of limitations: for example, it only includes runoff transported by major rivers, excluding locally important smaller waterways and coastal transport and recycling processes; it assumes a linear reduction of pollutant concentration with distance from the river mouth; and the assessment was limited to coral reefs. However, this model is a useful representation of the spatial extent of the coastal areas that are likely to be regularly exposed to land runoff.

Pinner (unpublished, after Devlin *et al.* 2003) has further refined this model (Figures 6 and 7; Appendix C). Pinner's refinement shows the risk to coral reefs (Figure 6) and seagrass (Figure 7) from the various catchments. The ecosystem risk index (ERI) determines the likelihood of flood plumes from the catchments reaching the reefs and seagrass beds of the GBR. The index is based on:

- a mean annual discharge rating for each catchment (as in Devlin *et al.* 2003)
- a measure of flow variability based on the number of days that mean annual flow was exceeded from 1968 to 1994 (as in Devlin *et al.* 2003)
- the distance and direction of all mapped coral reefs (for Figure 6) and of all mapped seagrass meadows (for Figure 7) in the GBR from the river mouth.

The direction function takes into account the dominance of northerly drift due to winds and the Coriolis effect (as in Devlin *et al.* 2003).

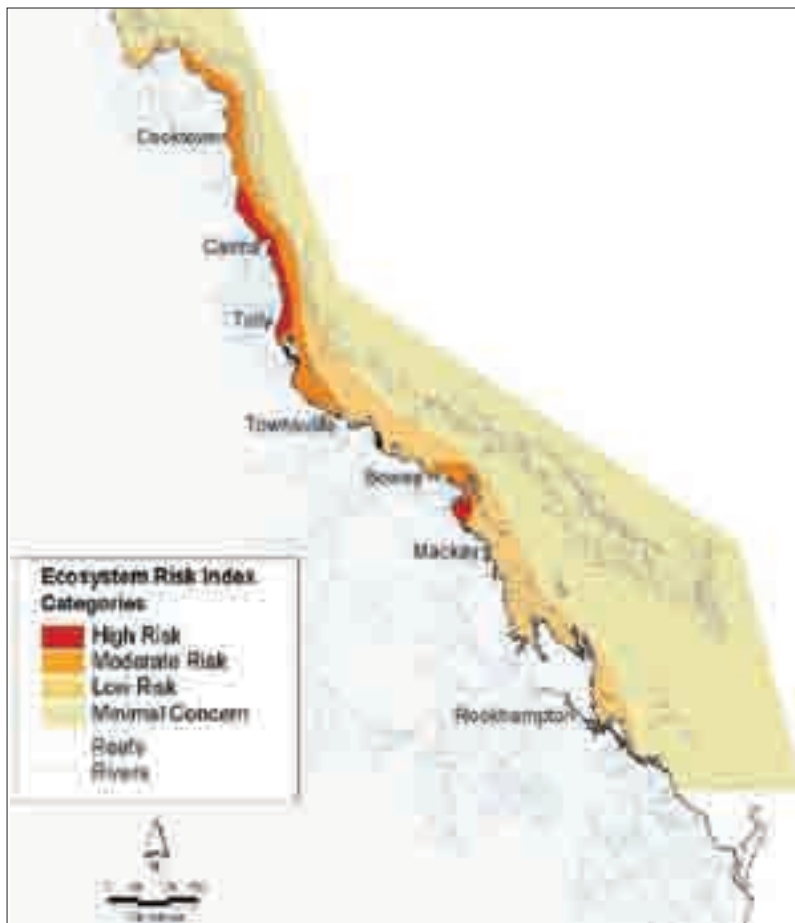


Figure 5: GBR risk assessment: estimated areas and degrees of ecological risk from land runoff. Source: Devlin *et al.* (2003)

It appears that more weight needs to be placed on risks to coral than to seagrass, based on two grounds. First, less confidence can be placed in the mapping data for seagrass: the mapping is based on relatively old data—the most recent reef-wide seagrass surveys date back to the 1980s (Lee Long *et al.* 1993) and the location of seagrass meadows is known to vary over time (Waycott *et al.* 2005). Second, the effect of increased nutrients on tropical seagrasses is not clearly established. Current knowledge indicates that seagrasses in the GBR may be nitrogen limited and may benefit from increases in nitrogen. However, seagrasses are often light limited and elevated nutrient levels may increase phytoplankton concentrations, which could reduce the light available to seagrasses (Waycott *et al.* 2005; Schaffelke *et al.* 2005).

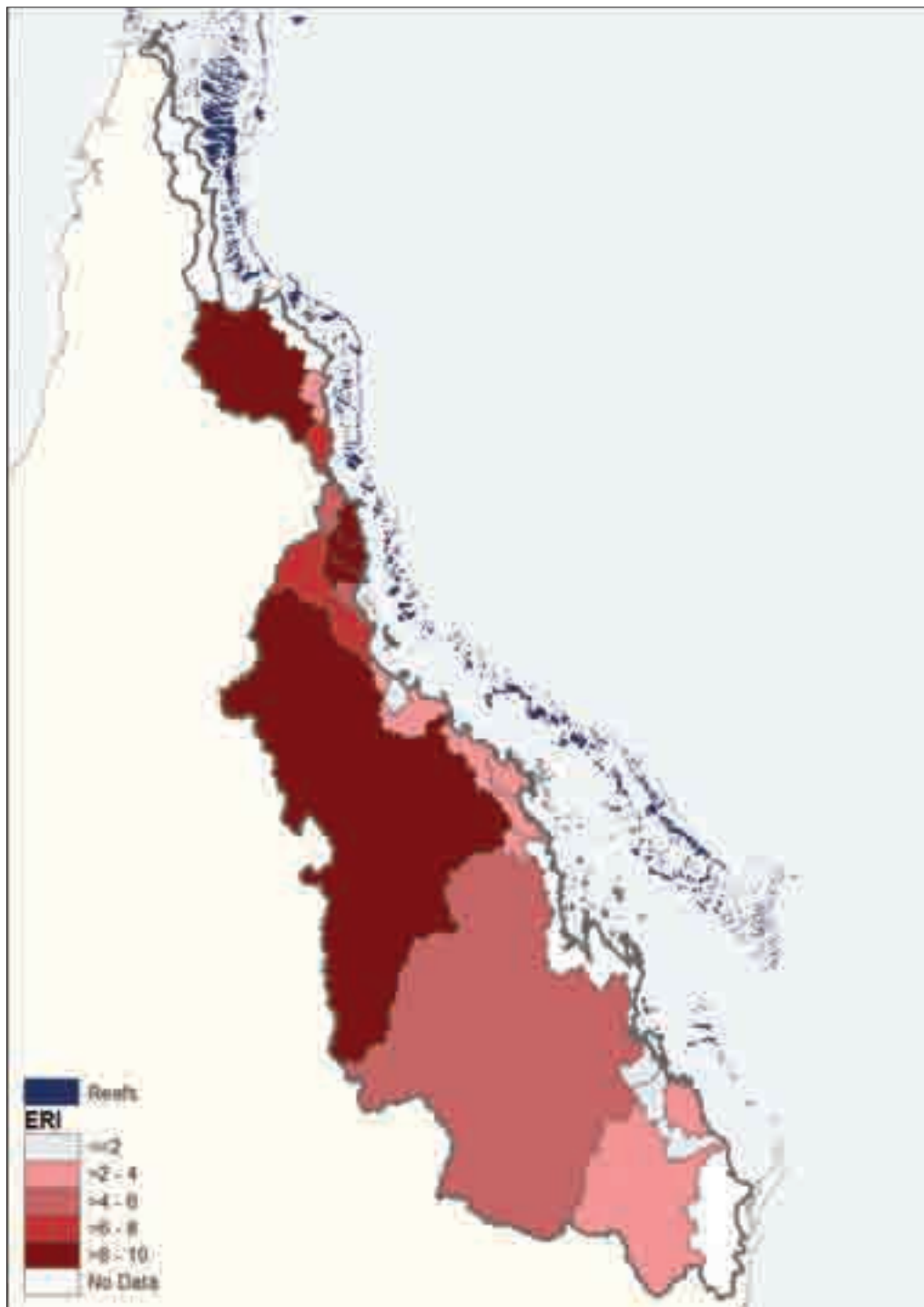


Figure 6: Relative threat of catchments to coral reefs of the GBR (Pinner, unpublished, after Devlin et al. 2003). ERI = ecosystem risk index. Larger numbers indicate the catchment may present a greater threat to the coral reefs of the GBR

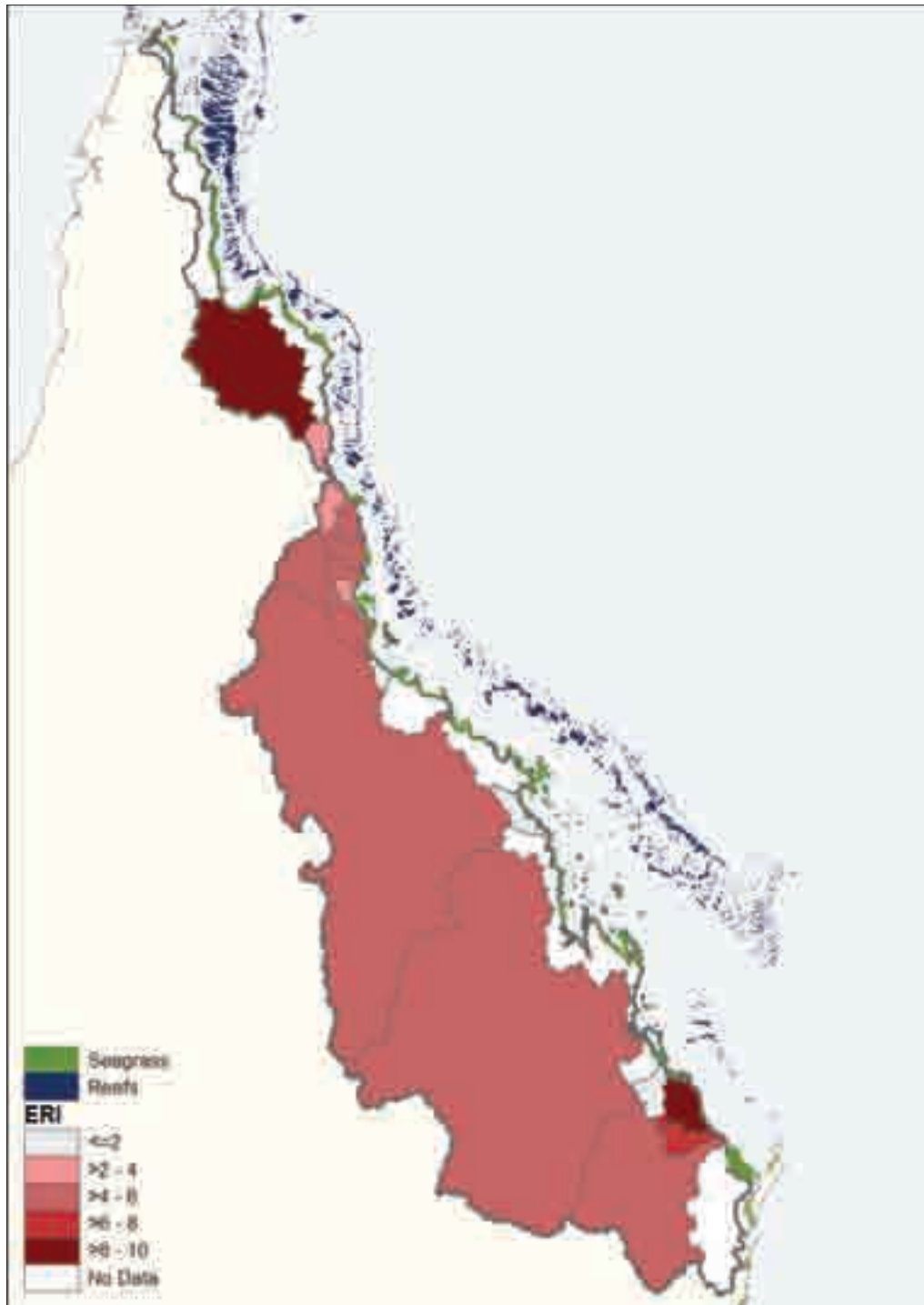


Figure 7: Relative threat of catchments to seagrass of the GBR (Pinner, unpublished, after Devlin et al. 2003). Source of seagrass data: CSIRO 1995, derived from Lee Long et al. 1993). ERI = ecosystem risk index. Larger numbers indicate the catchment may present a greater threat to the seagrass of the GBR

6. The Great Barrier Reef catchment and fertiliser use

6.1. Distribution of fertilised land uses

Figures 8 to 13 show the areas of cropping and dairy fertilised land uses in the GBR catchment. Total areas of each crop in the GBR catchment are uncertain; estimates from the Queensland Land Use Mapping Program (QLUMP) (1999) are as follows:

- Cropping: 18 700 km², of which approximately 5200 km² is estimated to be sugarcane
- Horticulture (including bananas): maximum of 650 km² made up of cotton 262 km², and the rest cereals and oilseed crops
- Dairy pasture: an estimated 50 km²
- Beef pasture: no firm estimate available of the area of fertilised beef pasturage as there are no data available distinguishing between fertilised and un-fertilised beef pasture.

Within the GBR catchment, sugarcane is grown under various levels of irrigation depending on local weather conditions. Table 1 shows the area of sugarcane under irrigation in each mill area, with approximately 15 per cent of this 520 000 ha under fallow, and not fertilised (T. Wrigley, CANEGROWERS 2006, pers. comm.).

High quality pastures, generally found in higher rainfall areas near the coast, are often used for improving stock condition before sale. The productivity of these 'beef finishing' pastures is often enhanced through fertiliser use, although in general only areas receiving more than 1000 mm of annual rainfall would be fertilised. Beef finishing takes place in the following regions:

- Wet Coast Tablelands (Johnstone, Herberton, Babinda, Innisfail, Douglas, Mossman, Cairns, Cardwell, Mareeba, Atherton, Eacham): approximately 168 000 ha carries approximately 240 000 head of cattle at any one time, with 65 000 turned off per year (Bernie English, Tablelands DPIF 2006, pers. comm.).
- Fitzroy Basin: there are approximately 3.5 million head of cattle within a 350 km radius of Rockhampton. Feedlotting is used for finishing more than pasture-based systems. Fertiliser in this industry is mostly used for forage crops such as sorghum, which may be harvested for stock feed or directly grazed. Beef finishing systems generally do not use fertiliser (pondage systems, feedlots, and leucaena are used instead) (Ken Murphy, DPIF Rockhampton 2006, pers. comm.).

Table 1: Area of sugarcane land use in Queensland in 1999 (Dwyer, unpublished a²)

| Mill area | Cane production area (ha) | Percentage irrigated | Area irrigated (ha) |
|--------------------------|---------------------------|-----------------------|---------------------|
| Mossman | 15 356 | 27 | 4 146 |
| Tablelands | 6 712 | 100 | 6 712 |
| Mulgrave | 18 740 | 5 | 937 |
| South Johnstone | 20 523 | 13 | 2 668 |
| Babinda/Mourilyan | 29 015 | 0 | 0 |
| Tully | 29 302 | 0 | 0 |
| Herbert ¹ | 68 004 | 15 | 10 201 |
| Burdekin | 84 004 | 100 | 84 004 |
| Proserpine ² | 24 716 | 89 | 22 000 |
| Mackay ³ | 98 324 | 70 | 68 827 |
| Sarina | 22 398 | 36 | 8 063 |
| Bundaberg ³ | 53 003 | 100 | 53 003 |
| Isis | 19 102 | 88 | 16 810 |
| Maryborough | 15 493 | 47 | 7 282 |
| Moreton | 9 828 | 0 | 0 |
| Rocky Point ⁴ | 6 043 | 2.3 | 139 |
| TOTALS | 520 563 | (average) 54.7 | 284 792 |

- Mackay–Whitsunday region: approximately 76 per cent (690 400 ha) of the region has grazing as the main land use. However this includes large areas of ranges and tree-covered areas seldom grazed plus native pasture not fertilised, Crown land and public areas etc. DPIF staff estimate that approximately 200 000–300 000 ha would be fertilised (Harry Bishop, DPIF Mackay 2006, pers. comm.).

² Sources: Hildebrand 2002; ¹Bella 2006, pers. comm.; ²Agnew 2006, pers. comm. (allocation ML/ha p.a.—9000 ha @ 4; 9000 ha @ 1.5; & 4000 ha @ 0.5); ³Hussey 2006, pers. comm.; ⁴Schwenke 2006, pers. comm.



Figure 8: Area in the GBR catchment under cotton (QLUMP, 2004)

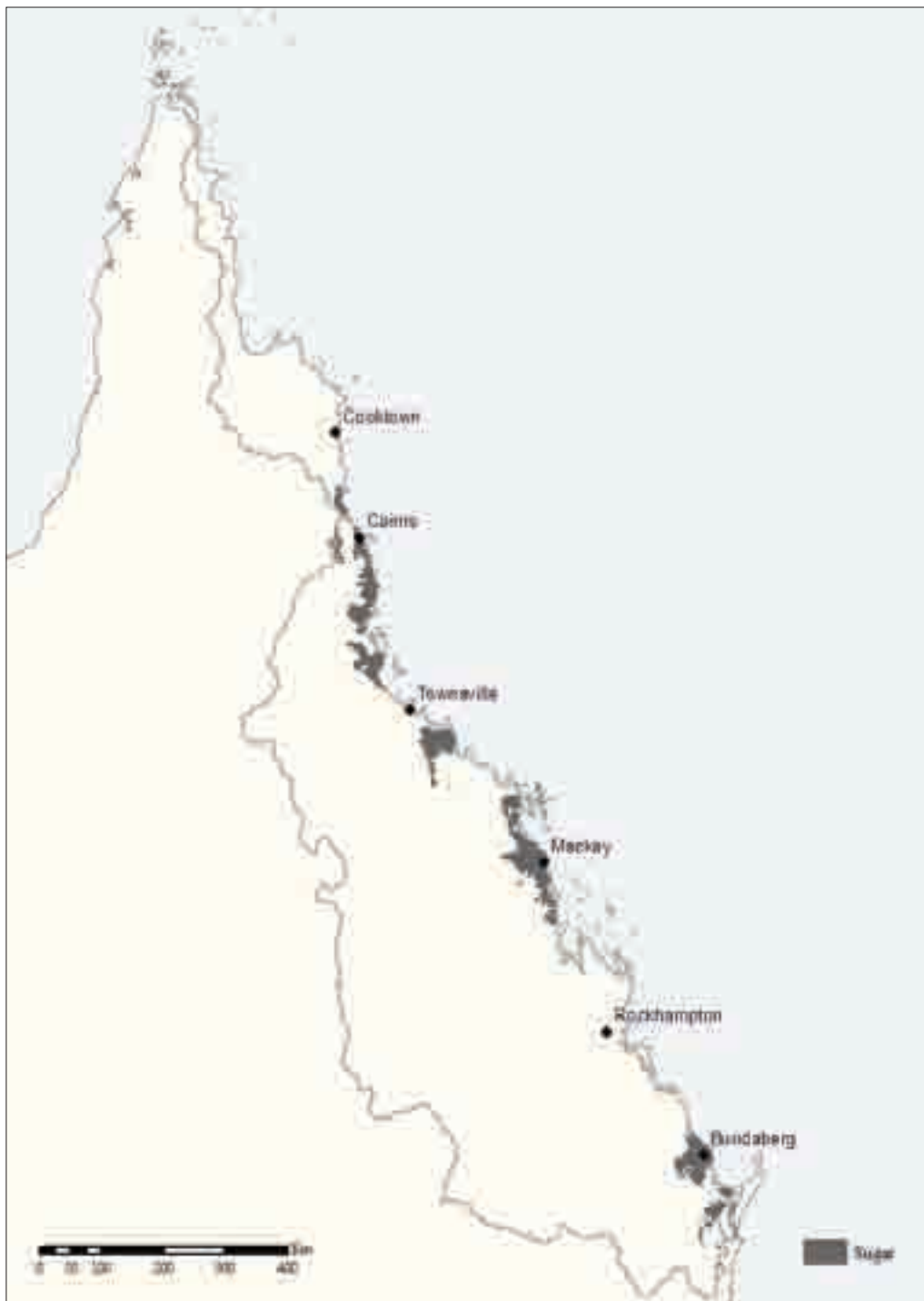


Figure 9: Area in the GBR catchment under sugarcane (QLUMP, 1999)



Figure 10: Area in the GBR catchment under horticulture (QLUMP, 1999)

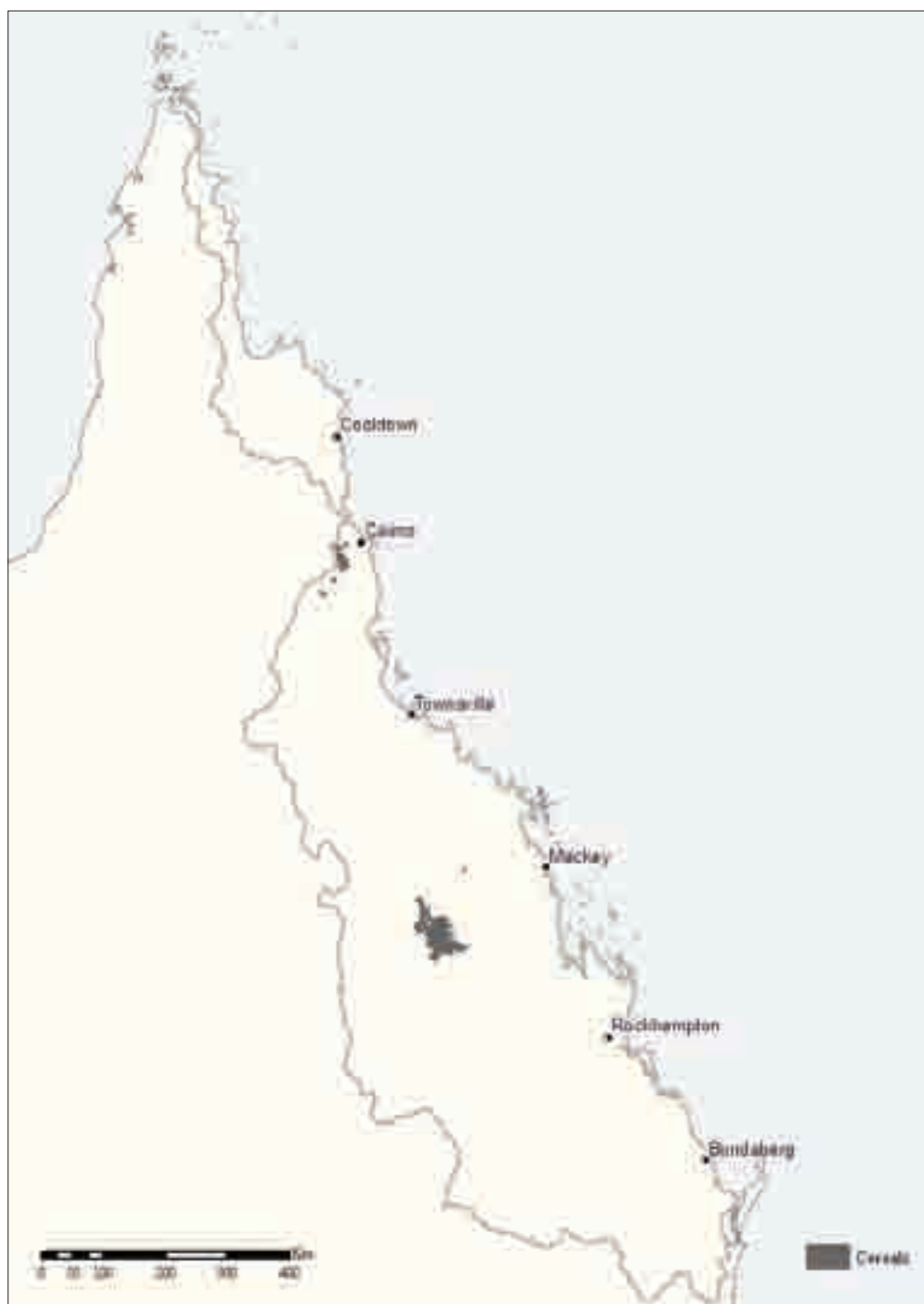


Figure 11: Area in the GBR catchment under cereals (QLUMP, 1999)



Figure 12: Area of dairy in the GBR catchment (QLUMP, 1999)



Figure 13: Area in the GBR catchment under oilseeds (QLUMP, 1999)

No map is available to show the coverage of fertilised beef pasture. Current QLUMP (1999) methods are unable to distinguish between fertilised and unfertilised pastures (C. Witte, NRW 2006, pers. comm.).

6.2. Significant areas of fertiliser use

For the purposes of this technical report, the GBR catchment can be divided into a small number of regions with similar land use types. The significant areas of fertiliser use in the GBR catchment can then be further broken down into 10 basically discontinuous regions. These regions are as shown in Figure 14:

- Inland Normanby
- Atherton and Evelyn Tablelands
- Wet Tropics Coastal
- Burdekin Coastal
- Inland Burdekin
- Bowen
- Mackay–Whitsunday Coastal
- Fitzroy
- Inland Burnett
- Burnett Coastal.

The Mary catchment is excluded, as its area of major influence, Hervey Bay, is outside the GBR World Heritage Area.

The 10 fertilised areas were selected using the land use maps above (Figures 8–13) to identify areas with fertilised land uses and dividing these based on catchment boundaries (e.g. Fitzroy catchment) and spatial separation (e.g. Burdekin Coastal and Inland Burdekin). In many cases, the fertilised areas are separated by areas of non-cropping land uses, either rangeland grazing e.g. between Bowen and Mackay–Whitsunday Coastal or ranges with forest e.g. between Wet Tropics Coastal and Atherton and Evelyn Tablelands. The fertilised areas were presented as a basis for discussion at the December 2005 Nutrient Management Zones Workshop. Detailed examination of land use maps for the GBR catchment (QLUMP 1999; where available (i.e. Burdekin, Johnstone and Fitzroy catchments) QLUMP 2004) was undertaken to determine the extent of each area and to determine if any significant cropping areas were not represented in the areas originally identified. Through this process the Inland Normanby area, which had not previously been selected, was identified. An area around Cooktown which had previously been identified was eliminated as it had only small areas of fertilised land uses.

The 10 areas are used as the basis of prioritising areas for fertiliser management. The extent and location of each area is described below and maps are provided for each area (Figures 15–24), showing land use and indicative boundaries³.

³ As QLUMP data are generally for 1999 land uses and based on satellite data with extensive, but still limited, ground truthing, boundaries are approximate only, enclosing estimated extent of fertilised land area.



Figure 14: Areas of fertilised land use in the GBR catchment. Please note areas have been drawn to show general location only. Background map source: CRES (2000), AWRC (1997) and GA (1999)

Inland Normanby

Cereal crops are grown in the far southern section of the Normanby catchment, over 200 km upstream from the coast (Figure 15).

Atherton and Evelyn Tablelands

A great variety of agricultural land uses occur on the Atherton and Evelyn Tablelands (e.g. tree fruits, sugar, cereals, dairy, tree nuts), with runoff flowing to a number of distinct catchments (e.g. the Johnston and Herbert rivers in the south, the Baron River in the north, and some flows west of the tablelands into the Gulf of Carpentaria). The general boundary is marked by high ground bounded by escarpments to the east, north and south, extending out to the western edge of the GBR catchment (Figure 16).

Wet Tropics Coastal

The Wet Tropics Coastal area extends west from the coastline on the floodplains and coastal areas up to the Tablelands escarpment, north of Daintree and south of Rollingstone. Sugar, bananas, pawpaws and other mixed horticulture are grown in this region (Figure 17).

Burdekin Coastal

Irrigated sugar and, to a lesser extent, horticulture are grown in the Burdekin Coastal area. Cotton has been trialled on a limited basis (approximately 30 ha) with reports of the potential for 20 000 to 30 000 ha (A. West, DPIF 2006, pers. comm.). This area is on the Burdekin River coastal floodplain extending west to Dalbeg from the coastline at Cape Cleveland down to the mouth of Yellow Gin Creek (Figure 18).

Inland Burdekin

The Inland Burdekin area includes the inland floodplain areas extending south from Avon Downs to the south end of the Fitzroy catchment, including West Logan, Brown, Falkner, Mazeppa and Diamond creeks (sub-catchments of Logan Creek). Cereals are the main crop grown on the fertile basalt soils (Figure 19).

Bowen

The Bowen area is a small irrigated horticultural area, with mixed fruit and vegetables, principally tomatoes, capsicums, melons, and mangoes. This area extends west on the coastal lowlands from Rocky Ponds Creek to Miowera (Figure 20).

Mackay–Whitsunday Coastal

The Mackay–Whitsunday Coastal area extends inland on coastal lowlands to the ranges from Eden Lassie Creek in the north to Clairview in the south. The area is primarily used for sugarcane production, with limited horticulture (Figure 21).

Fitzroy

Cotton and cereals are the main crops grown in the Fitzroy area, which is otherwise predominantly under extensive grazing. The Fitzroy area covers the entire Fitzroy River catchment (Figure 22).

Inland Burnett

The Inland Burnett area is the entire Burnett catchment upstream from Mount Perry and the Orange Creek Dam. The area's agricultural industries include scattered citrus, dairy, peanuts, irrigated horticulture and cereals (Figure 23).

Burnett Coastal

The Coastal Burnett Coastal area extends west on the coastal floodplain from the river mouths of Baffle Creek in the north to the Burrum River in the south. The area is used mainly for sugarcane, some horticulture and dairy (Figure 24).

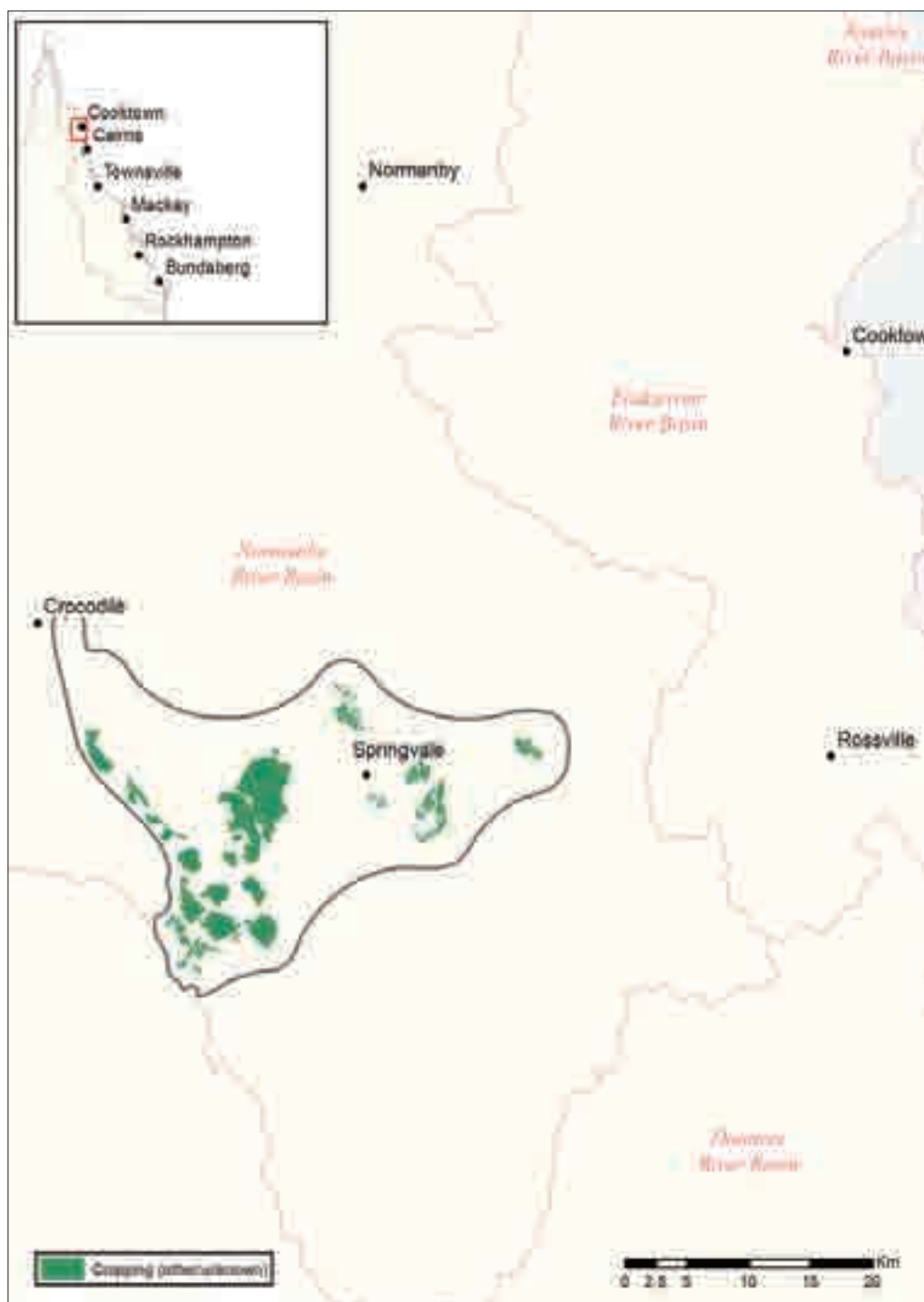


Figure 15: Inland Normanby area (QLUMP 1999)

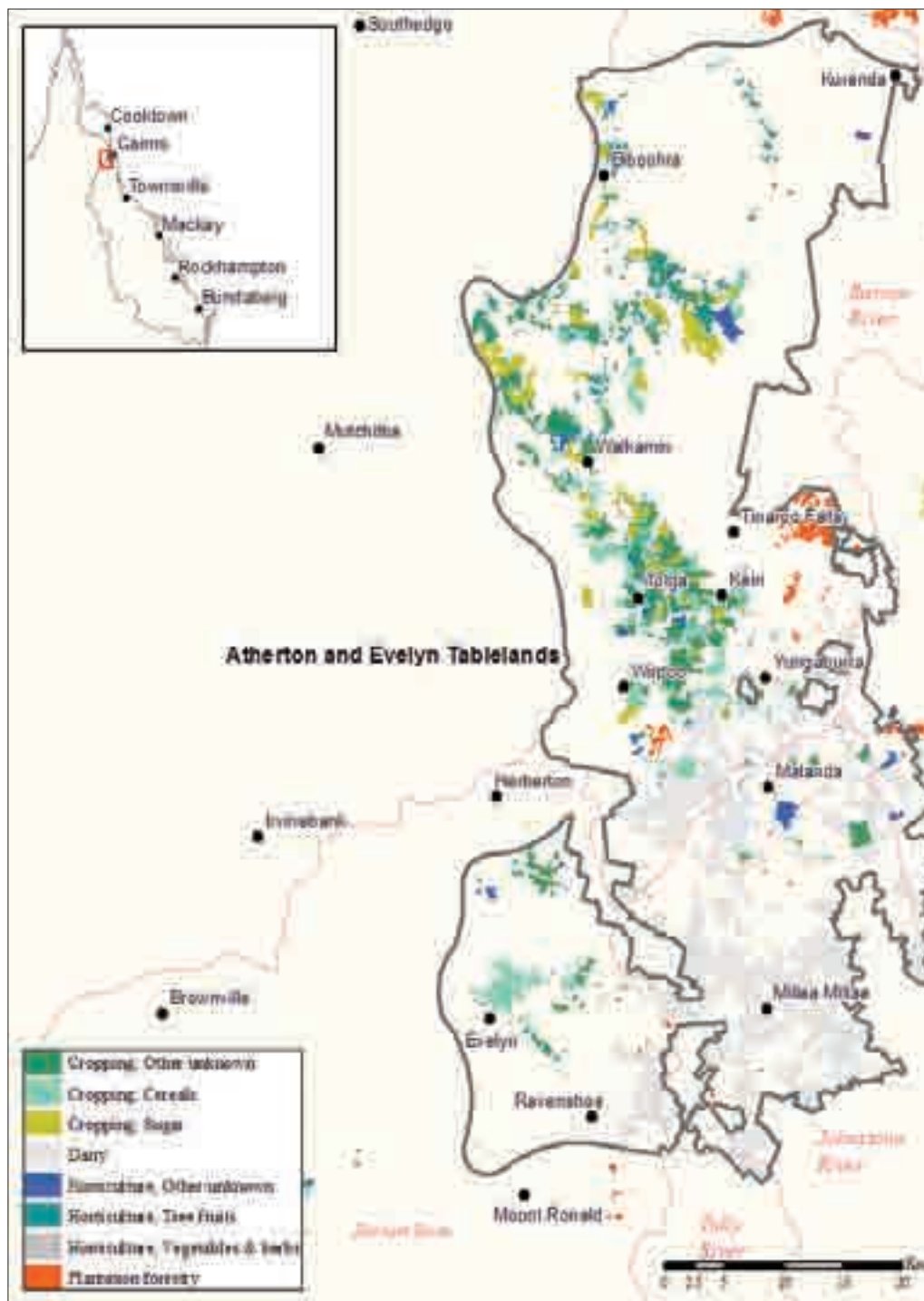


Figure 16: Atherton and Evelyn Tablelands area (QLUMP, 1999; for Johnstone catchment QLUMP 2004)

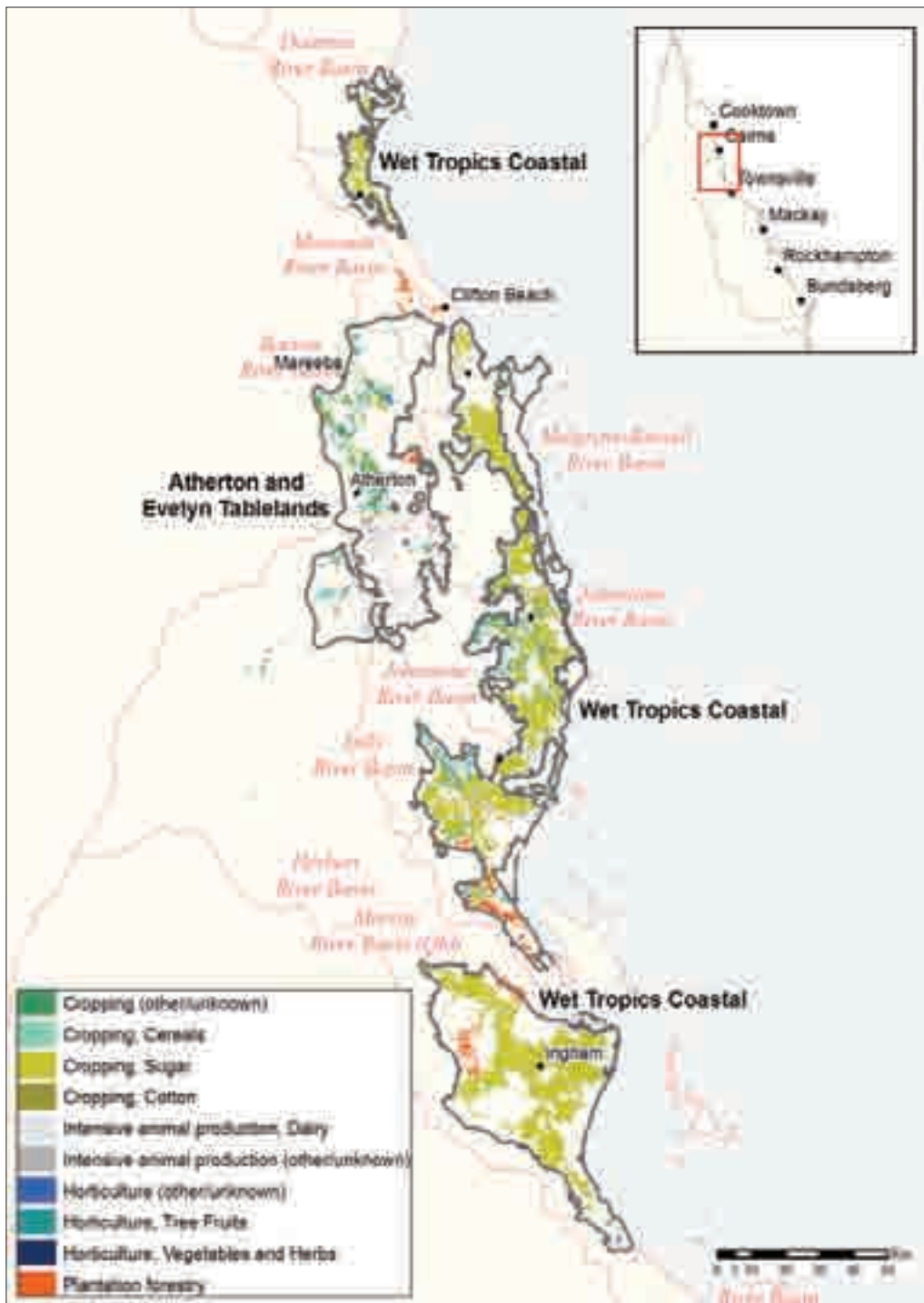


Figure 17: Wet Tropics Coastal area (QLUMP, 1999; for Johnstone catchment QLUMP 2004)

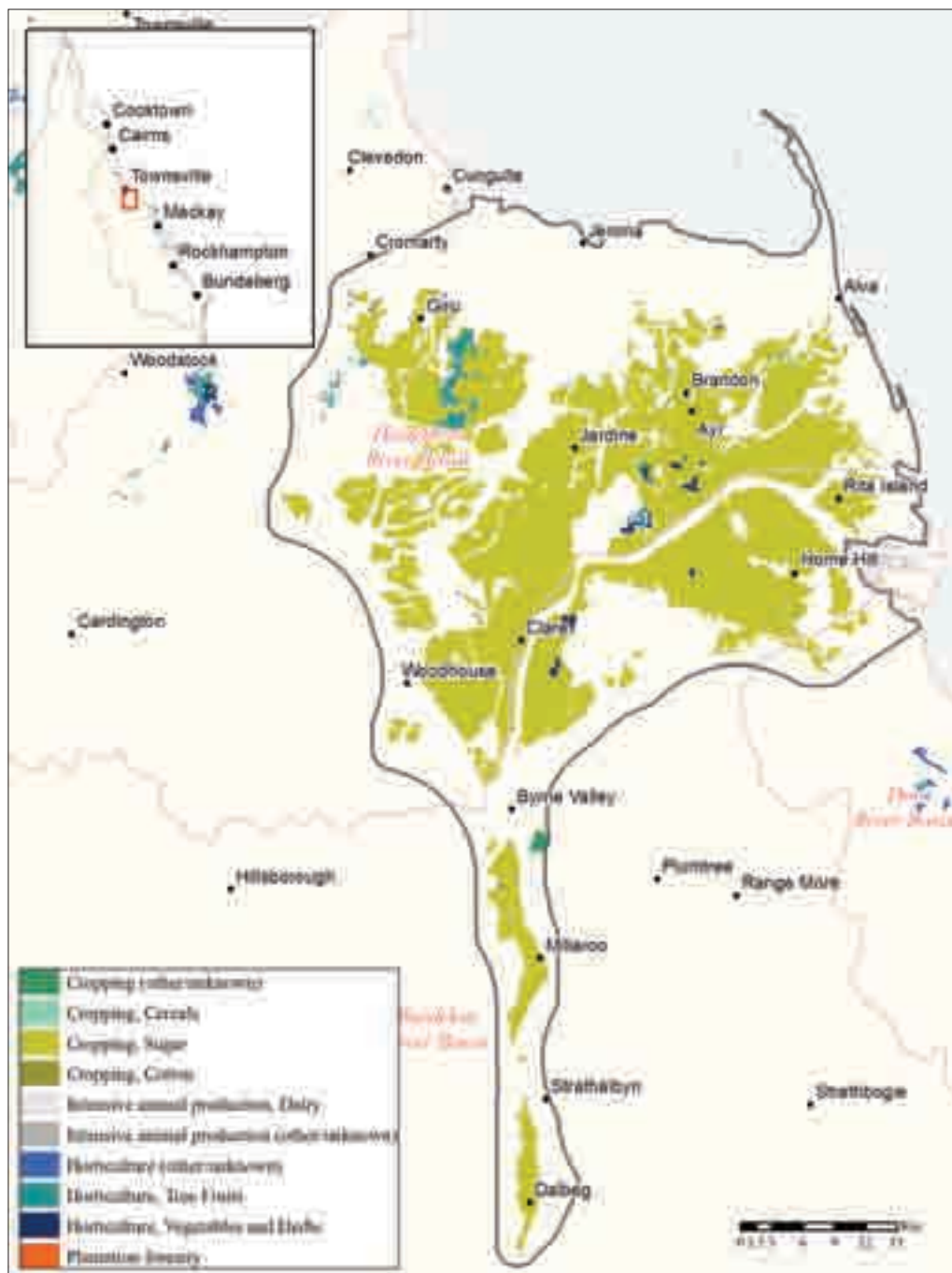


Figure 18: Burdekin Coastal area (QLUMP 2004)

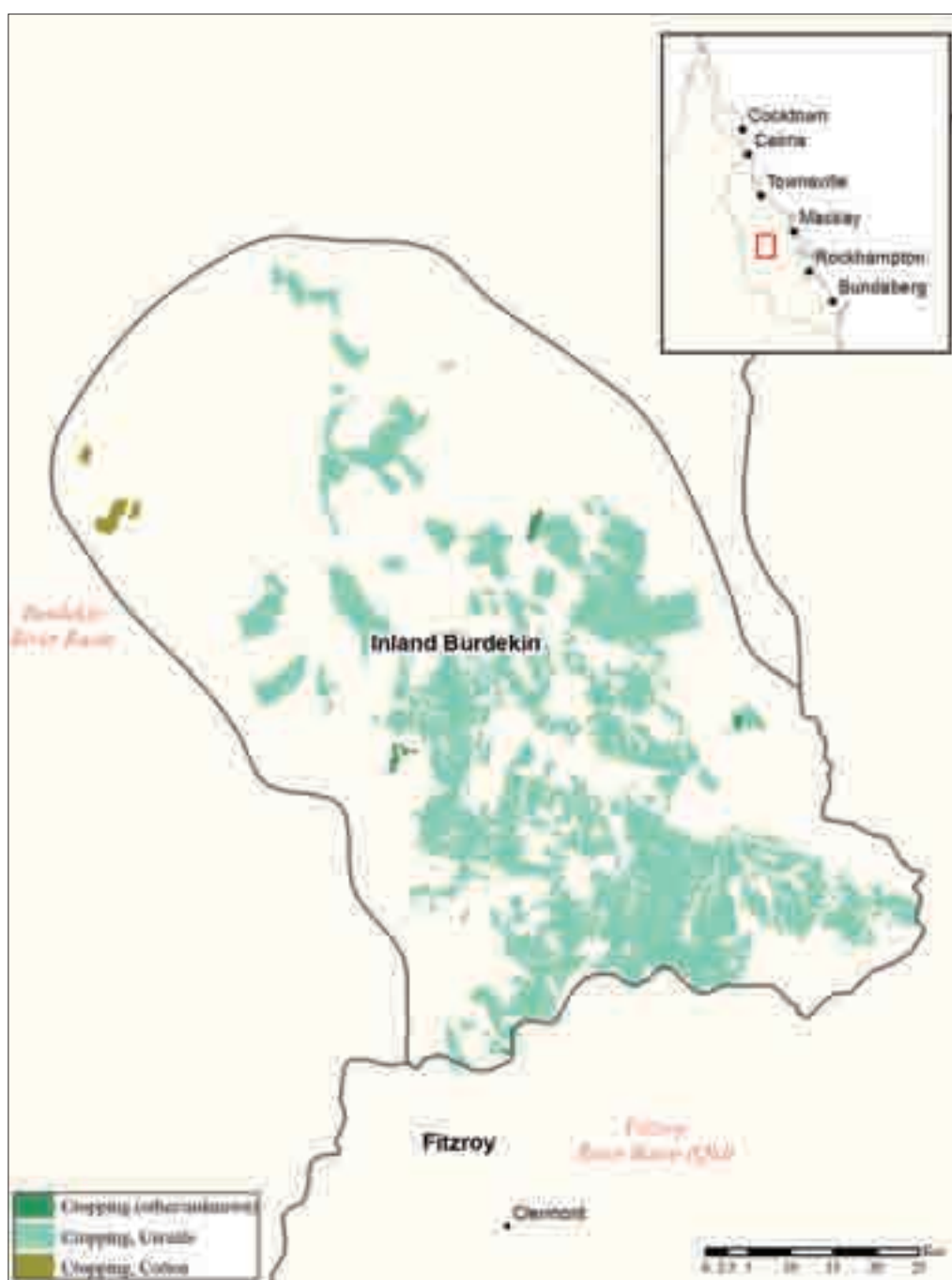


Figure 19: Inland Burdekin area (QLUMP 2004)

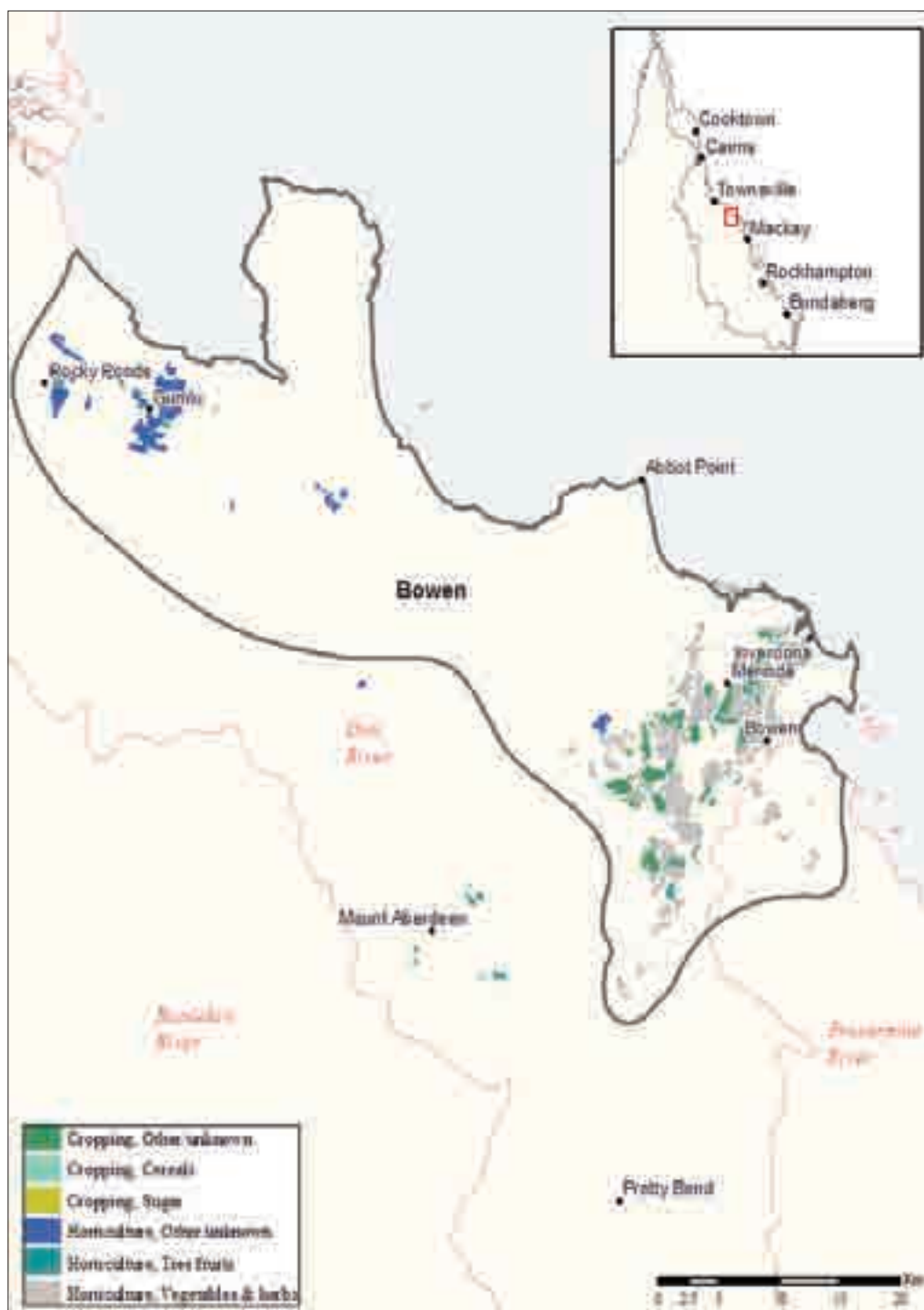


Figure 20: Bowen area (QLUMP 1999)

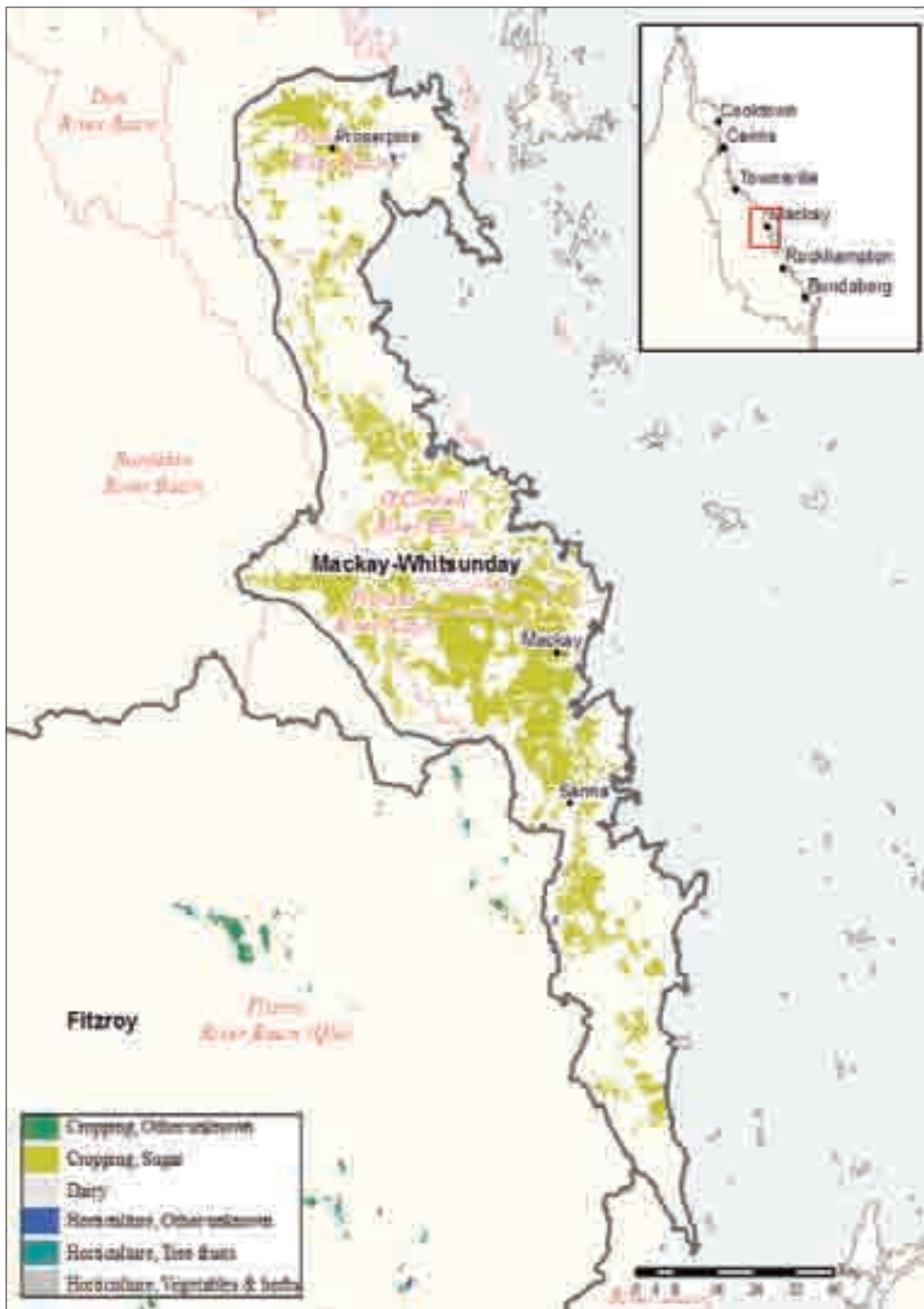


Figure 21: Mackay-Whitsunday Coastal area (QLUMP 1999)

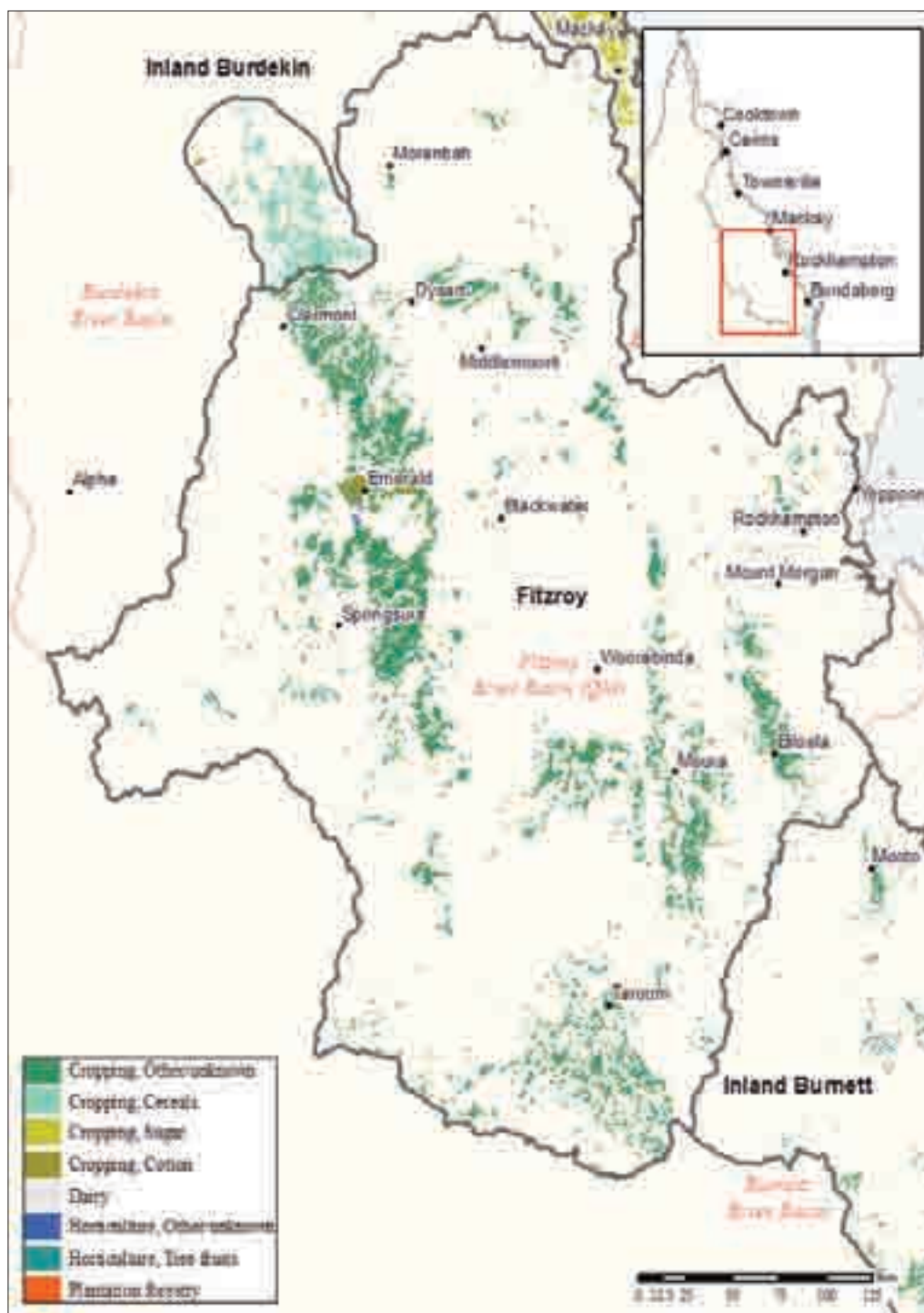


Figure 22: Fitzroy area (QLUMP 2004)

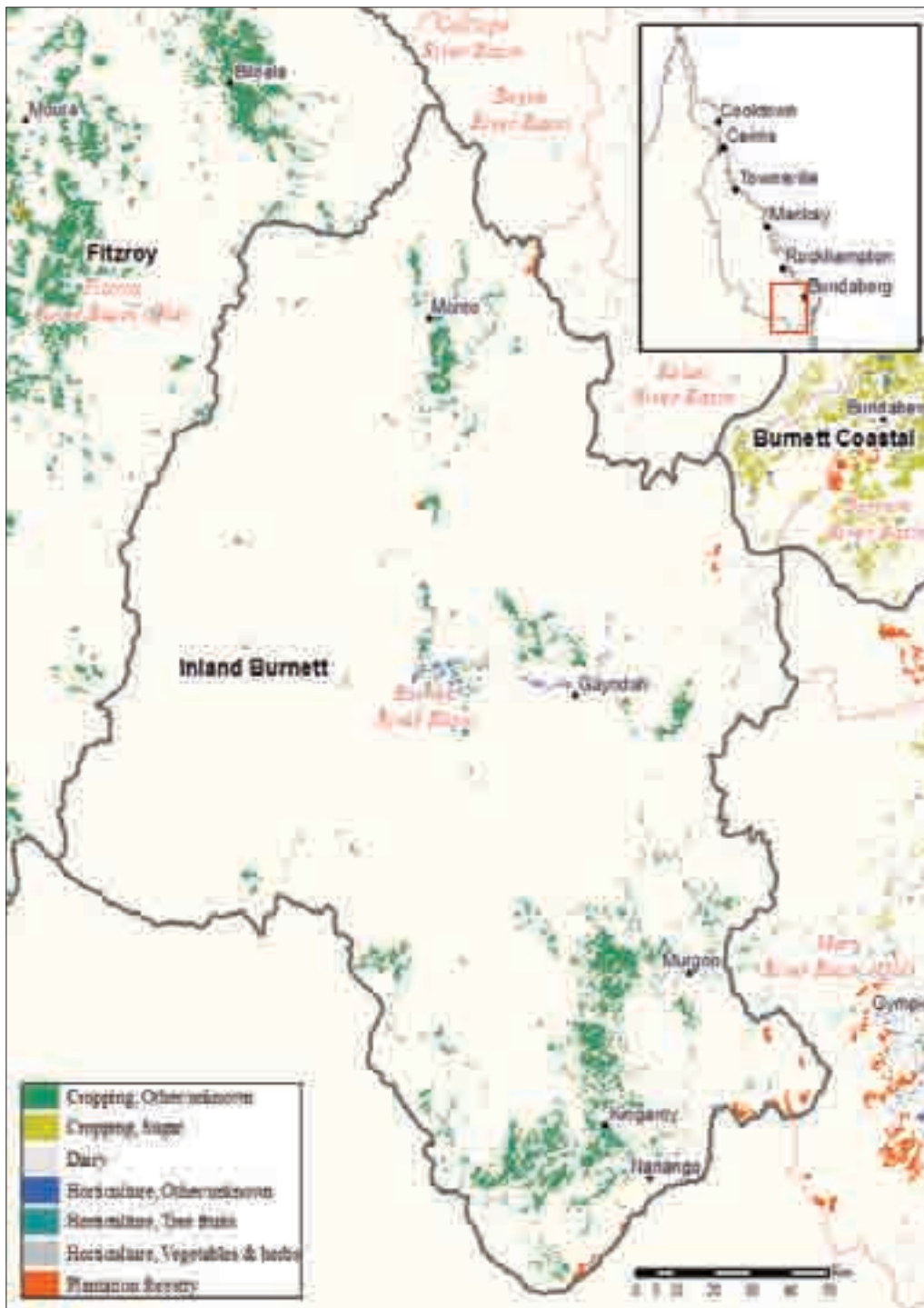


Figure 23: Inland Burnett area (QLUMP 1999)

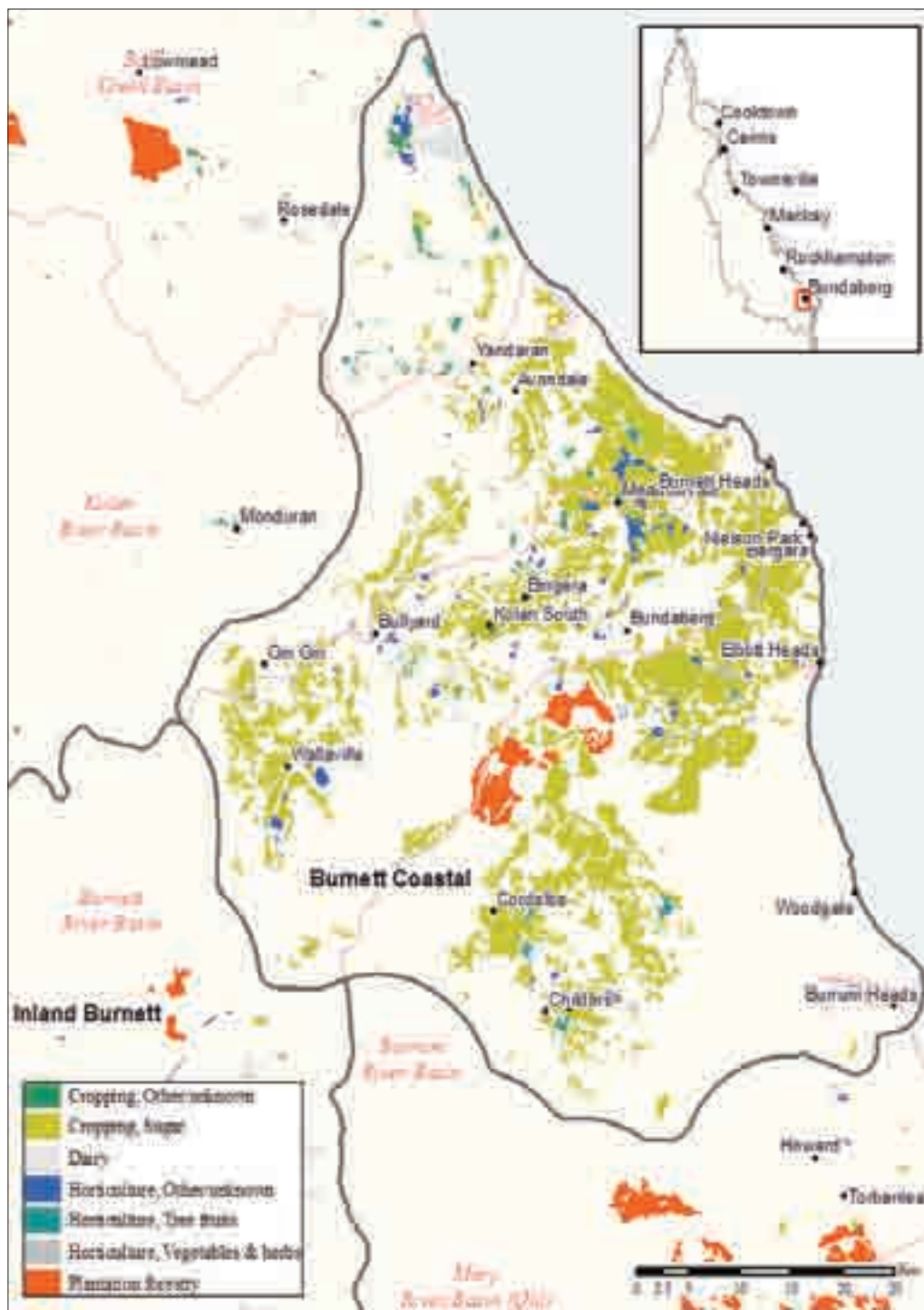


Figure 24: Burnett Coastal area (QLUMP 1999)

6.3. Fertiliser use by land use

For the purpose of this report, the term ‘fertiliser’ is defined as ‘a material added to crops containing nitrogen (N) and/or phosphorus (P)³. In this context ‘fertiliser’ includes conventional fertilisers such as urea or superphosphate, and less conventional materials such as mill mud, filter mud, boiler ash, dunder, sugarcane trash (Chapman 1996), rock dust, effluents and bore water with high nitrate content. As these materials are often added in addition to conventional fertiliser, overall statistics on rates of fertiliser use must include them wherever possible.

Fertilisers are used to varying degrees across all main agricultural industries in the GBR catchment. Total fertiliser use for both nitrogen (N) and phosphorus (P) fertilisers rose steadily from 1910 to 1990 (Pulsford 1996). Figures from the Fertiliser Industry Federation of Australia (FIFA 2000) showing fertiliser application rates averaged across Australia are shown in Table 2. These figures show only inorganic fertiliser use and do not include estimates of the contribution from crop residues, waste materials and bore water. In broad terms, however, this table indicates the relative differences between higher ‘N’ crops, such as sugarcane, horticulture and cotton, and lower ‘N’ crops such as cereals, pasture and oilseeds. In Table 3 more recent estimated application rates for Queensland crops and pastures are shown, compiled from unpublished data (Pulsford and Rayment unpublished). Generally data are for one crop per year but some horticulture may have more than one crop per year and rates per year may be twice the figures shown. Conversely, for plantations, which may take over 25 years to complete a cropping cycle, the yearly rates would be far lower.

Table 2: Fertiliser applications for various Australian crop groups in 2000 (FIFA 2000)

| Crop | P (average kg ha ⁻¹ yr ⁻¹) | N (average kg ha ⁻¹ yr ⁻¹) |
|---------------------|---|---|
| Sugarcane | 29 | 230 |
| Horticulture | 98 | 188 |
| Cotton | 9 | 121 |
| Cereals | 13 | 43 |
| Oilseeds | 10 | 13 |
| Pasture | 5 | 2.5 |
| Plantation forestry | Low (less than 13) | Low (less than 30) |

Table 3: Recent fertiliser use on Queensland crops (Pulsford and Rayment unpublished)

| Crop | P2O5 (range, kg ha ⁻¹ crop ⁻¹) | P (kg ha ⁻¹ crop ⁻¹ for highest rate) | N (range, kg ha ⁻¹ crop ⁻¹) |
|-------------------------------------|--|---|--|
| Sugarcane—plant | 20–40 | 18 | 100–150 |
| Sugarcane—ratoon | 0–20 | 9.1 | 120–200 |
| Horticulture e.g. bananas | 10–40 | 18 | 170–300 |
| Cotton | 10–20 | 9.1 | 100–160 |
| Cereals (grains, sorghum, maize) | 5–20 | 9.1 | 20–100 |
| Oilseeds e.g. sunflowers | 10–30 | 13.6 | 50–100 |
| Pasture—dairy | 20–30 | 13.6 | 100–200 |
| Pasture—rangeland beef | Low | Low | Low |
| Plantation forestry | 0–30 | 13.6 | 0–30 |

6.3.1. Sugarcane

Two by-products resulting from the crushing of raw sugar are used as fertilisers or soil conditioners:

- mill mud—the residue left after filtering the sugarcane juice
- ash—the residue produced when bagasse (the fibre remaining after the cane is crushed) is burnt in the mill boilers.

In addition, for the two milling companies that distil molasses a by-product of the fermentation, called dunder, can also be used as fertiliser.

The value added to the economy in 2004–05 by the sugar industry of the GBR catchment is estimated to be \$1297 million (Access Economics 2005). It is likely this figure would be greater for 2005–06 due to the recovery in sugar prices. Sugarcane makes up the largest area of crops grown in the GBR catchment and is the largest user of fertiliser. The cost of fertiliser is estimated at \$31 050 per year per farm or around \$4.72 per tonne of cane which equates to around 20 per cent of the total per hectare cost to the grower (CANEGROWERS 2002). In 2000, approximately 75 000 tonnes of nitrogen and 11 000 tonnes of phosphorus were applied to cane lands across the GBR catchment, based on 180 kg and 26 kg of nitrogen and phosphorus respectively per hectare (Productivity Commission 2003).

Data supplied by Incitec Pivot, the major supplier of fertilisers in Queensland, confirm that fertiliser use in the sugar industry declined over the period 1996–2005 (see Table 4). This decline has been accompanied by improved uptake of sustainable farming practices in recent years (QFF 2005; Wrigley 2005).

Table 4: Fertiliser use in the sugar industry 1996–2005 (Incitec Pivot 2006)

| Average N and P Rates (kg ha⁻¹) by year, Wet Tropics (Tully to Mossman) and Atherton Tablelands | | | | | | | | | | |
|---|------|------|------|------|------|------|------|------|------|------|
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| kg ha ⁻¹ N | 169 | 151 | 138 | 144 | 151 | 149 | 147 | 137 | 145 | 142 |
| kg ha ⁻¹ P | 28 | 25 | 22 | 19 | 23 | 24 | 20 | 21 | 20 | 21 |
| Average N and P Rates (kg ha⁻¹) by year, Herbert | | | | | | | | | | |
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| kg ha ⁻¹ N | 213 | 198 | 209 | 204 | 183 | 201 | 205 | 191 | 155 | 153 |
| kg ha ⁻¹ P | 28 | 26 | 25 | 21 | 21 | 30 | 26 | 24 | 16 | 16 |
| Average N and P Rates (kg ha⁻¹) by year, Burdekin | | | | | | | | | | |
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| kg ha ⁻¹ N | 272 | 246 | 247 | 269 | 233 | 229 | 234 | 219 | 223 | 213 |
| kg ha ⁻¹ P | 26 | 23 | 23 | 22 | 21 | 19 | 17 | 19 | 21 | 22 |
| Average N and P Rates (kg ha⁻¹) by year, Central Qld (Proserpine, Mackay, Sarina) | | | | | | | | | | |
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| kg ha ⁻¹ N | 225 | 232 | 214 | 233 | 176 | 175 | 166 | 171 | 174 | 172 |
| kg ha ⁻¹ P | 28 | 30 | 26 | 24 | 18 | 20 | 14 | 15 | 14 | 13 |
| Average N and P Rates (kg ha⁻¹) by year, South Qld (Bundaberg, Maryborough, Moreton, Rocky Point) | | | | | | | | | | |
| Year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| kg ha ⁻¹ N | 161 | 155 | 155 | 150 | 148 | 148 | 120 | 121 | 144 | 136 |
| kg ha ⁻¹ P | 24 | 27 | 26 | 21 | 24 | 27 | 19 | 21 | 25 | 23 |

Table 5 shows estimated nitrogen chemical application per region, based on the 1999 Dwyer (unpublished a) figures for area under cultivation, and the most recent Incitec Pivot (2006) data for chemical application rates in 2005.

Table 5: Estimated nitrogen fertiliser use in the sugar industry in the GBR catchment (excluding Maryborough)

| Region | Total area (ha) (Dwyer unpublished a) | Area (ha) without 15% under fallow | 2005 N rates, kg ha-1 (Incitec Pivot 2006) | Estimated tonnes/ region |
|-------------------|--|---------------------------------------|--|-----------------------------|
| Mossman | 15 356 | 13 053 | 142 | 1 854 |
| Tablelands | 6 712 | 5 705 | 142 | 810 |
| Mulgrave | 18 740 | 15 929 | 142 | 2 262 |
| South Johnstone | 20 523 | 17 445 | 142 | 2 477 |
| Babinda–Mourilyan | 29 015 | 24 663 | 142 | 3 502 |
| Tully | 29 302 | 24 907 | 142 | 3 537 |
| Herbert | 68 004 | 57 803 | 153 | 8 844 |
| Burdekin | 84 004 | 71 403 | 213 | 15 209 |
| Proserpine | 24 716 | 21 009 | 172 | 3 613 |
| Mackay | 98 324 | 83 575 | 172 | 14 375 |
| Sarina | 22 398 | 19 038 | 172 | 3 275 |
| Bundaberg | 53 003 | 45 053 | 136 | 6 127 |
| Isis | 19 102 | 16 237 | 136 | 2 208 |
| Total | 489 199 | 415 819 | (average) 164 | 68 093 |

Nitrogen fertiliser has been used by many sugarcane farmers at rates above those recommended for fallow plant cane (Reghenzani *et al.* 1996) while on replant and ratoon cane it has been applied in excess of recommendations by 45 per cent and 44 per cent of farmers respectively (Schroeder *et al.* 1998; Rayment 2003). More recent data from Incitec Pivot (2006, Table 4) suggest that chemical application rates have decreased by over 10 per cent in the last five to six years and are now nearer to, and in some cases less than, the Calcino (1994) recommendations. Calcino (1994) recommendations were aimed at the least fertile soils in the sugar growing industry (B. Schroeder, BSES 2006, pers. comm.). Table 6 shows Calcino (1994) nitrogen application rate recommendations, compared with averaged rates provided by Incitec Pivot for 2003–2005 (see Table 4).

Table 6: Recommended nitrogen application rates compared with average application rates by region

| District | Plant cane recommended application rate (kg ha ⁻¹ yr ⁻¹)* | Ratoon recommended application rate (kg ha ⁻¹ yr ⁻¹)* | Fertiliser recommendation/ha averaged across plant and ratoon # | Average application rate 2003–5** |
|-------------------|--|--|---|-----------------------------------|
| Wet Tropics | 120–150 | 160–200 | 172 | 141 |
| Herbert | 120–150 | 160–200 | 172 | 170 |
| Burdekin | 135–150 | 210–250 | 212 | 218 |
| Central (Mackay) | 120–150 | 160–200 | 172 | 172 |
| South (Bundaberg) | 120–150 | 160–200 | 172 | 134 |

* From Calcino (1994)

Estimating that 20% of area under cane is plant crop and 80% is ratoon

** Incitec Pivot (Table 4)

However, based on calculations of **total** fertiliser use, including the non-conventional types (Rayment 2003, 2005; Wegener 1999; Schroeder *et al.* 1998; Rayment *et al.* 1998), total application is likely to be higher than the Calcino (1994) recommendations.

Trash retention—the practice of cutting cane green (unburnt) and leaving the leaves (trash) on the soil as a trash blanket—is now the primary means of cultivation in north and central Queensland (excluding the Burdekin). After five years of trash retention about 50 kg ha⁻¹ year⁻¹ of N begins to be returned to the soil and potentially to the crop and off-farm environment (Robertson and Thorburn 2000; Thorburn *et al.* 2000). In some areas (Sarina–Mackay, Proserpine, limited areas in the Burdekin), dunder is also added to sugarcane soils. Mill mud may be added in areas close to mills (Barry *et al.* 1998). These materials also contain N and P. Rotational nitrogen-fixing break crops, such as soybeans, can also generate in excess of 250 kg ha⁻¹ yr⁻¹ of N. Due to N from these rotational crops, and the N and P from dunder, mill mud and trash mineralisation, substantial over-fertilisation occurs in many districts (Schroeder *et al.* 1998; Rayment 2003). Over-application of nitrogen fertilisers on sugarcane crops can lead to substantial leaching of nitrate below the root zone (Verberg *et al.* 1998). The sugar industry recognises that there is a need to reduce N use and there is evidence that application rates have reduced significantly in recent years (Table 4). However, above optimal N application rates continue despite the widely accepted view that nitrogen use can be reduced with little effect on yield and with better financial returns to farmers (Schroeder *et al.* 1998; Mallawaarachchi *et al.* 2002; Shannon 2002).

In many instances there is also an over-application of P fertiliser on cane lands (Bloesch *et al.* 1997; Bramley *et al.* 1998), an observation supported by soil test data from Queensland canelands (Rayment 2003). Around 80 per cent of canegrowers

have over-supplied P to their soils (Rayment 2003). Yet phosphorus use on most established canelands could be almost eliminated, as P content in sugarcane soils has built up to surplus levels following many years of P fertilisation (Rayment 2003, 2005; Rayment *et al.* 1998; Bloesch *et al.* 1997; Bramley *et al.* 1998).

The sugarcane industry is aware of the need to take into account nutrient supplementation provided by mill mud and other non-conventional fertilisers. BSES Limited is developing regionalised nutrient application rate recommendations which account for non-conventional fertiliser use and soil type (B. Schroeder, BSES 2006, pers. comm.).

6.3.2. Horticulture

Nitrogen fertiliser use in bananas has been traditionally very high, with rates of $>400 \text{ kg ha}^{-1} \text{ yr}^{-1}$ common until recently (Mitchell *et al.* 2001), and overuse of fertiliser has been a well-recognised problem for the industry (Rayment 1994). It is estimated that fertiliser use rates (particularly N) in bananas in the Wet Tropics have fallen sharply over the last 10 years (D. Pollock 2006, pers. comm.) and are now probably closer to $200 \text{ kg ha}^{-1} \text{ yr}^{-1}$ (J. Armour, NRW 2006, pers. comm.). There is little easily obtainable information on changes in fertiliser rates for cotton, cereals or other horticultural crops, but, as with bananas, increased uptake of best management practice in these industries in recent years (QFF 2005) supports the view that their usage is also likely to be steady or starting to decline.

There is very little information available on the fertiliser application rates used on other individual horticultural crop types. However, Table 7 provides some information on recommended rates for a number of horticultural crops.

Table 7: General recommended rates for nitrogen and phosphorus fertilisers for a number of horticultural crops. Recommended rates are per crop and vary depending on factors such as soil fertility, crop yield, seasonality, tree density, crop type, variety, age and plant tissue analysis. (Source: Dwyer, unpublished b)

| Crop | N recommendation (kg-1ha) | P recommendation (kg-1ha) |
|---|---------------------------|---------------------------|
| Banana plants (new rates) ^{1,3} | 150 | 0–20 |
| Banana plants (previous rates) ^{2,3} | 350–400 | 0–40 |
| Banana ratoon (new rates) ^{1,3} | 150–300 | 0–20 |
| Banana ratoon (previous rates) ^{2,3} | 400 | 0–20 |
| Cucurbits (general) | 30–180 | 20–90 |
| Lychees | 70 | 0–40 |
| Mangos | 0–40 | 0–50 |
| Papaws (bearing) ^{2,3} | 350 | 50–150 |
| Tea ⁷ | 200–250 | 10–20 |
| Coffee ⁶ | 300–400 | 15 |
| Tobacco ^{4,8} | 170–225 | 50–100 |
| Macadamia nuts | 40–120 | 15–60 ⁹ |
| Pineapples ⁵ (plant crop) | 400–600 | 20–80 |
| Pineapples ⁵ (ratoon crop) | 300–330 | 25 |
| Tomatoes | 40–120 | 30–110 |

¹ Crop fertigated fortnightly

² Crop fertilised with broadcast granular product every 4–6 weeks

³ Applied P rates may be higher depending on soil's phosphorus buffering index (PBI)

⁴ Tobacco is no longer grown within the GBR catchment

⁵ Reference Broadley et al. 1993

⁶ Reference Salvin et al. 2004

⁷ Reference –D. Steel, DPIF 2006. pers. comm.

⁸ Reference Wichmann 2001

⁹ These rates may be increased if the crop is grown on phosphorus 'fixing' soils (e.g. krasnozems)

6.3.3. Cotton

There is little information available on fertiliser rates used on Queensland cotton crops. General recommended rates for cotton are 20–280 N kg ha⁻¹ and 0–30 P kg ha⁻¹ (R. Dwyer, Incitec Pivot 2006 pers. comm.). Considerable research has been conducted on cotton nutrition in Queensland. The cotton industry agreed that any cotton in the GBR catchment should be grown in accordance with its environmental management system known as Cotton Industry's Best Management Practice System. This includes soil testing, nutrient monitoring and runoff management systems (G. Roth, Cotton Catchment Communities Cooperative Research Centre 2006, pers. comm.).

6.3.4. Cereals

According to data taken from the Grains Industry Environmental Assurance Pathways Project undertaken by the Grains Council of Australia, fertiliser use in the

main grain growing GBR catchment, the Fitzroy Basin, exhibits a negative balance of N and a slight over-input of P in grain production. Grains Council of Australia data (Umbers, unpublished) presented in Table 8 suggest that overall fertiliser rates on grain crops are low. Dividing the total amount of nitrogen (8 319 tonnes) and phosphate (1307 tonnes) applied by the total area producing grain (481 900 ha) results in average application values per hectare of cropping land of approximately 17 kg ha⁻¹ N and 3 kg ha⁻¹ P. Other figures suggest the N rates may be higher. Pulsford and Rayment (unpublished) present figures for cereals of 20–100 kg N ha⁻¹ and 2–9 kg P ha⁻¹. Therefore it is likely that actual rates for N are higher than the figures derived from the Grains Council (unpublished) data, but still at the lower end of the Pulsford and Rayment figures. A figure of 25 kg N ha⁻¹ is used in this technical report.

The data in Table 8 indicate that a number of best management practices are widely adopted in the cereals industry. Stubble retention is occurring on almost 90 per cent of the land under cropping in the Fitzroy Basin, which is the most significant region of cereal production in the GBR catchment.

Table 8: Central Queensland grain production data taken from the Grains Industry Environmental Pathways Project (A. Umbers, Grains Council of Australia unpublished)

| Agro-ecological zone Central Queensland | Total or average (2001) |
|--|-------------------------|
| Total hectares producing grain | 481 900 |
| Number of grain-only properties | 289 |
| Number of mixed properties | 346 |
| Value of grain production (\$) | 201 958 000 |
| Average crop area per property (ha) | 883 |
| Tonnes total grain produced | 426 500 |
| Area under 'no till' system (ha) | 183 000 |
| Area where stubble retained (ha) | 450 700 |
| Total N applied (tonnes) | 8 319 |
| Estimated total N contained in grain produced (tonnes) | 10 980 |
| N balance (tonnes) | -2 660 |
| N balance (kg ha ⁻¹) | -6.95 |
| Total P applied (tonnes) | 1 307 |
| Estimated total P contained in grain produced (tonnes) | 1 280 |
| P balance (tonnes) | 27.3 |
| P balance (kg ha ⁻¹) | 0.25 |

Figures on the number of soil tests undertaken by grain farmers each year are currently unavailable. According to qualitative assessments, farmers undertake

soil tests on each of their fields or on fields of similar type and cropping history approximately every two years.

Data are not available at this stage for the other catchments in the Grains Industry Environmental Pathways Project, but it is expected that they would show a similar trend (L. Krieg, AgForce Grains 2006, pers. comm.).

6.3.5. Beef/dairy

There is limited information available on fertiliser rates for dairy and beef finishing pastures in the GBR catchment. The fertiliser use rates for dairy and beef were suggested by extension officers as approximately 35–40 kg N ha⁻¹ and 10 kg P ha⁻¹ for beef finishing pastures and 250–450 kg N ha⁻¹ and 30–50kg P ha⁻¹ for dairy pastures (Lex Cogle, NRW 2006, pers. comm.).

The following nutrient application rates are those typically recommended by the fertiliser industry (Table 9). Average application rates may be less than this. N and P rates for irrigated ryegrass are for highly productive stands. Lower nitrogen rates are generally used in mixed ryegrass clover swards. Applications are specific to soil type, rainfall, and crop and pasture requirements.

Table 9: Fertiliser industry recommendations for different types of pasture (Source: G. Kuhn, Incitec Pivot 2006, pers. comm.)

| Fertiliser | Type of pasture | Quantity (kg ha ⁻¹) |
|------------|---|---|
| N | Legume-based pasture | Nil |
| | Rain-grown N fertilised grass pasture | 180 |
| | Irrigated N fertilised grass pasture | 300–350 |
| | Irrigated ryegrass | 350–400 |
| P | Dry tropics—600 to 1000 mm rainfall (e.g. spear grass country improved with legume introductions such as stylo, leucaena, wynn cassia) N.B. most of this country does not receive P fertiliser | 5–10 at establishment; 10 every 3–5 years thereafter |
| | Tropics—1000 to 1500mm rainfall (e.g. legume based pastures such as lotononis, siratro) | 10 |
| | High rainfall grass legume pastures (glycine, desmodium, centro, clover) and N fertilised grass pastures (Rhodes grass, setaria, signal grass) | 20–25 |
| | Irrigated ryegrass | 40 |

In established pure grass pastures and grass legume pastures, annual applications are determined by soil testing. Rates of 10–25 kg ha⁻¹ P are required at moderate

soil P levels, with rates of up to 40 kg P ha⁻¹ if soil phosphorus levels are low or where maintenance rates may be required in intensive dairy pastures, or where high P fixation soils occur (R. Dwyer, Incitec Pivot 2006, pers. comm.).

Fertiliser use varies widely between beef grazing regions:

- Wet Tropics Coast/Tablelands: Estimates are that small amounts of fertiliser are used on a small area (Kev Shaw, Kairi DPIF 2006, pers. comm.). General fertiliser rates of 15 kg ha⁻¹ N and 15 kg ha⁻¹ P are used on approximately 84 000 ha.
- Fitzroy Basin: Although approximately 85 per cent of the catchment is used for grazing, only a small proportion of the herd are finished on fertilised pastures (i.e. 5000–10 000 ha north of Bhaool) (Ken Murphy & Kev McCosker, DPIF Rockhampton 2006, pers. comm.).
- Mackay: The majority of soils in the region are phosphorus deficient and applications of P are required for optimal pasture and animal growth. Land managers apply around 40 kg ha⁻¹ of P (approx 200 kg ha⁻¹ of mostly triphos or diammonium phosphate–DAP) every two to three years for grass–legume mixed pastures. For grass only pastures most land managers use DAP to boost grass growth. A further application of 100 kg ha⁻¹ urea (45 kg ha⁻¹ N) in autumn is sometimes used to keep grass growing longer into cooler weather. In grass–legume pastures the legumes provide the N. General estimates of applied fertiliser range from 1200 to 3300 tonnes of product per year, depending on the season. However, from a fertiliser sales point of view, 100–300 tonnes of N and 90–270 tonnes of P are used, although this may be skewed by cane/cattle enterprises that purchase fertiliser for both (H. Bishop, DPIF Mackay 2006, pers. comm.).

A national Natural Resource Management on Australian Dairy Farms survey undertaken by the Land and Water Resources Audit and Dairy Research and Development Corporation (DRDC 2000) reported that 97 per cent of dairy farmers nationally use fertilisers, 80 per cent soil test to determine fertiliser needs, and 43 per cent adopt special measures to limit nutrient loss.

6.4. Fertiliser residue/nutrient dynamics

Nutrients can be lost from fertilised cropping lands in a particulate form, i.e. PN or particulate phosphorous (PP) in surface runoff; or in a dissolved inorganic form, i.e. DIN (nitrate, nitrite, ammonium) and DIP (dissolved inorganic P: phosphate) in surface runoff or leached to sub-surface water (called groundwater from now on).

Prove and colleagues studied nutrient budgets and losses of nutrients at the plot scale for bananas in the Johnstone catchment. Sugarcane and dairy pasture were

also examined with a rainforest plot used as a control (Moody *et al.* 1996; McShane *et al.* 1993; Prove *et al.* 1996). Large leaching losses of nitrate (38–152 kg N ha⁻¹ year⁻¹) were recorded under bananas with the losses particularly high in the plant crop. Runoff of nitrogen was a much smaller component of the total nitrogen loss. The retention of nitrate leached from ferrosols under sugarcane, bananas, dairy pasture and rainforest was as high as 1875 kg N ha⁻¹ to a depth of 10m (Rasiah and Armour 2001). At the only banana site, the N load was 145 kg ha⁻¹. Further work on sugarcane soils found that soil type had an important effect on nitrate retention, although only some of the nitrate leached below the root zone could be accounted for in the soil (Rasiah *et al.* 2003a). A study of shallow groundwater in the Johnstone catchment in an area under sugarcane showed highly dynamic fluctuations in depth to groundwater (1.5 to 11.5 m above base of bore) and in nitrate-N concentration (0.6–3.7 mg L⁻¹). These fluctuations resulted in calculated loads of 21–81 kg N ha⁻¹ delivered to streams during recession of groundwater at the end of rainy periods (Rasiah *et al.* 2003b). The major loss pathway for phosphorus was via suspended sediment in runoff. As suspended solid loads in runoff were generally low, phosphorus losses were small (Prove *et al.* 1996). More recent studies have shown considerable loss of N and P from banana cultivation where, in studies of runoff events, median concentrations of nitrate were 1600 µg L⁻¹, TP 240 µg L⁻¹ and FRP 80 µg L⁻¹ (Faithful and Finlayson 2004; 2005).

Ham (2006) studied runoff from nine irrigated sugarcane sites in the Burdekin River Irrigation Area. Ammonium—N concentrations in runoff waters rose to peaks of 3–6 mg L⁻¹ in post-planting periods (late April through May) and also in the main fertiliser application period (September to November). In addition to these short duration peaks, smaller, sharp peaks of ammonium—N (<2 mg L⁻¹) occurred in January to mid-April and appeared to be associated with rainfall events or temporary waterlogging. For the majority of the time levels were at or near zero.

Ham (2006) found higher losses of nitrate—N with peaks of greater than 5 mg L⁻¹ in the peak fertiliser application period. Some high loss events were associated with farm practices, including shallow application of fertiliser. However even correctly applied fertiliser was the subject of large losses due to rainfall events. Tailwater recapture played an important role in reducing nutrient losses off the farm.

On cotton, considerable quantities of suspended sediments and nutrients are lost from fields and can be detected in the stream waters of the Fitzroy catchment (particularly the Dawson sub-catchment) (Noble *et al.* 1997; Noble and Collins 2000). Techniques such as retaining surface cover and controlling wheel traffic are known to minimise soil erosion and high-sediment runoff from cotton fields (Silburn and Glanville 2002) but these are not widely adopted in the cotton industry in the Fitzroy catchment as yet.

Irrigation tailwater capture and recycling are also known to reduce nutrient and sediment movement from cotton-lands to streams (Rummenie and Noble 1996).

Considerable unpublished data are available for runoff from cotton on the Fitzroy catchment (C. Carroll, NRW 2006, pers. comm.; R. Noble, NRW 2006, pers. comm.) and, along with the published studies of water quality in the Fitzroy (Noble *et al.* 1997; Noble and Collins 2000; Carroll *et al.* 1992) these data can be used to increase our understanding of runoff from cotton. Nitrate concentrations in runoff from irrigated cotton can be very high (10–100 mg L⁻¹ NO₃—N, R. Noble, NRW 2006, pers. comm.) but, as the runoff tailwater is often reused several times before eventual release to the river, fluxes of nitrogen are considerably less than estimated from the runoff concentration data alone (R. Noble, NRW 2006, pers. comm.).

Overall, nitrogen is lost from Queensland cropping systems more easily than phosphorus, and in larger amounts. This is due to a number of factors, including that N is used in much larger amounts (see Tables 2, 3, 4 and 6) and is much more mobile than P. Nitrogen is more mobile because the main mechanism of N loss in fertilised systems is as nitrate, which is not strongly bound to the soil, whereas phosphate is normally strongly bound to the soil. These differences have been shown in many studies of N and P losses from cropping in Queensland, where nitrate concentrations are very high (up to 15 mg L⁻¹ NO₃—N), but phosphate concentrations are typically relatively low (up to 0.5 mg L⁻¹ PO₄) (Faithful and Finlayson 2005; Mitchell *et al.* 2005; Mitchell *et al.* 2006).

Therefore N fertiliser use and loss is treated as a higher hazard factor when prioritising NMZs.

Dissolved inorganic nutrients (especially nitrate) are the primary loss form from fertilised cropping in the GBR catchment (Brodie and Mitchell 2006a and b). Particulate nutrients are also important but modern cropping systems in the major industries of the GBR catchment have low erosion due to, for example, trash blanketing and minimum tillage in sugarcane (Rayment 2003). Thus particulate nutrient losses are relatively low. Hence the focus of this technical report has been on dissolved (inorganic) nutrients.

6.5. Fertiliser use in each of the 10 fertilised areas

Using land use data from the Queensland Land Use Mapping Program (QLUMP 1999, and for the Burdekin, Fitzroy and Johnstone catchments QLUMP 2004) and estimates of fertiliser application for each land use, estimates were made of the total fertiliser application for each of the 10 fertilised areas. Table 10 shows the results of this process and Appendix D presents the information used to produce the estimates.

Regions with higher fertiliser use present a greater hazard (other factors being equal) of nutrient loss to waterways. However, to rank regions for potential loss to waterways based purely on total estimated fertiliser usage will show a bias towards larger regions. It would be possible to increase a region's ranking by combining

the region with another region (that is, creating a larger region) to produce a larger total fertiliser use figure. For example, the Wet Tropics fertilising region and the Atherton Tablelands fertilising region could be combined to produce a larger total fertiliser use figure. To mitigate this effect, a further aspect of a region's fertiliser use could be used for ranking. This is the intensity of fertilisation, which could be measured as the average fertiliser rate in an area (total fertiliser application divided by area of fertilised land). The hazard of fertiliser loss is expected to be higher in regions with higher application rates, as high rates may exceed soil uptake capacities and the local uptake capacities of buffer zones. Figures for average application rates for each fertilised region are given in Table 10, and Appendix D presents the information used to produce these results.

Table 10: Estimated fertiliser application rates based on area under each land use (QLUMP 1999, 2004) and estimated application rate for each land use (see Appendix D)

| Fertilising area | N usage total (tonnes) | P usage total (tonnes) | Average N application rate (kg ha ⁻¹) | Average P application rate (kg ha ⁻¹) |
|------------------------------|------------------------|------------------------|---|---|
| Fitzroy | 25 400 | 2 930 | 29 | 3 |
| Wet Tropics | 31 300 | 4 230 | 143 | 19 |
| Mackay–Whitsunday | 29 000 | 2 370 | 172 | 14 |
| Burdekin Coastal | 21 500 | 2 100 | 216 | 21 |
| Burnett Coastal | 11 300 | 2 000 | 125 | 22 |
| Inland Burdekin | 3 400 | 400 | 26 | 3 |
| Inland Burnett | 5 700 | 640 | 72 | 8 |
| Atherton & Evelyn Tablelands | 6 400 | 730 | 118 | 13 |
| Bowen | 1 000 | 600 | 79 | 50 |
| Inland Normanby | 200 | 20 | 25 | 3 |

It should be noted that to more accurately assess the hazard of nutrient loss to waterways, a number of other factors could be taken into account which reflect the management regime in place. Such factors include timing and type of fertiliser application, amount taken into the harvested material, the use of buffer strips and retention dams. Unfortunately, information on these factors is currently not available across regions and industries and could not be included in the decision system for zone selection.

6.6. Nutrient dynamics in streams

Not all nutrients lost at the paddock scale immediately reach the coast. Nutrients can be trapped in riparian vegetation, wetlands, on the floodplain in overbank flow, in reservoirs and estuaries. The chances of this trapping occurring increase with the distance nutrients have to move through the catchment and hence the residence time in the catchment. SedNet/ANNEX allows for this trapping, including factors such as denitrification, sedimentation and biological uptake. Results from SedNet/

ANNEX clearly show that nutrients lost near the coast are efficiently delivered to the river mouth, whereas nutrients generated in upper catchment areas are more likely to be trapped and not delivered to the coast (Brodie *et al.* 2003; Cogle *et al.* 2006). The simplest proxy to account for this effect is to rank likelihood of reaching the coast as a function of distance from the river mouth.

For the 10 fertilised areas identified in this report, the DEW Environmental Resources Information Network (ERIN) determined the distance to the coast from the approximate mid-point of each area, both as a direct line and along the river channel. A geographic information system was used to determine the approximate centre of each area and to calculate the distances. The results, including the coordinates of the selected centre point, are at Table 11.

Table 11: Distances from mid-points of the 10 fertilised areas to the coast (Source, S. Butt, ERIN, DEW)

| Fertilised area | Distance to coast (km) | Distance by river (km) | Longitude | Latitude |
|--------------------------------|------------------------|------------------------|------------|------------|
| Inland Normanby | 56 | 263 | 144.858674 | -15.842464 |
| Atherton and Evelyn Tablelands | 47 | 119 | 145.531755 | -17.233384 |
| Wet Tropics Coastal 1 | 22 | 29 | 146.109567 | -18.664683 |
| Wet Tropics Coastal 2 | 15 | 22 | 145.980688 | -17.577683 |
| Wet Tropics Coastal 3 | 4 | 7 | 145.374807 | -16.401784 |
| Burdekin Coastal | 25 | 30 | 147.276839 | -19.668122 |
| Inland Burdekin | 214 | 365 | 147.500693 | -22.198687 |
| Bowen | 11 | 17 | 148.025689 | -19.997391 |
| Mackay–Whitsunday Coastal | 28 | 29 | 148.930006 | -21.144195 |
| Fitzroy | 232 | 306 | 149.046027 | -23.743360 |
| Inland Burnett | 171 | 217 | 151.225789 | -25.630599 |
| Burnett Coastal | 25 | 39 | 152.250887 | -24.999032 |

As the vast majority of nutrients are delivered to the coast in major river flow events, traditional estuarine processes (that is, in the traditional ‘between the banks’ estuary) do not apply in these circumstances. Mixing with salt water occurs outside the bounds of the estuary system as these rivers flush fresh to the mouth and into the marine environment (Devlin and Brodie 2005). This is shown in Figure 25, below, where mixing is occurring offshore from the mouth of Maria Creek. In general, ‘between the banks’ estuarine trapping is not considered to be a major factor in GBR river systems.



Figure 25: Flood plume from Maria Creek dispersing fresh water, sediments and nutrients offshore, 1994 (Source: GBRMPA)

6.7. Nutrient export through groundwater

There is currently only limited reliable information on groundwater as a transport pathway for nutrients to the GBR (however, see Rasiah *et al.* 2003a, b). There are large quantities of nitrate in coastal aquifers adjacent to the GBR, but the final fate of this material is not known. It has been suggested that denitrification is important (Thayalakumaran *et al.* 2004), but this is a preliminary finding. The role of groundwater as a transport pathway should be a priority for further research. Given the lack of current information, groundwater could not be considered in this decision system for zone selection.

7. Criteria for comparing fertilised areas

At the 5 December 2005 workshop, experts agreed to use the five criteria below to compare fertilised agricultural lands in the GBR catchment⁵. Under each criterion is a list of desirable attributes by which that criterion can be judged. At the workshop, experts agreed that data for many of the attributes are not currently available, and that the initial identification of zones will need to rely on attributes which have sufficient data to allow delineation between fertilised areas. Note that attributes written below in italics currently lack data to delineate zones and are to be used in future refinements of zone mapping/prioritisation as data become available.

Criterion 1 (to identify areas of concern)

1. Presence of significant areas of fertiliser-applying land uses where fertiliser is applied, generally at least annually (except for fallow years), and in significant quantities.

Criteria 2 to 5 (to prioritise the areas identified under criterion 1)

2. Potential for N and P losses from different fertiliser management regimes
 - a. At this stage, based on total fertiliser (N and P) use (= rates x area of use) and average application rate in each area. In most cases as N use and loss is far higher than for P, N becomes a more important factor at this stage than P. P losses are generally relatively small as P is bound to the soil and is not easily lost in a dissolved form
 - b. Physical properties of areas defined by criterion 1—soil type, rainfall, slope
 - c. Ratio of application to recommended rate (fertiliser excess)
 - d. Subtleties of timing (includes seasonality) and application method will be used when data become available
 - e. Tailwater capture/treatment
 - f. Exceedance of selected water quality criteria in downstream aquatic ecosystems
3. Likelihood of reaching the coast (i.e. mouth of river)
 - a. Residence time in waterway (use stream length as a measure of potential for biological uptake, denitrification, sedimentation etc.)
 - b. Presence of dams and wetlands (as potential sinks)
 - c. Extent of overbank flow in events (where this information exists)
 - d. Actual measured data (e.g. work by Bob Noble) from monitoring programs
 - e. Evaluate in-soil nutrient contributions and lag-times to deliver to waterways

⁵ At the workshop, another two criteria were also agreed. One was on the proximity of seagrass beds to the coast within the influence area of the discharge from the zones. The other criterion was 'other potential adverse marine impacts' which accounted for crown-of-thorns starfish concentrations. Following consultation with agricultural industry representatives and scientific experts, and an independent review by Hart et al. (unpublished), these two criteria were discarded as they added little additional discrimination, data were limited and there were concerns regarding their suitability.

Criteria 2 to 5 (to prioritise the areas identified under criterion 1)

4. Extent of transport of exported nutrients in the GBR lagoon—hence influence area
 - a. Size and frequency of large discharge events (and hence frequency of exposure)
 - b. Understanding the level of hazard between different rivers—modelling and mapping, including Pinner (unpublished)
 - c. Evaluating ambient and groundwater flux contributions

5. Number and proximity to the coast of coral reefs⁶ within the influence area of the discharge from areas defined by criterion 1 as a measure of likelihood of impact
 - a. Use maps of coral reefs and models (including Pinner, unpublished)
 - b. Use and build on the understanding of the ecological/biodiversity value of coral reefs in GBR lagoon

Note that Criterion 1 determines whether areas are of concern (this criterion was used to identify the 10 fertilising areas). The following four steps (that is, criteria 2 to 5) are used to determine the priority of each identified area. Descriptions of these four prioritising criteria defined according to four hazard levels (high, moderate, low, none) are given in Table 12.

⁶ This criterion will not include seagrass meadows at this stage. This is for two reasons. First, sufficient confidence cannot be placed on the mapping data for seagrass: the mapping is based on relatively old data—the most recent GBR-wide seagrass surveys were conducted between 1984 and 1990 (Lee Long et al. 1993). Given the ephemeral nature of some seagrass meadows (Waycott et al. 2005) the available data will not represent the current state of seagrass extent. Second, the effect of increased nutrients on tropical seagrasses is not clearly established. Current knowledge indicates that seagrasses in the GBR may be nitrogen limited and may benefit from increases in nitrogen. However, seagrasses are often light limited and elevated nutrient levels may increase phytoplankton concentrations, which could reduce the light available to seagrasses (Waycott et al. 2005; Schaffelke et al. 2005).

8. Probability of hazardous nutrient export to the Great Barrier Reef by land use.

Lawrence and Brodie (Appendix E) have prioritised the 10 discontinuous fertilised areas using a multiple criteria analysis. Appendix E demonstrates the multiple criteria analysis technique used. Lawrence and Brodie used total N usage and average N rates for criterion 2, and distance on river to coast for criterion 3. For criteria 4 and 5, Lawrence and Brodie converted the hazard ratings to quantitative (numerical) values and the scores were analysed via the multiple criteria analysis. Results of the prioritisation are outlined in Table 13. This process leads to a priority list of regions for action on fertiliser management.

A low hazard ranking does not preclude the need for improved nutrient management practices in that area. All the 10 fertilised areas carry some level of hazard and therefore should be considered as nutrient management zones. However, the prioritised hazard assessment from this analysis can be used to inform future investment, and discussions on management programs should be targeted on the basis of this priority listing. Further prioritisation of sub-regions within the 10 NMZs may be possible on the basis of biophysical characteristics of the landscape and more complete information on fertiliser practices but this should be pursued at the time of nutrient management programs are implemented.

Table 12: Descriptions of hazard levels for decision criteria 2 to 5

| Criteria | 2 | 3 | 4 | 5 |
|-------------------|---|--|--|---|
| Rating | Potential for N and P losses from different fertiliser management regimes - based at present on estimated total N fertiliser application and average N application rate (see Table 10) | Likelihood of reaching coast - based on distance mid-point of zone to river mouth (see Table 11) (measured as distance along channel) | Extent of transport of exported nutrients in the GBR lagoon and potential to expose GBR ecosystems to exported nutrients - hence influence area⁶ | Number and proximity to coast of coral reefs within influence area of the discharge as a measure of likelihood of impact |
| High | Usage: Greater than 20 000 tonnes N Rate: Greater than 135 kg ha ⁻¹ | Distance less than 100 km | Annual exposure of GBR reefs to floodwater | Many reefs. Determined by expert opinion and supported by modified version of Devlin <i>et al.</i> 2003 (Pinner, Appendix C). |
| Moderate | Usage: Between 20 000 and 10 000 tonnes N Rate: Between 135 and 50 kg N ha ⁻¹ | Distance 101 km to 250 km | Exposure of GBR reefs to floodwaters every 2–4 years | Some reefs |
| Low | Usage: Between 10 000 and 1000 tonnes N Rate: Between 50 and 10 kg N ha ⁻¹ | Distance 251 km to 600 km | Exposure of GBR reefs to floodwaters at intervals of 5+ years. | Few reefs |
| Negligible | Usage: Less than 1000 tonnes N Rate: Less than 10 kg N ha ⁻¹ | Distance greater than 600 km | No or rare exposure of GBR reefs to floodwaters | No reefs |

Table 13: Assessed levels of hazard for intensive agricultural regions of the GBR catchment

| Fertilised Area | 1. Fertilised land use | 2. Potential for N and P losses from different fertiliser management regimes - based at present on estimated total N fertiliser usage and average N fertiliser application rates | 3. Likelihood of reaching coast (i.e. mouth of river) - based on distance to river mouth (via channel) from mid point of fertilised area | 4. Extent of transport of exported nutrients in the GBR lagoon and potential to expose GBR ecosystems to exported nutrients - hence influence area | 5. Number and proximity to coast of coral reefs within influence area of the discharge as a measure of likelihood of impact | Potential status |
|---------------------------------------|--|--|---|--|--|-----------------------------|
| Wet Tropics Coastal | Sugar, horticulture (bananas, pawpaws, mangos, lychees, tea, coffee, melons) | High (total N usage): 31,300 tonnes High (average application rate): 148 kg N ha ⁻¹ | High: Average distance = 20 km | High: Multiple, frequent, moderate sized rivers | High: Reefs, main and inner shelf close to coast | High hazard |
| Mackay - Whitsunday Coastal | Sugar, all others small | High (total N usage): 29,000 tonnes High (average application rate): 172 kg N ha ⁻¹ | High: Average distance = 29 km | High: Multiple, frequent, moderate sized rivers | High: Reefs—inner shelf close to coast, outer shelf probably not at risk | High hazard |
| Lower Burdekin Coastal | Sugar, horticulture (fruit and vegetables) | High (total N usage): 21,500 tonnes High (average application rate): 216 kg N ha ⁻¹ | High: Average distance= 30 km | Moderate: A few episodic, small rivers. Infrequent major Burdekin River flows | High / moderate: Discharge from small systems (Haughton, Barratta, Sheep Station) may not be transported far. Reefs—some inner shelf, outer shelf reefs less affected | High/moderate hazard |
| Atherton and Evelyn Tablelands | Mixed—sugar, dairy, horticulture, beef—each of relatively small area | Low (total N usage): 6400 tonnes Moderate (average application rate): 118 kg N ha ⁻¹ | Moderate: Average distance = 119 km Some trapping by Tinaroo dam but most cropping downstream of dam (Lex Cogle, NRW 2006, pers. comm.) | Moderate: Two frequent, moderate sized rivers (Barron and North Johnstone) | Moderate: Reefs, main and inner shelf close to coast | Moderate hazard |
| Burnett Coastal | Sugar, some horticulture | Moderate (total N usage): 11,300 tonnes Moderate (average application rate): 125 kg N ha ⁻¹ | High: Average distance= 39 km | Moderate: Small, infrequent rivers | Moderate: Reefs—very few inner shelf, large distance to outer shelf | Moderate hazard |
| Bowen | Horticulture (tomatoes, mangos, capsicums, melons) | Low/negligible (total N usage): 900 tonnes Moderate (average application rate) 79 kg N ha ⁻¹ | High: Average distance= 17 km | Low: Small, very infrequent rivers | Moderate: Reefs—sparse inner shelf reefs | Low/moderate hazard |
| Inland Normanby | Opportunistic cereals | Negligible (total N usage): 200 tonnes Low (average application rate), 25 kg N ha ⁻¹ | Low: Average distance= 263 km | Moderate: Infrequent, large flows | Moderate: Inner shelf reefs close to coast, but outer shelf distant | Low hazard |
| Fitzroy | Cotton, cereals, citrus | High (total N usage): 25,400 tonnes Low (average application rate), 29 kg N ha ⁻¹ | Low: Average distance= 306 km. Some trapping through irrigation tailwater recycling. Bob Noble data show relatively effective transport of contaminants to the coast | Low: Highly infrequent river flow | Moderate: Reefs—inner shelf (Keppel Islands) | Low hazard |
| Burnett Inland | Cereals, citrus, peanuts | Low (total N usage): 5700 tonnes Moderate (average application rate): 72 kg N ha ⁻¹ | Moderate: Average distance= 217 km | Low: Single infrequent river | Low: Reefs—very few | Low hazard |
| Inland Burdekin | Opportunistic cereals, cotton | Low (total N usage): 3400 tonnes Low (average application rate), 26 kg N ha ⁻¹ | Low: Average distance= 365 km Effective trapping by Burdekin dam | Low: Large but very infrequent river | Moderate: Reefs—some inner shelf, outer shelf reefs less affected | Low hazard |

9. Validation of the decision system results

A number of studies which have examined and identified the areas of the GBR most damaged by land pollutant discharge can be used to validate the prioritisation of NMZs arrived at in this study. There is evidence to indicate that increased pollutant discharge to the GBR, associated with agricultural development of the GBR catchment, has degraded inner shelf reef ecosystems in Wet Tropics coastal waters (Fabricius and De'ath 2004; Fabricius *et al.* 2005; Devantier *et al.* 2006) and Whitsunday Islands waters (van Woesik *et al.* 1999). This is in stark contrast to the reefs in the inner shelf waters of Princess Charlotte Bay on Cape York, which are also impacted by river flood plumes, but where agricultural pollutant discharge is minimal and reefs are in excellent condition (Fabricius *et al.* 2005). Similarly located reefs in the Wet Tropics i.e. impacted by river flood plumes but adjacent to highly agriculturally developed catchments, are in poor condition with about 50 per cent lower coral diversity than expected and apparent slow recovery from disturbance (Fabricius *et al.* 2005; Devantier *et al.* 2006). The correlation of reef damage with the priority NMZs identified in this technical report is complicated by the fact that nutrients are not the only agriculturally derived pollutants (there are also sediments and pesticides). However, given that complication, it is still clear that the two areas of the GBR apparently most affected by land pollution are adjacent to the two highest priority NMZs (Wet Tropics Coastal and Mackay–Whitsunday Coastal).

A more indirect effect of increased nutrients on coral reef ecosystems is an increased probability of the formation of population outbreaks of the crown-of-thorns starfish (*Acanthaster planci*), a major coral predator. *A. planci* outbreaks have been a principal cause of coral mortality on the GBR (and throughout the Indo-Pacific coral province) over the last 40 years. Its planktonic larvae feed on large phytoplankton, and experiments suggest that the successful development of these planktonic larvae to benthic starfish juveniles is food limited: their survival increases steeply with increasing availability of suitable food at environmentally relevant concentrations. In the field, increased nutrient availability can enhance the abundance of large phytoplankton cells. Present-day chlorophyll concentrations in the central and southern GBR lagoon in summer average levels at which the survival rate of *A. planci* is higher than at concentrations found in the far northern part of the GBR. If experimental findings also apply in field settings, it appears that increased survival of *A. planci* larvae, and subsequent adult population outbreaks, may be best explained by high nutrient concentrations facilitating larval survival (Brodie *et al.* 2005). All three waves of outbreaks of *A. planci* on the GBR have started in the Cairns–Cooktown area where high nutrient waters from Wet Tropics rivers are believed to first enhance survival of the *A. planci* larvae.

The Wet Tropics and Mackay–Whitsunday regions are also the regions for which we have the best information connecting fertilised land uses with nitrate concentrations in runoff water and streams (Brodie and Mitchell 2006a and b). Long-term data

from the Tully catchment (Mitchell *et al.* 2006) show a strong linear relationship between percentage of a sub-catchment under fertilised cropping and mean nitrate in stream flow. Similarly when nitrate concentrations are measured in water discharging from different land uses (forest, sugarcane, urban, beef grazing) in the Mackay–Whitsunday region a strong link between sugarcane and nitrate losses is evident (Rohde *et al.* 2006).

A conceptual model has been developed to illustrate the transport of nutrients from diffuse sources of pollution within the GBR catchment out to the GBR lagoon (Figure 26). This model shows the generation of fertiliser, losses, transport in stream, transport across the lagoon, and likely ecological impacts. These steps are explained as follows:

1. Generation

Inputs of fertiliser to the system through agricultural practices generate additional nutrients (Rayment 2003).

2. Losses

Excess fertiliser is lost from the system during rain events through runoff (Faithful and Finlayson 2004).

3. Transport in stream

Dissolved and particulate nutrients are transported through the river systems, but some (mainly particulate nutrients) may be trapped by wetlands, retention ponds and other trapping mechanisms (Mitchell *et al.* 2001).

4. Transport across the lagoon

Nutrients are transported out into the marine environment, where particulate nutrients are mixed into the water column quite quickly, while dissolved nutrients may be carried for hundreds of kilometres offshore and along-shore, depending on currents and winds (Devlin *et al.* 2001a; Devlin and Brodie 2005).

5. Likely ecological impacts

Nutrients impact the ecology of ecosystems within the GBR through muddy marine snow, microalgae/algal enhancement, and crown-of-thorns starfish (Fabricius 2005; Fabricius *et al.* 2005).

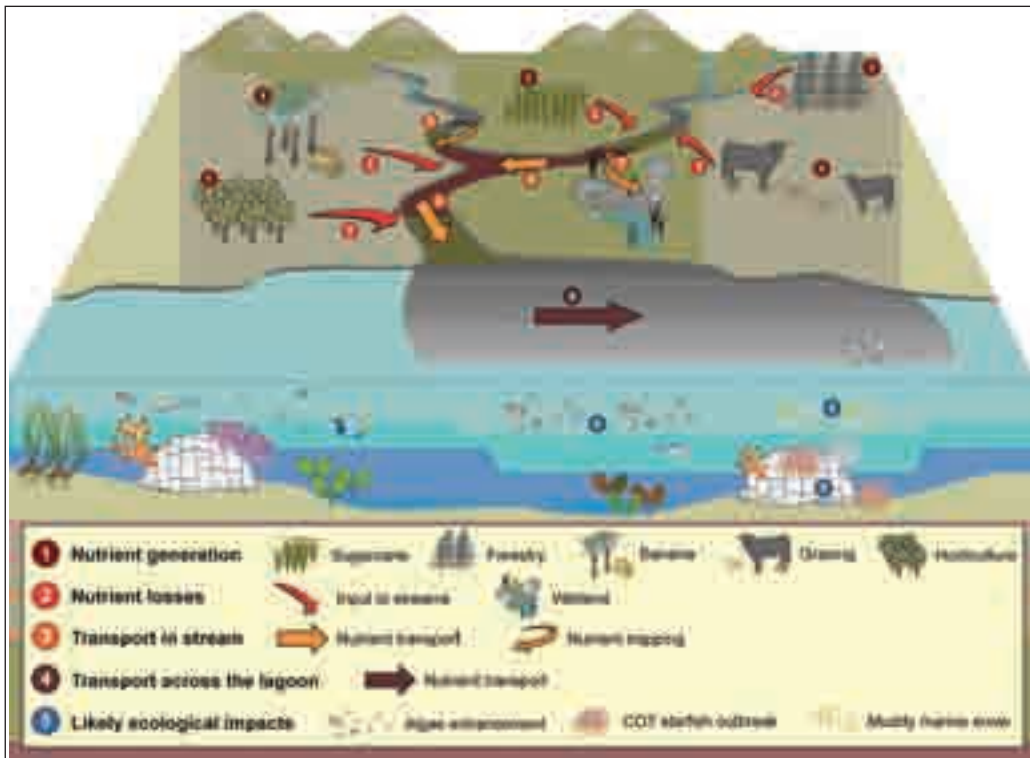


Figure 26: Conceptual model for nutrient transport from diffuse sources of pollution within the GBR catchment and lagoon

10. Management mechanisms within NMZs

An additional criterion for ranking fertilised areas was considered based on the effectiveness of available management options. Such a criterion would give higher rankings to areas where greater reductions in nutrient export were achievable by improving management practices.

Currently there is a great deal of research being conducted on best management practices in agriculture within the GBR catchment. However, to date the effectiveness of nutrient management options has not been clearly summarised and articulated for either of the major fertilised crops of the GBR catchment—sugarcane and horticulture. This information should become available as best management practices are developed, quantified and rolled out across the catchment, and their effectiveness can then be monitored, measured and considered in future reviews of the effectiveness of NMZs.

This technical report focuses on known fertiliser application rates and likelihood of nutrient loss in the absence of effective nutrient management options. Mitigation measures—such as targeted application, sediment retention basins, improved infiltration, and wetland and riparian rehabilitation—are mentioned in this report, but require further information before they can be used to re-assess zone ratings. Future changes in zone status would be related to changed land use within the GBR catchment.

The rating of a fertilised area based on the level and effectiveness of the management practice applied could have major implications for the development and future implementation of policy in that zone, and therefore land use practices, including measures of best management practice uptake, would be addressed through policy. A policy paper being developed by DPIF in collaboration with the Australian Government and industry bodies identifies management practices that will improve nutrient management. It will be through the implementation of this policy that the effectiveness of available management options is assessed.

11. Possible future refinements

Many of the processes used in this decision system for NMZ selection can be improved and more recent data will also make the tool work more precisely. Some suggested improvements are as follows:

- a. It is known that some beef finishing areas use fertilisers. However, no reliable data are currently available on the size of area involved or the amount of fertiliser used. Future land use mapping and fertiliser use documentation may allow inclusion of this activity in the NMZ decision system.
- b. Similarly for mixed farming, such as commonly occurs in the Atherton Tablelands and parts of the Burnett catchment, better land use area and fertiliser use data will allow more accurate selection of high priority NMZs.
- c. QLUMP data from 2004 may become available for other catchments (Johnstone, Burdekin and Fitzroy are already available and have been used). These data will better separate crop types, e.g. cereals, cotton, bananas, than the 1999 QLUMP data currently used for the majority of catchments, as well as being more up to date. Use of 2004 data can improve the selection of NMZs.
- d. An update of marine ecosystem risk models used in the current process but based on the work of Devlin *et al.* (2003), Greiner *et al.* (2003, 2005) and updated by Pinner (Appendix C) is required. Improved understanding of the process, more recent data and more comprehensive spatial coverage can greatly improve this information.
- e. Generally more data (more recent, more spatially explicit, more accurate) on parameters used in the selection process will improve the NMZ decision system. This is particularly the case for criterion 2, potential for N and P losses from different fertiliser management regimes, which is currently based on the amount of fertiliser used. While higher fertiliser loads represent a higher potential for loss, many other factors influence loss (see Ham (2006)). As information on fertiliser management regimes (including fertiliser type, timing, method of application, ratio of amount used to recommended rates, use of tailwater recapture) becomes available on a GBR catchment wide scale, it would provide a more accurate assessment of the potential for N and P losses.
- f. Refinement of multiple criteria analysis will improve the prioritisation process.

- g. Weighting of factors in the future to more accurately reflect their true importance (as distinct from the equal weighting applied in this technical report) will improve the process. The effect of some changes in weighting is explored in Appendix E of this report, which shows that with preliminary changes the Wet Tropics Coastal and Mackay–Whitsunday Coastal NMZs remain the highest priority areas (based on the means of the multi-criteria values).
- h. There are large quantities of nitrate in coastal aquifers adjacent to the GBR, but the final fate of this material is not known. Further research into the fate of nitrate in coastal aquifers is considered a priority.
- i. Use of ANNEX-type modelling could be useful to validate the choice of NMZs. Currently the most recent ANNEX modelling results (Cogle *et al.* 2006) provide some support for the prioritisation process used in this report. However, both data and results from ANNEX may be able to be used to refine the process. ANNEX could be useful as a layer to include runoff risk factors such as rainfall and slope. Factors such as slope may affect the likelihood of DIN reaching the coast as much as distance from the coast (B. Sherman, CSIRO 2006, pers. comm.). For example, many regions in the Fitzroy and Burdekin are so flat that little runoff (and therefore DIN from crops) would reach waterways. Caution must, however, be used when applying ANNEX for the following reasons (B. Sherman, CSIRO 2006, pers. comm.):
 - Absolute values from ANNEX are not reliable due especially to uncertainties in the input data used to configure the model. Relative differences are more reliable.
 - Differences between catchments could be used but this is only reliable when the relative differences are large. Differences of 20–40 per cent between catchments should not be used, but if the differences were very large (say 300 per cent) they could be used.

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