GREAT BARRIER REEF
MARINE PARK AUTHORITY

RESEARCH PUBLICATION NO. 66

A Review of Water Quality Issues Influencing the Habitat Quality in Dugong Protection Areas

Water Quality Unit
Great Barrier Reef Marine Park Authority

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FOREWORD

The seagrass meadows in the Great Barrier Reef Region are important feeding grounds for a critical proportion of the world population of the dugong species *Dugong dugon*. The dugong has high biodiversity value and is considered by the World Conservation Union to be vulnerable to extinction. A rapid decline of the dugong population in the southern Great Barrier Reef over the last 10 years has raised concerns about the survival of the species in that region. Reasons for the reported decline in dugong numbers are not fully understood, however, because dugongs have very low rates of population growth any impacts such as degradation and loss of seagrass habitat and deterioration of water quality have the potential to threaten the integrity of dugong populations.

Zoning of the Great Barrier Reef Marine Park has provided a certain level of protection of dugongs, especially in the Cairns and Far Northern Section of the Park. In addition, in 1997–98, a system of 16 Dugong Protection Areas was established by the Commonwealth and Queensland Governments as a key strategy to help recover the declining dugong population in the southern Great Barrier Reef. These areas centre on significant habitat and feeding grounds of the dugong population and were declared to minimise the risk to dugongs from anthropogenic effects such as drowning in fishing nets and collision with boats. However, land based pollutants from the Great Barrier Reef catchment are also recognised as a threat to dugong populations through degraded water quality. These pollutants may either directly affect them or indirectly contaminate them through seagrasses on which the dugong feed. Loss of feed by smothering and killing seagrasses with sediment is also a concern due to detrimental land use practices.

The Great Barrier Reef Marine Park Authority is concerned about all potential effects on dugongs in the Dugong Protection Areas, and has therefore documented information relating to water quality in the Areas. The information and associated risk analysis was reported on 30 July 1999 to the Great Barrier Reef Ministerial Council, comprising the Commonwealth and Queensland Government Ministers for the Environment and for Tourism. At the meeting, Queensland Ministers undertook, among other things, to pursue legislative protection of riparian zones and wetlands; to implement Integrated Catchment Management strategies; and to progress agricultural industry Codes of Practice from voluntary to mandatory. The Council also undertook to support studies into habitat quality issues related to seagrass and land runoff; and requested publication of this report subject to favourable peer review.

In accordance with the Council's request, the Great Barrier Reef Marine Park Authority is pleased to make this report available for general consideration.

Hon Virginia Chadwick
Chair
Great Barrier Reef Marine Park Authority

January 2002

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SUMMARY

The Queensland dugong population has declined significantly in the Great Barrier Reef (GBR) south of Cooktown during the past decade. In response to this decline 16 Dugong Protection Areas (DPAs) were established in 1997 in the Great Barrier Reef World Heritage Area (GBRWHA) and the Hervey Bay–Great Sandy Strait Region. The establishment of the DPAs has been a key strategy to protect dugongs from direct anthropogenic effects such as drowning in fishing nets and collision with boats.

Dugongs are also threatened by indirect anthropogenic impacts to their habitats from deterioration in water quality that cause either direct adverse effects on dugong health or indirect effects on the distribution and performance of seagrasses, the main food source of dugong. Seagrass growth and productivity is adversely affected by high water turbidity, smothering by sediment or mud, high nutrient availability and the presence of herbicide residues.

The most important water quality issues in the GBRWHA are high loads of river-borne nutrients, pesticides and sediments that reach the GBR lagoon. The nutrient and sediment loads of rivers draining the Queensland catchments have increased since European settlement as a result of intensified land use. The predominant land uses in the 17 major catchments adjacent to the GBRWHA are grazing, cropping, urban development and mining. Intensive cropping requires the application of fertilisers and pesticides, whereas land clearing, removal of wetlands and riparian zones, and over-grazing have caused increased erosion of terrestrial sediments. Consequently, increased loads of sediments, nutrients and pesticides are now exported to the coastal zone of the GBRWHA.

A qualitative risk assessment was completed as a tool to screen the potential of adverse effects on habitat quality to occur in DPAs as a result of activities on adjacent catchments. The level of risk reflects the development and land use on the adjacent catchments and the associated pollution pressures to the marine environment, as well as basic site-specific attributes of the DPAs. The output of the risk assessment is a summary rating of low, moderate or high risk for each of the 16 DPAs, as follows:
High risk - Hinchinbrook, Repulse Bay, Newry Region, Sand Bay, Llewellyn Bay, Ince Bay, Rodds Bay;
Moderate risk – Taylors Beach, Cleveland Bay, Bowling Green Bay, Upstart Bay, Edgecumbe Bay, Clairview Region, and Hervey Bay–Great Sandy Strait; and
Low risk –Shoalwater Bay and Port Clinton.

A significant reduction in nutrient, sediment and contaminant inputs to the GBR inner lagoon is essential to ensure that the DPAs provide favourable habitats. Current land-based pollution control measures have not been adequate to prevent an ongoing decline in water quality. Further steps are required to ensure the protection of downstream habitats. These may include measures such as:

- Queensland to pursue legislative protection of riparian zones and wetlands;
- Queensland to implement ICM strategies as a matter of priority; and
- Queensland to progress Industry Codes of Practice.

With the cooperation of government agencies, peak industry organisations and the community, the protection of water quality and seagrass habitat will form a key part of the strategy for the recovery of the severely depleted dugong population in the GBRWHA.

ACKNOWLEDGMENTS

We thank Tony Stokes, Jon Brodie, David Haynes, and Hugh Yorkston from the GBRMPA for their contributions to the content and editing of the report. We are grateful to Ian Prosser (CSIRO Land & Water) for making available data from the National Land and Water Resources Audit. Thanks are also due to the reviewers of the draft document, Rob Coles (Queensland Department of Primary Industries), George Rayment (Queensland Department of Natural Resources) and Miles Furnas (Australian Institute of Marine Science) for their valuable input.

1. INTRODUCTION

In August 1997, the Commonwealth and Queensland Governments established 16 coastal Dugong Protection Areas (DPAs) to reduce the threat of mesh nets to dugongs (*Dugong dugon*). The DPAs are situated in the Central and Mackay/Capricorn Sections of the Great Barrier Reef Marine Park (GBRMP) and the Hervey Bay–Great Sandy Strait region (Figure 1), and were enacted by Regulation No. 11 (1997) under the Queensland *Fisheries Act 1994* and the *Nature Conservation (Dugong) Conservation Plan 1999* under the *Nature Conservation Act 1992*. The establishment of DPAs was considered the key strategy to address the rapid decline of the Great Barrier Reef (GBR) dugong population south of Cooktown.

There are two types of DPAs. The Dugong Protection Area 'A' (DPA 'A') zones prohibit or restrict the use of fishing nets considered to pose a threat to dugong, while Dugong Protection Area 'B' (DPA 'B') zones are less restrictive in the use of nets. The DPAs are:

Dugong Protection Area 'A'	**Dugong Protection Area 'B'**
Hinchinbrook	Taylors Beach
Cleveland Bay	Cape Bowling Green Bay
Upstart Bay	Edgecumbe Bay
Newry Region	Repulse Bay
Ince Bay	Sand Bay
Shoalwater Bay	Llewellyn Bay
Port Clinton	Clairview Region
Hervey Bay–Great Sandy Strait	Rodds Bay

The seagrass meadows in the GBR region are important feeding grounds for a critical proportion of the world population of the dugong species *Dugong dugon* (Great Barrier Reef Marine Park Authority 1981). The dugong is considered by the IUCN to be vulnerable to extinction (IUCN 1990). Aerial surveys of the dugong population in the inshore waters of the GBRMP were conducted in 1986 and 1987 and then repeated in 1992 and 1994 (Marsh et al. 1995). The surveys indicated a dramatic decline over the eight year period with approximately a 50% reduction of dugong numbers (Marsh et al. 1995). Reasons for the reported decline in dugong numbers are unclear, however, because dugongs have very low rates of population growth (Marsh 1992) any impacts such as loss of seagrass habitat and deterioration of water quality have the potential to threaten the integrity of dugong populations (Marsh 1992; Marsh et al. 1995).

Dugong are threatened by both direct anthropogenic impacts such as entanglement in fishing nets, boat strikes, displacement by boating activities in feeding areas, indigenous hunting, and indirect anthropogenic impacts such as deterioration of water quality and degradation of seagrass meadows. The indirect anthropogenic impacts are difficult to determine and define, and consequently it is problematic to mitigate their impact on dugong populations. Such impacts are predominantly caused by changes in water quality that cause either either direct adverse effects on dugong health or indirect effects on the distribution and performance of seagrasses, the main food source of dugong.

Changes in water quality as a result of agriculture, urban expansion and industrial activities include increased exports to coastal waters of sediments, nutrients, and other

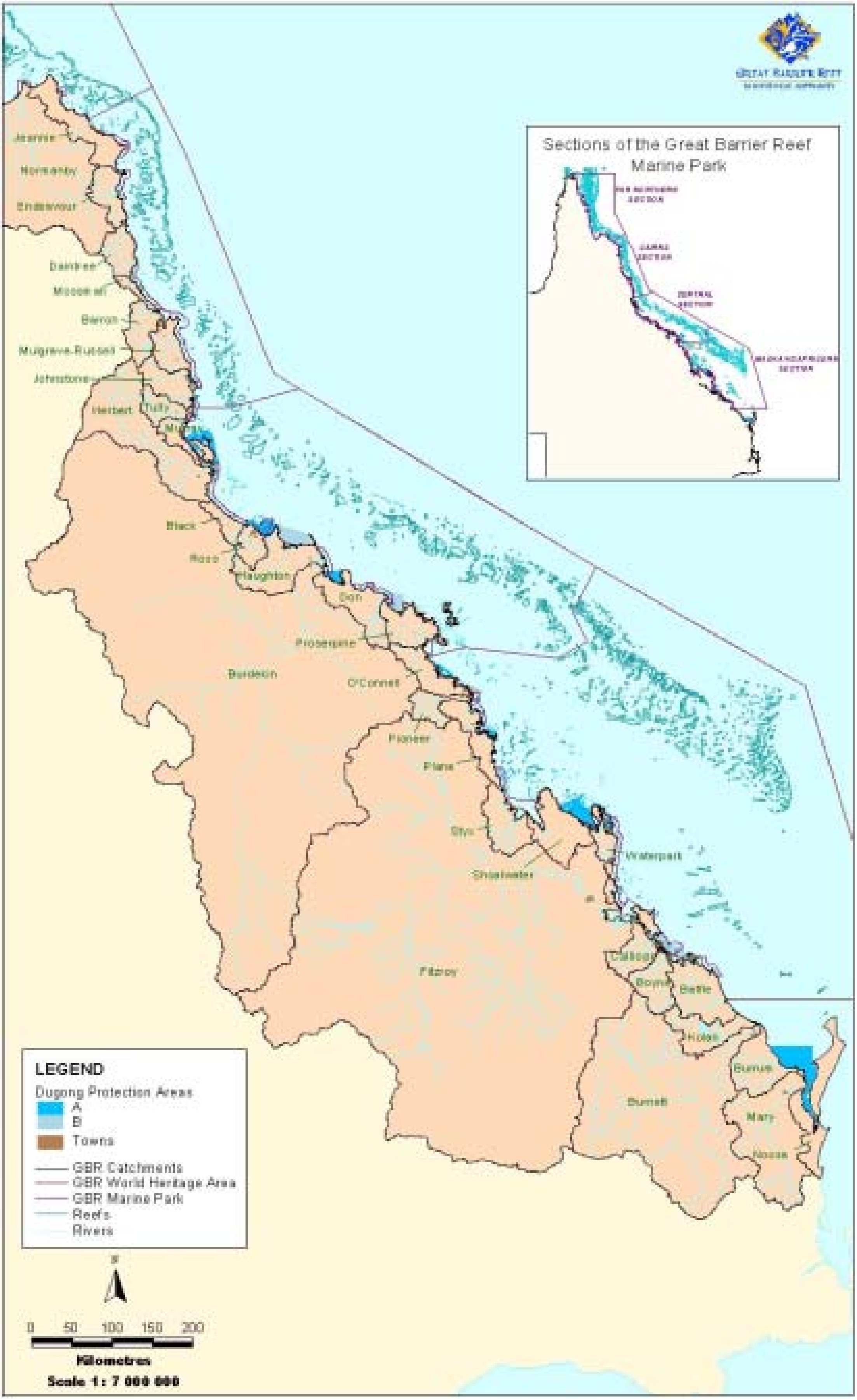

Figure 1. Location of Dugong Protection Areas and the adjacent river catchment areas of the Great Barrier Reef World Heritage Area

contaminants such as heavy metals, organochlorine compounds, and polycyclic aromatic hydrocarbons (PAHs) (Fowler 1990; Tatsukawa et al. 1990; Brodie 1995; Connell 1993). These pollutant groups present a potential risk to dugongs and seagrass meadows.

The purpose of the present review is to synthesise available information to address the following questions:
What and how severe are the effects of water quality on habitat quality in the existing DPAs?
How do water contaminants affect dugongs and their food source, seagrasses and other dugong habitat features?

Using this information the risks to dugong health and habitat quality in DPAs associated with poor water quality are assessed, and options to better manage these risks are suggested.

1.1 Geographical and Biological Setting

The GBRWHA covers an area of about 350 000 km^2 on the north-eastern Australian continental shelf. It encompasses the long, narrow band of the GBR, stretching 2000 km along the coast from 10.5°S at Cape York to 24.5°S near Bundaberg. The GBR is the largest assemblage of coral reef ecosystems found anywhere in the world and comprises nearly 3000 individual reefs. Approximately 350 species of hard coral, 1500 species of fish, 240 species of seabirds, more than 4000 species of molluscs and numerous other biota are found in the GBR region (GBRMPA 1981). In general, there is a strong cross-shelf component in the abundance and diversity of both reef and inter-reefal taxa in the GBR. These cross-shelf patterns vary with latitude due to variability in key physical factors (Kerrigan et al. in press). The principal habitats of the system have only existed in their present form since the sea level rose 9000 years ago, flooding the shelf. Mangroves are widespread along the coastline with a total area of about 2000 km^2 (Galloway 1982), interspersed with areas of low energy, sandy beachline and limited rocky shorelines. In the shallow areas along the coast, seagrass meadows are present and have been documented to cover an area of approximately 3000 km^2 (Lee Long et al. 1993). Deep water (> 10 m) seagrasses have been discovered further offshore in the northern GBR with an area of about 2000 km^2 (Lee Long et al. 1996a). The soft-bottom of the GBR lagoon floor is colonised by communities of algae, sponges, bryozoans and echinoderms (Birtles & Arnold 1988).

1.2 Dugong Habitats

Dugongs inhabit coastal areas of the GBRWHA. They can travel distances of several hundred kilometres (Marsh & Corkeron 1997) and have been observed on the outer shelf of the Far Northern Section of the GBRMP (Marsh & Saalfeld 1989). The Far Northern Section of the GBRMP is the most important dugong habitat in the GBRWHA with a relatively large and stable dugong population (approximately 10 000 animals; Marsh & Corkeron 1997). The dugong population from Cooktown to the southern boundary of the GBRWHA is smaller and from 1986 to 1994 has been critically reduced by approximately 50% to about 1700 animals (Marsh & Corkeron 1997).

Generally the coastal dugong habitats correspond with the distribution of shallow water seagrasses in the GBR. However, dugongs have also been observed feeding on deep water seagrass meadows at depths of more than 20 metres (Lee Long et al. 1989, 1996a). Most seagrasses found in the GBR region grow in the inshore lagoon in shallow waters (< 10 m), less than 10 kilometres from the coast (Lee Long et al. 1993). In deeper waters (10 to 60 m depth), considerable areas of seagrass meadows have recently been discovered in the inter-reefal areas of the GBRWHA (Lee Long et al. 1996a). Baseline seagrass surveys carried out by the Queensland Department of

Primary Industries in the 1980s provide important information on the large scale distribution of seagrass meadows in most areas of the GBRWHA inner lagoon (Lee Long et al. 1993). This information, however, is now dated. Recent re-surveys at a few locations indicate that at a small spatial scale (hundreds of metres) distribution of seagrass meadows can change markedly over time (Lee Long et al. 1996b, 1998). There is also very limited information on seasonal changes in seagrass abundance (Mellors et al. 1993; Lanyon & Marsh 1995). The current survey information regarding the extent of seagrass meadows in the GBR is incomplete so is not presented in this report.

The main food source for dugongs are ephemeral seagrasses of the genera *Halophila* and *Halodule* (Preen 1993a), however, all seagrass species described for the GBRWHA have been found in stomach contents of dugongs (Lanyon et al. 1989). The 15 seagrass species described to date for the GBRWHA are: *Cymodocea rotundata*, *C. serrulata*, *Enhalus acoroides*, *Halophila decipiens*, *H. ovalis, H. ovata*, *H. spinulosa*, *H. tricostata*, *Halodule pinifolia*, *H. uninervis* (possibly two species), *Syringodium isoetifolium*, *Thalassia hemprichii*, *Zostera capricorni*.(Lee Long et al. 1993) and *Halophila capricorni* (Larkum 1995). *Enhalus acoroides* only occurs in the Far Northern Section of the GBRMP (Lee Long et al. 1993). *Cymodocea serrulata*, *H. spinulosa*, *Z. capricorni*, and the wide-leafed form of *H. uninervis* contribute most of the seagrass biomass between Cape York and Hervey Bay (Lee Long et al. 1993).

In addition to being the essential food sources for dugong and green sea turtles (*Chelonia mydas*), seagrass communities are of major importance to coastal ecosystems. Seagrasses stabilise bottom sediments; are important benthic primary producers; are part of the nutrient cycle in the aquatic system; supply habitat for adult fish, juvenile fish and invertebrates; contribute substratum for encrusting animals and plants. In the GBR region seagrass meadows are also important as habitat for juvenile prawns (Coles et al. 1987), and the seeds of *Z. capricorni* are a seasonal food source for juveniles of the species *Penaeus esculentus* (Dall et al. 1992).

2. CATCHMENT ACTIVITIES POTENTIALLY AFFECTING DUGONG PROTECTION AREAS

Land use changes in the GBR Catchment are significant to the water quality status in the GBR. The land use activities in the GBR Catchment determine the quality of the terrestrial runoff that influences the water quality in the DPAs.

2.1 Changes in Land Use

Land within the 17 major river catchments adjacent to the GBR has been extensively modified since European settlement. Land clearing, removal of wetlands and riparian vegetation zones, grazing and cultivation have all occurred to enable the development of agriculture, mining and urban centres within each of the catchments to a greater or lesser extent. Only very small areas of the catchments adjoining the DPAs are considered to be pristine lands. In the Herbert and Haughton River catchments (Central Section of the GBRMP) approximately 10% of the catchment area is pristine lands whereas in the Kolan River catchment (Mackay/ Capricorn Section of the GBRMP) there is no pristine land (Rayment & Neil 1997).

Land clearing during the past 130 years has resulted in loss of rainforest in coastal lowlands (Johnson et al. 1998) and on the ranges and tablelands (Gardiner et al. 1988), loss of coastal wetland forest (Johnson et al. 1998), and extensive loss of open woodland. Forest and woodland clearance in Queensland has been quantified from satellite imagery (Graetz et al. 1995). In the Herbert River catchment *Melaleuca* wetlands have been reduced in area from 30 000 hectares in pre-European times to less than 5000 hectares in 1996, while in the lower Johnstone River catchment a 78% loss occurred between 1951 and 1992. In the Fitzroy River catchment, during the Brigalow (*Acacia harpophylla*) woodland clearance schemes (1950 to 1975) approximately 4 million hectares of Brigalow woodland were cleared for conversion to grasslands for cattle grazing. The National Greenhouse Gas Inventory Committee Report (1999) estimated that in the period between 1988 and 1998 approximately 3 million hectares of land would have been cleared in Queensland. Most of this clearing is now occurring on marginal agricultural land, particularly in central Queensland, where soil fertility is considered to be inadequate for agricultural purposes. In recent reports summarising the status and quality of freshwater streams in Queensland catchments, the loss and disturbance of riparian vegetation zones in agricultural areas is emphasised, primarily because it causes increased erosion and enhanced turbidity in stream waters (Moller 1996; Johnson 1997; Russell & Hales 1994, 1997; Russell et al. 1996a, b).

Use statistics and usage trends for the GBR Catchment have been quantified by Gilbert et al. (in press). Of the catchments flowing into the GBR the primary land use is cattle grazing for beef production, which occupies 77% of the total catchment area. In 1996 there were approximately 4.9 million beef cattle grazing in the GBR Catchment with the highest stock numbers recorded in the Fitzroy River catchment (Gilbert et al. in press). Other land uses, namely cropping (mainly of sugarcane) and urban/residential development, each occupy approximately 3% of the total catchment area.

The largest crop grown on the GBR Catchment is sugarcane which is primarily grown in lowland coastal areas. The catchment area used for sugarcane cropping has increased steadily over the last 100 years with 390 000 hectares being cultivated for sugarcane by 1997 (Figure 2). Sugarcane cropping requires the application of fertiliser which has resulted in a rapid increase in total fertiliser application since 1950 (Pulsford 1996).

The estimated human population in the GBR Catchment is steadily increasing, by 1995 it was 1.2 million. This population growth has been associated with an increasing demand on land for urban development. Other significant land uses, in specific catchments, include mining (coal and metalliferous) and cotton cropping, however, these land uses occupy only a small area of land relative to the total GBR Catchment. Industries such as aquaculture, cotton (mostly on the Fitzroy catchment) and horticulture (particularly bananas) are presently expanding and consequently fertiliser application associated with these uses is increasing in the GBR Catchment. For example, in the Tully River catchment the area under sugarcane has doubled and fertiliser nitrogen use has increased by 130% (Mitchell et al. 2001).

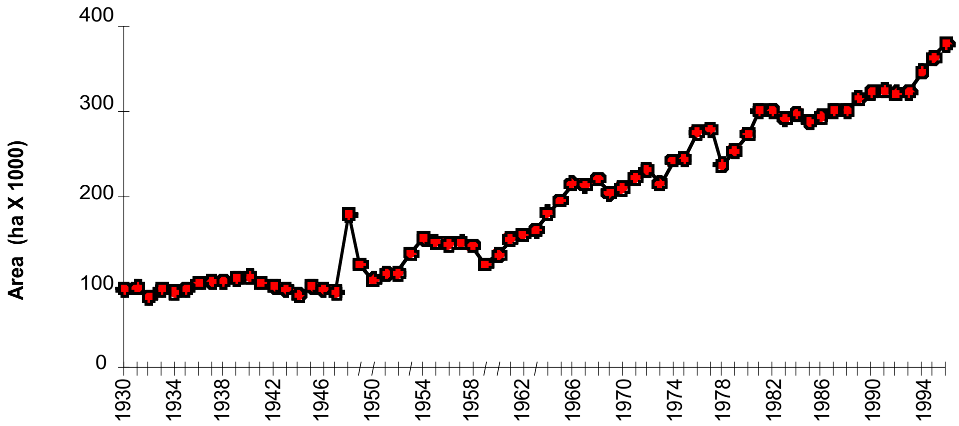

Figure 2. Increase in land area used for sugar cultivation from 1930 to 1996 (Gilbert et al. in press)

2.2 Terrestrial Runoff

Terrestrial runoff is considered one of the most significant anthropogenic impacts on the water quality of the GBRWHA because it carries sediments, nutrients, heavy metals and other contaminants, acid sulfate soil leachate and litter. There has been an ongoing and often controversial discussion on the biological and physical impacts of terrestrial runoff on the health of the GBR (e.g. Bell 1991; Bell & Gabric 1991; Kinsey 1991; Walker 1991; Baldwin 1992; Brodie 1995; Larcombe & Woolfe 1999). However, there is now agreement that “there is significant risk that terrestrial runoff is currently or may in future damage areas of high exposure along the tropical and central Queensland coasts of the GBRWHA” and that “there is a continued urgency to work towards a reduction in the runoff of sediments, nutrients, herbicides and other pollutants into the Great Barrier Reef Marine Park World Heritage Area.” (statement by the CRC Reef Research Centre, December 2001).

The main sources of terrestrial runoff to the GBR are via point sources and river discharge.

2.2.1 Point Sources

Point source discharges include sewage outfalls, discharge from aquaculture operations and industrial effluent.

Sewage discharges contribute only a few per cent of the 'new' nutrients to the coastal waters of the GBR (Figure 3) however they can be significant on a local scale (Brodie 1995). A majority of the large coastal cities and most of the smaller coastal settlements adjacent to the GBRWHA, have secondary treatment sewage systems. Many of these treatment plants use a proportion of the effluent for land irrigation and several have sewage outfalls, as point-source discharges, either into coastal streams or directly into the GBRWHA. The operation of treatment plants (greater than 21 equivalent persons capacity) is regulated by the Queensland *Environmental Protection Act 1994*. Problems may arise from these point-source discharges, particularly in dry season conditions, where discharge into a stream may constitute the total stream flow. Under these conditions eutrophication, algal blooms and anoxia in the vicinity of the point-source discharge may result. In some areas with significant urban populations septic systems are still in operation, for example, most of the Magnetic Island and Mission Beach residential areas. Plans to upgrade the sewage systems in these communities are being investigated.

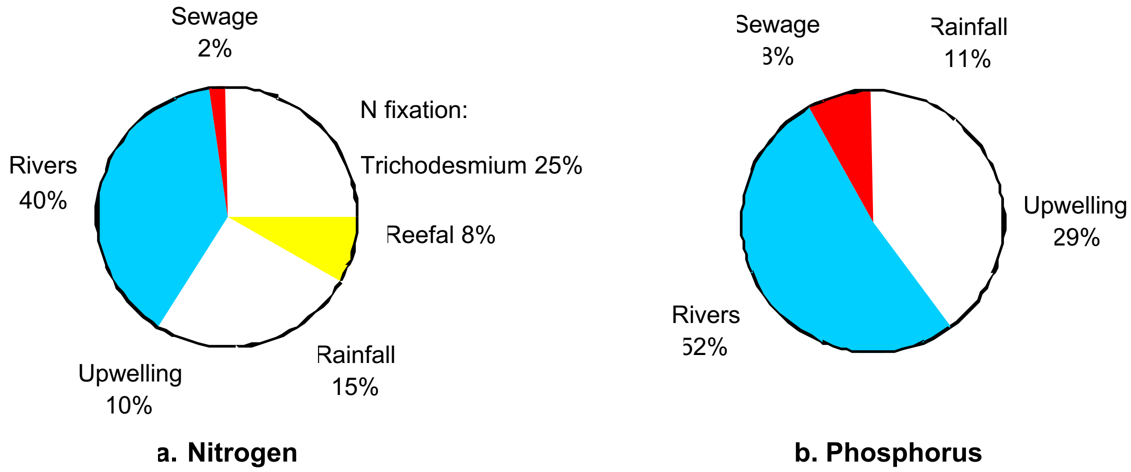

Figure 3. Sources of new nitrogen and phosphorus to the Great Barrier Reef shelf waters (Source: Furnas et al. 1995).

Aquaculture of saltwater prawns is a small but expanding industry along the coast adjacent to the GBRWHA. Wastewater from prawn ponds is periodically released into coastal streams or potentially, directly into the GBRWHA, and may be a considerable local source of nutrients (Macintosh & Phillips 1992). Such point-source discharges are high in nutrients, suspended solids, algae and bacteria and thus have potential impacts on the GBRWHA. Again such point-source discharges are regulated under the Queensland *Environmental Protection Act 1994* through a licensing system however compliance is self-regulated by individual prawn farms once a license is obtained. More recently, regulations have been introduced under Section 66(2)(e) of the *Great Barrier Reef Marine Park Act 1975* that regulate discharge of aquaculture waste from the coastal boundary of the GBRMP to 5 km inland from the highest astronomical tide. The *Great Barrier Reef Marine Park (Aquaculture) Regulations 2000* came into effect in February 2000 to manage aquaculture waste discharge immediately adjacent to the coast and the estuaries of the GBRWHA. These Regulations allow for accreditation of the Queensland assessment and approval processes when these processes adequately address the Commonwealth assessment and approval requirements, which aim to minimise impacts on marine ecosystems. At present, Queensland is encouraging new prawn farms to minimise the volume of discharge and to install biofiltration systems to reduce the concentration of contaminants in their wastewater by filtering the discharge water through beds of bivalves (e.g. oysters and mussels) or algae, or through mangroves. Currently, publications from a number of research projects addressing the environmental impacts of prawn farm effluents are in preparation (M. Burford, CSIRO Marine Research, pers. comm.).

The major industrial sites on the coast adjacent to the GBR are concentrated near Gladstone and Townsville. Only a few of these sites discharge wastewater into coastal streams or directly into the GBRWHA. These discharges are regulated under the Queensland *Environmental Protection Act 1994*. Recently developed industrial sites are encouraged to have no ocean wastewater discharge, for example, the Korea Zinc smelter in Townsville.

2.2.2 River Discharge

River discharges make a substantial contribution to the inputs of 'new' nutrients (N and P) to the shelf ecosystems of the GBR (Figure 3). The actual river flows in all catchments adjacent to the GBR are highly variable, both between and within years. Discharge in both wet and dry river systems is dominated by large flood events associated with tropical cyclones and monsoonal rainfall (Mitchell & Furnas 1997; Mitchell et al. 1996). While the large 'dry' catchments of the Burdekin and Fitzroy Rivers have the greatest average flows, significant flood events only occur episodically at intervals ranging between several years and a decade. Limited information suggests that area-specific erosion is higher in the 'wet' catchments of the central GBR (16 to 19°S), but overall sediment and nutrient inputs are dominated by the large dry catchments as a consequence of their larger average water flows.

The coastal region adjoining the DPAs is divided into a number of wet and dry tropical catchments. Most catchments are small (< 10 000 km^2), but the Burdekin (133 000 km^2) and Fitzroy River catchments (143 000 km^2) are among the largest in Australia. Estimates of the long-term average volume of water discharged annually into the whole of the GBRWHA by rivers range from 40 km^3 (Furnas & Mitchell 1997) to 84 km^3 (Wasson 1997).

Approximately 37 % of this discharge originates from the Burdekin and Fitzroy Rivers and 30% originates from the relatively small rivers in the Wet Tropics region (16°S to 19°S).
How far terrestrial runoff is transported in river discharge depends on the velocity of the waterway, the size of the transported material and whether or not the material is dissolved or in suspension. While sand and silt sized sediment fractions may be re-deposited within the catchments during low flow events, most of the fine clay fraction is transported downstream to the river mouth (Arakel et al. 1989). During major flood events associated with tropical cyclones, the sediment re-deposited in the streams may be resuspended and transported downstream. These major events are responsible for almost all the transport of material from catchments to the inner lagoon (Cosser 1989; Furnas & Mitchell 1991; Hunter 1997; Bramley & Johnson 1996; Mitchell et al. 1997). Intense rainfall associated with tropical cyclones causes massive river flows and flood plumes, which intrude into the GBR lagoon (Figure 4).

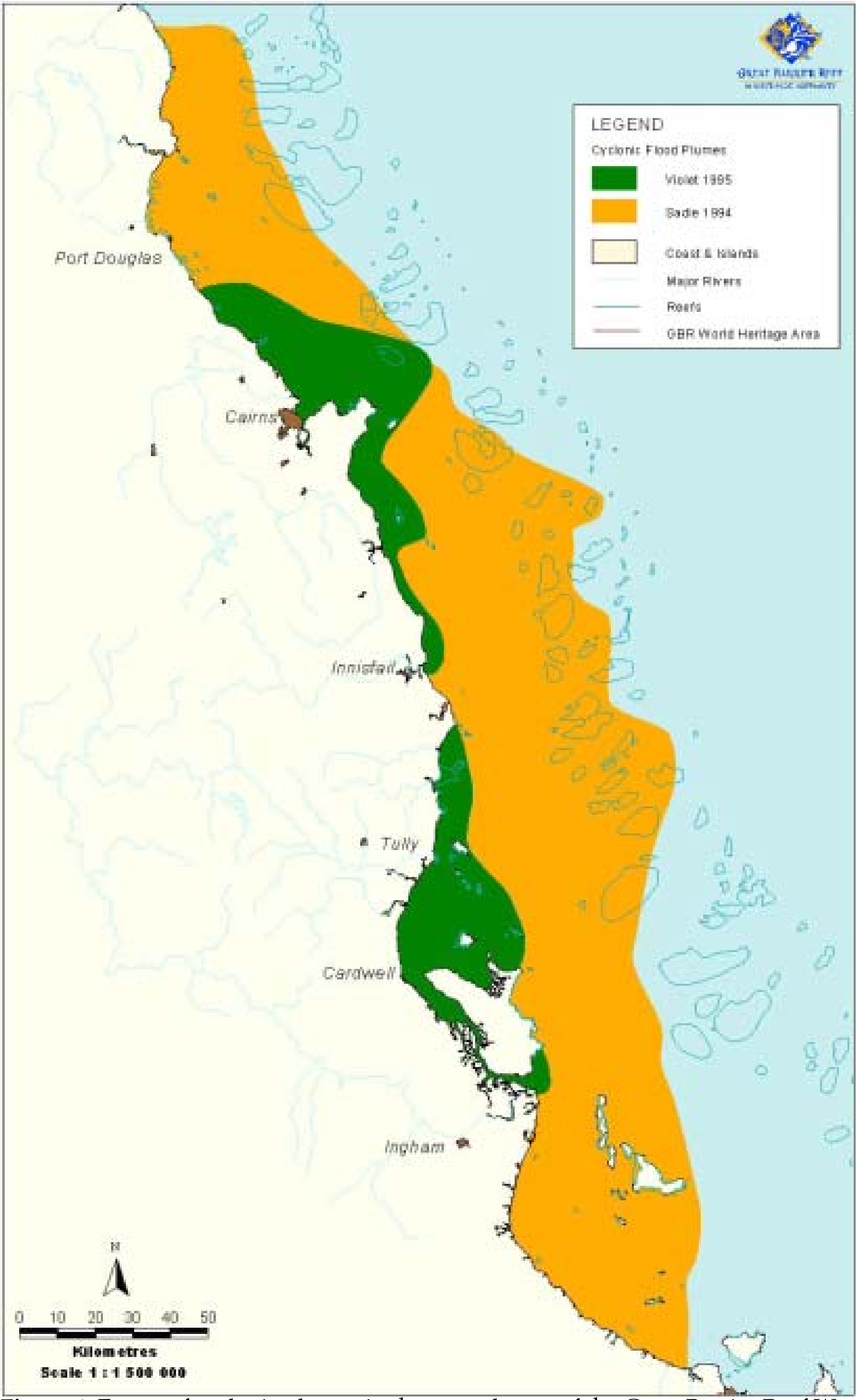

Figure 4. Extent of cyclonic plumes in the coastal zone of the Great Barrier Reef World Heritage Area

2.2.3 Cyclonic Flood Plumes

The buoyancy of low salinity water and geostrophic forces are major factors controlling the movement of flood waters on the GBR shelf (Wolanski & Jones 1981; Wolanski 1994; Wolanski & King 1997), but wind-forcing of surface water may be an important factor during moderate and strong winds (Brodie & Furnas 1996). As a result the direct effects on GBR ecosystems are primarily concentrated close to the coast. For example, the flood plume following cyclone Violet was restricted to a shallow, nearshore band by strong south-east tradewinds whereas in the relatively calm conditions following cyclone Sadie, the flood plume extended seaward over much of the continental shelf (Figure 4).

The annual discharge from the Burdekin and Fitzroy Rivers varies considerably from year to year. Major flood events are separated by drier periods, often of many years, with little river flow. During major floods, high discharge rates persist for several weeks. Flood plumes extend for several hundreds of kilometres away from the river mouth (Wolanski & Van Senden 1983; O'Neill et al. 1992) and low salinity water masses can be identified for several weeks along the coast.

In the major flood events of 1979–80 and 1980–81 in the Burdekin and northern rivers, low salinity waters were tracked along the central GBR shelf between the Burdekin River mouth and Cairns, 350 km to the north, and as much as 40 km away from the coast (Wolanski & Jones 1981; Wolanski & Van Senden 1983). Mostly, however, the low salinity flood waters remained close to the coast, well away from outer shelf reefs. High suspended sediment loads were restricted to the coast, with most fine particulate matter settling out of the water column at salinities < 10 ppt, near the river mouth (Wolanski & Jones 1981).

Most of the sediment transported by river systems is deposited within 10 km of the coast. In particular, the northward facing embayments, trap large amounts of sediment (Johnson et al. 1997; Woolfe & Larcombe 1998). Isotopic and geochemical markers indicate that the bulk of terrestrial organic matter discharged from rivers is deposited in coastal sediments (Gagan et al. 1987; Risk et al. 1994; Currie & Johns 1989; Pailles et al. 1993; Walker & Brunskill 1997a, b). Only small amounts of terrestrial sediments appear to reach the outer shelf reefs, primarily during major cyclonic floods when river plumes can cover extensive areas of the shelf (Brodie & Furnas 1996; Devlin et al. 2002), and mid- and outer-shelf reef sediments contain very low proportions of siliceous, terrestrially derived sediments (Okubo & Woolfe 1995).

Early observations of the presence of flood plumes in the GBR lagoon around Low Isles in 1929 were made by Orr (1933) who noted that the adjacent Daintree River was in flood. Widespread loss of coral cover associated with the major floods of 1918 (the 'Mackay' cyclone) in the Whitsundays area was reported by Rainford (1925) and Hedley (1925).

2.2.4 Other Sources - Water Dynamics and Sediment Resuspension

The volume of the GBR lagoon, from the coast to the 100 metre isobath on the edge of the continental shelf, is approximately 8000 km^3. Water in the GBR lagoon typically has a salinity of 34 to 36 ppt (Furnas & Brodie 1996; Andrews 1983), except during monsoonal rainfall periods when salinity close to the coast may range from 28 to 33 ppt for long periods, and in major river plumes when salinity may range from 2 to 30 ppt (Brodie & Furnas 1996; Devlin et al. 2001).
Water circulation within the GBR lagoon is largely driven by tides and the dominant south east tradewinds (Wolanski 1994). Exchanges of water between the GBR lagoon and the Coral Sea occur through tidal exchange and episodic upwelling of Coral Sea water along the edge of the continental shelf (Furnas & Mitchell 1997; Wolanski 1994). Vertical mixing induced by wave action, currents and the reef matrix keep the water

column well mixed. The general water flow on the outer GBR, south of 16°S, is to the south. Inshore, where the effects of the south-east trade winds predominate, average water flow is to the north (Wolanski & King 1997). Generally, a significant barrier exists between mixing of inshore and offshore GBR waters due to the current regimes (King 1995). This hinders the movement of materials, including contaminants, from inshore to the mid-shelf area and from the Coral Sea to the inshore reefs. Flushing of the GBR lagoon is limited by the enclosure formed by the main reef. Residence times of water in the inner lagoon, while not precisely known, may be prolonged (Wolanski 1994). Suspended solids, and potentially nutrients and other contaminants may remain in the inner lagoon, that is to the 20 metre isobath, for periods of weeks to months due to recycling and resuspension processes (Wolanski 1994; Furnas et al. 1995).

It is assumed that suspended particles carried by terrestrial runoff are not transported beyond the inner lagoon (Currie & John 1989; Larcombe & Woolfe 1999). Suspended solids stay in the inner lagoon for prolonged periods due to wind-driven resuspension in the shallow waters of the inner shelf (Wolanski 1994; Larcombe et al. 1995). Suspended sediment concentrations of up to 50 mg/l in the upper water column and 200 mg/l near the bottom are common in areas such as Cleveland and Halifax Bays under windy conditions (Larcombe et al. 1995). Additional particles that are rich in organic material are formed during mixing processes in estuaries by aggregation and microbial colonisation of fine particles (Ayukai & Wolanski 1997; Wolanski et al. 1997), and by planktonic biomass. During resuspension, significant amounts of nutrients are released from the sediments and the sediment porewater (Ullman & Sandstrom 1987; Chongprasith 1992). Nutrient release from suspended sediments during storm events stimulates phytoplankton growth during subsequent days (Walker & O'Donnell 1981) when chlorophyll *a* concentrations may reach 1.5 μg/l compared to background concentrations of 0.4 μg/l. The concentration of phytoplankton, measured as chlorophyll *a* concentration, is used as an integrative parameter to monitor nutrient concentrations in the GBRWHA (Brodie et al. 1997; Steven et al. 1998). In cyclonic wind conditions large masses of sediment are resuspended and moved (Gagan et al. 1987; Gagan et al. 1990). After a cyclone, the nutrients released by resuspension stimulated a phytoplankton bloom in southern GBR shelf waters with chlorophyll *a* concentrations reaching 18 μg/l (Furnas 1989).

Sediment resuspension and the coastal northward current flow are the principal mechanism for the northward and shoreward transport of sediments along the GBR (Orpin & Ridd 1996). These mechanisms concentrate materials, such as suspended solids, nutrients, and associated contaminants in the inner lagoon.

During low flow conditions, either during the dry season or caused by flow restriction from dams, weirs, etc., very little material is transported out of the rivers. This may occasionally lead to pollutant concentration problems in sheltered bays and inlets, which are not flushed out. Generally, however, the discharge into the sea is event driven and largely dependent on large flood events during the summer (Bramley & Johnson 1996; Mitchell et al. 1997).

2.3 Constituents of Terrestrial Runoff

The main constituents of concern in terrestrial runoff include nutrients and sediment, heavy metals and other contaminants, freshwater, and highly acidic water and litter.

2.3.1 Nutrients and Sediment

The GBR is characterised by low nutrient concentrations so GBR ecosystems naturally derive most of their nutrient supply from internal recycling processes (Furnas et al. 1995). 'New' nutrients are introduced into the GBR lagoon by river discharge and point sources (section 2.2). Rain, upwelling of the Coral Sea and nitrogen fixation by cyanobacteria are natural sources of 'new' nutrients (Furnas et al. 1995).

In the central GBR it is estimated that terrestrial runoff of nutrients provides approximately 41% of the 'new' nitrogen (N) and 60% of the 'new' phosphorus (P) inputs to shelf waters from external sources (Figure 3, Furnas et al. 1995). These terrestrial nutrient inputs enter the shallow coastal areas of the GBR lagoon that comprise only a small percentage (< 10%) of the total GBR shelf area and water volume. Consequently, any changes in water quality caused by terrestrial activities will be most apparent in the coastal areas of the GBR lagoon.

The findings of several nutrient (N and P) monitoring programs in the GBR region over the past 20 years provide a good overview of the ambient nutrient concentrations in the GBR lagoon (Bellamy et al. 1982; Furnas & Mitchell 1984a, b; Furnas et al. 1988, 1990, 1995). Minimum concentrations of almost all measured nutrient species are observed in the Far Northern Section of the GBRMP. This Section is adjacent to the north-east Cape York catchment, an area predominantly used for cattle grazing at low-stocking rates that remains relatively undisturbed (DPI 1993a). Elevated concentrations of a number of nutrient species are found in the Torres Strait, the Cairns Section and the Central Section of the GBRMP.

The water quality of the shelf area adjacent to Cairns and Innisfail (Cairns Section) has been studied intensively and local cross-shelf gradients in nutrient concentrations are evident (Furnas et al. 1995; Furnas & Brodie 1996; Furnas & Mitchell 1997). In general the data indicate that in the absence of local river runoff, the very low dissolved nutrient conditions which prevail in mid-shelf and lagoonal waters of the GBR are also characteristic of shallow nearshore waters. However, particulate nutrient concentrations are consistently higher inshore (Furnas et al. 1995, 1997); particulate nitrogen (N) and particulate phosphorus (P) are approximately 30–50% and 70% higher respectively (Furnas et al. 1997).

Dissolved nutrient concentrations from inshore waters, in the absence of local river runoff, range from non-detectable to 2 μM for dissolved inorganic nitrogen (DIN) and from non-detectable to 0.2 μM for phosphate (Furnas et al. 1995; Furnas & Brodie 1996; Devlin et al. 1997; Schaffelke et al. in press).

Sediment and nutrient runoff from the coastal catchments of Queensland have been estimated using existing data and catchment models (Moss et al. 1992; Neil & Yu 1996; Rayment & Neil 1997). The most current and sophisticated modelling effort has been completed within the National Land and Water Resource Audit (NLWRA) by CSIRO Land & Water (NLWRA, unpub. Data; methodology in Prosser et al. 2001). According to these latest estimates 12 million tonnes of sediment, 47 thousand tonnes of nitrogen and 10 thousand tonnes of phosphorus are exported to the inner GBR lagoon via river discharge annually. Even though there are large differences between the catchment models employed (Wasson 1997) all estimates indicate an increase in terrestrial nutrient and sediment delivery to the GBR of at least four-fold since European settlement. A river monitoring program, presently being conducted by the Australian Institute of Marine Science (M. Furnas, AIMS, pers. comm.) will supply data for improved ground-truthing of the nutrient export estimates.

Cattle grazing is the largest contributor of nutrients and sediments to terrestrial runoff (Figure 5). Even when there is minimal runoff from grazing lands they lose significant amounts of sediment and associated nutrients in comparison with natural or plantation forests and woodlands. Average soil erosion rates for Queensland grazing lands range from 0 to 4 t ha^{-1} yr^{-1} (Elliott et al. 1996). The principal cause for nutrient losses is the clearing of vegetation and overgrazing, which in turn leads to the loss of nutrients naturally present in the soil (Prove & Hicks 1991). This is significant as extensive removal of grass and vegetation cover occurs in grazing lands particularly during extended drought periods.

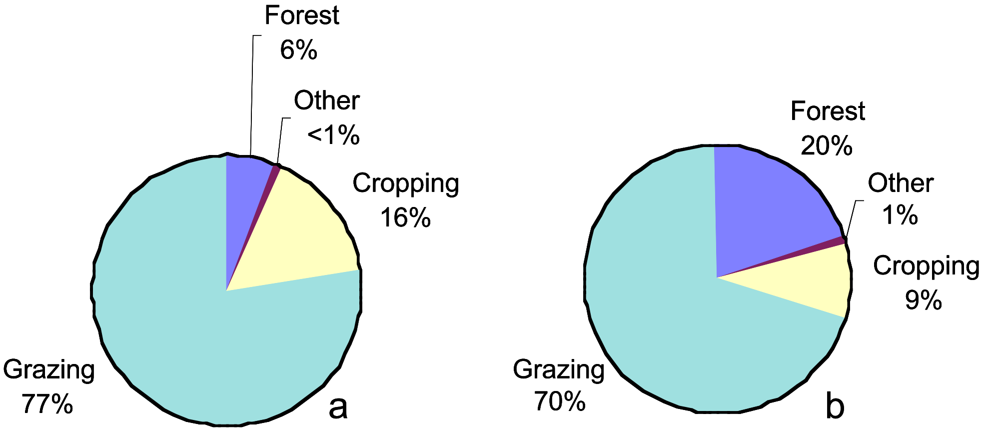

Figure 5. Contribution of different land uses to a) nutrients and b) sediments in terrestrial runoff. *(Sources: a) Moss et al. 1992, b) NLWRA and CSIRO Land & Water, unpub. Data; methodology in Prosser et al. 2001).*

Soil losses as high as 500 t ha^{-1} yr^{-1} have been reported from sugarcane cropping areas (Prove et al. 1995). With the adoption of modern land-management practices, such as trash blanketing and soil conservation plans, this rate has been lowered to about 14 t ha^{-1} yr^{-1} in recent years (Rayment & Neil 1997). However, the amount of land used for sugarcane cultivation in lowland areas continues to expand, primarily into marginal lands, such as wetlands (Zann et al. 1996) and as a result higher rates of downstream soil transport may be expected. The nutrients in runoff from cropping lands are a combination of natural soil nutrients and nutrients added to the soil in fertilisers. Sugarcane cropping utilises the highest proportion of fertiliser in Queensland (Pulsford 1996). Large increases in the use of fertilisers in the last 30 years have occurred in the coastal catchments (Pulsford 1996) and a high proportion (50–70%) of the applied fertiliser is lost to the off-farm environment (Moody et al. 1996; Rayment et al. 1996; Mitchell et al. 2001). Rayment and Neil (1997) compared actual and recommended fertiliser application rates in sugarcane cropping and concluded that more phosphorus fertiliser but, in most cases, less nitrogen fertiliser than recommended is applied. At regional scales, nitrogen losses from fertilised sugarcane growing sub-catchments are detectable in river systems during major flood events (Mitchell et al. 1997; Hunter 1997). Long term sampling of nutrients in the Tully River has shown a near doubling of levels of particulate nitrogen and phosphorus and a small increase in nitrate at a downstream site over the last thirteen years (Mitchell et al. 2001).

2.3.2 Heavy Metals

Heavy metals are naturally found in rocks and soils and can be applied to crops as either essential micronutrients in fertiliser (copper, zinc, iron) or as contaminants in fertilisers (cadmium, lead, mercury). The mean concentrations of the heavy metals arsenic, cadmium, cobalt, copper, chromium, lead, nickel and zinc, were found by Rayment and Neil (1997) to be higher in sugarcane cropping soils than in similar soil types nearby that are without sugarcane.

The major processes for transportation of heavy metals are soil erosion or sediment mobilisation as most heavy metals are bound to soil particles. Agriculture, mining, metal processing, and other industrial processes have the potential to release elevated levels of the toxic heavy metals (primarily arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc), via these processes, into the GBR lagoon. Also of concern is the mobilisation of heavy metals by acid leaching from oxidised acid sulfate soils (ASS) (section 2.3.5). Atmospheric transport of dust is also a possible pathway for heavy metals to be transported to the GBR lagoon (Rayment 1995).

Evidence for elevated metal levels from past mining activity has been found off the Burdekin River in Bowling Green Bay (Walker & Brunskill 1997a, b). Significantly elevated mercury levels (up to 20 μg/kg) were found in sediment cores and this has been linked to the use of mercury in gold recovery during the peak (1870–1890) of gold mining in Charters Towers, a small town approximately 100 kilometres inland on the Burdekin River. Sediment cores taken in the Hinchinbrook Channel and Missionary Bay show close correlation between elevated mercury levels in marine sediments, and the application of Shirtan mercury as a fungicide on cane land in the Herbert River from 1950 to 1996 (Brunskill et al. unpub. data). Accumulated concentrations of mercury in these soils have almost doubled since 1950. In harbour and port areas, such as those of Townsville and Gladstone, very high concentrations of metals are often found in sediments (Jones & Thomas 1988). This is usually attributed to ore spillage, stormwater runoff and ship building and repair.

Once in the water column, heavy metals may be bioaccumulated by marine organisms (Chester & Murphy 1990; Rainbow 1990). Elevated heavy metal concentrations, particularly of cadmium, have been found in dugong tissues (especially liver and kidney) from the GBR (Denton et al. 1980; Gladstone 1996) and in crustaceans (prawns, crayfish and spanner crabs) from Torres Strait (Evans-Illidge 1997). These are, however, believed to be naturally high and not associated with contamination sources.

2.3.3 Other Contaminants

Organochlorines are carbon-based chemicals compounds containing chlorine. Many of these compounds are artificial and have a wide range of industrial and agricultural applications. They include pesticides and herbicides such as DDT, lindane, diuron and 2,4-D and polychlorinated biphenyls (PCBs). Organochlorine pesticides were widely used in Australia until the use of many were banned in the late 1980s. The main organochlorine pesticide still in use today is the insecticide endosulfan. Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) form as unwanted by-products of processes such as waste incineration, coal burning, metal smelting, car exhausts, pulp and paper manufacture and sugarcane and trash burning (Anon. 1989; Müller et al. 1996a, b). They also occur as contaminants in a range of herbicides and in polychlorinated benzene (PCB) compounds (Safe & Hutzinger 1989).

Organochlorines enter the aquatic environment through terrestrial runoff, urban stormwater runoff, and as aerosols (Clendening et al. 1990). Once in the water column, organochlorines adsorb to fine particulates or are bioaccumulated into lipids in aquatic biota (Olsen et al. 1982). The bioaccumulation of organochlorine pesticides and PCBs has been linked to reproductive and immunological abnormalities in terrestrial bird populations and in marine mammal populations (Boon et al. 1992). Many of these compounds are also assumed to be carcinogens (Richardson 1995). Herbicides have the potential to adversely impact seagrasses (section 3.2). Measurable quantities of the herbicide diuron and of other pesticides have been detected in sediments and seagrass at a number of locations along the GBRWHA coast and in Moreton Bay (Haynes et al. 1999). Pesticide residues were also detected in estuarine sediments and biota along the Queensland coast (Mortimer 2000) and in surface water of streams in the Johnstone River catchment (Hunter et al. 1996). Cavanagh et al. (1999), however, did not detect pesticide residues in coastal sediments in Bowling Green Bay or around Hinchinbrook Island.

High levels of octa-chloro-*p*-dioxin (OCDD) were detected in intertidal and/or estuarine sediments along the Queensland coast between Brisbane and Cardwell although the source of the dioxin has not yet been clearly identified (Müller et al.

1999). The Queensland OCDD levels were higher than levels in areas that are regarded as polluted such as waterways close to urban areas in Europe and the United States.

Polycyclic aromatic hydrocarbons (PAHs) are derived from petroleum products. They are known carcinogens and mutagens (Clark 1992; Benlahcen et al. 1997) that are easily bioaccumulated in some aquatic organisms (Connell 1995) and have been implicated in a wide range of human health effects as well as disease problems in aquatic organisms (Grimmer 1983; Plesha et al. 1988).

2.3.4 Freshwater

In Queensland catchments, as in many catchments overseas, the area of land covered with vegetation has been reduced and replaced by consolidated surfaces in urban areas, roads, and drainage schemes that result in higher volumes of water runoff. Conversely, the presence of dams on many GBR rivers may moderate flows and an estimated 13% (8 km^3) of the average annual discharge from the GBR Catchment is potentially captured in existing reservoirs (Gilbert et al. in press). The implications of changes in mean freshwater flow and the impacts of river regulation on estuarine and marine habitats are largely unknown (Robertson et al. 1996), however, low salinity events from cyclonic rainfall floods have caused coral reef bleaching and mortality in the GBRWHA (e.g. Berkelmans & Oliver 1999; Hoegh-Guldberg 1999).

2.3.5 Acid Sulfate Soils

Acid sulfate soils (ASS) is the common name for soils that contain iron sulphides. ASS are potentially widespread in coastal Queensland especially below 5 AHD; an estimated 2.3 million hectares of coastal lands contain actual or potential ASS (Powell & Ahern 1999). These soils occur naturally in water-logged soils in low-lying coastal areas and are harmless when they remain below the water table. When ASS become exposed to air, by disturbance or drainage, the iron sulphides are oxidised and produce sulphuric acid (White et al. 1996). Acid leaching leads to severe acidification of adjacent waterways (pH as low as 2) as well as the mobilisation of toxic heavy metals (iron and aluminium) naturally present in the soil. The impact on coastal biota and habitats is severe, including fish kills and fish diseases (Sammut & Lines-Kelly 1997).

The more recent identification of the toxic cyanobacterium *Lyngbya majuscula* (forming extensive benthic mats) as the cause of dermatitis in fisherman around northern Deception Bay in south-east Queensland has raised further concerns about the effects of ASS runoff (Dennison et al. 1999a). Blooms of *Lyngbya majuscula* in Queensland coastal waters are triggered by dissolved iron runoff from acid sulfate soils and the leaching of 'coffee rock', an organic iron-rich geological deposit formed in vegetated sandy soils (Dennison et al. 1999b) and can cause severe damage to seagrass beds. In addition to the contact dermatitis, *Lyngbya* has been linked to breathing irritation and eye inflammation. Further investigation is required into the occurrence of these blooms in the GBRWHA.

2.3.6 Litter

Stormwater discharge, particularly from urban areas, carries quantities of litter into the GBR. Surveys of litter on GBR islands have shown that much of the material is ship-sourced however a significant proportion may come from terrestrial sources (Haynes 1997). As well as aesthetic concerns, litter may be implicated in the entanglement of marine animals such as turtles (Carr 1987), birds (Laist 1987), mammals (Beck & Barros 1991) and fish (Laist 1987).

3. POTENTIAL IMPACTS OF DEGRADED WATER QUALITY ON DUGONG

3.1 Potential Direct Impacts of Water Quality on Dugong Health

There are several potential direct effects of terrestrial runoff on dugong health. Contaminants can cause several symptoms in marine mammals that are reported by Boon et al. (1992) and Garcia Hartmann (1997) to include:

- hormonal effects caused by a range of contaminants known to act as endocrine disruptors, in particular organochlorines, pesticides, and tri-butyl-tin;
- reproductive disorders such as reduced reproductive rate and success, especially caused by PCBs and DDT;
- tumor development such as development of benign and malignant tumors, probably caused by a range of contaminants;
- development of adrenal hyperplasia and cysts related to organochlorines and to stress; and
- immune deficiency related to PCBs and increased stress levels.

Other symptoms reported include reproductive and immunological dysfunction, due to accumulation of pesticides and herbicides (Kuiken et al. 1994; Johnston et al. 1996), and chemical inactivation of cellular enzymes (Förstner 1989) that interfere with growth, reproduction and behaviour (Langston 1990) due to elevated levels of heavy metals.

Three dugong carcasses from animals that were suspected to have drowned in fishing nets at Magnetic Island, Bowen and Mackay were sampled in 1996. The samples collected were analysed for several contaminants and elevated levels of arsenic, chromium and nickel were found (D. Haynes, GBRMPA, pers. comm.). The levels of total dioxins, in particular OCDD, in these dugongs were high, compared to other marine mammals from temperate regions (Haynes et al. 1999). To date, the source of these dioxins is unknown and is the subject of current research (Müller et al. 1999). There is no information on the implications of elevated contaminant levels for dugong health however due to the presence of measurable quantities of contaminants in coastal sediments the potential risk of these contaminants to the health of dugongs and other marine organisms inhabiting the GBRWHA cannot be excluded.

Detailed pathological examinations of stranded or recovered dugong carcasses from the GBRWHA have been conducted (P. Corkeron, JCU, pers. comm.), but results are not available from these examinations. Hence, the incidence of pollutant-related disorders or deaths of GBRWHA dugongs is currently not known.

3.2 Potential Impacts of Terrestrial Runoff on Dugong Habitats

The temporal and spatial effects of terrestrial runoff on GBR ecosystems are difficult to determine and define, and consequently problematic when it comes to mitigating their impact on DPAs. Three significant problems are:

- the frequent natural disturbance of GBRWHA coastal ecosystems by cyclones and floods;
- the short duration of accurate water quality and ecosystem monitoring data (approximately 15 years of data); and
- the lack of unambiguous pristine controls for comparison, because many of the major changes in land use occurred before monitoring of coastal and reefal ecosystems was initiated.

The close proximity of seagrass meadows to the coast means that they are likely to be affected by material originating from land and are vulnerable to changes in coastal processes. Seagrass decline, which is a global problem, has been linked to anthropogenic activities in coastal areas (Sheperd et al. 1989; Walker & McComb 1992; Dennison et al. 1993; Short et al. 1996). Seagrass and corals along the GBR coast have recruited, grown and evolved in the presence of natural freshwater, terrestrial nutrient and sediment inputs. Coral reefs are found in similar coastal areas as seagrass meadows and have been found to be damaged and even killed by extended periods of freshwater inundation (e.g. Van Woesik 1991; Jokiel et al. 1993). Over longer periods, high sediment and nutrient loads are also known to smother or otherwise affect coastal reefs (e.g. Smith et al. 1981; Rogers 1990). Short and Wyllie-Echeverria (1996) suggest that human activities are now the most serious cause of seagrass habitat loss. These include nutrient and sediment loading from agricultural runoff and sewage disposal, dredging and filling, urban stormwater, and land development. Seagrasses are also at risk of physical damage caused by human activities, such as trawling, certain fishing practices and anchor damage (Clarke & Kirkman 1989).

The distribution and growth of seagrasses is dependent on a variety of factors such as temperature, salinity, nutrient availability, substratum characteristics, and underwater light availability (turbidity). The causes for the extensive mortality of seagrass after flood events in the GBRWHA and in Hervey Bay have not been clearly established, but it is most likely that the causes were a combination of low salinity, sedimentation, turbidity and nutrient stress (Pringle 1989; Preen et al. 1995). Reduced light availability is the most significant cause for the decline of seagrass meadows and for the decrease in seagrass depth distribution and is caused by either increased concentrations of phytoplankton, (as a result of more nutrients being available), or by increased loads of suspended solids (Abal & Dennison 1996; Dennison 1987; Dennison & Kirkman 1996; Duarte 1991).

3.2.1 Increased Nutrients

Approximate ranges for (non-flood) inshore water nutrient concentrations have been measured between non-detectable and 2 μM for dissolved inorganic nitrogen (predominantly ammonia) and non-detectable and 0.2 μM for phosphate (Furnas et al. 1995; Furnas & Brodie 1996; Devlin et al. 1997; Schaffelke et al. in press). Inshore seagrass systems are episodically subjected to high dissolved nutrient and suspended loads, more typical of a eutrophic system, during monsoonal flood conditions. Water samples taken in flood plumes have consistently recorded elevated dissolved inorganic nitrogen concentrations of 0.6 to 10 μM and phosphate levels of 0.13 to 1.98 μM (Brodie & Mitchell 1992; Steven et al. 1996; Brodie & Furnas 1996; Devlin et al. 2001). These nutrient levels have remained high in the inshore lagoon for periods of several days to weeks.

Direct effects of higher nutrient availability on seagrass have been observed. Moderate levels of nitrate additions (3.5 to 7.0 μM) promoted the decline of the temperate seagrass species *Zostera marina* (Burkholder et al. 1992; Short et al. 1995). Increased levels of ammonia (1.85–5.41 μM) and phosphate (0.22–0.50 μM) lead to a reduction in shoot density and biomass of *Z. marina* (Short et al. 1995). Research into nutrient effects on GBR seagrasses is currently underway (J. Mellors, DPI, pers. comm.).

There is increasing evidence from temperate waters that anthropogenic nutrient enrichment of coastal areas stimulates higher abundance of seagrass epiphytes (Borum 1985; Cambridge et al. 1986; Williams & Ruckelshaus 1993; Short et al. 1995). Epiphytes are important components in the seagrass ecosystem, however, high epiphytic biomass reduces the light availability to seagrass, inhibits the gas exchange, competes for nutrients and imparts physical drag that may lead to seagrass leaves and shoots being torn off (Borowitzka & Lethbridge 1989). In sheltered environments, epiphytic macroalgae respond quickly to water-column enrichment and may outgrow grazing pressure, leading to a decline of the underlying seagrass (Sand-Jensen 1977; Harlin & Thorne-Miller 1981; Orth & Moore 1983; Burkholder et al. 1992).

Increased nutrients can also enhance the growth of fleshy macroalgae, which coexist with seagrass in shallow tropical ecosystems. This effect has been demonstrated in

Kaneohe Bay, Hawaii (Smith et al. 1981) and, perhaps less dramatically, at other sites (e.g. Grigg 1994; Grigg & Dollar 1990; Tomascik & Sanders 1985, 1987a, b). In the GBR lagoon this has occurred as a result of pulses of dissolved inorganic nutrients, such as those experienced during cyclonic floods (Schaffelke & Klumpp 1998; Schaffelke 1999). This indicates that certain species of macroalgae in the GBR benefit from increased nutrients and may have a competitive advantage over seagrasses.

Higher nutrient availability in a seagrass system may also enhance phytoplankton growth that also decreases the light availability to seagrass (Lin et al. 1996). Nitrogen and phosphorus are often limiting nutrients for the growth of phytoplankton, especially in warm, clear tropical waters where light is unlikely to be limiting. Evidence of eutrophication in the GBR phytoplankton record is unclear. Comparing present chlorophyll *a* data with historic data, Bell (1991, 1992), and Bell & Elmetri (1995) concluded that the inner GBR lagoon is becoming eutrophic. This argument has been abated by the long-term data of Brodie et al. (1997) which show very high temporal variability in chlorophyll *a* data. However, higher chlorophyll *a* concentrations in coastal waters compared to waters further offshore (Brodie et al. 1997) indicates that more nutrients are available in coastal waters.

3.2.2 Increased Sedimentation

Seagrasses are susceptible to sedimentation damage, suffering from both the lack of light caused by more turbid water and direct smothering from deposited mud (Hatcher et al. 1989; Robertson & Lee Long 1991). In recent times large areas of seagrass meadow have been lost during flood events that discharged terrigenous sediment into the inner lagoon. Over 1000 km^2 of seagrass meadows were lost in Hervey Bay in February 1992, following two large floods of the Mary and Burrum rivers (Preen 1993b; Preen et al. 1995). As a result, the population of dugongs in the area, dependent on the seagrass for food, decreased from an estimated 1466 animals in 1988 to 92 in November 1992. In particular a decrease in the numbers of dugong calves was observed (Marsh & Corkeron 1997). A similar loss of seagrass appears to have occurred around Townsville in the early 1970s (Pringle 1989), possibly associated with cyclone Althea (1971), but this was not fully studied at the time and the sequence of events is not as clear as in the Hervey Bay case.

A large scale decline of Moreton Bay seagrass meadows that occurred during the 1970s was also attributed to increased sedimentation (Kirkman 1978). Fungi was found in all seagrass samples sampled from Moreton Bay at this time, however, it was suggested that this was a natural phenomenon. In other parts of the world, fungi and slime moulds have been significant factors in the decline of seagrass meadows. The catastrophic breakdown of North Atlantic eelgrass meadows in the 1930s has been attributed to the 'wasting disease' caused by the pathogenic slime mould *Labyrinthula zosterae*. Recent studies showed that most seagrass species have their specific *Labyrinthula* species (Vergeer & Den Hartog 1994). Den Hartog (1996) suggests that *Labyrinthula* is omnipresent in senescent seagrass leaves of otherwise healthy plants and that disease outbreaks are rather triggered by environmental factors such as high temperatures and low light, which may be caused by human activities.

3.2.3 Contaminants

Impacts on nearshore environments by contaminants is an additional stressor for seagrass meadows (Walker & McComb 1992; Ralph 1999, 2000). However, the significance and the potential impacts of contaminants in seagrass meadows in Queensland waters is largely unknown. The herbicides atrazine and diuron are used extensively by the sugar industry in Queensland (Hamilton & Haydon 1996). Preliminary investigations of the toxicity of atrazine and diuron to *Halophila ovalis*, which is the preferred food source of dugongs, indicated that short-term herbicide exposure resulted in reduced photosynthesis and leaf loss (Ralph 2000).

In recent studies, marine sediment samples were collected from 51 subtidal locations between Torres Strait and Gladstone in 1998 and 1999 and analysed for a range of herbicides. All sampling sites were located in shallow water in major estuaries and northward facing bays along the northern and central Queensland coast. The herbicide diuron was detected at all sampling sites between Townsville and Cairns (Haynes et al. 2000a) and in Repulse Bay, Whitsundays, and at the mouth of the Fitzroy River. Highest concentrations of diuron were detected adjacent to the mouths of the Herbert and Johnstone Rivers.

Subsequent diuron toxicty trials on three tropical seagrass species (*Halophila ovalis*, *Cymodocea serrulata* and *Zostera capricorni*) using Pulse-Amplitude-Modulated (PAM) fluorometry indicated that environmentally relevant levels of diuron (0.1-1.0 μg/l) exhibited some degree of toxicity to one or more of the tested seagrass species (Haynes et al. 2000b). Seagrasses are known to accumulate heavy metals, but appear to be moderately resistant to the direct effects of metals. However, the fauna associated with seagrass meadows is considered to be at great risk (Ward 1989).

3.2.4 Other Considerations

Recovery and recolonisation of seagrass meadows can be very slow, or nonexistent, because of chronic environmental pressures and poor dispersal capabilities of most seagrass species (Preen et al. 1995; Dennison & Kirkman 1996). It was 10 years after the seagrass meadows in Cockle Bay, Magnetic Island, were destroyed by a cyclone, before the pioneer genus *Halophila* reached a steady state and was then slowly replaced by a presumed climax community of *Halodule* species (Birch & Birch 1984).

The chronic decline of seagrasses may lead to an ecosystem shift from seagrass meadows to a lagoonal system with high turbidity and abundant growth of filamentous algae or with bare, silty substratum (Cambridge & McComb 1984).

3.3 Other Pressures to Water Quality and Dugong Habitat Quality

Although terrestrial runoff is considered to be the most significant impact on water quality and dugong habitat quality in the GBR, other activities such as shipping, oil spills and trawling may influence dugong populations.

3.3.1 Shipping

A number of significant ports line the GBR coast. Access channels to many of these ports need to be regularly maintained by dredging, which leads to problems caused by increased concentrations of suspended solids and nutrients released from dredged material. Other impacts associated with ports and shipping activities result from increased levels of petroleum hydrocarbons and anti-fouling residues in coastal waters and significant amount of ship-borne litter.

3.3.2 Oil Spills

Oil spills represent a significant threat to the viability of GBR environments. Prediction of the effects of an oil spill is difficult, because of a wide range of potential impacts depending on the specific conditions under which the spill occurred (Commonwealth Department of Transport 1995). For the purposes of impacts upon DPAs, the following effects need to be considered:

- direct impacts upon the animals and key habitats within the DPA;
- effects of response actions, e.g. use of dispersants; and
- chronic pollution from oil trapped in mangrove and saltmarsh communities.

Marine mammals, apart from sea otters, have not been demonstrated to be vulnerable to large oil spills. This may be a result of an ability of these animals to avoid oil, or just because no large spills have occurred under conditions that might cause significant impacts.

Direct impacts on critical habitats for dugong may be of greater concern, particularly on intertidal seagrasses. Areas of most concern are the mid-upper intertidal zone where oil will settle. On shorelines and bays with gentle slopes, more extensive effects may occur. Deeper water habitats may be impacted through direct response actions such as the use of dispersants. The GBRMPA's policy on dispersant use clearly states that dispersants may be used in waters over seagrasses to protect mangrove habitats downstream. Other response actions such as shoreline washing where oil is washed off the shore into the water may also cause similar impacts should the oil mix into the water column.

In general research has indicated that seagrass communities recover well from single oiling events, but that chronic contamination may have a greater effect on the long-term viability of the seagrass community. Many of the DPAs are fringed by mangrove systems, which are significant traps for oil that can remain there for many years. Seepage of this oil into the marine environment represents a chronic source of contamination (Commonwealth Department of Transport 1995).

3.3.3 Trawling

Seagrasses are susceptible to damage from trawling activities in the GBR. Although seagrasses are listed as protected marine plants in section 51 of the *Queensland Fisheries Act 1994*, they are often disturbed or removed by trawl fisheries. Most seagrasses in shallow, coastal bays and inlets are in water too shallow for trawlers to operate, and damage to these meadows should be minimal under the fisheries management policy of strip closures (Lee Long & Coles 1997a, b). Dense meadows in deeper water (> 10 m) are usually avoided by trawlers, however, sparse meadows are more at risk. Many of these areas are dugong feeding habitats (Lee Long et al. 1989), but receive no special protection from trawling.

4. CONDITION OF CATCHMENTS ADJACENT TO DUGONG PROTECTION AREAS

The condition of the river catchments adjacent to each DPA, their hydrology and present catchment activities, effectively determine the water and habitat quality that exists in the adjacent DPAs. The condition of the catchments adjacent to each DPA is discussed below. Specific information regarding each of the DPA catchments is provided in Appendix 1, namely:

- Land use and terrestrial runoff statistics (Table A1);
- Fertiliser and pesticide application rates (Table A2);
- Sediment and nutrient export (Table A3);
- Catchment fertiliser use in the past 100 years (Figures A1 to A6).

4.1 Hinchinbrook and Taylors Beach DPAs

The most northern DPAs, Hinchinbrook and Taylors Beach DPAs, are adjacent to each other (Figure 6). They are located around and to the south of Hinchinbrook Island, approximately half way between Cairns and Townsville. The islands included in the Hinchinbrook Region DPA, i.e. Hinchinbrook, Goold and Brook Islands, are predominantly undeveloped except for a small resort at the northern end of Hinchinbrook Island. Small urban centres close to the DPAs include Ingham, Cardwell, Taylors Beach and Lucinda. An integrated residential and resort complex is currently under construction on the adjacent mainland at Oyster Point, south of Cardwell, and a 200 berth marina has been completed. A 50 berth marina is proposed at Dungeoness in the Enterprise Channel which flows into the southern end of the Hinchinbrook Channel, and Lucinda has a major port facility for the export of raw sugar.

The Herbert River catchment drains the hinterland of the Hinchinbrook and Taylors Beach DPAs. The Herbert River flows from the Atherton Tablelands into the floodplains of the lower Herbert River catchment, past Ingham, and then enters the sea at the border of the two DPAs, just north of Lucinda. The Herbert River has both wet and dry catchment areas, which result in a high year-to-year variability in rainfall and associated river discharge (Mitchell & Furnas 1997). Cattle Creek, which drains the floodplain adjacent to the coast of the Taylors Beach DPA and enters the sea just south of it, is an important local watercourse. The coastal area in which the two DPAs are located is also influenced by the Burdekin River (Figure 6), which enters the sea approximately 150 km further south. Cyclonic flood plumes from the Burdekin River are reported to extend as far north as Innisfail, which is north of the Hinchinbrook DPA (Wolanski & Jones 1981; Devlin et al. 2001).

The principal land uses in the Herbert River catchment are cattle grazing, sugar cane cultivation and other cropping in the coastal plains (Table A1), as well as some alluvial tin mining in the upper catchment (DPI 1993a). Moller (1996) notes several areas of serious habitat degradation in the Herbert River catchment and emphasises in particular the degradation of riparian vegetation, erosion problems and the intrusion of exotic weeds. Figure 7 shows the there has been a significant increase in the area of land utilised for sugarcane cultivation in the lower Herbert River catchment over the past 140 years, and the natural vegetation cover has decreased correspondingly. Although less than 7% of the Herbert River catchment area is used for crop farming (mainly sugarcane), the fertiliser used, per hectare of catchment area, is one of the highest of the Queensland coast. For example, a total of 9800 tonnes of nitrogen and

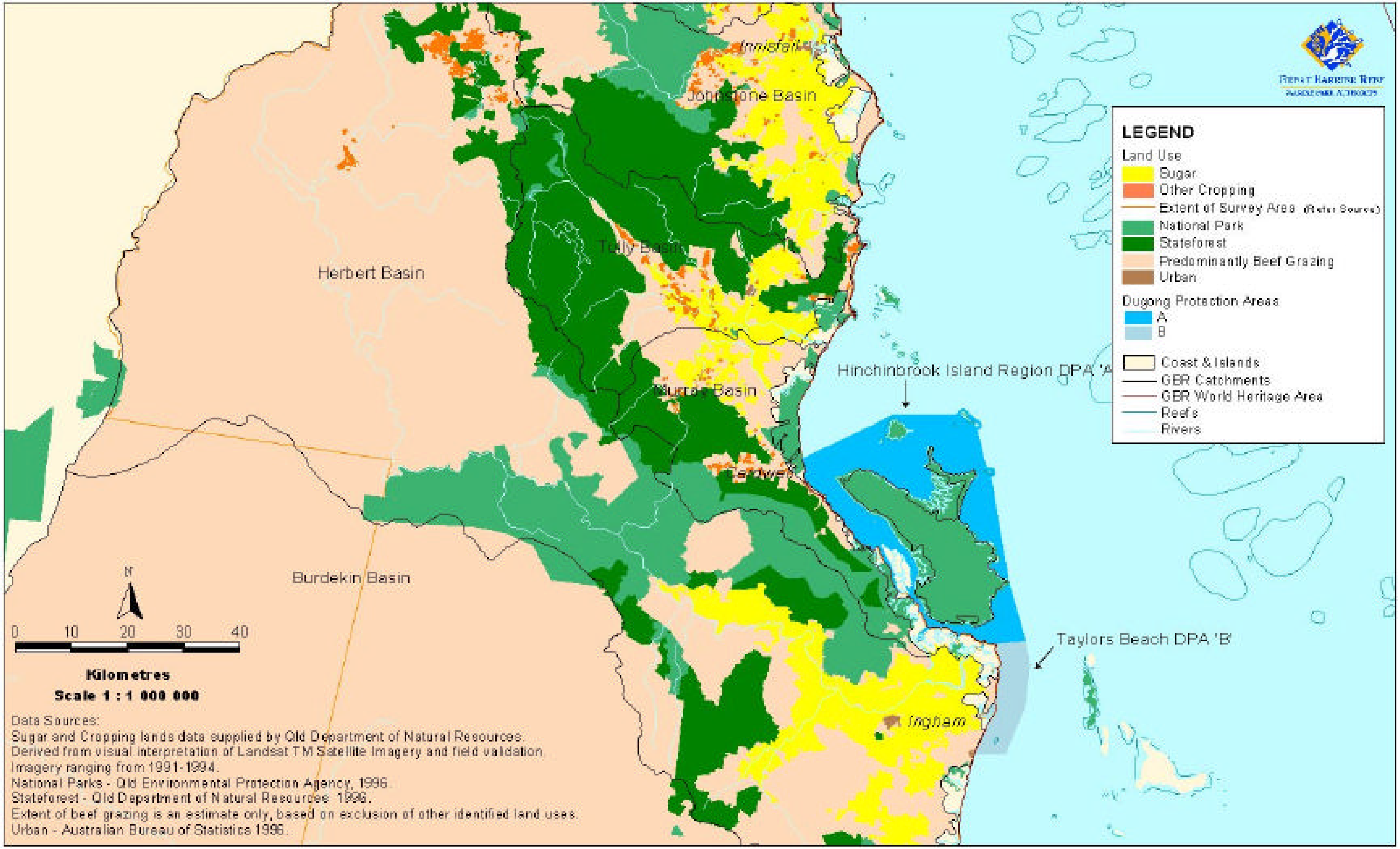

Figure 6. Land use in river catchments adjacent to the Hinchinbrook Island Region and Taylors Beach Dugong Protection Area

1330 tonnes of phosphorus were applied in 1990 (Table A2). In the Herbert-Burdekin area a 65% expansion of the area harvested for sugarcane has occurred during 1990-99, predominantly in the Herbert catchment (Australian Sugar Year Book 2001). This expansion has likely to have led to an increase in fertiliser and pesticide use in this catchment.

The concentrations of nutrients in the Herbert River water are much higher during flood conditions, with the highest concentrations measured during the first flow of the season (Table 1), when most of the suspended sediment is also discharged (Mitchell et al. 1997). The model estimates of riverine sediment and nutrient export data (Table A3) are currently being verified by *in situ* measurements of suspended solids and nutrient concentrations in flooding rivers (Mitchell & Furnas, 1997). First estimates of the exports during the flood of cyclone Sadie in 1994 are presented by Mitchell et al. (1997).

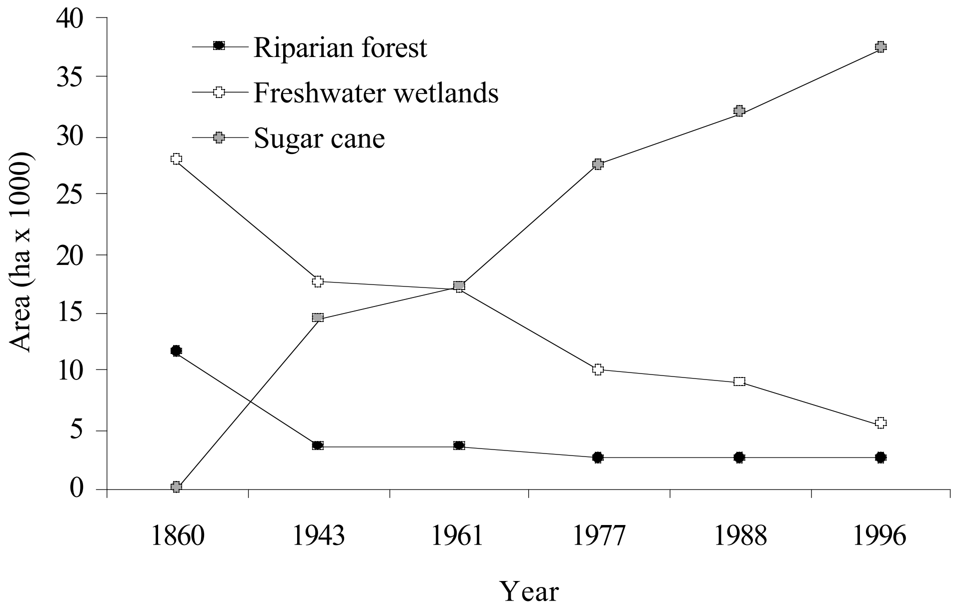

Figure 7. Change of land use in the lower Herbert River catchment over the past 140 years *(data from Johnson et al. 1998).*

Table 1. Summary of dissolved inorganic nitrogen (DIN) and phosphate (μM)in the water column of the Herbert River (lower catchment) and the Hinchinbrook Channel. Data are overall arithmetic means and/or ranges of means from different sites and/or seasons.

	Herbert River water, non-flood conditions[1]	Herbert River water, flood conditions[2]	Hinchinbrook Channel[3]
DIN	7.8 (2.7–12.8)	14.5 (3–26.5)	0.7–8.9
Phosphate	0.06 (0.04–0.09)	0.5 (0.1–0.7)	0.01–0.19

(Sources: [1]Furnas et al. 1995, [2]Mitchell et al. 1997, [3]A. Mitchell, AIMS pers. comm.)

Water column nutrient concentrations in the inshore areas of the Herbert River region are slightly higher compared to data from further offshore (Table 1; Furnas et al. 1995, 1997), which indicates the retention of terrestrial runoff in the coastal waters.

Point sources of nutrients into the DPAs from the Herbert River include sewage effluent from the Ingham sewage treatment plant, sugar mill effluent and runoff from active and closed tin mines. There are also a number of aquaculture operations in the Hinchinbrook Channel (prawn and barramundi farms), which discharge nutrient and particle-enriched water. Recently, the Hinchinbrook Channel has been focus of a number of collaborative research projects, examining sedimentary processes, carbon and nutrient fluxes, and contaminant loadings (Ayukai 1998).

Marine surface sediments in the Hinchinbrook region have elevated concentrations of mercury, which is suggested to indicate the past and present use of herbicides and fungicides containing mercury in the area (Walker & Brunskill 1997a, b). Also, low levels of DDT (3 ng/g) were detected in one surface sediment sample collected in Hinchinbrook Channel (G. Brunskill, AIMS, pers. comm.). Cavanagh et al. (1999), however, did not detect pesticide residues in coastal sediments around Hinchinbrook Island or in Rockingham Bay.

4.2 Cleveland Bay, Cape Bowling Green Bay and Upstart Bay DPAs

The Cleveland Bay DPA is located adjacent to the city of Townsville; a major residential, industrial, tourist and defence centre in north Queensland. Townsville has significant heavy industries including nickel, copper, and zinc refineries. Townsville Port is a major facility for the import and export of ore and export of refined metal products and the city is also a major private and commercial boating centre in this area of the Queensland coast. The Bowling Green Bay and Upstart Bay DPAs are located adjacent to a relatively undeveloped section of the coastline, except for the residential areas around Ayr and Home Hill.

The Ross River and Black River (including the Bohle River) catchments drain the hinterland of the Cleveland Bay DPA. An important local watercourse is Barratta Creek. The water quality in Cleveland Bay is also influenced by the northward flowing water of the Burdekin River during major flood events (Wolanski & Jones 1981).

The Haughton and Burdekin Rivers drain into the Bowling Green Bay and Upstart Bay DPAs respectively. These rivers drain the second largest catchment in north-east Queensland, and it is estimated that the Burdekin River is the second largest contributor of sediments to the GBRWHA (Table A3). The Elliot River is an important local watercourse in the Upstart Bay DPA.

The principal agricultural land use in the Ross and Black River catchments is cattle grazing, although grazing occupies only 30% of the catchment land (Figure 8, Table A1). The fertiliser usage in the two catchments is negligible (Table A2). Both the Ross and Black Rivers enter the sea in the Cleveland Bay DPA. The pressures on these catchments are mainly due to urban and industrial development that may lead to the loss of wetlands, introduction of contaminants, stream bed disturbance by sand and gravel extraction, and competition for groundwater resources (DPI 1993a).

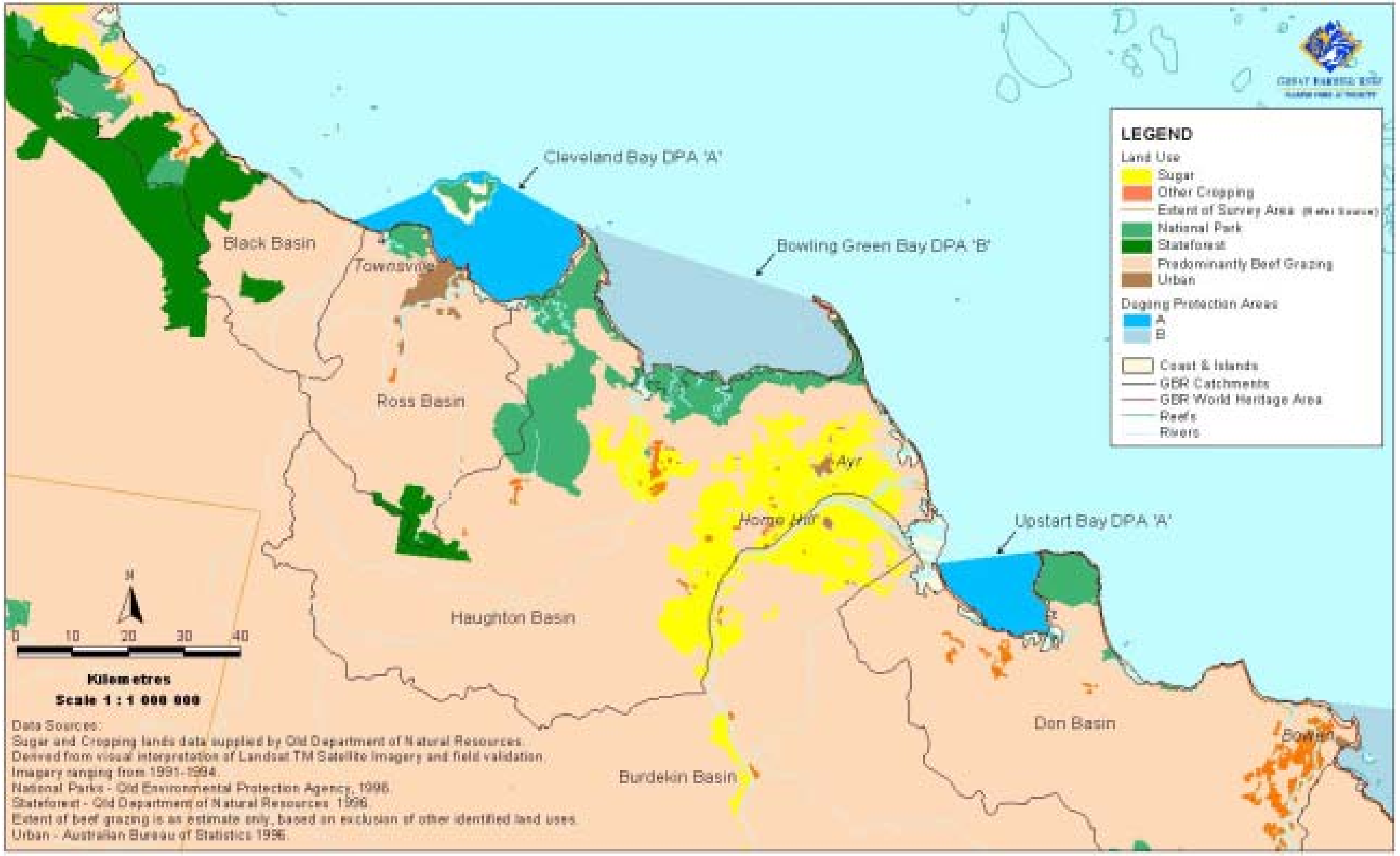

Figure 8. Land use in river catchments adjacent to the Cleveland Bay, Bowling Green Bay and Upstart Bay Dugong Protection Areas

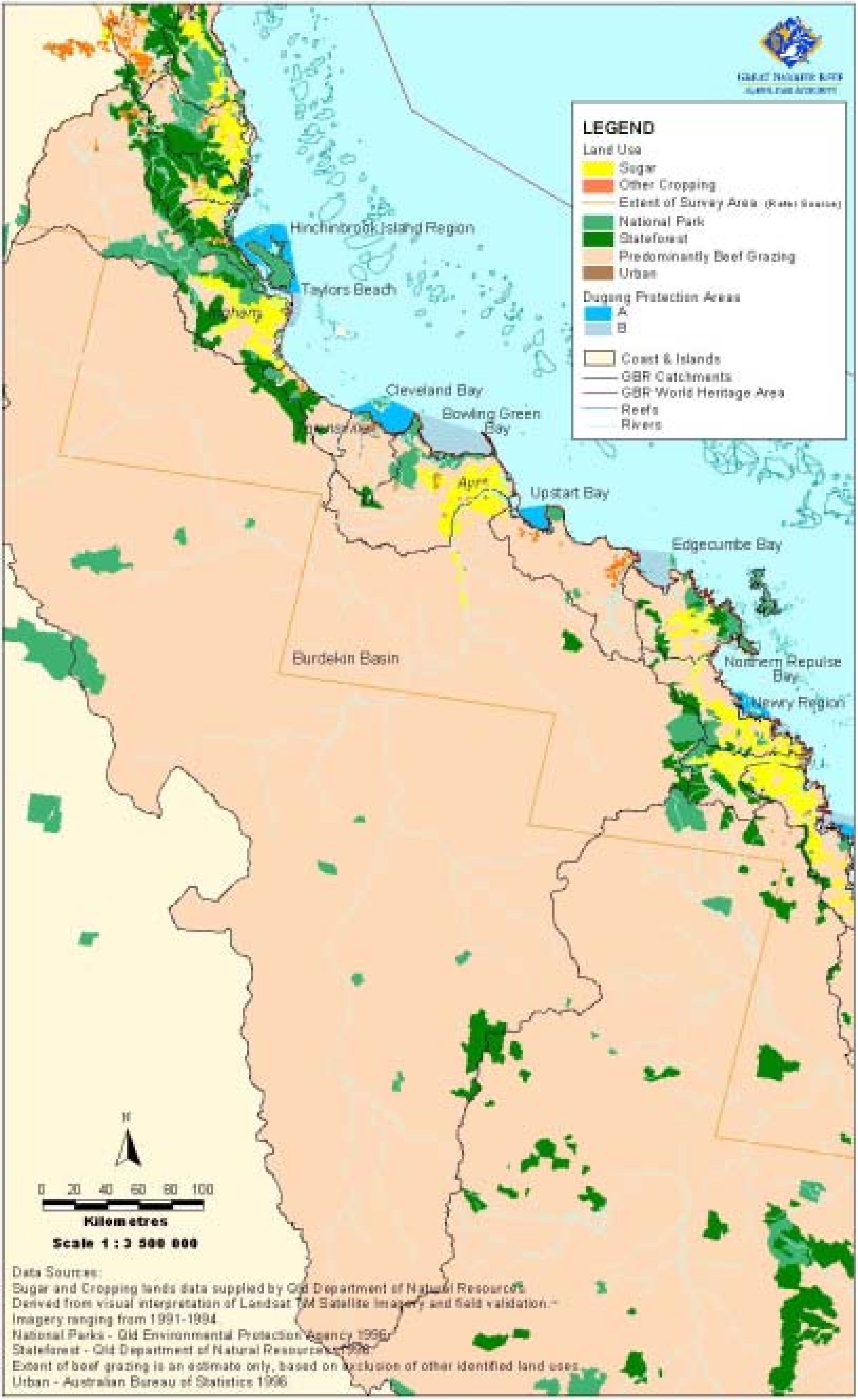

Figure 9. Land use in the Burdekin River Catchment Area

The Bowling Green Bay and Upstart Bay DPAs include the river mouths of the Haughton and Burdekin Rivers, respectively (Figure 8). The Haughton and Burdekin Rivers drain a dry tropical catchment with grazing as the major land use (Figures 8 and 9, Table A1). However, the sugarcane and other crop cultivation areas in the Haughton basin lead to the third highest fertiliser application rates of all GBR catchments (Table A2). There are also significant coal and gold mining activities in this catchment area, that produce waste which may contain silt and contaminants, such as heavy metals and cyanide.

The pressures on the Burdekin and Haughton River catchments include widespread erosion caused by overgrazing, introduction of exotic weeds, wetland degradation due to flow alteration caused by the Burdekin Dam, and salinity problems in irrigated areas.

Water column nutrient concentrations in Cleveland Bay and Bowling Green Bay have been measured for several years and at different sampling points (Walker & O'Donell 1981; Revelante & Gilmartin 1982; Ullman & Sandstrom 1987; Blake 1994). The values are variable and range from 0.1 to 1.2 μM for dissolved inorganic nitrogen, from 0.2 to 0.3 μM for phosphate and from 3 to 5 mg/l for suspended solids. These data are relatively high compared to average data for the GBRWHA (Furnas et al. 1997). All water quality parameters are strongly influenced by seasonal flood events (discussed above). The concentrations of suspended solids in the Bays are largely controlled by wind-driven resuspension of sediments and levels of up to 200 mg/l have been measured (Larcombe et al. 1995).

The runoff from the Burdekin catchment can vary by two orders of magnitude between wet and dry years (Table A1). The data for sediment export to the coast are derived from mathematical models (Table A3), however, research currently underway provides first estimates of directly measured nutrient concentrations in the Burdekin River (Table 2), and hence improved estimates of nutrient export (Furnas et al. 1996; Mitchell & Furnas 1997). These authors also emphasise the importance of the impact of the first discharge of a flood event (first flush), which transports the bulk of suspended sediments and high concentrations of dissolved nutrients. During cyclonic conditions the high sediment and nutrient loads are transported as flood plumes into waters further offshore.

Point source discharges from the Townsville and Thuringowa sewage treatment plants and industrial inputs are significant contributors of nutrients and contaminants into Cleveland Bay (Moss et al. 1992). The major point sources of pollution in the Burdekin and Haughton River catchments are inputs from the Ayr and Home Hill sewage treatment plants although these plants are relatively small.

Table 2. Nutrient concentrations in Burdekin River water (μM). Data are mean values for the period 1987–95.

Dissolved Nitrogen	9.3–28.9
Particulate Nitrogen	6.3–75.1
Phosphate	0.2–0.8
Particulate Phosphorus	0.4–2.7

(Source: Furnas et al. 1996)

The concentration of heavy metals in samples collected from nearshore waters between 1976–77 in Cleveland and Bowling Green Bays and between Townsville and Cardwell in 1979 were within the range of mean world data reported at that time (Burdon-Jones et al. 1982; Klumpp & Burdon-Jones 1982). Background concentrations of metals have been assessed in nine species of bivalves in the greater Townsville region in 1979 (Klumpp & Burdon-Jones 1982). High levels of manganese and zinc were detected in seagrasses of the region (Denton et al. 1980). Elevated mercury levels have been detected in the upper layers of a sediment core from Upstart Bay, and are suggested to originate from the use of herbicides and fungicides containing mercury in the Burdekin River catchment, or are a result of using mercury to extract gold at Charters Towers in the 1870–1890s (Walker & Brunskill 1997a, b).

Polyaromatic hydrocarbons (PAHs) have also been detected in sediments from Townsville Port and are probably caused by fuel discharges and motor exhaust emissions to the water (Smith et al. 1985). Concentrations of chlorinated organics and pesticides (PCBs, DDTs, HCHs, aldrin, dieldrin and chlordanes) in fish tissue were low in the Townsville region compared to the Brisbane region and other urbanised areas (Kannan et al. 1995). Lindane was detected in Burdekin River sediment (Dyall & Johns 1985) and lindane and heptachlor in groundwater of the Burdekin region (Brodie et al. 1984). The levels were below the Australian drinking water standard of 30 ng/l and 10 ng/l for lindane and heptachlor, respectively, but in some cases exceeded the water quality guidelines for the protection of the aquatic environment (1 ng/l for lindane, 0.3 ng/l for heptachlor) (Nicholson 1984).

Denton et al. (1980) reported high concentrations of several metals in the tissues of 48 dugongs collected from Torres Strait to Townsville between 1974 and 1978, compared to other marine mammals. It was considered unlikely that these high concentrations were a reflection of anthropogenic impacts, given the remoteness of the sampling sites (Denton et al. 1980). However the long life span and large spatial range of these animals may complicate the understanding of any causal relationships. Recent studies show migratory activity for dugong over significant distances (Preen 2001). Low levels of lindane, dieldrin and PCB have been found in the small sample number of dugongs collected in the Townsville region (Heinsohn & Marsh 1978; Smillie & Waid 1985).

Molongle Creek boat ramp and access channel extends into the Upstart Bay DPA. This channel extends beyond the mean low water mark and has been dredged regularly in the past to maintain all tide boat access.

4.3 Edgecumbe Bay, Repulse Bay, Newry Region and Sand Bay DPAs

These DPAs are located in a relatively undeveloped section of coastline between Bowen and Mackay (Figure 10). The urban area of Bowen is immediately adjacent to the Edgecumbe Bay DPA and the mouth of the Don River enters the sea close to the northern border of this DPA. The mouths of the Proserpine and O'Connell Rivers are just south of the Repulse Bay DPA, and the city of Mackay and the mouth of the Pioneer River are just south of the Newry Region and Sand Bay DPAs.

In northerly winds, the Edgecumbe Bay DPA is influenced by terrestrial runoff from the Don River catchment, where grazing is the primary land use (Figure 10, Table A1). The Repulse Bay DPA is mainly affected by the Proserpine and O'Connell Rivers (Figure 10). The Newry Region and Sand Bay DPAs are largely influenced by the Pioneer River, which enters the sea just south of these two adjacent DPAs, at Mackay. The Newry Region and Sand Bay DPAs are also possibly influenced by the Fitzroy River, which enters the sea approximately 300 km south. The Fitzroy River has the largest river catchment in north-east Queensland and, under certain wind conditions, river plumes after severe cyclonic floods may affect coastal areas far to the north. Further details on this river are included in section 4.4. Important local watercourses are the Gregory River draining into Edgecumbe Bay DPA and the St Helens River draining into the Newry Region DPA.

The city of Bowen is located at the coast of the Edgecumbe Bay DPA, which may result in some impact from urban runoff, a sewage outfall and of the Bowen Port activities, however, no data are available. The catchment issues in the adjacent Don River catchment are related to pasture degradation and erosion (DPI 1993a).

The Proserpine River drains a catchment with grazing as the main land use and large cropping areas (mainly sugarcane) in the coastal plains (Figure 10, Table A1). Fertiliser application rates are relatively high (Table A2). Impacts from urban inputs from the town of Proserpine can also be expected. The Peter Faust Dam upstream of Proserpine largely altered the flow pattern of the Proserpine River, and the downstream impacts of this are still unknown. The O'Connell River catchment has large grazing and some sugarcane cropping areas (Figure 10, Table A1), which lead to the sixth highest fertiliser application rates of all GBR catchments (Table A2). However, about 20% of the combined Pioneer-O'Connell River catchment area is forested (Figure 10, Table A1).

The predominant land-use in the Pioneer River catchment is grazing (Figure 10, Table A1). Sugarcane cultivation areas occupy almost 14% of the combined Pioneer and O'Connell River catchment (Figure 10, Table A1), and this area has the highest fertiliser application of all GBR catchments (Table A2). The main issues in the catchment are erosion and soil degradation (DPI 1993a). The flow of the Pioneer River has been largely modified by aggradation, and by several weirs (DPI 1993a).

The Bowen sewage outfall is the major point source discharge that is likely to impact on the Edgecumbe Bay DPA. There are no other major discharges in this region that are likely to influence the DPAs.

There is very little water quality data available in this region. Water quality data from Pioneer Bay, which is located south of the Edgecumbe Bay DPA, and from Repulse Bay indicate high nutrient and suspended solids values (DIN 1.1 μM, phosphate 0.2 μM, suspended solids 6 mg/l) in the inshore waters compared to waters further offshore (Blake 1994). This may indicate the influence of terrestrial runoff on coastal water quality.

Some adverse effect of urban runoff from Mackay on the DPAs may be expected, however, there are no coastal water quality data available to quantify this possibility. The surface waters of the Pioneer and O'Connell Rivers have been rated as being in a good to moderate condition, regarding dissolved N and P concentrations and other water quality characteristics (Queensland Department of Environment and Heritage 1999).

No data was available on pollutant concentrations in this region.

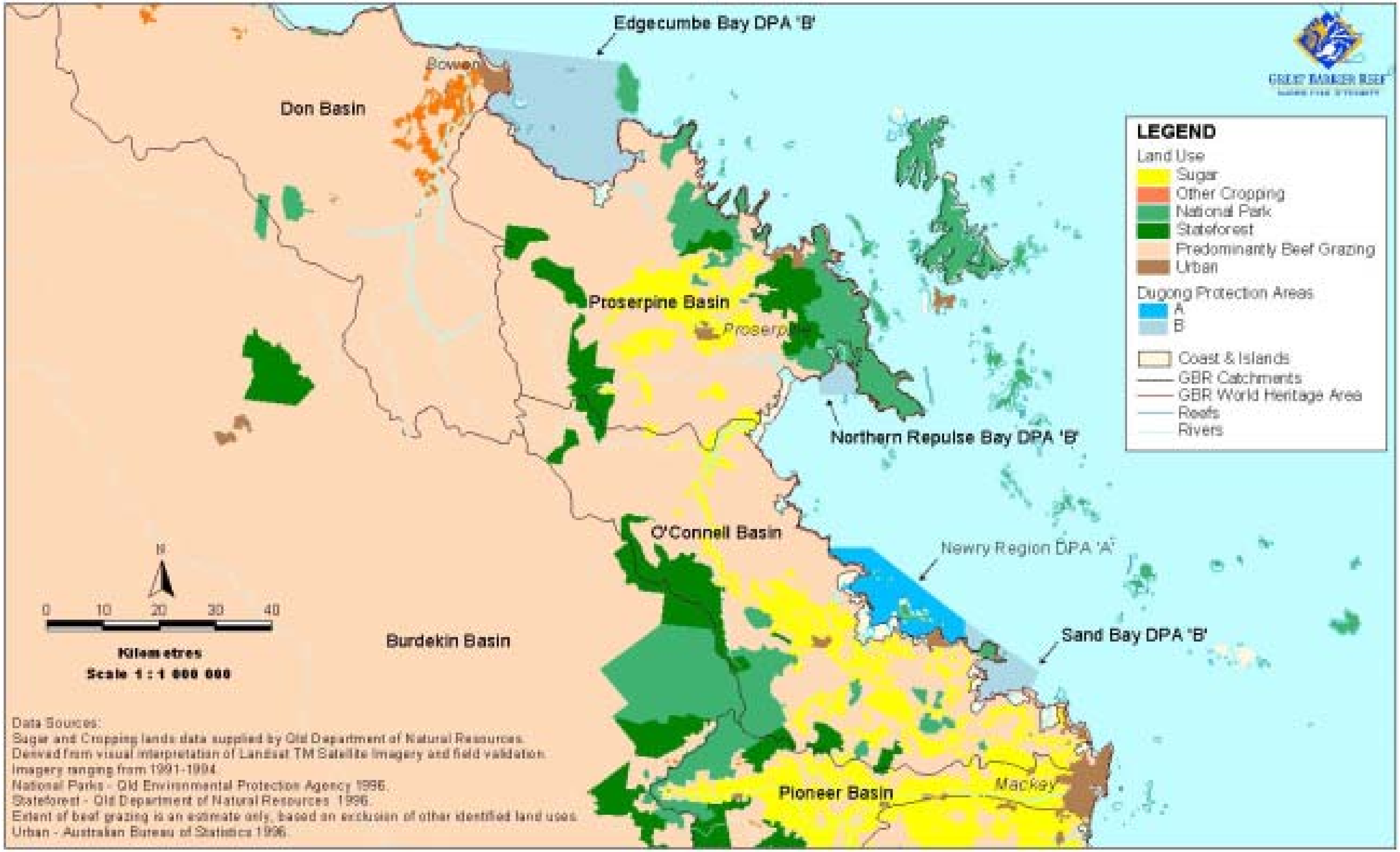

Figure 10. Land use in river catchments adjacent to the Edgecumbe Bay, Repulse Bay, Newry Region and Sand Bay Dugong Protection Areas

4.4 Llewellyn Bay, Ince bay, Clairview Region, Shoalwater Bay and Port Clinton DPAs

The Llewellyn Bay and Ince Bay DPAs are located just south of Sarina, and the Clairview region, Shoalwater Bay and Port Clinton DPAs are a further 50 to 100 km south (Figure 11).
The Llewellyn Bay and Ince Bay DPAs may be influenced by Plane Creek, in the Plane Creek catchment, which enters the sea at the Sarina Inlet just north of Llewellyn Bay. All DPAs in this region are influenced by the Styx River, which enters the sea south of Clairview. The Clairview Region, Shoalwater Bay and Port Clinton DPAs are also influenced by the Shoalwater catchment. The two latter DPAs may also be affected by activities in the Waterpark River catchment. Shoalwater Bay is considered to be the most important dugong habitat in the GBRWHA, south of Cooktown (Marsh & Corkeron 1997). All five DPAs are influenced by the Fitzroy River, which enters the sea near Rockhampton, about 100 km south of Shoalwater Bay. An important local watercourse is Carmila Creek draining into the Clairview Region DPA.

There is no major urban development along the mainland coast that adjoins this group of DPAs, although Port Clinton has been identified as a potential port site.

The Plane Creek catchment has a sugarcane cultivation area of more than 20% (Figure 11) and has the third highest rate of fertiliser application of all GBR catchments (Table A2).

Most of the mainland coastline adjoining the Shoalwater Bay and Port Clinton DPAs is located within the Shoalwater Bay Military Training Area. Approximately 22% of the area of the adjacent Shoalwater Bay–Plane Creek catchment is forested (Figure 11, Table A1). The adjacent Shoalwater catchment is also of importance for the Clairview DPA. Both the Styx River and Plane Creek catchments have some cleared, grazing areas at low stocking rates (Figure 11, Table A1) and fertiliser application is negligible (Table A2).

The Waterpark River catchment is relatively small and is used for extensive grazing and some pineapple cultivation (Figure 11), however, fertiliser application rates are low (Table A2).

The Fitzroy River drains the largest catchment in Queensland and has the second highest flow rates, after the Burdekin River (Table A3). The Fitzroy catchment is predominantly used for grazing with some significant areas of grain, legume, and cotton cultivation (Figure 12, Table A1). The increase in crop cultivation has lead to an increase in fertiliser application rates over the last 20 years (Figure A4). Land clearing for grazing and cultivation in this catchment resulted in the loss of 3 million hectares of Brigalow woodland from 1960 to 1975 (a decrease from 30% cover to only 1% cover of the total catchment area). Increased soil erosion on the resulting grazing lands, exacerbated by droughts and seasonal overgrazing, has led to large increases in sediment and nutrient delivery to the inner lagoon. Model estimates for sediment and nutrient runoff are given in Table A3. There are also significant coal mining activities in the Fitzroy River catchment (Gilbert et al. in press), which have the potential to release contaminated or acidic runoff. Additional pressure on the coastal areas caused by urban runoff from the city of Rockhampton can be assumed. The Fitzroy barrage, just upstream of the Rockhampton township, prevents flushing of the Fitzroy estuary during low flow events and has resulted in the increase of nutrient concentrations downstream. These increases may be attributed to urban sewage and abattoir outfalls (Connell et al. 1981). These nutrients may be flushed out during major floods and transported northward towards the DPAs.

An ongoing research program monitors the water quality in the Fitzroy River (M. Furnas, AIMS, pers. comm.) and the data from the period 1992–95 are presented in Table 3. The estimates of annual inputs of nutrients have to be regarded with caution, because during the study period no major flood event occurred.

Table 3. Nutrient concentrations (μM) in the Fitzroy River. Data are mean values for the period 1992–95.

Dissolved Nitrogen	15.8–29.4
Particulate Nitrogen	4.6–74.9
Phosphate	0.1–1.8
Particulate Phosphorus	0.4–2.5

(Source: Furnas et al. 1996)

In 1991 cyclone Joy caused major flooding of the Fitzroy River, with an estimated discharge of 19 million ML of water, containing average concentrations of nitrogen and phosphorus of 43 μM and 5 μM, respectively (calculated after Brodie & Mitchell 1992). This flood resulted in the mortality of 90% of the hard corals on the fringing reefs in the adjacent Keppel Bay (Byron & O'Neill 1992). Chapman (1992) estimated a flood-related loss of 1300 t of soil per hectare from some paddocks, which was presumably deposited in adjacent areas.

A multidisciplinary project from 1993 to 1996 addressed the health of the streams in the Fitzroy River catchment and indicated some areas of concern (Noble et al. 1997). The levels of suspended solids and nutrients in river water were very high, especially under high flow conditions. In the Fitzroy River suspended solids concentrations ranged from 82 to 693 mg/l and the median concentrations of total nitrogen and total phosphorus were 107 μM and 13 μM, respectively (calculated after Noble et al. 1997). Pesticide residues were detected in a number of samples, and some atrazine and endosulfan levels exceeded the Australian Drinking Water Guidelines and the water quality guidelines for the protection of aquatic ecosystems. Also noted was the poor state of the riparian vegetation in the Fitzroy River catchment and the appearance of cyanobacterial blooms in the upper catchment (Noble et al. 1997; Fabbro & Duivenvoorden 1996).

Metal concentrations have been assessed in a number of seagrass species from Shoalwater Bay in 1975 (Denton et al. 1980). No other information on pollutant levels in these four DPAs is available.

4.5 Rodds Bay and Hervey Bay–Great Sandy Strait DPAs

The Rodds Bay DPA is located south of Curtis Island along the coast adjacent to the city of Gladstone (Figure 13). The Calliope and Boyne River enter the sea inside the DPA, and the mouth of the Baffle River is approximately 70 km further south. The Hervey Bay–Great Sandy Strait DPA is located south of Bundaberg between Fraser Island and the mainland (Figure 14). The urban areas of this region include the coastal settlements of

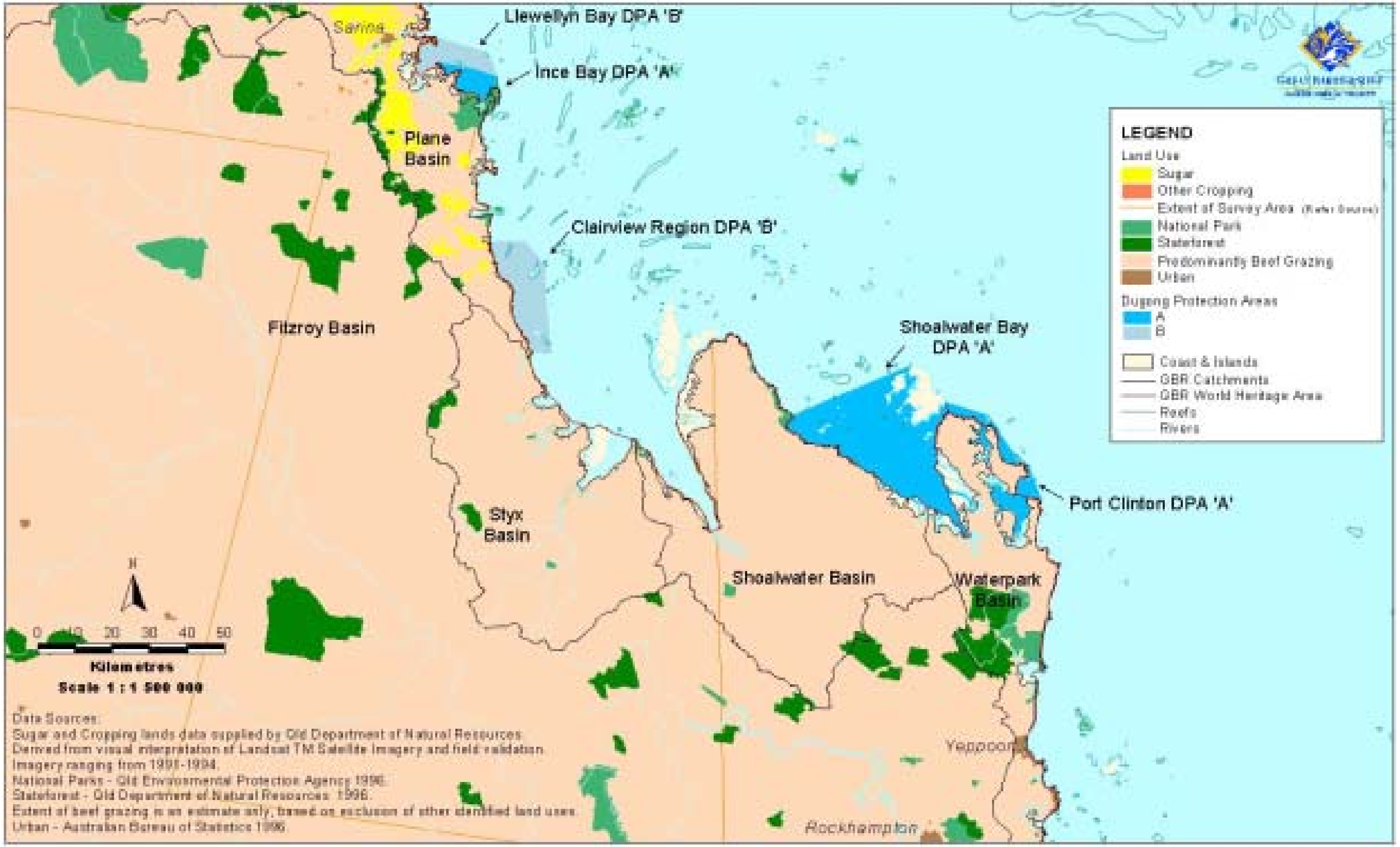

Figure 11. Land use in river catchments adjacent to the Llewellyn Bay, Ince Bay, Clairview Region, Shoalwater Bay and Port Clinton Dugong Protection Areas

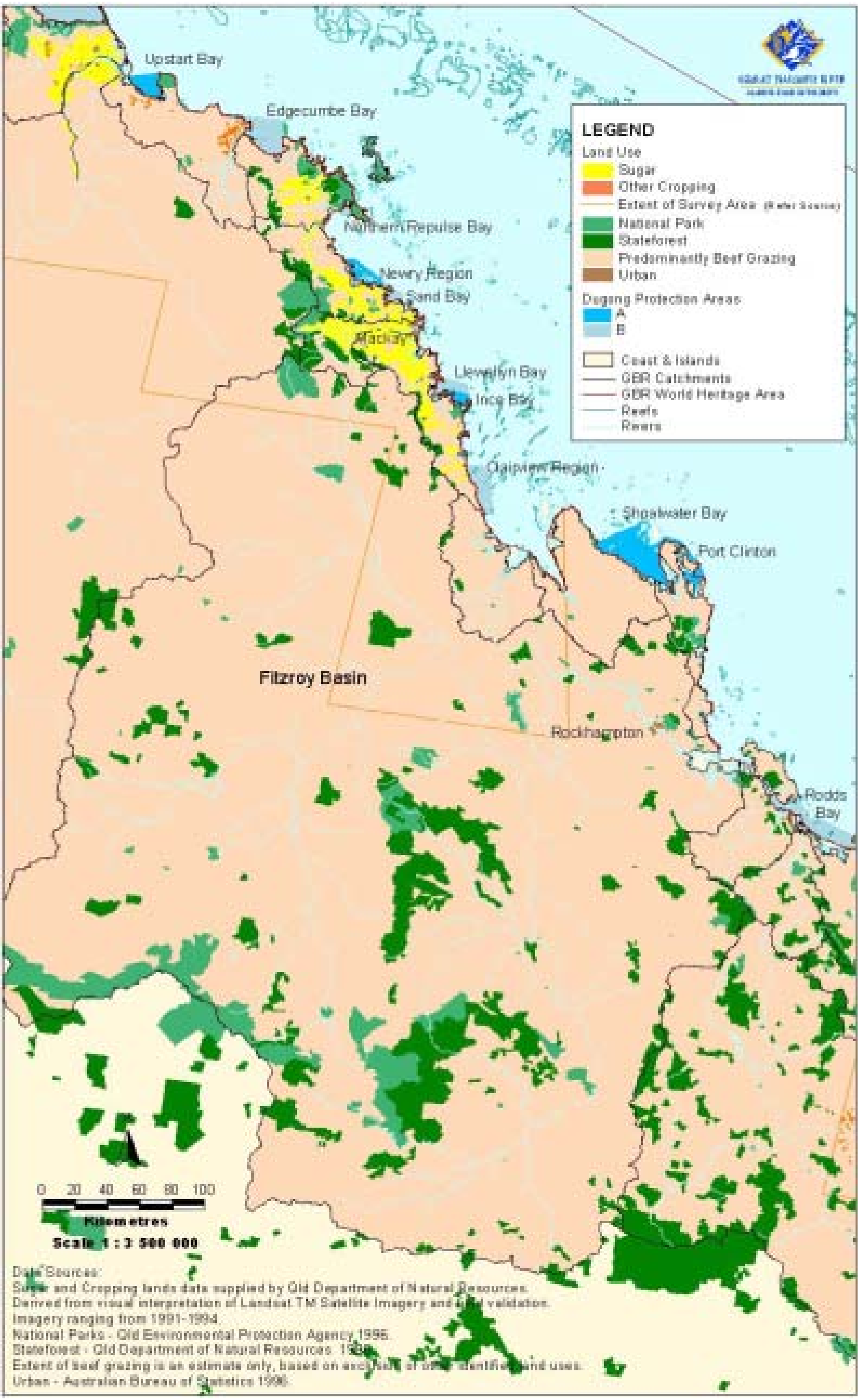

Figure 12. Land use in the Fitzroy River Catchment Area

Hervey Bay, Tin Can Bay and Maryborough. The Mary River drains into this DPA. An important local watercourse is Auckland Creek draining into the Rodds Bay DPA.

The principal land use in the Curtis Coast catchment area, which includes the catchments of the Calliope, Boyne, and Baffle Rivers, is grazing (Figure 13, Table A1). Some areas in the Baffle River catchment have sugarcane cultivation that involves low rates of fertiliser application (Table A2). The Curtis coast catchment has been extensively cleared, which results in severe erosion problems (DPI 1993a). Also of concern is the effect of the heavy industrial development around Gladstone. Adjacent to the Rodds Bay DPA, a pilot plant for the open-pit mining of shale oil is operational and expansion of the development is expected however the environmental consequences of such mining activities are uncertain.

The Burnett-Kolan River catchment area is located between the Rodds Bay and Hervey Bay–Sandy Strait DPAs and may affect the water quality in both DPAs. The Kolan and Burnett Rivers enter the sea close to Bundaberg. The main land use in this catchment area is grazing (Figure 14, Table A1). In the Bundaberg irrigation area a large number of different crops (sugarcane, maize, peanuts, citrus fruit) are grown (Figure 14), which result in moderate fertiliser application rates in the Kolan and Burrum River catchments (Table A2). Problems caused by urban runoff from Bundaberg can be expected, however no data on contaminants are available. The irrigation infrastructure may lead to flushing problems due to flow alterations and salinity problems in irrigated areas (DPI 1993a).

The Mary River catchment has been extensively cleared for agriculture and the lower catchment is under significant pressure from grazing and agriculture (DPI 1993a). The main land use is cattle grazing with some area of sugarcane cultivation in the lower catchment areas (Figure 14, Table A1). The fertiliser use is relatively low (Table A2). The State of the Rivers Report rates most of the streams in the Mary River catchment as being in a moderate to poor overall condition, specifically in relation to erosion problems and the poor status of riparian vegetation (Johnson 1997). An input of contaminants from the Maryborough urban area can be expected, although there are no data available.

Land clearing and subsequent increases in erosion and sediment transport to the inner lagoon were implicated as causes of massive losses of seagrass meadows from Hervey Bay following a flood event (ex-cyclone Fran) in 1992 (Preen et al. 1995). The catastrophic decline of seagrass meadows was followed by a mass migration of dugongs from Hervey Bay as well as mortality of a large number of dugong as a result of starvation (Preen & Marsh 1995).

Herbicide and insecticide concentrations present in the Mary River and in Hervey Bay sediments were measured between 1993 and 1996 (Queensland Department of Environment 1996). Sediment and river water pollutant concentrations were below detection limits for most compounds however the herbicides 2,4-D and Triclopyr were detected at trace concentrations ($<0.2\ \mu g/l$).

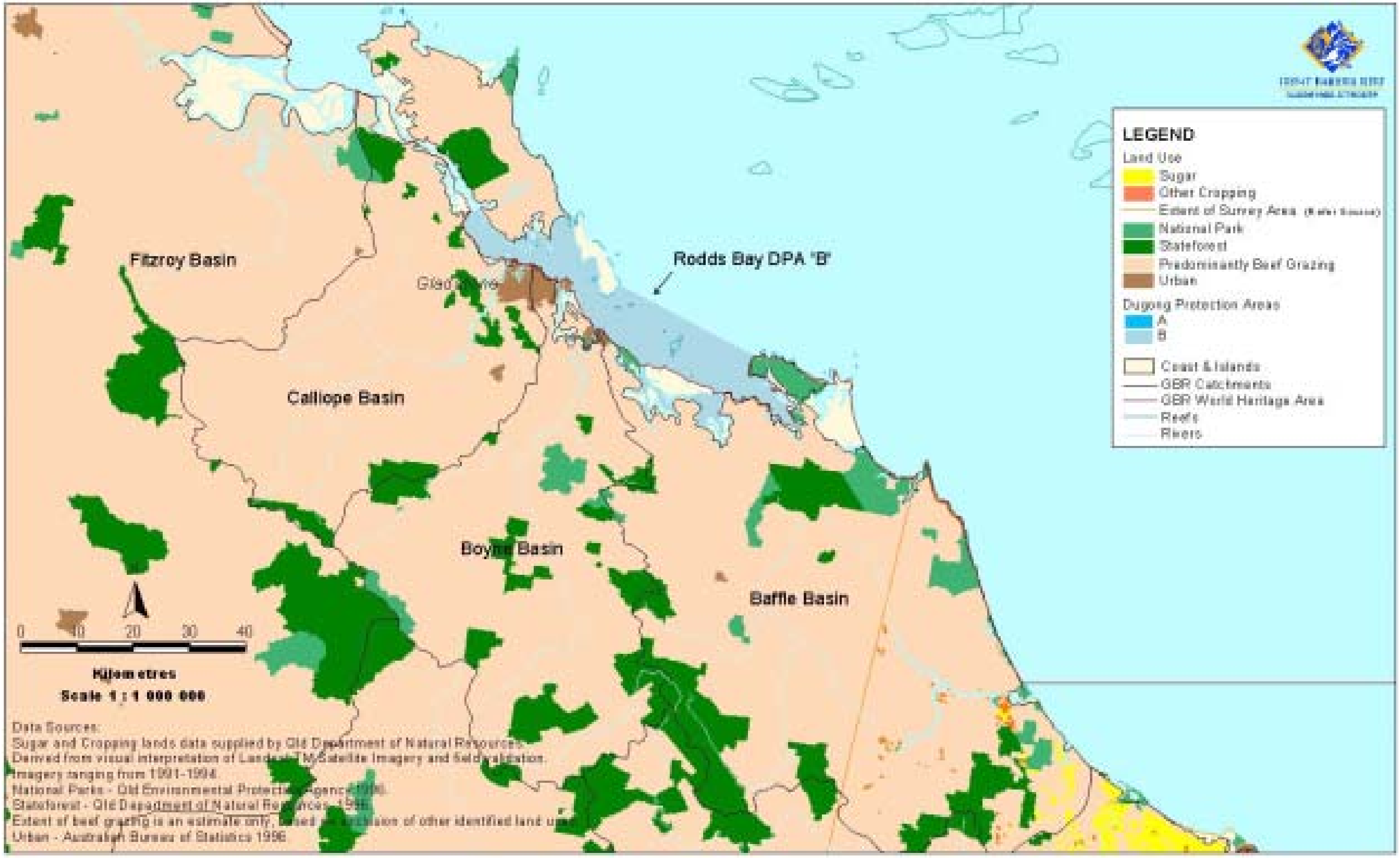

Figure 13. Land use in river catchments adjacent to the Rodds Bay Dugong Protection Area

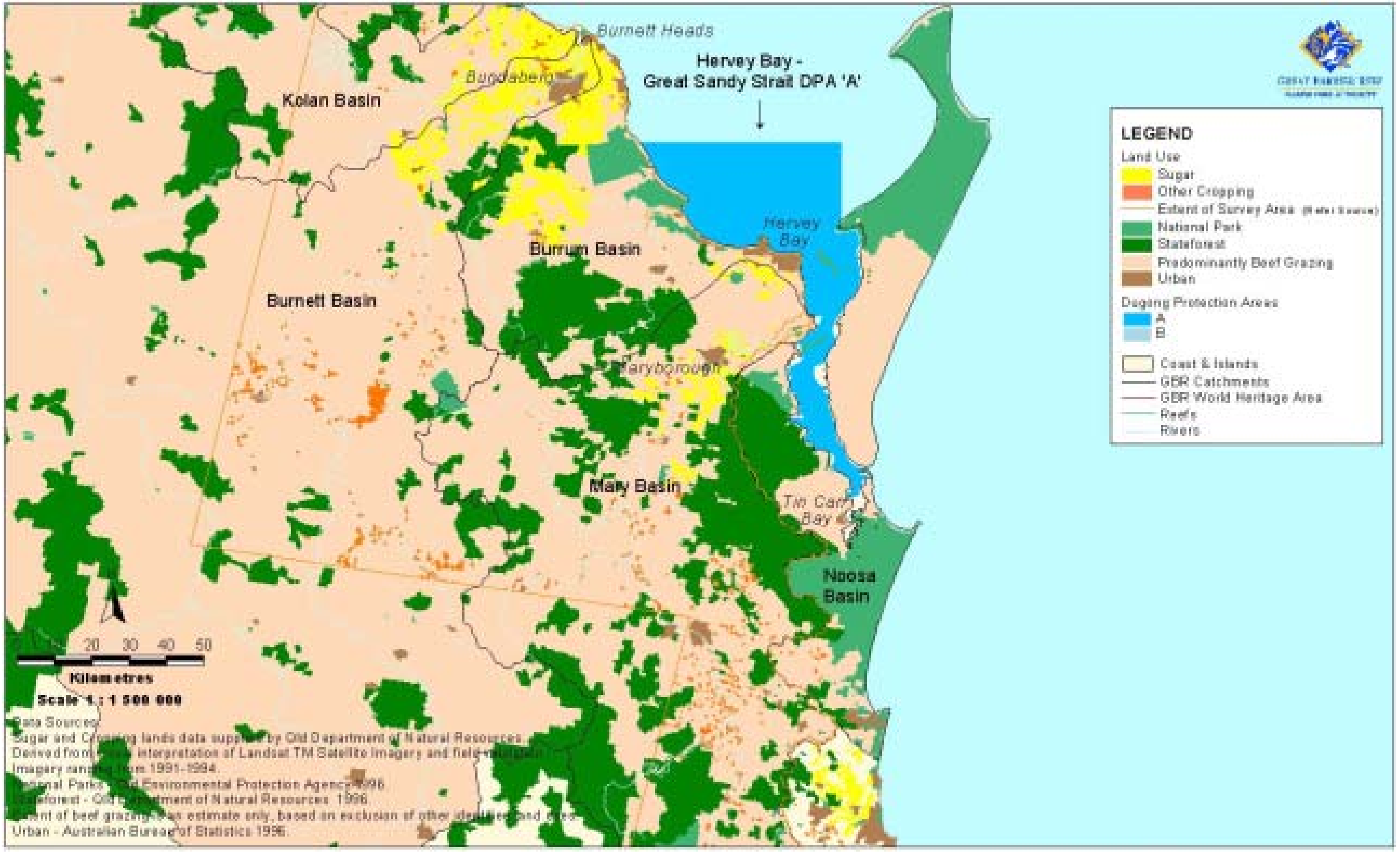

Figure 14. Land use in river catchments adjacent to the Hervey Bay – Great Sandy Strait Dugong Protection Area

5. QUALITATIVE RISK ASSESSMENT FOR HABITAT QUALITY IN DUGONG PROTECTION AREAS

Sections 2 and 3 of this report established some of the significant anthropogenic impacts on habitat quality in the existing DPAs, such as the deterioration of coastal water quality and the degradation of seagrass habitats by:

increased turbidity due to sediment held in suspension;
increased turbidity due to the formation of particles by physico-chemical and biological processes in the presence of increased nutrients;
increased turbidity due to increasing phytoplankton populations as a result of increased nutrients; and
direct effects on seagrass performance due to increased nutrient availability.

Based on the above and the information on catchment condition outlined in Section 4 a qualitative risk assessment was completed as a screening tool to determine the potential for adverse impacts on the habitat quality to occur in DPAs as a result of activities on adjacent river catchments. The level of risk reflects the development and land use on the adjacent catchments and the associated pollution pressures to the marine environment, as well as basic site-specific attributes of the DPAs, such as the presence of significant local watercourse close to the DPA. The output of the risk assessment is an overall rating of low, moderate or high risk for each of the 16 DPAs (see Table 4), considering five water quality risk categories outlined below.

The limitations of the qualitative risk assessment are recognised as it does not quantify probabilities for impacts to occur, nor does it account for species- or site-specific differences such as pollution tolerance levels of different seagrass communities, which are generally unknown, and physical factors affecting exposure to land-based pressures. A qualitative risk assessment for river-borne contaminants has also been completed for a number of coral reefs in the GBRMP, based on pollution ratings, river discharge volumes and frequencies, and flood plume directions (Devlin et al. 2001). Our assessment does not include consideration of local government planning instruments or Integrated Catchment Management strategies that may be implemented to better manage inputs to the DPAs from land-based activities. However, the risk assessment provides an overview of current pressures to DPAs, and highlights regional issues that warrant further consideration. Better guidance for management to optimise risk reduction will be possible with a more detailed risk assessment, which requires further monitoring of pollutants in seagrasses and marine sediments at a local scale, i.e. inside the DPAs, as well as availability of results of current research into the effects of land run-off constituents on inshore biota and ecosystems.

The categories considered in the risk assessment are:

Presence of a significant local watercourse to the DPA

A number of minor river systems and small watercourses have a high priority in terms of the risk to water quality in the DPAs. These smaller watercourses drain the floodplains, which are in most catchments developed for intensive cropping. The coastal creeks and small rivers export only a small proportion of the total pollutant load to the GBR. They are, however, significant on a local scale because they flow directly into the coastal zone and can carry very high nutrient, sediment and pollutant loads with very little reduction by re-settlement and biological uptake due to the short in-stream passage.

Presence of an urban area, industrial or marine development close to the DPA

Higher levels of contaminants and disturbances by dredging, channel maintenance and vessel traffic may be expected in DPAs in the vicinity of urban centres, industrial areas, ports, marinas, or dredged access channels. Regular vessel traffic in these areas has additional implications for dugong populations through increased potential for boat strikes and the evasion of dugong from feeding areas.
The small urban areas of Ingham, Bowen, and Proserpine are located adjacent to Taylors Beach, Edgecumbe Bay and Repulse Bay DPAs, respectively. Small ports, loading facilities, marinas or access channels are located close to the Taylors Beach (Lucinda port and loading facility), Upstart Bay (Molongle Creek access channel), Edgecumbe Bay (Bowen marina), Sand Bay (Mackay port and marina), Llewellyn Bay and Ince Bay (Hay Point port and loading facility), and Hervey Bay-Great Sandy Strait (Hervey Bay marina) DPAs. Two significant marina facilities and dredged access channels occur adjacent to the Hinchinbrook DPA, these are the Port Hinchinbrook marina and the dredged access to Enterprise Channel which also includes a proposed marina at Dungeness. The significant urban and industrials areas and major ports of Townsville and Gladstone, with associated marinas and dredged access channels, are located inside the Cleveland Bay and Rodds Bay DPAs, respectively.

Fertiliser application on adjacent catchments

Higher nutrient concentrations may be expected in the runoff from catchments that have high fertiliser application. Average fertiliser application rates per catchment area and per unit of runoff on the adjacent catchments are presented in Table A2. The efficiency of applied fertiliser, that is the amount actually taken up by the crop, is low (Rayment et al. 1996). Hence it may be assumed that high fertiliser application rates are reflected in high nutrient concentrations in the water of receiving streams and rivers. However, the actual nutrient loading in the rivers depends on additional factors such as flow rate and status of wetlands, aquatic and riparian vegetation, which is generally in a poor state in the GBR catchments (DPI 1993a; Johnson et al. 1997). Areal fertiliser use was rated as low, moderate or high according to the following rating scale: low = <7 kg N ha^{-1} and <1 kg P ha^{-1}, moderate = 7-14 kg N ha^{-1} and 1-5 kg P ha^{-1}, high = >14 kg N ha^{-1} and >5 kg P ha^{-1} (Table A2). A mixed fertiliser rating denotes different ratings for N and P fertiliser. Fertiliser use was rated as low for three DPAs, low/moderate for one DPA, moderate for two DPAs and high/moderate for six DPAs (Bowling Green Bay, Repulse Bay, Newry Region, Sand Bay, Llewellyn Bay and Ince Bay; Table 4).

Pesticide use on adjacent catchments

Higher pesticide concentrations may be expected in the runoff from catchments where large amounts of herbicides, insecticides and fungicides are applied. Data for pesticide application were only available for sugar cane areas (Hamilton & Haydon 1996). The scale for the rating of pesticide use on the adjacent catchments was low = <10 g/ha, moderate = 10–100 g/ha and high = >100 g/ha (Table A2). For a number of catchments where grazing is the main land use no data for fertiliser application were available and the fertiliser application was rated as being low. Pesticide use on the adjacent catchments were rated as being low for six DPAs, moderate for three DPAs and high for the remaining seven DPAs (Bowling Green Bay, Repulse Bay, Newry Region, Sand Bay, Llewellyn Bay, and Ince Bay, and Hervey Bay-Great Sandy Strait; Table 4).

Sediment export from adjacent catchments

Eroded soil particles increase the turbidity in the receiving coastal areas and also transport particle-associated nutrients and contaminants. For the rating of sediment export from catchments to the coast we used the model estimates of the National Land and Water Resource Audit (NLWRA and CSIRO Land & Water, unpub. Data; methodology in Prosser et al. 2001) for the ratio of current to natural sediment export

(Table A3), which indicates the increase of sediment export after European settlement. The scale adopted for rating of the sediment export ratio was low= 1-5-fold, moderate= 5-12-fold, and high= >12-fold. Sediment export ratios from the adjacent catchments were rated as being low for four DPAs, moderate for two DPAs, and high for ten DPAs (Repulse Bay, Newry Region, Sand Bay, Llewellyn Bay, Ince Bay, Clairview Region, Shoalwater Bay, Port Clinton, Rodds Bay and Hervey Bay-Great Sandy Strait DPA, Table 4).

Using the individual ratings for the five risk categories a summary rating was generated using a point score system. In the first two risk categories, significant local watercourse and development close to DPA, the presence or absence of the potential pressure was scored as 0 or 1 points, respectively. The risk ratings for the remaining three categories (fertiliser and pesticide use, sediment export) of low, moderate and high were converted into 1, 2, and 3 points, respectively. In conclusion, a score of 3 to 11 points was possible.

For three DPAs the summary risk ratings were modified (Table 4) to reflect additional information that was not formally considered in the risk assessment. The fertiliser and pesticide application rates used in the risk assessment were based on the best available data, which are from 1990 and 1991-94, respectively (Table A2). In the Herbert-Burdekin area a 65% expansion of the area harvested for sugarcane has occurred during 1990-99, predominantly in the Herbert catchment (Australian Sugar Year Book 2001). Based on this recent, continued expansion of the sugar industry in the Herbert catchment the summary risk rating for the Hinchinbrook DPA was upgraded form a moderate to a high risk rating. The risks associated with the major urban, industrial and port activities to the water and habitat quality in the Cleveland Bay and Rodds Bay DPAs were considered to be significant. Consequently, the summary risk rating for the Cleveland Bay DPA, which was rated to be under low risk by general catchment activities, was upgraded to a moderate risk rating (Table 4). The risk rating for the Rodds Bay DPA was accordingly upgraded from moderate to high risk.

When the point score was 3 to 5, the habitat quality in the DPA was considered to be under low risk from upstream activities. As a result, the Shoalwater Bay and Port Clinton DPAs attain a low risk rating. Dugong Protection Areas with a point score of 6 to 8 were considered to be at moderate risk. The majority of the existing DPAs fall into this risk group, i.e. Taylors Beach, Cleveland Bay, Bowling Green Bay, Upstart Bay, Edgecumbe Bay, Clairview Region, and Hervey Bay–Great Sandy Strait DPAs. DPAs with a point score of 9 to 11 were rated to be at high risk, i.e. Hinchinbrook, Repulse Bay, Newry Region, Sand Bay, Llewellyn Bay, Ince Bay, and Rodds Bay DPAs.

Table 4. Qualitative risk assessment of impacts by catchments activities on water and habitat quality in Dugong Protection Areas (DPAs) in the Great Barrier Reef World Heritage Area. For rating scales see text.

		Potential risks to water and habitat quality in DPAs					
DPA	Adjacent catchments	Significant local watercourse	Development close to DPA[#]	Fertiliser use	Pesticide use	Sediment export	Summary risk rating
Hinchinbrook	Herbert River		Ingham U, Port Hinchinbrook M, Dungeness AC	moderate	high	low	high*
Taylors Beach	Herbert River	Cattle Creek	Lucinda P	moderate	high	low	moderate
Cleveland Bay	Black, Ross River	Barratta Creek	Townsville U, P, M	low	low	low	moderate*
Bowling Green Bay	HaughtonRiver		-	high/mod.	high	low	moderate
Upstart Bay	Burdekin River	Elliot River	Molongle Ck AC	low	low	moderate	moderate
Edgecumbe Bay	Don River	Gregory River	Bowen U, M	low	moderate	moderate	moderate
Repulse Bay	Proserpine, O'Connell River		Proserpine U	high/mod.	high	high	high
Newry region	Pioneer River	St Helens River	-	high/mod.	high	high	high
Sand Bay	Pioneer River		Mackay U, P, M	high/mod.	high	high	high
Llewellyn Bay	Plane Creek		Hay Pt. P	high/mod.	high	high	high
Ince Bay	Plane Creek		Hay Pt. P	high/mod.	high	high	high
Clairview	Styx River	Carmila Creek		low	low	high	moderate
Shoalwater Bay	Shoalwater Creek		-	low	low	high	low
Port Clinton	Waterpark, Fitzroy River		-	low	low	high	low
Rodds Bay	Calliope, Boyne River Baffle Creek	Auckland Creek	Gladstone U, P, M	low	low	high	high*
Hervey Bay-Great Sandy Strait	Kolan, Burnett, Burrum, Mary Rivers		Maryborough U, Hervey Bay M	moderate	moderate	high	moderate

[#] U= urban area, P= port or loading facility, M= marina, AC= access channel; *= modified summary rating, see text.

6. ASSESSMENT AND MONITORING OF POLLUTANTS IN DUGONG PROTECTION AREAS

The GBRMPA is supporting several research and monitoring programs, the outcomes of which will contribute to the future management of DPAs, and in particular, will facilitate the completion of more detailed interagency environmental risk assessments for dugong habitats and stocks in Queensland waters.

6.1 Monitoring of Pollutant Levels in Marine Mammals

Tissue samples are being collected from dugongs (and other marine mammals) reported stranded in or adjacent to the GBRMP. The level of contaminants in the animal tissue is analysed with regard to the age, sex, condition, and home range of the animals. Potential hazard to human health from tissue consumption is also examined.

6.2 Monitoring of Pollutant Levels in Dugong Habitats

Sediment, seagrass, selected invertebrate and fish samples are collected from up to 11 locations from Cape York to Moreton Bay. Sites include Hinchinbrook Channel, Cleveland Bay, Upstart Bay, Shoalwater Bay, Keppel Bay, Port Curtis and Morton Bay. All sites selected are recognised as important dugong habitat and are influenced by a range of human urban and agricultural activities. Samples are analysed for organochlorines, PCBs, atrazine and heavy metals. First results of samples, taken at non-flood conditions, show relatively low concentrations of a range of pesticides in sediments and seagrass along the GBR coast. The future sampling program will also include flood conditions to measure potential peak concentrations.

6.3 Long-term Water Quality Monitoring

Additional to the programs specifically targeting dugong conversation issues, two general water quality monitoring programs are in place at GBRMPA, which deliver important information for the management of water quality in the DPAs and elsewhere in the GBRWHA.

6.3.1 Chlorophyll Monitoring

This program uses the concentrations of chlorophyll *a* in the water column as an indicator for nutrient levels, i.e. eutrophication (Steven et al. 1998). Higher chlorophyll *a* concentrations close to the coast, and hence higher nutrient availability, compared to further offshore have been detected in samples extending south of Cooktown. The catchments adjacent to this area are used for intensive agriculture (grazing and crop cultivation).

6.3.2 Flood Plume Monitoring

Since 1991, a multi-institutional research program targets flood plumes associated with tropical cyclones, and investigates their temporal and spatial extent and the chemical composition. Results to date indicate that these flood events are especially important because the bulk of terrestrial material, such as sediments, nutrients, and associated contaminants, is then transported into the inner lagoon (Devlin et al. 2001). At these times, inshore seagrass meadows experience the highest concentrations of nutrients, suspended solids, and possibly contaminants during the year.

7. JURISDICTIONAL LIMITATIONS

The previous sections have clearly demonstrated that the major sources of water quality problems for DPAs and the GBRWHA originate from land uses in the adjacent river catchments. The catchments are outside the boundaries of the GBRMP and the GBRWHA. Thus the *Great Barrier Reef Marine Park Act 1975* (GBRMP Act) provides little opportunity for GBRMPA to control activities within these catchments. There is a provision in Section 66(2)(e) of the GBRMP Act that enables the Commonwealth Minister for Environment and Heritage to develop regulations pertaining to activities (whether in the Marine Park or elsewhere) that may pollute water in a manner harmful to animals and plants in the Marine Park. This provision has recently been utilised with the introduction of the *Great Barrier Reef Marine Park (Aquaculture) Regulations 2000* to regulate aquaculture discharges in waters contingent to the GBRWHA.

The Commonwealth Government has an obligation with regard to the areas of 'National Environmental Significance', such as the GBRWHA, under the *Environmental Protection and Biodiversity Conservation Act 1999.* This Act came into force on 16 July 2000 and under this Act it is an offence for someone to take an action that has a significant impact on a matter of 'National Environmental Significance' without approval from the Commonwealth Minister. For example, an action outside the Marine Park but within the GBRWHA may require Commonwealth Ministerial approval. Several areas, which potentially fall within the jurisdiction of the new Act, are located within or adjacent to the DPAs. Issues identified as matters of 'National Environmental Significance' are:
World Heritage;
Wetlands of international importance;
Listed migratory species and threatened species and communities;
Protection of the environment from nuclear actions;
Marine environment; and
Additional matters of national environmental significance (related to constitutional issues such as international trade or commerce).

Management of catchment contamination sources is primarily under the control the Environmental Protection Agency (Queensland *Environmental Protection Act 1994*) and the Department of Natural Resources and Mines (Queensland *Water Act 2000*). Management of point source discharges adjacent to the GBRWHA is a less complex situation and a majority of these discharges are licensed under the Queensland *Environmental Protection Act 1994*.

A range of regional planning processes exists in the GBR Catchment—both statutory and non-statutory—including the development of the Regional Coastal Management Plans under the *Coastal Protection and Management Act 1995*. Eleven areas have been identified along the Queensland coast for these plans, nine of which include the GBR coast. Twenty local governments adjoin the boundary of the GBRWHA, with a total of 42 in the GBR Catchment. Local governments play a significant role in development assessment and approvals through Planning Schemes. The *Integrated Planning Act 1997* (IPA), with a primary aim to achieve ecologically sustainable development, is the basis for those schemes and most local government's are reviewing existing schemes to meet the requirements of the IPA by 2003. The GBRMPA has the opportunity to comment on the strategies contained in these schemes from the initial stages of development.

8. DISCUSSION

At present, DPAs essentially only protect dugongs from netting and other pressures that are related to fishing practises, thereby raising concerns that general dugong health in the existing 16 DPAs may not be adequately protected. The risk assessment in Section 5 indicates a clear need to address water quality issues in DPAs, particularly in those DPAs that were rated to be at a high or moderate risk, to ensure that the existing DPAs are sanctuaries for the protection and rehabilitation of GBR dugong stocks.

It is now widely recognised that the loss of sediment, nutrients, fertilisers and pesticides from the rivers of the GBR catchment needs to be reduced. The GBRMPA has recently prepared a report on targets for pollutant loads to the GBRWHA in response to the Great Barrier Reef Ministerial Council meeting on 8th June 2001. A scientific working group was established, which:
reviewed the available water quality data and existing national water quality guidelines;
prioritised the Queensland catchments according to the risk present to the Reef; and
recommended minimum targets for pollutant loads that would halt the decline in water quality entering the Reef.

Data and guidelines included in the scientific working group's review were drawn from a variety of sources, such as the National Land and Water Resources Audit, the Australian Institute of Marine Science, the CRC Reef Research Centre, the Australian and New Zealand Environment and Conservation Council, and the GBRMPA.

These data and guidelines were used to formulate 10-year targets (2011) for reduction of pollutant loads entering the GBR. The targets set for the entire Great Barrier Reef catchment are as follows:
Sediment – 38 % reduction from 5,000,000 tonnes per km^3 to 3,100,000 tonnes per km^3
Nitrogen – 39% reduction from 19,500 tonnes per km^3 to 12,000 tonnes per km^3
Phosphorous – 47% reduction from 3,800 tonnes per km^3 to 2,000 tonnes per km^3
Chlorophyll –30 to 60% reduction below present levels.
Heavy metals and pesticides –reductions in detectable levels.

These targets are included in the Water Quality Action Plan (WQAP) prepared by the GBRMPA for Ministerial Council. This is the first phase in a staged approach aiming to reverse the trend in declining water quality and eventually allowing for the recovery of inshore reefal ecosystems.

The water quality targets need to be specifically considered in relevant plans under the National Action Plan for Salinity and Water Quality (NAP) (which covers the Burdekin, Fitzroy and Burnett River Catchments) and within the Natural Heritage Trust 2 framework for catchments not covered by the NAP. In this way, the water quality targets for the Great Barrier Reef will be delivered within a framework that ensures strategic Commonwealth input but with the responsibility for on-ground implementation at the appropriate level.

Examples of actions that will contribute to reducing land-based inputs to the GBRWHA include:
Maintenance of sufficient vegetation cover on agricultural lands to minimise sheet erosion and thus minimise the amount of sediment lost from the GBR catchment.
- Implementation of effective waterway, bank erosion management strategies to minimise the amount of sediment lost from the waterways of the GBR catchment.

Introduction of legislative regulation regarding disturbance and management of acid sulfate soils.
Inclusion of soil nutrient analysis as a necessary component of land and water management plans.

Management of fertiliser and pesticide application rates in the GBR catchment through land and water management plans.

Application of measures to reduce pollutant loads will be critical to maintain and preserve the health of the water quality in the GBR. In particular, measures to protect water quality will be essential to the DPAs that were rated as being at high or moderate risk of water and habitat quality impacts, if these areas are to be maintained as suitable protected habitats for dugong populations in the long term. From the risk analysis, the major catchments that require management focus include the catchments of the Herbert, Proserpine, O'Connell, and Pioneer Rivers, and Plane Creek.

An integrated, whole of government approach is required for successful management of this issue. The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area (GBRMPA 1994) was developed by Commonwealth, Queensland and Local government agencies, industries and community groups to identify a clear set of management objectives for all decision-making related to the GBRMP. This plan includes a commitment by all groups to better catchment management and the reduction of pollutant input from the land to the GBRWHA.

9. CONCLUSION

The DPAs in the Great Barrier Reef World Heritage Area are under threat from land-based activities in the adjacent Great Barrier Reef catchment. These activities influence water quality, particularly in coastal areas, which has potential negative impacts on dugong health and dugong habitat, especially seagrass beds.

With the cooperation of Government agencies, peak industry organizations and the community, water quality and habitat protection can form a key part of the strategy to help recover the declining dugong population in the Great Barrier Reef south of Cooktown.

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APPENDICES

APPENDIX 1.

Table A1. Land use statistics of catchments adjacent to Dugong Protection Areas (DPAs). n/a= data not available.

Catchment	Basin No.[1]	Adjacent DPA	Area (km^2)[1]	Mean runoff (km^3 y^{-1})[2]	Runoff (% of rainfall)[2]	Land use (% of total area)				Population[5]
						Grazing[3]	Cleared[4]	Sugar[1]	Other crops[1]	
Herbert River	116	Hinchinbrook Taylors Beach	9843	4.0	27.1	82.2	15.0	7.0	0.4	8778
Black River	117	Cleveland Bay	1057	0.4	23.5	75.9	48.3	0.9	0.4	1579
Ross River	118		1707	0.5	28.0	86.8	72.5	<1	0.1	106445
HaughtonRiver	119	Bowling Green Bay	4044	0.7	20.6	85.1	77.9	13.1	0.5	10343
Burdekin River	120	Upstart Bay	130126	10.3	10.9	98.9	74.1	0.1	0.0	17497
Don River	121	Edgecumbe Bay	3695	0.8	19.4	96.9	92.1	1.3	1.7	3404
Proserpine River	122	Repulse Bay	2535	1.1	31.3	81.7	60.6	7.7	0.1	16286
O'Connell River	124		2387	1.5	43.9	79.8	51.3	11.1	0.0	5082
Pioneer River	125	Newry region Sand Bay	1570	1.2	54.7	74.3	30.1	18.8	0.0	44159
Plane Creek	126	Llewellyn Bay Ince Bay	2539	1.5	52.2	72.1	34.0	21.6	0.0	6911
Styx River	127	Clairview	3012	0.8[6]	23.0[6]	98.3	41.2	n/a	n/a	n/a
Shoalwater Creek	128	Shoalwater Bay	3705[6]	0.8[6]	20.0[6]	n/a	n/a	n/a	n/a	n/a
Waterpark	129	Port Clinton	1840	0.7[6]	29.0[6]	n/a	n/a	n/a	n/a	n/a
Fitzroy River	130		142537	6.1	5.8	93.0	61.7	0.0[7]	3.3[7]	114536
Calliope River	131		2236	0.3	17.0	90.9	83.7	n/a	n/a	24387
Boyne River	133	Rodds Bay	2590	0.3	11.6	86.0	75.8	n/a	n/a	5009
Baffle Creek	134		3996	0.8	21.9	87.5	80.5	0.4	0.2	447
Kolan River	135		2901	0.4	13.3	81.0	86.1	5.5	0.2	1471
Burnett River	136	Hervey Bay-Great Sandy Strait	33248	1.2	4.5	84.0	71.8	0.7	0.2	59284
Burrum	137		3340[6]	0.7[6]	20.0[6]	53.4[7]	n/a	8.8[7]	0.1[7]	n/a
Mary	138		9595[6]	2.3[6]	21.0[6]	64.5[7]	n/a	1.2[7]	0.1[7]	58000[8]

Sources: [1]Department of Natural Resources basin coverage (1994); [2]Furnas, unpub. data; [3]estimated by substraction of available land use data from the total catchment area; [4]Bureau of Rural Sciences (1996); [5]Australian Bureau of Statistics Census data (1996); [6]Pulsford 1996, [7]Rayment & Neil 1997; [8]DPI 1993a.

Table A2. Fertiliser and pesticide application rates in river catchments adjacent to Dugong Protection Areas. Fertiliser application rates are from 1990, averaged over the whole catchment area and averaged per unit of mean annual runoff volume. Data for annual pesticide application rates (g active ingredient per ha) are from 1991–94, for sugarcane lands only. Pesticides have been pooled into use groups (herbicides, insecticides, fungicides), which is considered adequate for the scope of this assessment, however, does not account for potentially different behaviour of metabolites in the aquatic environment. ai=active ingredient, n/a= data not available.

River catchment	Fertiliser Application Rates[1]				Pesticide application rates[2]		
	Nitrogen (kg /ha)	Nitrogen (kg /1000 ML)	Phosphorus (kg/ha)	Phosphorus (kg /1000 ML)	Herbicide (g ai/ha)	Insecticide (g ai/ha)	Fungicide (g ai/ha)
Herbert	9.67	1.96	1.31	0.27	95.9	3.2	0.5
Black	0.05	0.01	0	0	7.9	0.3	0.0
Ross	0.11	0.06	0	0	n/a	n/a	n/a
Haughton	24.12	11.65	1.68	0.81	136.0	0.8	0.8
Burdekin	0.24	0.31	0.02	0.03	3.1	0.0	0.0
Don	3.72	2.10	0.98	0.55	20.1	0.1	0.1
Proserpine	12.23	2.12	1.85	0.32	174.7	14.1	0.0
O'Connell	18.03	2.63	2.21	0.32	459.3	10.2	0.7
Pioneer	36.85	5.52	4.35	0.65	533.1	32.7	0.9
Plane	28.78	5.61	3.73	0.73	1132.3	70.5	1.7
Styx	<0.01	<0.01	0.01	<0.01	n/a	n/a	n/a
Shoalwater	<0.01	<0.01	0.07	0.03	n/a	n/a	n/a
Waterpark	2.58	0.68	0.40	0.10	n/a	n/a	n/a
Fitzroy	0.51	1.02	0.06	0.11	n/a	n/a	n/a
Calliope	0.27	0.18	0.09	0.06	n/a	n/a	n/a
Boyne	0.03	0.02	0.01	<0.01	n/a	n/a	n/a
Baffle	1.05	0.54	0.27	0.14	4.3	1.1	0.1
Kolan	5.67	3.64	1.21	0.78	40.1	9.6	0.3
Burnett	1.37	2.61	0.35	0.67	6.6	1.5	0.1
Burrum	8.89	4.14	1.95	0.91	69.5	31.4	0.5
Mary	2.92	1.21	1.09	0.46	15.4	3.0	0.0

Sources: [1]Pulsford 1996, [2]calculated from Hamilton & Haydon 1996

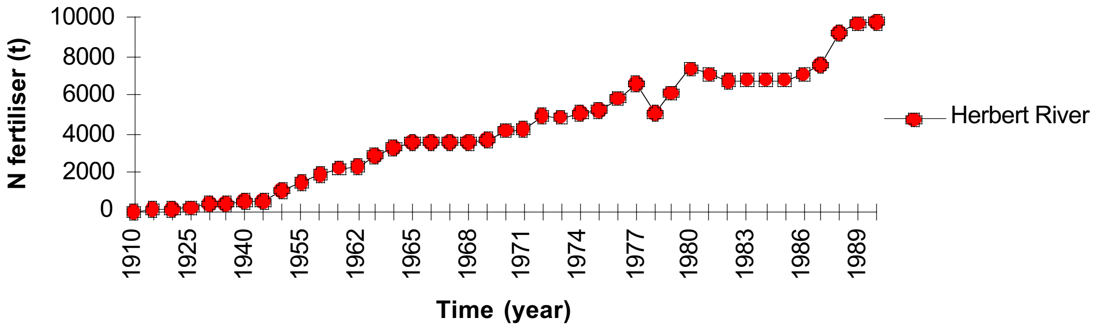
Table A3. Sediment and associated nutrients export from catchments adjacent to Dugong Protection Areas.

Basin Name	Sediment supply (t/ha/y)	Sediment export to the coast (t/ha/y)	Sediment export to the coast (t/y)	Sediment export ratio (current: natural)	Sediment export to the coast by land use (% of total)					Total N export rate (kg/ha/yr)	Dissolved N (% of total)	Total P export rate (kg/ha/yr)	Dissolved P (% of total)
					Forest	Grazing	Sugar	Other crop	Other				
Herbert River	1.4	0.7	665,000	2	25	63	11	1	<1	3.1	21	0.6	13
Black River	1.7	1.2	83,000	3	25	70	1	3	<1	3.8	16	0.5	8
Ross River	1.8	0.5	58,000	2	3	76	<1	2	18	2.1	22	0.3	8
Haughton River	1.9	0.5	172,000	5	12	76	11	0	6	1.5	15	0.3	5
Burdekin River	1.4	0.2	2,443,000	6	6	93	<1	1	<1	0.8	18	0.2	3
Don River	3.1	1.7	510,000	7	6	93	<1	2	<1	3.7	8	1.0	2
Proserpine River	2.0	1.2	227,000	19	32	50	12	4	3	2.5	20	0.7	8
O'Connell River	2.4	1.9	366,000	22	44	44	9	3	0	5.2	15	0.9	6
Pioneer River	2.3	1.7	288,000	41	37	23	47	<1	<1	6.2	24	1.6	10
Plane Creek	1.1	0.7	115,000	38	39	28	30	2	1	1.6	34	0.3	13
Styx River	1.2	0.5	136,000	27	21	76	<1	2	<1	1.5	18	0.4	4
Shoalwater Creek	0.5	0.2	45,000	15	10	86	0	4	<1	0.6	58	0.1	30
Water Park Creek	0.2	0.1	8,000	27	55	44	0	<1	<1	0.3	63	0.0	41
Fitzroy River	1.1	0.2	2,635,000	18	12	70	0	14	0	0.6	25	0.1	5
Calliope River	0.8	0.3	61,000	31	17	63	0	<1	20	0.9	32	0.2	8
Boyne River	0.4	0.1	17,000	4	18	70	0	0	12	0.6	56	0.1	25
Baffle Creek	0.6	0.3	103,000	26	40	53	<1	6	1	1.2	39	0.2	15
Kolan River	0.7	0.2	62,000	31	29	56	10	5	<1	1.0	34	0.2	15
Burnett River	0.9	0.2	729,000	32	24	67	3	4	2	0.7	32	0.1	8
Burrum River	0.3	0.1	34,000	34	54	23	17	5	1	0.9	64	0.1	25
Mary River	0.7	0.3	268,000	19	41	48	2	7	3	1.7	42	0.2	12

Source: CSIRO Land & Water and the National Land and Water Resource Audit (I. Prosser, unpub. data, 2001, will be publicly available at www.nlwra.gov.au), methodology described in Prosser et al. (2001)

APPENDIX 2

Increase in fertiliser use on catchments adjacent to Dugong Protection Areas.
Source: Pulsford (1996).



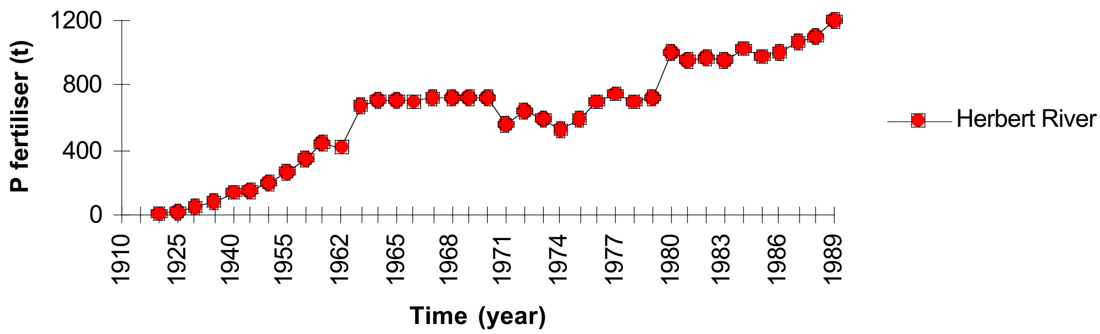
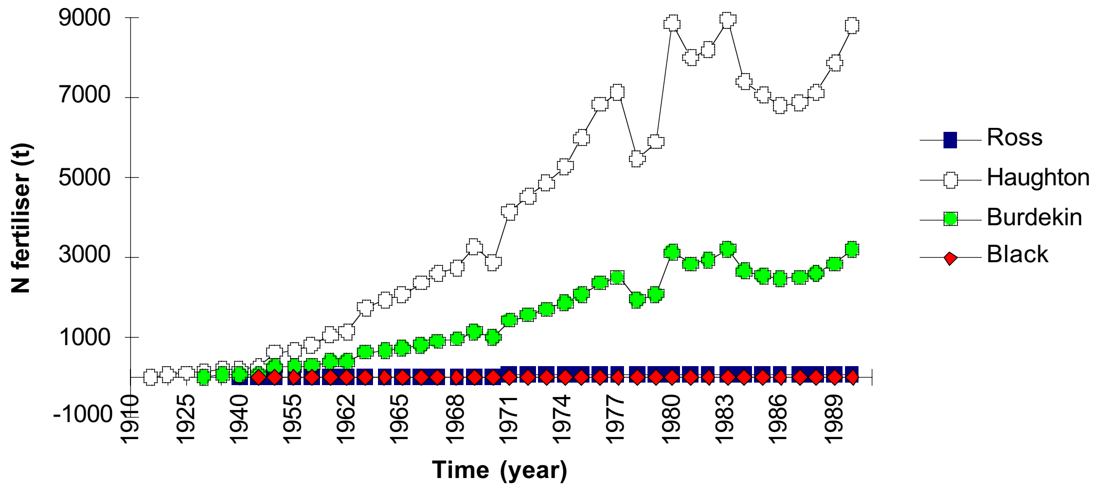


Figure A1. Increase in fertiliser use in catchments adjacent to the Hinchinbrook and Taylors Beach Dugong Protection Areas.



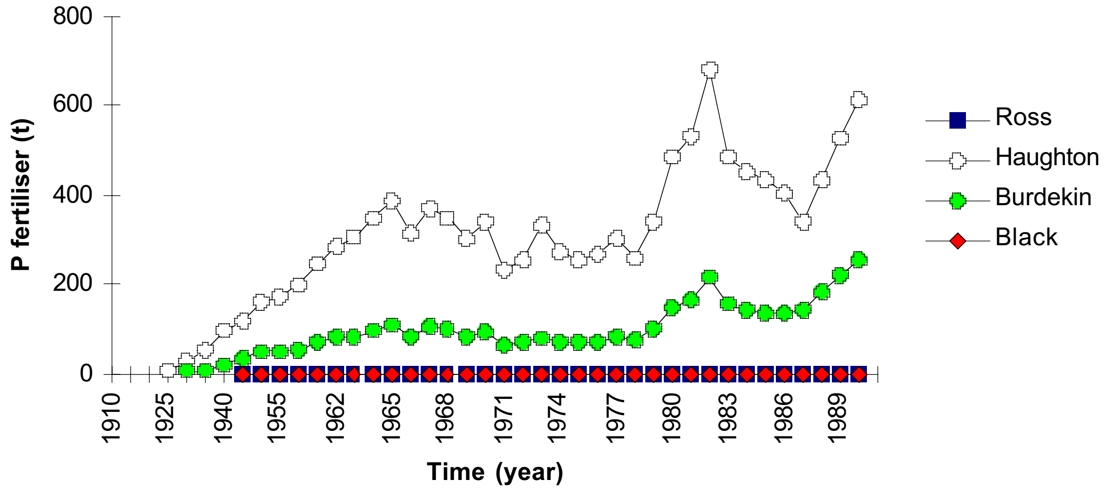
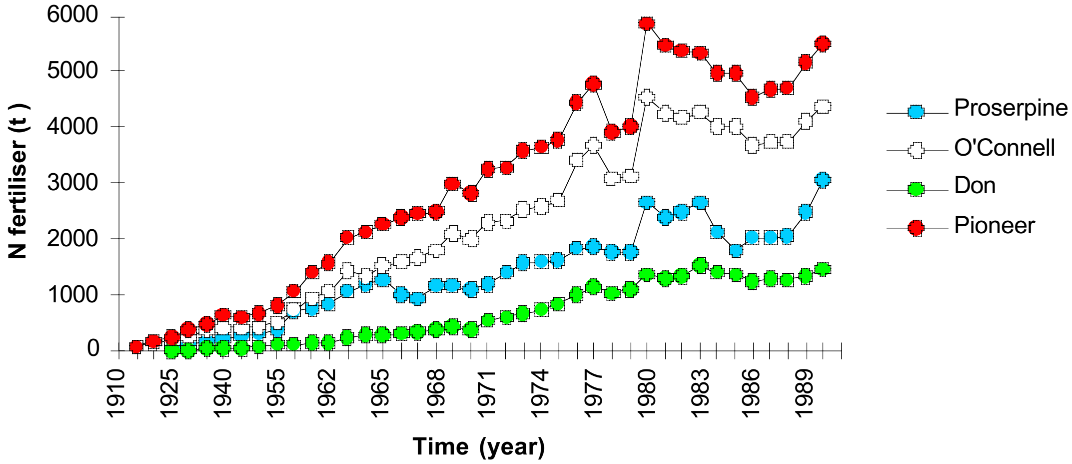


Figure A2. Increase in fertiliser use in catchments adjacent to the Cleveland Bay, Cape Bowling Green Bay, and Upstart Bay Dugong Protection Areas.



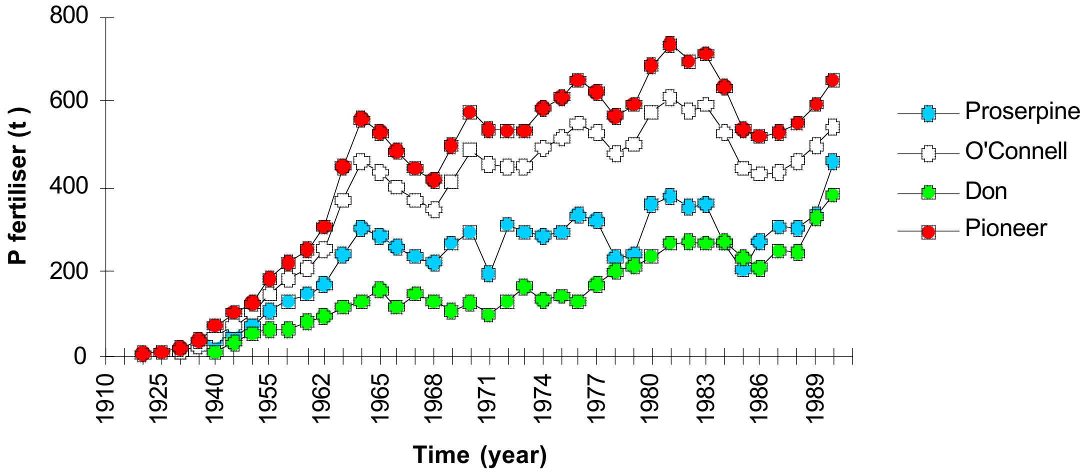
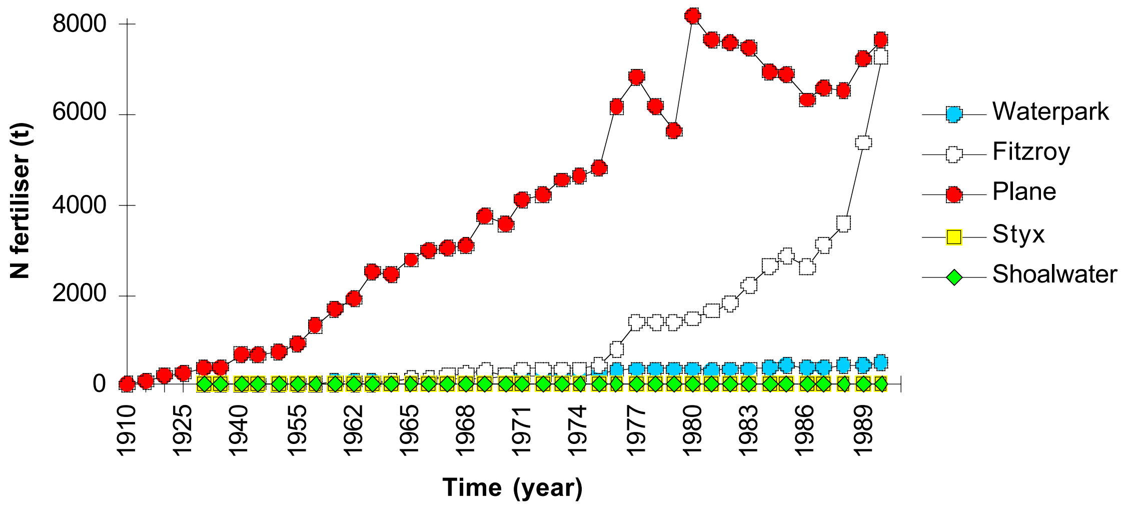


Figure A3. Increase in fertiliser use in catchments adjacent to the Edgecumbe Bay, Repulse Bay, Newry Region and Sand Bay Dugong Protection Areas.



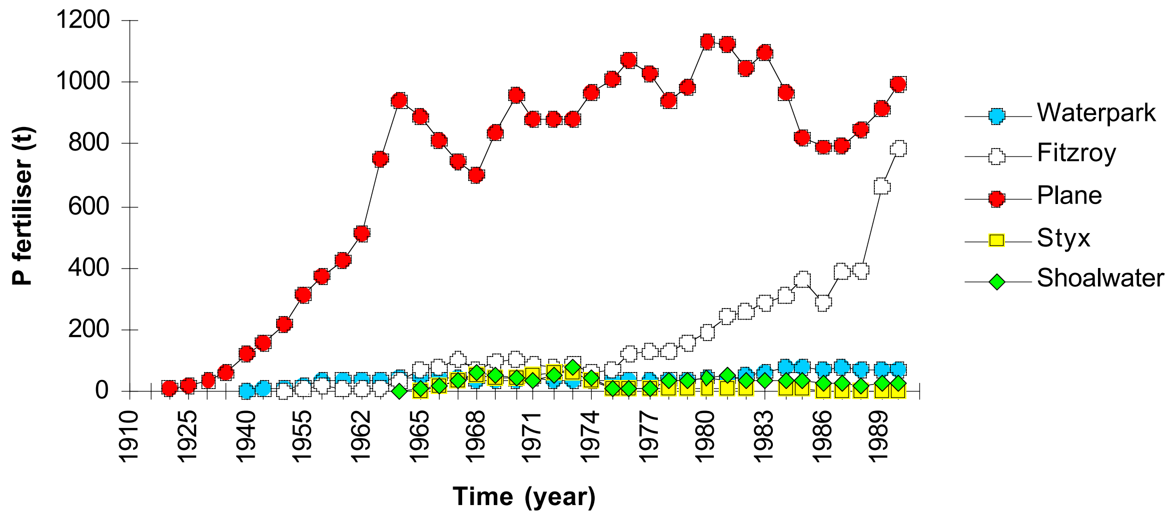
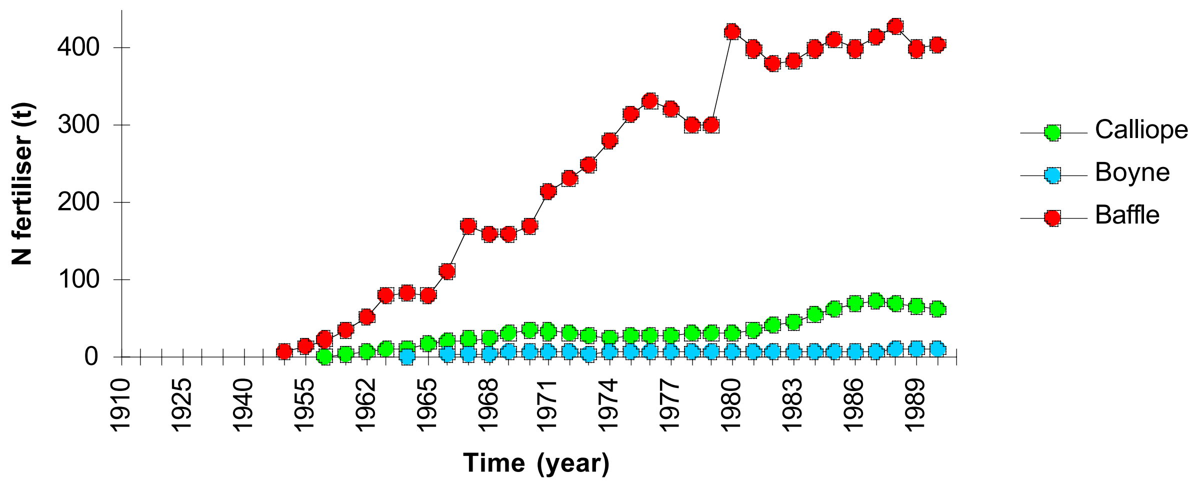


Figure A4. Increase in fertiliser use in catchments adjacent to the Llewellyn Bay, Ince Bay, Clairview Region, Shoalwater Bay and Port Clinton Dugong Protection Areas.



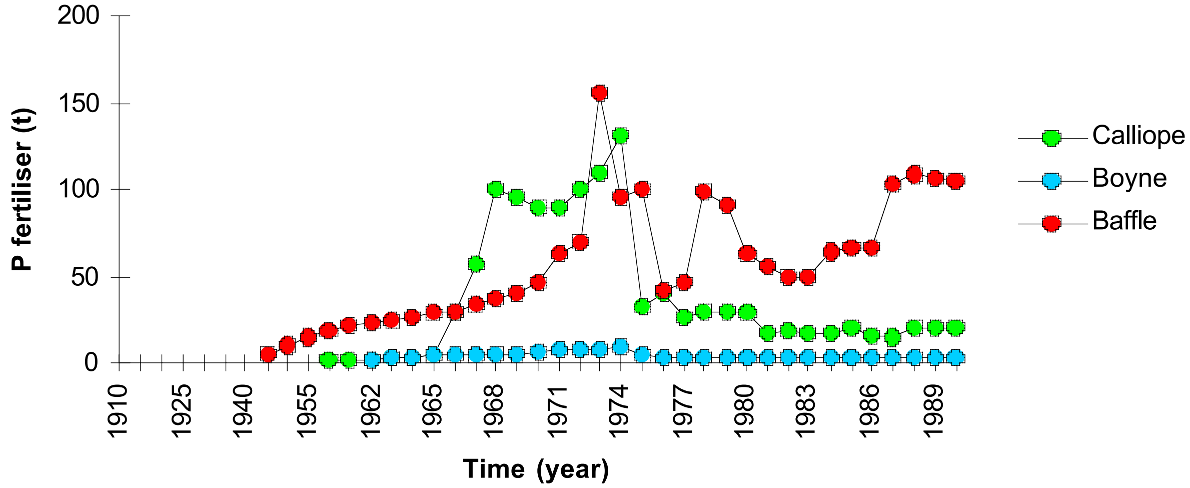
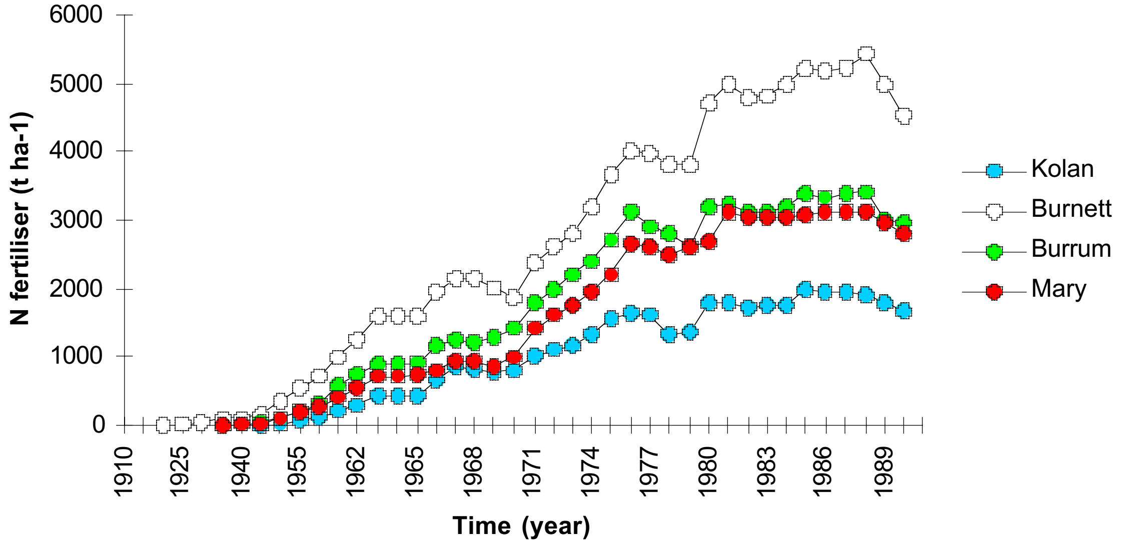


Figure A5. Increase in fertiliser use in catchments adjacent to the Rodds Bay Dugong Protection Area.



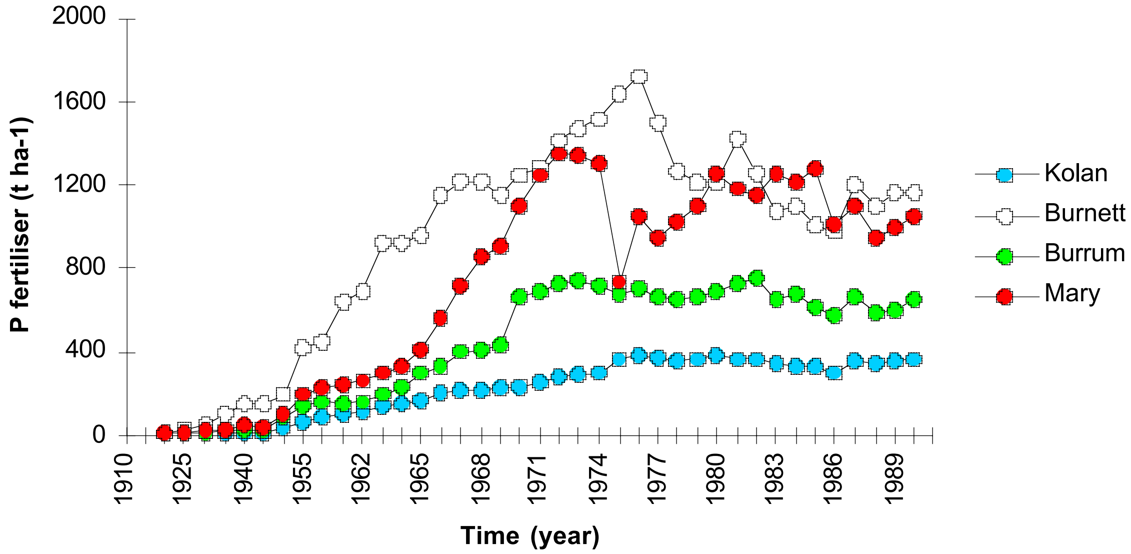


Figure A6. Increase in fertiliser use in catchments adjacent to the Hervey Bay–Great Sandy Strait Dugong Protection Area.