



Marine and Tropical Sciences Research Facility

Proceedings of the 2008 Marine and Tropical Sciences Research Facility Annual Conference



Compiled by R. Taylor and S. Long



Australian Government
Department of the Environment,
Water, Heritage and the Arts

 **Reef &
Rainforest**
RESEARCH CENTRE

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Contents

Minister's Note.....	iii
Note from the Chair, Reef and Rainforest Research Centre.....	iv
Introduction	v
The acoustic and surface behaviour of coastal dolphins in Queensland: Implications for management	1
A. Berg Soto, H. Marsh, G. Parra and M. Noad	
Visitation and recreation in the Wet Tropics World Heritage Area: A comparison of urban and regional residents.....	8
J. Carmody and B. Prideaux	
Dating and mapping historical changes in Great Barrier Reef coral communities	12
T. R. Clark, G. Roff, J-X. Zhao, T. Done and J. M. Pandolfi	
Designing a policy package solution for a cassowary population objective	16
A. Coggan and S. Whitten	
Developing a technique to quantify spatial variation in herbivory on coral reefs	21
C. Cvitanovic, A. S. Hoey and D. R. Bellwood	
Developing indicators of social resilience to changes in water quality – a Townsville case study	29
M. Gooch, L. Cullen, C. Manning and J. Butler	
Assessing the habitat quality of remnant and riparian vegetation	36
M. Goosem, L. Searle and C. Pohlman	
Community monitoring of Great Barrier Reef coral reefs	44
J. Hill	
Cassowary conservation through adaptive, collaborative planning at Mission Beach.....	51
R. Hill, K. Williams, P. Pert and E. Harding	
An assessment of wetland connectivity in the Tully-Murray floodplain using a hydrodynamic model	64
F. Karim, A. Henderson, J. Wallace, P. Rash, A. H. Arthington and R. Pearson	
Just a bunch of pretty trees? Rainforest tourism in the Wet Tropics World Heritage Area	71
K. McNamara and B. Prideaux	
Managing scientific knowledge as a basis for management of the Great Barrier Reef Marine Park	75
R. Reichelt	
<i>Symbiodinium</i> diversity on the Great Barrier Reef	81

E. M. Sampayo, L. Tonk, A. H. Baird, M. J. H. van Oppen and O. Hoegh-Guldberg	
Climate change projections for the tropical rainforest region of North Queensland.....	88
R. Suppiah, D. Abbs, I. Macadam, J. L. McGregor, K. Nguyen, J. Ricketts, M. Thatcher and P. H. Whetton	
Attitudes of recreational fishers to the rezoning of the Great Barrier Reef Marine Park.....	96
S. Sutton and O. Li	
Update on the status of reefs of the Great Barrier Reef from the AIMS Long-term Monitoring Program: Status Report # 8	102
H. Sweatman	
Ecological impacts of tropical cyclones on terrestrial ecosystems of the Wet Tropics region: Insights from Tropical Cyclone <i>Larry</i>	107
S. M. Turton	
The impacts of climate change on above-ground productivity in the Australian Wet Tropics	114
V. Valdez-Ramirez	
Assessing the cost-effectiveness of market-based instruments for water quality improvement in linked terrestrial and marine ecosystems using a spatial environmental-economic modelling approach.....	119
M. E. van Grieken and P. C. Roebeling	
Sediment and nutrient export from the Tully and Murray catchments during floods .	126
J. S. Wallace, L. S. Stewart, A. Hawdon and R. Keen	
Current, pre-clearing and 2025 scenarios of vegetation cover and cassowary habitat in Mission Beach and surrounds	130
K. J. Williams, R. Hill, P. Pert, E. Harding and T. O'Malley	
Potential gaps in the complementary representation of regional ecosystems within protected areas of the Wet Tropics natural resource management planning region..	150
K. J. Williams, D. P. Faith, S. Ferrier, R. Hill and P. Pert	
List of Available Conference Abstracts	184
Registered Delegates of the 2008 MTSRF Annual Conference.....	215

Minister's Note

Edited Transcript of Video Message Aired at the 2008 Annual Conference



“Hi, I’m Peter Garrett, the Federal Minister for the Environment, and welcome to the 2008 Marine and Tropical Sciences Research Facility conference in Cairns. Apologies for not being there, I’m at a conference in Paris of the OECD [Organisation for Economic Cooperation and Development] environment ministers.

We recognise that there are increasing challenges facing our reefs, our rainforests and our fragile coastline. Of course, one of our greatest challenges is climate change, with some of the adverse impacts already evident in this area such as the mass bleaching of corals, declining rainforest biodiversity and coastal erosion and inundation in the Torres Strait island region, to name just a few.

These threats, combined with declining water quality and increasing population, present a real collective challenge to us all. The Australian Government has committed forty million dollars over four years to the Marine and Tropical Sciences Research Facility [MTSRF] to fund scientific research to support the conservation and sustainable use of our environment. The value of our reef and rainforest can be directly measured through industries such as tourism that rely on the environment to generate over eight billion dollars annually and employ nearly fifty thousand people.

The cultural and spiritual value of this amazing area is less easily quantified in dollar terms but no less important to Australia as a vital part of our natural heritage. Through the MTSRF program over three hundred of Australia’s best scientists are working on the issues of climate change, threatened species, declining water quality and sustainable use of the environment. The program has formed strong partnerships between research institutions, environmental managers and industries. It is through these partnerships that we can collectively benefit from the outcomes of the broad initiative research with a direct pathway to influencing the management and sustainable use of our environment. This is a distinguishing feature of this work and active involvement of the users of this information and setting the direction of the research is essential in achieving the outcomes that we want to see.

I think we have reached a time when many of these difficult ecological challenges need to be tackled head on. Collaboration across all areas of the community and government is clearly essential to secure the future of the reef and rainforest systems. So this conference provides a tremendous opportunity to share information and explore solutions to the challenges facing the reef and the rainforest today. I trust that the 2008 MTSRF Conference will be a success and a benefit to all. Thanks very much and good luck.”

The Hon. Peter Garrett AM MP

Minister for the Environment, Heritage and the Arts

Note from the Chair, Reef and Rainforest Research Centre



It is with pleasure that the Reef and Rainforest Research Centre (RRRC) presents the Proceedings of the 2008 Annual Conference of the Marine and Tropical Sciences Research Facility (MTSRF).

The Australian Government's \$40 million MTSRF brings together a consortium of over three hundred researchers from fifteen research providers and end users from at least 38 organisations, including government departments, industry, and community and Indigenous groups.

The RRRC manages and delivers the MTSRF on behalf of the Department of the Environment, Water, Heritage and the Arts, with the aim of increasing the sustainability of use and management of North Queensland's key environmental assets – the Great Barrier Reef, Wet Tropics rainforests and catchments, and the Torres Strait.

This volume contains short papers describing some of the work in progress towards developing science solutions to some of North Queensland's most pressing environmental problems.

For more information about the MTSRF or the RRRC, please visit our website: <http://www.rrrc.org.au/>.

Mr Richard Ireland

Chair, Reef and Rainforest Research Centre Limited

Introduction

The Reef and Rainforest Research Centre convened the annual MTSRF Synthesis Conference over four days in Cairns, North Queensland, from 28 April to 1 May 2008.

Over 160 researchers, representatives of end user organisations and interested community members listened to 66 presentations from across the entire research spectrum of the MTSRF. Of particular note was the attendance of key personnel from the Parliamentary Standing Committee on Climate Change, who were briefed on the major relevant MTSRF outcomes to date.

Two out-of-session meetings were held alongside the conference, the establishment of a MTSRF environmental offset policy working group, and a workshop designed to bring together end users and developers of the *Atlas of Australia's Tropical Lands and Seas (ATLAS)*.

In addition to the full delegates and abstracts lists, this proceedings volume features some of the presentations in the form of short summary papers. Please visit the MTSRF website (<http://www.rrrc.org.au/mtsrf/>) for more detailed technical reports or access to formal scientific publications relevant to these and other MTSRF projects. Many conference presentations are also available for download in .pdf format from the relevant project pages on the MTSRF website.



The acoustic and surface behaviour of coastal dolphins in Queensland: Implications for management

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Introduction

The marine wildlife values of the Great Barrier Reef World Heritage Area are a major reason for the region's World Heritage listing. These values include internationally significant populations of two species of coastal dolphins: the Indo-Pacific humpback dolphin (*Sousa chinensis*), the Australian stocks of which may be a new species of cetacean (Frere *et al.* in press; Hale *et al.* 1998); and the Australian snubfin dolphin (*Orcaella heinsohni*) which was first described in 2005 and is Australia's only recognised endemic cetacean (Beasley *et al.* 2005). As top predators, coastal dolphins play an important role in the function and structure of marine communities. Despite the importance of these populations, the scientific information needed for their conservation management is inadequate (Corkeron *et al.* 1997; Parra *et al.* 2006). This research project will increase knowledge of the behavioural ecology of these animals.

Incidental bycatch from fisheries and shark-control programs is amongst the most serious dangers to marine wildlife (Cockcroft and Krohn 1994; Hall 1996; Hoffman 1990; Marsh *et al.* 2003; Perrin *et al.* 1994; Silvani *et al.* 1999). Marine megafauna become entangled in fishing gear and drown (Brothers *et al.* 1999; Chan *et al.* 1989; Julian and Beeson 1998; Read 1994). Approaches to the bycatch problem being trialled by the Queensland Department of Primary Industries and Fisheries include: (1) attempts to change the behaviour of the fishers (e.g. using acoustic tracking and detection systems to alert them to the presence of dolphins) and (2) attempts to change the behaviour of the bycatch species (e.g. using acoustic alarms or pingers to alert the dolphins to the presence of nets). However, despite their success in reducing the bycatch of harbour porpoises (Kastelein *et al.* 2000; Kraus *et al.* 1997; Laake *et al.* 1998), pingers may not elicit the same response from other cetacean species (Dawson 1994). It is clear that potential solutions such as pingers should only be considered effective if they both reduce entanglements of at least one species, and have no adverse effects on any other species of concern (Hodgson *et al.* 2007).

The research project described here aims to inform conservation management agencies in Queensland of the potential effectiveness of acoustic alarms as bycatch mitigation measures for populations of the Indo-Pacific humpback dolphin and the Australian snubfin dolphin. The aims of the project are:

- To develop a comprehensive description of the acoustic behaviour of Indo-Pacific humpback and snubfin dolphins and relate it to their surface behaviour;
- To investigate and quantify the behavioural responses of dolphins to acoustic alarms to reduce bycatch in gillnets;

- To compare dolphin movement tracks around active and inactive pinger arrays simulating a net arrangement; and
- To use a spatial risk assessment approach to assess the likelihood of effectively implementing avoidance techniques (dolphin acoustic detection devices) and/or minimisation systems (acoustic alarms alerting dolphins) to reduce bycatch in gillnets by Queensland fisheries.

Methods

This PhD project is being conducted at two main study sites:

- Off Amity Point (27°24' S, 153°26' E), North Stradbroke Island, where Indo-Pacific humpback dolphins occur at relatively high density and a mixture of land-based observations and vessel-based opportunistic experiments was conducted from September 2007 to April 2008;
- In Cleveland Bay (19°15' S, 146°50' E) near Townsville, which supports an important population of Australian snubfin dolphins (Parra *et al.* 2002), and where a boat-based approach is being used during 2008-2009.

Relating acoustic and surface behaviour

During the vessel-based approaches, a behavioural observer scans for dolphin pods, while the vessel traverses areas where previous experience indicates there is a high likelihood of encountering dolphins (Parra 2005). Once a pod is detected, the vessel engine is turned off, the boat secured, and the observer begins recording observations by stating the current GPS position. Concurrently with Photo-ID, the behavioural observer records species identification, group size, school composition and all behavioural events visible using reticle binoculars (Fujinon Mariner 7x50). Behavioural states are recorded every five minutes. The surface behaviour of the dolphins is later analysed and categorised into four main behavioural states, based on Parra (2005): foraging, socialising, travelling or milling. To relate surface behaviour to acoustic behaviour, dolphins' vocalisations are also being recorded, by lowering a single High Tech Inc. hydrophone (model HTI-96-MIN) from the side of the vessel into the water. The hydrophone is connected to a Micro Track (M-Audio 24/96 digital recorder). Acoustic recordings are being analysed as spectrograms in the laboratory using an acoustic analysis program (Adobe Audition). Only medium to good quality samples are being analysed and categorised into vocalisation types, based on Van Parijs and Corkeron (2001). These vocalisation types are being matched to the surface behaviours concurrently recorded by the observer. This approach will provide us with the most complete possible description of the dolphins' behavioural repertoire.

Investigating behavioural responses to pingers

During the field seasons in Moreton Bay and Cleveland Bay, vessel-based surveys are being used to investigate the acoustic and surface behavioural response to acoustic alarms by using a pre-post observation protocol (Hodgson *et al.* 2007). Once animals are detected, we follow the observation approach described above. Behavioural observations are conducted for ten minutes. Once this period is over, a single pinger is introduced into the water. Observational recordings continue for another ten minutes, whereupon the pinger is removed and observations continue for another ten minutes. Both acoustic and surface behavioural responses of dolphins to the active pingers are being quantified by comparing frequency of behavioural events and duration rates for behavioural states in the absence and presence of the pinger.

Comparison of dolphins' movement tracks around a pinger array

During 2007-2008, 280 hours of land-based observations were conducted in Moreton Bay from a 4 m x 2 m wooden platform on the shoreline at Amity looking northwest onto the Rainbow Channel. Acoustic alarms were positioned in a line perpendicularly in front of this platform and across the channel, emulating their distribution in a gillnet. Two alternate programs were followed: (1) on odd-numbered days, three Fumunda pingers operating at the same frequency were deployed approximately fifty metres apart and lowered to an estimated depth of five metres; (2) on even-numbered days, inactive pingers were deployed in the same manner as controls.

The movements of dolphin pods around the acoustic stimuli array (Fumunda pingers and controls) were tracked with the use of a viodolite positioned on the platform to study the potential aversion and/or attraction of *Sousa chinensis* to the pingers. The viodolite (developed with assistance from Dr Eric Kniest) combines a video camera (Canon XM2) and a theodolite (Leica TC407) to obtain an accurate position of any surfacing dolphin within camera range. The theodolite communicates in real time with the computer to measure the horizontal angle or bearing by which the camera (attached on top) is recording the animals. Movement-tracking software (Cyclopes) matches the angles obtained by the theodolite to exported frames from the video footage, showing the dolphins recorded at the same time the theodolite angle was captured. The software then calculates the vertical angle of the surfacing dolphin by taking the difference between the animal and the horizon on the exported frame. This system is being used to measure any differences in the dolphins' movements in the presence of active and non-active pingers.

We have also deployed an in-water acoustic recording system to record vocalisation changes that may be linked to changes in dolphin movements during land-based observations. This system has been adapted from the experimental protocol used by the Humpback Whale Acoustic Research Collaboration (HARC) based at the University of Queensland. Two custom-made sonobuoys (frequency response of 0 Hz – 20 kHz) were placed in a straight line, parallel and close to the shore, 150 m apart and equidistant to the land-based observational platform. These sonobuoys sent sound data gathered by attached High Tech Inc. hydrophones (model HTI-96-MIN) via FM transmission to two receivers located on land and, finally, into a computer. As vocalisations are captured by the sonobuoys, the recording software (Ishmael) interprets the time delay reaching each instrument to provide a bearing. In this way we can verify that the sound is coming from the surfacing pod being followed with the viodolite. To date, we have recorded 36 hours with the viodolite and 80 hours with the in-water acoustic recording system.

Results to date

Acoustic and surface behaviour

Both behavioural states (general behaviour as a whole) and events (detailed surface actions) were recorded for *S. chinensis* during two hundred hours of boat surveys in Moreton Bay in 2007-2008. As these records include a series of new whistles and sounds for this species, which will require detailed description and categorisation, we have begun the acoustic analysis by creating an appropriate vocalisation catalogue for this dolphin population.

Our initial findings show that during the day, acoustic and surface behaviours do not always occur together. On the 36 occasions that dolphins were recorded, both behaviours were observed simultaneously only 61% of the time. On five occasions, the dolphins were heard but not seen; on nine occasions the dolphins were seen and not heard (Table 1). These preliminary results indicate that relying on hydrophones to warn fishers of dolphin presence is likely to be unreliable for about 25% of the time during the day.

Table 1: Number of occasions (days) on which Moreton Bay dolphins were detected visually or acoustically.

	Heard	Not heard
Day time observations		
Seen	22	9
Not seen	5	–
Night time observations		
Seen	7	1
Not seen	1	2

We also attempted to record the dolphins from the end of a fishing pier on eleven nights, under an intense light source that created a wide focal area. Dolphins were detected on nine occasions, on seven of which acoustic and surface behaviours were observed simultaneously (78%). Other silent pods may have been present in the vicinity but outside the focal arena, and thus undetectable to our instruments. Although limited visibility during the night reduces the area in which dolphins can be observed, the animals appear to exhibit both acoustic and surface behaviour more frequently during our night observations than during the day.

S. chinensis may be more vocal during the night, as sound may become a more reliable communication system under reduced light conditions. As most gill netting occurs at night, relying on hydrophones to detect dolphins may be more reliable than the day-time observations suggest. However, these preliminary results should be treated with caution as sample sizes are small and the differences are probably not significant.

Behavioural responses to pingers

Data were obtained from the Indo-Pacific humpback dolphin population present off Amity Point. Although this data set is small due to irregular dolphin presence, adverse weather conditions and equipment difficulties, it provides the first descriptions of the behavioural responses of Australian *S. chinensis* to acoustic alarms. Initial analysis of the observations of the behavioural states of dolphins in the presence or absence of pingers suggests there is no significant response by the dolphins to one type of acoustic alarm currently in use by the Queensland Shark Control Program, apart from some increase in travelling in the presence of active pingers (Table 2).

Table 2: Proportion of time dolphins recorded in various behavioural states in the presence and absence of pingers.

	Proportion of time dolphins recorded in various behavioural states		
Pinger	Foraging	Socialising	Travelling
Absent	60%	27%	12%
Present	57%	23%	20%

Acoustic responses by the dolphins to the pingers were recorded but the significance of these responses requires further analysis. The number of whistle vocalisations appears to increase around single pings emitted by Fumunda pingers. Spectrograms (frequency vs.

time) show a similar whistle arrangement during whistle interactions among different dolphins, suggesting that whistle vocalisations are used to establish contact with novel sounds among different individuals.

The only definite aversion response to pingers recorded from *S. chinensis* was a series of encounters with an individual that was trying to steal the bait from drum-line buoys deployed by the Queensland Shark Control Program in Rainbow Channel. On the first five test occasions, the individual left the buoy as soon as an active pinger was deployed. Some weeks later, the same dolphin did not respond to the pinger under the same experimental conditions. Although we are cautious about interpreting results based on one individual, these anecdotal observations confirm that dolphins can hear the acoustic alarm and suggest that reactions may be individualistic.

Movement tracks

The preliminary analyses of dolphin movement tracks around active and inactive pinger arrays during land-based observations on Amity Point are nearly complete. After frame processing, only tracks containing two or more fixed positions were included on the Cyclopes outputs displayed for each day. Fumunda acoustic alarms were active on half the field days. Summary data suggest that the active pingers did not affect the behaviour of the dolphins, except with respect to the percentage of days when pods crossed the array (Table 3). Statistical analyses on these data are being conducted in 2009.

Table 3: Preliminary analyses (expressed as averages) of the movement tracks of *S. chinensis* around and active/inactive pinger arrays during land-based observations from Amity Point.

	Pingers on	Pingers off
Number of pods / day	3	5
Minimum distance from dolphin to pinger (m)	31	31
Percentage of days with array crossings	29	86

Discussion

Initial findings suggest that Indo-Pacific humpback dolphins may vocalise more frequently at night than during the day, a result which needs to be checked with larger sample sizes. If it is confirmed, such behaviour may improve the chances of detecting dolphins from a fishing vessel during nocturnal gear deployment, and nocturnal dolphin acoustic detection systems may prove a useful mitigation measure to reduce bycatch of these animals.

Preliminary analysis of the field data obtained in 2007-2008 suggests that pingers do not substantially change the behaviour of *S. chinensis*. However, more sophisticated analyses are required to obtain a more complete understanding of behavioural responses by this species to acoustic alarms. The anecdotal observation of a dolphin grabbing bait from a shark buoy suggests that their response to pingers may be individualistic and situation dependent.

Although preliminary analysis detects very few behavioural differences between active and inactive pingers, the presence of active pingers may reduce the likelihood of dolphins crossing a net. Dolphins may avoid a sound emitting array, even though they are not repelled from an area. Further analysis is required to extract more information from these

observations. The acoustic tracking data must also be analysed to ratify the results found with the viodolite.

Our preliminary assessment suggests that acoustic alarms alone will not be adequate to solve the bycatch problem for Indo-Pacific humpback dolphins, although they may have some value in combination with other mitigation measures.

Acknowledgments

We would like to acknowledge the financial contribution from the different funding institutions that have made this research project possible, including the Australian Government's Marine and Tropical Sciences Research Facility, the Great Barrier Reef Marine Park Authority and the Sea World Research and Rescue Foundation. Support from James Cook University and the University of Queensland have been invaluable to the project. Collaboration from Dr Wayne Sumpton and Dr Neil Gribble from Queensland Department of Primary Industries and Fisheries has greatly contributed to the development of this research, as has logistic support from Moreton Bay Research Station and Straddie Holiday Parks. The helpful assistance of all volunteers involved in the project is gratefully acknowledged.

References

- Barlow J. and Cameron G.A. (2003) Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. *Marine Mammal Science* 19, 265-283.
- Beasley I., Robertson K. and Arnold P.W. (2005) Description of a new dolphin, the Australian snubfin dolphin, *Orcaella heinsohni*, Sp. N. (Cetacea, Delphinidae). *Marine Mammal Science* 19: 265-283.
- Brothers N.P., Cooper J. and Lokkerberg S. (1999) *The Incidental Catch of Seabirds by Longline Fisheries: Worldwide Review and Technical Guidelines for Mitigation*. FAO Fisheries Circular.
- Chan E.H., Liew H. and Mazlan A.G. (1989) The incidental capture of sea turtles in fishing gear in Terengganu, Malaysia. *Biological Conservation* 43, 1-7.
- Cockcroft V.G. and Krohn R. (1994) Passive gear fisheries of the Southwestern Indian and Southeastern Atlantic Oceans: An assessment of their possible impact on cetaceans. *Reports of the International Whaling Commission* (special issue) 15, 317-328.
- Corkeron P.J., Morissette N. M., Porter L.J. and Marsh H. (1997) Distribution and status of hump-back dolphins, *Sousa chinensis*, in Australian waters. *Asian Marine Biology* 14, 49-59.
- Culik B., Koschinski S., Treganza N. and Ellis G. M. (2001) Reactions of harbour porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. *Marine Ecology Progress Series* 211, 255-260.
- Dawson S.M. (1994) The potential for reducing entanglement of dolphins and porpoises with acoustic modifications to gillnets. *Reports of the International Whaling Commission* (special issue) 15, 573-578.
- Dawson S.M., Read A. J. and Slooten E. (1998) Pingers, porpoises and power: uncertainties with using pingers to reduce bycatch of small cetaceans. *Biological Conservation* 84, 141-146.
- DPI (2001) *Review of the Queensland Shark Control Program, Consultation Draft*. Queensland Fisheries Service, Department of Primary Industries, Brisbane, Australia.
- DPI&F (2006) *Report on the Eastern Fin Fish Fishery*. Department of Primary Industries and Fisheries, Brisbane.
- Frere C., Hale P., Porter L. J., Cockcroft V. G. and Dalebout M. L. (in press) Phylogenetic analysis of mtDNA sequences suggests revision of humpback dolphin (*Sousa* spp.) taxonomy is needed. *Marine and Freshwater Research*.
- Great Barrier Reef Marine Park Authority (2003) *Great Barrier Reef Draft Zoning Plan: Consultation Draft for Public Review*. Great Barrier Reef Marine Park Authority, Townsville, Australia.

- Hale P., Long S. and Tapsall A. (1998) *Distribution and conservation of delphinids in Moreton Bay*. In 'Moreton Bay and Catchment' eds. I. R. Tibbets, N. J. Hall and W. D. Dennison, pp. 477–486. School of Marine Science. University of Queensland, Brisbane, Australia.
- Hall M.A. (1996) On bycatches. *Review of Fish Biology and Fisheries* 6, 319-352.
- Hatakeyama Y., Ishii K., Soeda H., Shimamura T. and Kojima T. (1994) A review of studies on attempts to reduce the entanglement of Dall's porpoise, *Phocoena dalli*, in the Japanese salmon gillnet fishery. *Reports of the International Whaling Commission* (special issue) 15 549-563.
- Hodgson A., Marsh H., Delean S. and Marcus L. (2007) Is attempting to change marine mammal behaviour a generic solution to the bycatch problem? A dugong case study. *Animal Conservation* 10, 263-273.
- Hoffman R.J. (1990) Cetacean entanglement in fishing gear. *Marine Mammal Review* 20, 53-64.
- Julian F. and Beeson M. (1998) Estimates of marine mammal, turtle, and seabird mortality for two California gillnet fisheries: 1990-1995. *Fishery Bulletin* 96(2), 271-284.
- Kastelein R.A., Rippe H.T., Vaughan N., Shooneman N. M., Verboom W. C. and DeHaan D. (2000) The effects of acoustic alarms on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen. *Marine Mammal Science* 16, 46-64.
- Kraus, S. D., Read A.J., Solow A., Baldwin K., Spradlin T., Anderson E. and Williamson J. (1997) Acoustic alarms reduce porpoise mortality. *Nature* 388, 525.
- Laake J., Rugh D. and Baraff L.S. (1998) *Observations of harbour porpoises in the vicinity of acoustic alarms on a set gill net*, pp. 40. US Dept of Commerce, NOAA Tech Memo NMFS-AFSC-84.
- Marsh H., Arnold P.W., Freeman M., Haynes D., Laist D., Read A.J., Reynolds J. and Kasuya T. (2003) *Strategies for conserving marine mammals*. In 'Marine Mammals: Fisheries, Tourism and Management Issues', eds N. Gales, M. Hindell and R. Kirkwood, pp. 1–19 CSIRO Publishing: Melbourne, Australia.
- Parra G.J. (2005) *Behavioural ecology of Irrawaddy, Orcaella brevirostris (Owen in Gray 1866), and Indo-Pacific humpback dolphins, Sousa chinensis (Osbeck 1765), in northeast Queensland, Australia: a comparative study*, p. 357. School of Tropical Environment Studies and Geography, James Cook University, Townsville, Australia.
- Parra G. J., Azuma C., Preen A.R., Corkeron P.J. and Marsh H. (2002) Distribution of Irrawaddy dolphins, *Orcaella brevirostris*, in Australian waters. *Raffles Bulletin of Zoology Supplement* 10, 141-154.
- Parra G.J., Corkeron P.J. and Marsh H. (2006) Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: Implications for conservation. *Biological Conservation* 129, 167-180.
- Perrin W.F., Donovan G.P. and Barlow J. (1994) Gillnets and cetaceans. *Reports of the International Whaling Commission* (special issue) 15, 1-53.
- Read A.J. (1994) Interactions between cetaceans and gillnet and trap fisheries in the Northwest Atlantic. *Reports of the International Whaling Commission* (special issue) 15, 133-148.
- Ross G.J.B. (2006) *Review of the Conservation Status of Australia's Small Whales and Dolphins*, prepared for the Department of Environment and Heritage. Available from: www.deh.gov.au/coasts/publications/conservation-smaller-whales-dolphins.html. Accessed: 7 July 2008.
- Silvani L., Gazo M. and Aguilar A. (1999) Spanish driftnet fishing and incidental catches in the western Mediterranean. *Biological Conservation* 90, 79-85.
- Van Parijs S.M. and Corkeron P.J. (2001) Vocalizations and behaviour of Pacific humpback dolphins, *Sousa chinensis*. *Ethology*, 701-716.

Visitation and recreation in the Wet Tropics World Heritage Area: A comparison of urban and regional residents

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Introduction

Queensland's World Heritage-listed Wet Tropics rainforests contain numerous sites that are used by nearby residents for a range of recreational activities. The forests are also a popular site for tourists. The Wet Tropics Management Authority (WTMA), which manages this important resource, has a long-term agenda of proactively developing and maintaining close relationships with local communities. As part of this process of engagement the WTMA actively consults with a range of community groups and business organisations that have an interest in the Wet Tropics World Heritage Area (WTWHA). These groups include Aboriginal rainforest communities, the tourism industry, local residents and landholders. To facilitate this engagement, the WTMA has established a number of advisory groups.

Understanding the patterns of visitation to the forests and the forms of recreation that visitors participate in is essential information for management. The WTMA has maintained an active research program into aspects of visitation and recreation since 1992. The research reported in this paper relates to the latest survey of community use and engagement with the rainforests. The results reported here relate specifically to visitation and recreation.

About 350,000 people live within fifty kilometres of the World Heritage Area boundary, and visitation to the WTWHA is estimated at 4.4 million visits per year, with seventy percent of these visits occurring at sites north of Cairns (Bentrupperbäumer and Reser 2003). An estimated 1.76 million of these visits (40%) are made by residents of nearby local communities (Bentrupperbäumer *et al.* 2004).

Methods

A comprehensive nine-page survey consisting of 47 closed and open-ended questions based on the previous study conducted in 2002 (Bentrupperbäumer and Reser 2003) was distributed widely to residents of the Wet Tropics bioregion. Between May and October 2007, residents were targeted by a postal method and a drop-off / pick-up / mail-back procedure. Surveys were posted to residents of rural communities and the drop-off / pick-up / mail-back procedure was used in suburban and semi-urban residential areas. A total of 4,142 surveys were distributed (2,001 by post and 2,141 by drop-off/ pick-up / mail-back) and 853 valid surveys were returned (20.6%). Most respondents were urban (suburban and semi-urban) residents (75%). A number of limitations were encountered within the project which should be considered if results are generalised over the whole Wet Tropics population. These limitations include an over-representation of older respondents and female respondents.

Results

Residents who completed the community survey came from 79 towns and suburbs within the Wet Tropics bioregion. Most respondents resided in suburban (56%) and semi-urban (19%) areas and had spent an average of 24 years in tropical North Queensland. The mean age of respondents was 49 years, with more than half (54%) of residents reporting they had a technical or university qualification. Table 1 details the socio-demographic profile of respondents.

Table 1: Profile of 2007 community survey respondents.

Gender	%
Male	52.9
Female	47.1
Age	%
< 20 years	1.9
20-29 years	10.1
30-39 years	16.7
40-49 years	22.9
50-59 years	18.7
> 60 years	29.6
Occupation	%
Pensioner / unemployed	22.8
Professional / associate professional	17.7
Management and administration	17.5
Clerical and service industries	12.7
Tradesperson	11.9
Home duties	7.5
Labourer	5.3
Student	2.5
Production and transport	2.1
Educational Background	%
No schooling	0.1
Primary	5.7
Secondary	40.0
Technical or further education	28.4
University	25.7
Style of Residence	%
Suburban	55.3
Rural residential	21.5
Semi-urban	19.0
Rural	4.3
Period of Residency	%
≤ 10 years	31.3
> 10 years	68.7

The findings relating to visitation of the rainforest by residents highlights the importance of the WTWHA to the community. Since 2002, the number of respondents visiting the World Heritage Area at least once has increased by 4% to 84%. Half of the respondents visit the WTWHA between one and four times a year. The main reason for their last visit to a WTWHA site was for a 'recreational activity' (55.8%), including swimming, walking and recreation in general. 'Other reasons' (21.8%) included visits to family or friends, to look for property, for tourism, to visit their own property and revegetation work. Across the sample of residents, those living on the Atherton Tablelands appear to visit sites near their homes while residents from Cairns over the age of forty years will visit the Atherton Tablelands as well. Townsville residents less than forty years of age will drive to the Atherton Tablelands, and older residents of Townsville prefer to visit sites in the southern section of the WTWHA.

Recreational activities were the reason for visiting the rainforest for 59.4% of suburban respondents and 46.8% of rural respondents. Suburban residents chose to visit WTWHA sites on the Atherton Tablelands (30.7% of suburban residents) or sites in the northern section of the WTWHA (29.2% of suburban residents). Suburban residents visiting sites in the northern section were mostly aged thirty years and over. Those aged sixty years and over living in suburban areas also visited the Atherton Tablelands on their last visit to the WTWHA.

Respondents were asked to list their favourite places in the Wet Tropics. The most popular sites were Mission Beach (n = 71) and the Daintree (n = 65). A site's beauty was given as the main reason for visiting, indicating an appreciation of the natural attractions of the Wet Tropics rainforests. A number of sites recorded twenty or fewer responses. Overall, 751 responses were received for 143 sites and areas. Table 2 details the favourite sites of urban and rural residents. Rainforest sites nominated by urban residents as the most popular included Daintree and Cape Tribulation, Mission Beach (Licuala Rainforest Walk and Lacey Creek), Kuranda and the Atherton Tablelands. Reasons for visiting were for recreation and to appreciate nature. Rural residents indicated the site they most enjoyed was 'not specified', indicating either that they are wary of naming the site for fear of increased visitation, or they did not know the name of their favourite site. The Daintree / Cape Tribulation, Licuala / Lacey Creek and Babinda Boulders were also nominated as favourite sites for recreation by rural residents.

Table 2: Respondents' favourite sites within the WTWHA.

Rank	Urban residents	Rural residents
1.	Daintree / Cape Tribulation	Not specified
2.	Licuala / Lacey Creek	Daintree / Cape Tribulation
3.	Kuranda	Licuala / Lacey Creek
4.	Tablelands	Babinda Boulders
5.	Mossman Gorge	Palmerston Highway

Less than a quarter of respondents (23%) indicated there were places within the WTWHA they no longer enjoyed. Respondents indicated dissatisfaction with increasing tourist numbers, specifically at popular sites such as Mossman Gorge, Cape Tribulation and Barron Gorge. General reasons for no longer enjoying sites anywhere in the WTWHA mostly relate to issues of access, rules and regulations, and the inability to walk family dogs within protected areas. Those who said they did not use the WTWHA for any leisure, recreational,

cultural or work activities indicated it was due to their own lack of time or opportunity, age restrictions or having other interests or pastimes to occupy their time.

Discussion

This paper reports on results of a 2007 survey of residents in the Wet Tropics bioregion. Respondents indicated that they mainly visited WTWHA sites to pursue recreational activities. Almost three-quarters of the respondents lived in a suburban or rural residential location. Differences between suburban and rural residents relating to use and visitation patterns of the WTWHA are minor. Both suburban and rural residents enjoy the Mission Beach and Daintree / Cape Tribulation visitor sites and visit between one and four times per year. Sites in the northern region of the WTWHA are popular with suburban residents aged over thirty years, and the Atherton Tablelands are visited by suburban residents over sixty years of age. Understanding visitation to Wet Tropics rainforest sites by residents from suburban and rural residential areas is essential for planning, including allocation of resources for site infrastructure and managing visitor flows in the more sensitive parts of the forest.

References

- Bentrupperbäumer J.M. and Reser. J.P. (2003) *The role of the Wet Tropics in the life of the community: A Wet Tropics World Heritage Area Community Survey*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns.
- Bentrupperbäumer J.M. and Reser J.P. (2000) *Impacts of visitation and use: Psychosocial and biophysical windows on visitation and use in the Wet Tropics World Heritage Area*. James Cook University and Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns.
- Bentrupperbäumer J.M., O'Farrell S-E. and Reser J.P. (2004) *Visitor Monitoring System for the Wet Tropics World Heritage Area: Volume 2 Visitor Monitoring Process – From Pre-destination to Post-destination*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns.

Dating and mapping historical changes in Great Barrier Reef coral communities

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Introduction

There is a general consensus that coral reef ecosystems have become seriously degraded worldwide, suffering a recent massive long-term decline in abundance, diversity and habitat structure (Bellwood *et al.* 2004; Hughes *et al.* 2003; Pandolfi *et al.* 2003; Pandolfi *et al.* 2005). While the Great Barrier Reef (GBR) is considered to be one of the least degraded coral reefs in the world, increasing evidence suggests that this may not be the case with periodic declines in hard coral cover (DeVantier *et al.* 2006; Done *et al.* 2007). However, conclusions about the long-term status of inshore reefs are difficult to draw without detailed ecological baselines of the past condition of many of these reefs, and how they have changed over time.

While a detailed account exists on the structure and ecology of Low Isles and nearby reefs from a 1928-1929 GBR expedition (Stephenson *et al.* 1931), ecological research and long-term monitoring on the GBR only began to gain momentum in the early 1980s through the Australian Institute of Marine Science. The only glimpse into long-term changes in benthic community structure from hard to soft coral and macroalgal dominated communities are anecdotal comparisons of a collection of historical photographs taken from 1893 onwards of reef flat communities to later communities (Wachenfeld 1997). However, this technique is quantitatively limited and cannot provide insight into whether or not inshore reefs of the GBR have been steadily declining. Thus, prior to the 1980s, little is known about the extent and timing of historical mortality in hard coral communities and whether their losses can be attributed to human or environmental impacts.

Inshore reefs of the GBR lie within about twenty kilometres of the coastline (Sweatman *et al.* 2007) and, consequently, are at risk of the effects of coastal development. Since European settlement (~1850), there has been an estimated three- to four-fold increase in the average annual delivery of sediment and nutrients to the GBR lagoon as a result of changes in land use in catchment areas (Furnas 2003). Suspended sediments, nutrients, pesticides and other chemical pollutants adsorbed to fine clay particles can have several deleterious effects on coral health and productivity (Fabricius 2005) and are believed to be the likely cause of the widespread degradation of inshore reefs in the central GBR (Brodie *et al.* 2001). The interaction between chronic stressors such as sedimentation and eutrophication may threaten the resilience of inshore reef communities and their ability to recover from acute disturbances such as increased sea surface temperatures and cyclonic events (McCook *et al.* 2007).

Objectives

While increasing anthropogenic disturbance and climate change continue to threaten inshore reefs, an understanding of the timing, frequency, duration and cause of mortality events in hard coral communities is necessary to help direct management efforts towards ameliorating potential impacts. Furthermore, assessing the spatial and temporal variability of changes in community structure before and after European settlement will provide an invaluable management tool to overcome the 'shifting baseline' syndrome (Bellwood *et al.* 2004; Pauly 1995). By dating and mapping historical changes in coral communities of inshore reefs of the GBR, we hope to provide a detailed baseline assessment on coral community structure and an accurate chronology of the history and nature of mortality events. The highly-precise ($2\sigma \pm$ up to one year) thermal ionisation mass spectrometry (TIMS) uranium-series (U-series) dating method has been used to successfully date coral mortality events in the South China Sea over the past 200 years (Yu *et al.* 2006).

Progress to date

Our research has focused mainly on the Palm Islands region (~60km NNW of Townsville) which is influenced by flood plumes from the Burdekin and Herbert Rivers, as well as many smaller rivers and streams that pass through catchments which have been cleared for agricultural practices. Our results indicate a remarkable disparity between the composition and diversity of modern coral communities (live assemblages) and *in situ* coral rubble collected adjacent to living reef framework (death assemblages) across the entire region, with large extents of reef dominated by dead branching acroporid rubble (Figure 1). Using TIMS U-series dating, our preliminary results suggest that the mortality of acroporid corals at some sites occurred 40-70 years before the mass bleaching episode of 1998 and 2002.

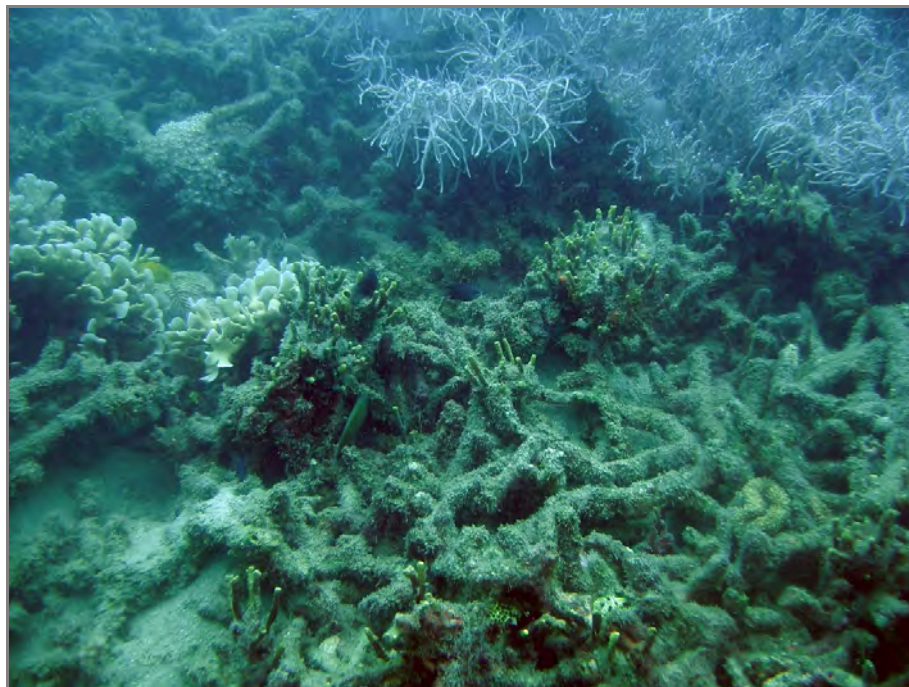


Figure 1: Dead *Acropora* substrate characteristic of the back reef environment of Pelorus Island, Great Barrier Reef. Living *Pavona cactus* (far left) and a variety of soft corals (background) are also common.

Acroporid corals are among the most susceptible taxa to environmental stress (Marshall and Baird 2000) and are therefore the primary focus of U-series dating throughout our research. However, as dominant massive corals (e.g. *Porites* spp.) are differentially susceptible to injury compared to acroporid corals (Wesseling *et al.* 1999); our research also aims to date partial mortality in massive corals to determine the history of mortality and whether the frequency of mortality has increased since European settlement. With a life span that can extend over several centuries and the ability to resist environmental/anthropogenic disturbances (Done 1987), the life history strategies of massive corals makes them potential subjects for detecting slow, chronic perturbations on the reef. U-series dating of partial mortality events in massive poritid corals has indicated that mortality also occurred at a similar time period as in the *Acropora* death assemblage. If high age precisions (up to ± 1 year) are achievable for well preserved, dead massive corals, our additional objective is to determine whether there is an existing relationship between massive coral mortality episodes and recent El Nino events in the GBR. Such a relationship has recently been observed in the southern South China Sea (Yu *et al.* 2006).

We plan to expand our approach to inshore reefs of the far northern GBR as well as other regions where declines in coral cover have been observed, such as the inshore reefs influenced by the Pioneer River (van Woosik and Done 1997), to determine whether the demise of inshore reefs occurred at a similar time or sequentially over a larger spatial scale since European settlement. Comparing the disturbance history of coral communities across broad gradients of human population size is advantageous in that it allows for comparisons of ecological processes and resilience between reefs exposed to different levels of human disturbance (Knowlton and Jackson 2008). Results will be valuable in (1) determining whether there is any difference in disturbance history at different latitudes or between high and low impact regions; and (2) elucidating the effects of anthropogenic disturbance (namely declining water quality) from natural impacts (such as climate change).

References

- Bellwood D.R., Hughes T.P., Folke C. and Nystrom M. (2004) Confronting the coral reef crisis. *Nature* 429, 827-833.
- Brodie J., Christie C., Devlin M., Haynes D., Morris S., Ramsay M., Waterhouse J. and Yorkston H. (2001) Catchment management and the Great Barrier Reef. *Water Science and Technology* 43, 203-211.
- DeVantier L.M., De'Ath G., Turak E., Done T. and Fabricius K.A. (2006) Species richness and community structure of reef-building corals on the nearshore Great Barrier Reef. *Coral Reefs* 25, 329-340.
- Done T. (1987) Simulation of the effects of *Acanthaster planci* on the population structure of massive corals in the genus *Porites*: evidence of population resilience? *Coral Reefs* 6, 75-90.
- Done T., Turak E., Wakeford M., DeVantier L.M., McDonald A. and Fisk D. (2007) Decadal changes in turbid-water coral communities at Pandora Reef: loss of resilience or too soon to tell? *Coral Reefs* 26, 789-805.
- Fabricius K.A. (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50, 125-146.
- Furnas M.J. (2003) *Catchments and corals: terrestrial runoff to the Great Barrier Reef*. Australian Institute of Marine Science and CRC Reef, Townsville, Australia.
- Hughes T.P., Baird A.H., Bellwood D.R., Card M., Connolly S.R., Folke C., Grosberg R., Hoegh-Guldberg O., Jackson J.B.C., Kleypas J., Lough J.M., Marshall P.A., Nystrom M., Palumbi S.R., Pandolfi J.M., Rosen B. and Roughgarden J. (2003) Climate change, human impacts, and the resilience of coral reefs. *Science* 301, 929-933.
- Knowlton N. and Jackson J.B.C. (2008) Shifting baselines, local impacts and global change on coral reefs. *PLoS Biol* 6: e54.

- Marshall P.A. and Baird A.H. (2000) Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. *Coral Reefs* 19, 155-163.
- McCook L.J., Folke C., Hughes T.P., Nystrom M., Obura D. and Salm R. (2007) *Ecological resilience, climate change and the Great Barrier Reef*. In 'Climate change and the Great Barrier Reef: a vulnerability assessment', eds J.E. Johnson, and P.A. Marshall, pp. 75-96. Great Barrier Reef Marine Park Authority and Australian Greenhouse Office: Canberra, Australia.
- Nugues M.M. and Roberts C.M. (2003) Partial mortality in massive reef corals as an indicator of sediment stress on coral reefs. *Marine Pollution Bulletin* 46: 314-323.
- Pandolfi J.M., Jackson J.B.C., Baron N., Bradbury R.H., Guzman H.M., Hughes T.P., Kappel C.V., Micheli F., Ogden J.C., Possingham H.P. and Sala E. (2005) Are U.S. coral reefs on the slippery slope to slime? *Science* 307, 1725-1726.
- Pandolfi J.M., Bradbury R.H., Sala E., Hughes T.P., Bjorndal K.A., Cooke R.G., McArdle D., McClenachan L., Newman M.J.H., Paredes G., Warner R.R. and Jackson J.B.C. (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* 301, 955-958.
- Pauly D. (1995) Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution* 10, 430.
- Stephenson T.A., Stephenson A., Tandy G. and Spender M. (1931) Great Barrier Reef expedition 1928-1929: the structure and ecology of Low Isles and other reefs. *Scientific Reports* 3: 17-112.
- Sweatman H., Thompson A., Delean S., Davidson J. and Neale S. (2007) *Status of near-shore reefs of the Great Barrier Reef 2004*. Marine and Tropical Sciences Research Facility Research Report Series. Reef and Rainforest Research Centre Limited, Cairns, Australia 169 pp.
- van Woesik R. and Done TJ (1997) Coral communities and reef growth in the southern Great Barrier Reef. *Coral Reefs* 16: 103-115.
- Wachenfeld D.R. (1997) *Long-term trends in the status of coral reef-flat benthos – The use of historical photographs*. Great Barrier Reef Marine Park Authority, Townsville.
- Wesseling I., Uychiaoco A.J., Alino P.M., Aurin T. and Vermaat J.E. (1999) Damage and recovery of four Philippine corals from short-term sediment burial. *Marine Ecology Progress Series* 176, 11-15.
- Wesseling I., Uychiaoco A.J., Alino P.M., Vermaat J.E. (2001) Partial mortality in Porites corals: variation among Philippine reefs. *International Review of Hydrobiology* 86, 77-85.
- Yu K.-F., Zhao J.-X., Shi Q., Chen T.-G., Wang P.-X., Collerson K.D. and Liu T.-S. (2006) U-series dating of dead Porites corals in the South China Sea: Evidence for episodic coral mortality over the past two centuries. *Quaternary Geochronology* 1, 129-141.

Designing a policy package solution for a cassowary population objective

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Introduction

The southern cassowary (*Casuarius johnsonii*) is a keystone species significant to the highly valued environment of the Wet Tropics. The species is under threat directly from development where clearing has reduced the size and quality of the birds' habitat. It is also threatened indirectly as the human population increases, through incidents such as dog attacks and vehicle strike. Because of the importance of the cassowary to the overall biodiversity of the Wet Tropics, research into the refining, tailoring and application of a market based instrument (MBI) to manage for environmental conservation in developing areas has adopted 'establishing and maintaining a viable cassowary population' as the overall policy objective.

The objective of the research summarised in this paper was to analyse the type and mixes of policies that might be most effective at achieving the viable cassowary population objective. Here we present a promising instrument mix for future investigation.

Policy options

Environmental policy decisions should be targeted to best meet the objective at the least cost. Included in the mix of actions is doing nothing, which will incur low policy costs but not necessarily achieve the objective of a viable cassowary population, thereby incurring significant ongoing public costs.

To achieve a viable cassowary population, an above-threshold level of suitable habitat needs to be maintained, and the incremental impacts of human interaction also need to be managed. These conditions do not currently exist because the market is failing to provide appropriate signals to those who can supply these goods. The current market reflects the real estate/development potential or private value of the land but not the publicly held values for habitat. Consequently, habitat is undersupplied. Incremental impacts are also significant and generally not costed in private decision making. Current government regulation is inadequate to manage direct and indirect impacts, thus some form of policy adjustment is required.

For this project we considered four possible policy options:

1. Remove perverse incentives – a potentially low-cost way of generating change, but difficult to implement as policies contributing to the problem are embedded in legislation;
2. Create demand for good (suasion) – has the advantage of being low cost, ongoing and self-enforcing, but the disadvantage of no formalised requirement and low incentives;
3. Voluntary financial and non-financial incentive – a flexible approach which encourages innovation, but the risk is that no change will occur if there are no mandatory requirements, and it may be costly; and

4. **Mandatory** – capable of achieving universal change but inflexible, no innovation and potentially high cost.

In many instances an approach involving a mix of these intervention options may be considered the most appropriate intervention framework. For example, a community campaign designed to communicate the undesirability of certain practices may be combined with financial incentives to improve management, or followed by regulations restricting the most damaging actions. Using the framework to consider the various options indicated that a mix of voluntary incentive (Option 3) and non-voluntary incentives (regulation) is most likely to achieve the policy objective of a viable cassowary population. The next stage of this research will test the parameters of application for this instrument mix.

When do you use incentives, information or regulation?

Positive incentives are those that generate a positive change (such as information and support or even payments for increased conservation) and negative incentives are those that are in place to stop an action with environmentally negative outcomes from occurring (such as clearing legislation). The type of incentive to use and when to use it then becomes a question of which best achieves the policy objective at the least cost, and at what distribution of costs and benefits across public and private stakeholders (see Pannell 2008 for more detail on this approach to policy type decision making).

Positive incentives

Positive incentives may be non-financial measures such as information and support, or involve a payment as either a flat rate financial incentive or a financial incentive that varies according to the assessed value for money of the actions. Positive incentives are most appropriate when the public benefit is greater than the private cost and when the private cost is not large. When to use financial or non-financial mechanisms depends on if any private benefit is being gained from actions, the level of private cost, the nature of the threat and landholder motivation (see Reeson 2007 for more on crowding-out of initial conservation motivation by using the wrong instrument).

In the study area, landholders engaged in ecotourism-type businesses would gain a private benefit from development that minimised cassowary impact, and management that provided the ongoing protection of this benefit. Information programs, management agreements and covenants could be used to maximise this potential. It may not be efficient to use payments here.

Allow flexible actions

This approach is suitable when the private benefit is slightly greater than the public cost. In these circumstances, land use changes should be accepted if they occur, however due to the incursion of some public cost, no policies should be introduced that would encourage such land use change (i.e. don't make it easier to develop). Measures should be put in place to protect the baseline as much as possible.

In this study area, this approach would be applied on land that does not provide significant cassowary value. This may be land that is highly isolated from other cassowary habitat hotspots, already extensively cleared or does not contain any of the features that cassowaries prefer. Offsets operate here, where areas of low public cost can be used to generate public benefits elsewhere.

Negative incentives

This approach is more suitable when public cost is greater than private benefit and the private benefit is likely to be large, e.g. prime development land on prime cassowary habitat.

In these circumstances negative incentives would be appropriate to stop land use change that was privately rewarding but publicly damaging.

There are many development opportunities in the study area. Those with the highest private benefit also tend to be those with the greatest public cost due to their location on significant cassowary habitat. A negative incentive, such as a regulation, will be most appropriate where there is a high threat to land use change (i.e. extremely high private benefit to develop) with significant consequences (high public cost due to impact on cassowaries).

No action

This approach is appropriate when public and private costs of land use change are positive and neither party should be interested in promoting change. No action is the best course of action here.

Proposed instrument mix

Based on the public/private benefit and cost split, community expectation of conservation of cassowaries to a point that they can fulfil their significant rainforest function and the assumption that any approach to conserve cassowaries will be one applied at a regional level and therefore across both regional and local governance structures, the proposed instrument mix for further investigation includes:

- Information and support to landholders with high-value cassowary habitat but with minimal threat of removal of habitat. This would be considered a short-term measure with the optimal long-term measure being a conservation covenant placed on title into perpetuity. This covenant could be accompanied by a management agreement specifying what can't be done on this land and actions for positive management of the land.
- Payments to landholders, either through government agencies from fixed amounts of public funds, or as a result of flexible requirements on development provisions (such as an offset). Payments could occur for both habitat management (which would probably be the application of a fixed budget competitive payment scheme) or for actions that alleviate the third-party impacts of development. The operation of different types of schemes and associated issues are discussed below.
- Regulation to remove cassowary population threats.

Refining, designing and implementing instruments for the policy objective

We do not go as far as to describe implementation of the instrument mix in this paper. This section focuses on market based instruments, particularly offsets.

The most common form of positive financial incentive for a net gain in land management has historically been through flat rate grants. However, when making payments to individuals, different actions occurring at different places in the landscape will have different cassowary conservation impacts and occur with differing cost to landholders. Payments utilising competitive systems (such as auctions or competitive tenders) are an efficient way of allocating scarce conservation funding among alternative proposals.

Using experimental economics, another CSIRO project (Reeson *et al.* 2008) is already testing the effectiveness of an auction mechanism to efficiently allocate positive financial incentives to achieve a net gain in connected cassowary habitat.

A positive incentive, such as a competitive payment approach, will work best to make gains in environmentally positive actions. This approach tends to be applied where habitat is not heavily threatened by development. With a large proportion of essential cassowary habitat

located in areas of high development potential, this approach must be coupled with an instrument such as an offset that protects the baseline, to reach the policy objective.

The basic development offset

An offset allows assets to be reduced on one site, as long as the impact is counterbalanced by the production or protection of equivalent assets on another site. The most basic form of offset is one that offsets the direct impact. For example, Landholder *a* can cut down trees so long as Landholder *b* plants or protects an equivalent number of trees (supplies an offset credit). This exchange usually occurs with a payment. Offsets can achieve a no net impact result with greater efficiency than a regulation because, rather than specifying and requiring actions for no net impact on site, they allow flexibility in how perpetrators neutralise their impacts, facilitating least-cost actions.

This narrow form of offset is inadequate for managing impacts on a broader landscape scale. To truly offset the impacts of development on the cassowary, indirect and third party impacts such as encroachment on habitat, encroachment on open space, vehicle strike and animal attack need to be included in the offset baseline.

An offset for landscape scale outcomes (broad offset)

Rather than focusing the development offset on individual incremental impacts and offsetting accordingly, a broad offset requires the establishment of a baseline for impact at a level that reflects regional landscape sustainability objectives – it is a regional rather than an individual property baseline. By offsetting against sustainability objectives, the offset takes into account both the direct and indirect impacts of a development. In the case of the viable cassowary objective, the offset will need to include the development impact on quality adjusted habitat¹ as well as mitigating the ongoing impact of the completed development (more people and more vehicles). The focus of this project is on the best way to design an offset towards this end.

A well designed Market Based Instrument (MBI) is one that addresses the reasons why the good is undersupplied in the first place. In the case of cassowaries, the market fails to maintain a viable population because the property rights for this good are ill defined and poorly allocated. Design of this MBI should therefore focus on specifying and allocating property rights as well as facilitating a means by which these can be exchanged.

Who will demand / buy offsets? Offset buyers are those who are required to provide actions to the baseline and can legally do this through a third party. In the case of Mission Beach, the local council through planning policy and processes would determine who can generate demand for an offset (Coggan *et al.* 2007).

Who will supply offset credit? Even if the demand for offsets is created, offsets will not achieve targets unless there are landholders who can supply the required on-ground actions. It is inefficient to purchase offset credits for actions that landholders should have been doing anyway or are already being paid to do. In the case of Mission Beach, the largest gains will be made by supply of credits from landholders with high value habitat and where habitat is most threatened. The greatest gains may also be where habitat is the furthest distance from day to day human interactions.

¹ Different species types located in different parts of the landscape will have differing values to the cassowary. For example, connected riparian vegetation consisting of many varieties of native fruiting trees will be more valuable to the cassowary population objective compared with disconnected non fruiting vegetation.

A clear process will be needed to support the value of the offset rights and minimise transaction costs of the offset exchange. To be effective at achieving environmental outcomes and to maintain the property right value, the offset credit must be enforceable over time. Agreed measures and ongoing monitoring with penalties for non-compliance will be part of the scheme.

Summary of parameters to test for an offset market

Critical questions for testing can be summarised as the effectiveness and efficiency outcomes that occur under different institutional arrangements. Further research is needed to test assess outcomes when:

- There is no brokering in an offset market;
- Terrain NRM Ltd operates as a broker of exchange (aiding in finding exchange partners but with no use of other instruments to do this); and
- Terrain NRM Ltd operates as a broker of exchange using an auction to generate supply.

Conclusions and next steps

Maintaining a viable cassowary population is significant to the survival of the Wet Tropics rainforest and, by extension, survival of the region. Government programs which have been introduced to address the declining cassowary population generally do not address the cause of market failure, and therefore tend to have only a marginal impact on human behaviour or the cassowary population. At the same time, other government policies permit or enable actions with significant direct and indirect negative impacts on cassowaries.

In this paper, we have applied a best management framework for considering policy interventions to achieve an environmental objective of a viable cassowary population. This approach indicates that a mix of positive (financial and non-financial) and negative incentives could secure the objectives. We have shown that a mix of two approaches – a competitive tender and an offset – has a number of advantages. A number of key questions regarding instrument mixes will be tested in a simulation and with the regional body in the next step of this research project.

References

- Coggan A., Hill R., Whitten S.M., Harman B. (2007) *Market Based Instruments, Ecosystem Services and Development in Mission Beach, Far North Queensland. Background Report 3: Institutions and structures currently in place for the management of development and the cassowary – what do they do, what are the gaps and what does this mean?* Draft Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Ltd, Cairns (69pp.).
- Pannell D.J. (2008) Public Benefits, Private Benefits and Policy Mechanism Choice for Land-Use Change for Environmental Benefits. *Land Economics* 84(2), 225-240.
- Reeson A., Whitten S., Nolles K., Windle J. and Rolfe J. (2008) *Designing auctions for conservation corridors. An experimental approach.* Paper presented at the 52nd Annual Conference of the Australian Agricultural and Resource Economics Society, Canberra, February 2008.
- Reeson A. (2007) *Institutions, motivations and public good: Theory, evidence and implications for environmental policy. Socio-Economics and the Environment in Discussion.* CSIRO Working paper series 2008/01. Available from: <http://ideas.repec.org/p/cse/wpaper2008-01.html>. Date accessed: 22 August 2008.

Developing a technique to quantify spatial variation in herbivory on coral reefs

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Introduction

Coral reefs worldwide are in serious decline (Connell 1997; Jackson 1997, Jackson *et al.* 2001; Wilkinson 2002; Pandolfi *et al.* 2003). Even the Great Barrier Reef (GBR), previously considered one of the most pristine reef systems globally, is showing signs of system-wide degradation (Bellwood *et al.* 2004). In many cases, through the combined effects of over fishing, pollution and/or climate change, the loss of coral cover is commonly followed by an increase in the biomass of large, fleshy macroalgae (Hughes 1994; Jackson *et al.* 2001; Gardner *et al.* 2003; Hughes *et al.* 2007). This transition from a healthy, coral dominated state to a degraded system characterised by macroalgae is termed a phase shift. Over the past two decades these phase shifts have been recorded from the Indian and Pacific Oceans and the tropical Atlantic (Hughes 1994; McClanahan *et al.* 2001; Ledlie *et al.* 2007).

It is widely acknowledged that the one key element to resisting phase shifts is the maintenance of successful larval colonisation by the full range of coral functional groups characteristic of the region (Brock 1979; Tanner 1995; Bellwood *et al.* 2004; Hughes *et al.* 2007). Through the removal of algae that prevents coral larval settlement (Birkeland 1977; Tanner 1995; Hughes and Tanner 2000), herbivores mediate the balance between coral and algae and contribute significantly to the resilience of coral reef systems (Russ 2003; Hughes *et al.* 2007). As such, grazing of the substrate by herbivorous organisms plays a fundamental role in the dynamics and functioning of modern day coral reefs (Steneck 1988; Done 1992; Nyström and Folke 2001).

Traditionally, assessing the importance of individual species in maintaining ecosystem processes such as herbivory has been through direct diver observation (e.g. Klumpp and Polunin 1989; Polunin and Klumpp 1992). This direct method, however, has attracted significant attention due to the potential bias that it imposes on our understanding of the system (Sale and Douglas 1981; Brock 1982; Sale and Sharp 1983; Kulbicki 1998; Willis 2001). For instance, Hemmings (1971) suggested that the noise produced by a diver's breathing apparatus may result in an avoidance reaction in fish and that the 'avoidance distance' may exceed the diver's visibility. As such, visual estimates of fish populations may not be a true representation of the population's status. This is supported by the data of Jennings and Polunin (1995) who concluded that visual census techniques consistently underestimated the exploitable biomass of *Lethrinus* spp. in Fijian fishing grounds.

To remove such bias, several recent studies have employed the use of remote underwater video techniques (Willis *et al.* 2003; Tessier *et al.* 2005; Bellwood *et al.* 2006; Mantyka and Bellwood 2007; Fox and Bellwood 2008). For herbivory, in particular, such methods have provided a new perspective. Following a long-term herbivore exclusion experiment aimed at simulating over-fishing on the GBR (Hughes *et al.* 2007), a single species of batfish, *Platax pinnatus*, was shown to be primarily responsible for the reversal of the simulated phase shift back to coral dominance (Bellwood *et al.* 2006).

Similarly, through the use of remote underwater video cameras, two separate studies have demonstrated that the primary herbivore responsible for the removal of macroalgae on in-shore reefs of the GBR is the rabbitfish, *Siganus canaliculatus* (Mantyka and Bellwood 2007; Fox and Bellwood 2008). The common feature of all three of these studies is that the roving herbivores identified through visual census played a minimal role in macroalgal removal. All of these studies however, have been carried out in a single bay, Pioneer Bay on Orpheus Island, and, as such, the degree of spatial variability in herbivore feeding activity on the GBR has not been quantified. The aim of this study was to develop and evaluate a technique that is capable of detecting spatial variation in herbivory on coral reefs.

Materials and methods

This study was conducted between February and March 2007 at Orpheus Island (18°35'S, 146°20'E), in the central region of the Great Barrier Reef, Australia. Three bays on the leeward side of the island were chosen (Cattle Bay, Pioneer Bay and Hazard Bay) and within each bay, three sites one hundred metres apart were established. The macroalgal genus chosen for this study, *Sargassum*, represents one of the most common and conspicuous forms of macroalgae on the inner shelf of the GBR.

Sargassum was harvested from the reef flat at Orpheus Island, ensuring that holdfasts were still attached. The macroalgae were then transported in salt water to Orpheus Island Research Station where they were weighed (to 0.1 of a gram) and transferred into raceways (large flow-through water tanks) for keeping overnight. To standardise the influence of water on weight measurements, all samples were spun for thirty seconds using a salad spinner to remove excess water. The following morning, one sample was haphazardly deployed into each of the nine sites along the leeward margin of Orpheus Island between 8:00am and 11:00am. Deployments were made onto the reef crest following the findings of several previous studies indicating that grazing intensity was highest in this part of the reef (Hay 1984; Holt *et al.* 1994; Fox and Bellwood 2007; Hoey and Bellwood 2008). *Sargassum* strands were attached to pieces of rubble or dead coral using a short piece (~10 cm) of wire and a rubber-band around the holdfast. The band and wire were hidden as much as possible to minimise the impact on feeding behaviour. Following each three hour period, the algal material was removed and transported back to the research station where samples were immediately weighed and measured using the procedure described above. Grazing intensity was calculated in terms of the percentage decrease in mass observed for each replicate (following Hay 1981; Lewis and Wainwright 1985; Reinthal and Macintyre 1994).

The relative contribution of individual herbivorous fish species to the removal of *Sargassum* was obtained using remotely deployed video cameras. Immediately following the deployment of macroalgae, a camera was mounted on a weighted tripod and placed approximately two to three metres from the macroalgae so that the entire strand of *Sargassum* and surrounding area was in the field of view. Filming was continuous for the three hour duration of macroalgal deployment.

The video footage revealed a total of three herbivorous fish species that fed consistently on *Sargassum* assays over the duration of the study; *Siganus doliatus*, *S. canaliculatus*, and *Kyphosis vaigiensis*. For each of these species, it was possible to approximate the weight (g) of mass removed by an individual with each bite. This was achieved by developing a series of algebraic equations. On several occasions, *S. doliatus* was the only species observed feeding on a particular assay. Therefore, by dividing the total mass loss for that particular assay by the total number of bites by *S. doliatus*, the approximate impact of a bite for *S. doliatus* was determined.

There were then several occasions where only *S. doliatus* and *S. canaliculatus* or *S. doliatus* and *K. vaigiensis* were observed feeding on a particular assay. As such, by multiplying the total number of bites by *S. doliatus* on that particular assay by the impact of a single *S. doliatus* bite as previously quantified, it was possible to calculate how much of the macroalgal mass lost could be attributed to *S. doliatus*. The remaining mass lost therefore, could be attributed to the other species feeding on the assay. Once again, by dividing the total number of bites taken by either *S. canaliculatus* or *K. vaigiensis* on that particular assays by the remaining mass lost, the impact of a bite for these species was quantified. It is important to note that this technique only provides an approximate estimate of bite sizes. However, it does provide an insight into the relative bite sizes of the various species.

Results

Through the use of macroalgal assays, it was possible to quantify the potential for herbivores to remove macroalgae from the reef crest at a range of spatial scales. In the most extreme case, herbivores removed up to $88.3 \pm 1.0\%$ of *Sargassum* in three hours (in Hazard Bay) while in Cattle Bay, removal was as low as $27.81 \pm 0.8\%$ (Figure 1). Furthermore, by using the bioassay in combination with remotely deployed video cameras, it was also possible to determine the species responsible for the removal of *Sargassum*. Overall, the video footage revealed a total of ten herbivorous and 'nominally' herbivorous reef fish species feeding on the *Sargassum* assays. These included members of the families Kyphosidae (*Kyphosus vaigiensis*), Pomacanthidae (*Pomacanthus sexstriatus*), Labridae (*Scarus rivulatus*, *S. flavipectoralis*, *S. schlegeli*, *Chlorurus microrhinos*) and Siganidae (*Siganus canaliculatus*, *S. doliatus*, *S. javus*, *S. puellus*).

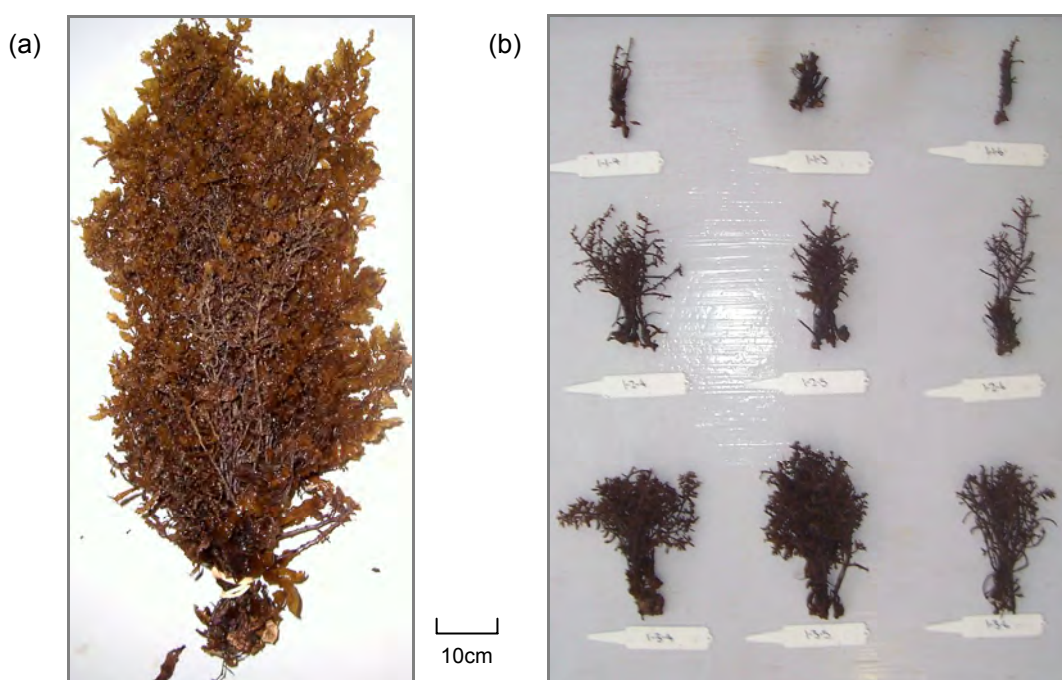


Figure 1: (a) Original sample of *Sargassum* prior to deployment onto the reef crest; (b) Photographs of *Sargassum* three hours after deployment in Hazard Bay, showing among-site variation. The stands in the first row were transplanted into site one, second row into site two, and third row into site three.

The bite size of the three main herbivore species feeding on the *Sargassum*, *S. doliatus*, *S. canaliculatus* and *K. vaigiensis* also showed high levels of variation (Figure 2). Of these species, a single bite from *K. vaigiensis* was found to have the greatest impact in the removal of macroalgae, removing approximately 0.72 g of *Sargassum* per bite. Following this, *S. canaliculatus* removed approximately 0.28 g of macroalgae per bite while *S. doliatus* was found to have the smallest bite size at approximately 0.11 g of macroalgae removed per bite.

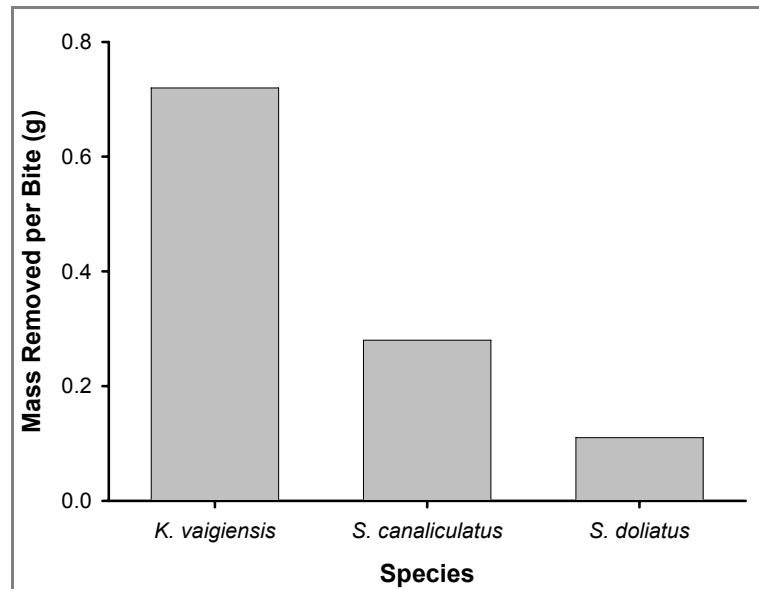


Figure 2: Approximate mass of *Sargassum* removed in a single bite by *K. vaigiensis*, *S. canaliculatus* and *S. doliatus* (based on six hours of feeding for *S. doliatus*, and three hours of feeding for *S. canaliculatus* and *K. vaigiensis*).

Discussion

Algal assays have been used extensively as a means of quantifying herbivory on coral reefs (e.g. John and Pople 1973; Reinthal and Macintyre 1994; McCook 1997). Previous techniques, however, employed tools such as clothes pegs or fishing line to attach the algal samples to the reef (Hay 1981, 1984; Mantyka and Bellwood 2007), which may potentially affect the behaviour of the species feeding on the assays. The technique described in the present study removes such bias, because the macroalgae were attached to the reef in a way that gave a more natural appearance. Furthermore, the technique was sensitive enough to detect both small and large-scale spatial variation in herbivory on coral reefs.

Other studies have assumed that macroalgae were removed by one or more of the herbivorous fish species observed during visual surveys (e.g. Hay 1981, 1984; Lewis 1986). For example, Nelson and Tsutsui (1981) concluded that the surgeonfish (Acanthuridae) *Naso lituratus* was responsible for the removal of *Gracilaria* assays in Guam, given that it was the most abundant fish in the area.

Similarly, in the Indian Ocean, Sluka and Miller (2001) concluded that parrotfishes were responsible for the removal of *Thalassia* assays as the removal rates were directly correlated with the abundance of scarids.

However, in the present study, the removal of macroalgal assays was not simply attributed to the most abundant herbivore observed within the study site. Rather, through the use of

remote underwater video in combination with the algal assays, the relative contribution of each individual herbivore species was quantified. In total, over forty herbivorous fish species have previously been identified at Orpheus Island; however the results of this study show that only ten of these species fed on the assays. These findings are consistent with previous studies on Orpheus Island which demonstrated that the removal of algal assays was limited to only a few herbivore species (Bellwood *et al.* 2006; Cvitanovic and Bellwood, 2008; Fox and Bellwood 2008).

The technique described in the present study also allows for individual bite sizes of different herbivore species to be approximated and for observations to be made regarding the different feeding behaviours of these species in the absence of SCUBA divers. Observation of feeding by *S. canaliculatus* from the video footage revealed a consistent feeding methodology. Individuals would arrive in groups of four to fifteen individuals and commence feeding from various locations along the *Sargassum* strand (when feeding they consumed an average of 13.9 ± 4.6 g SEM per minute $n=20$, and dislodged, i.e. broke off but not ingested, a further 0.16 ± 0.04 g as a result of this activity). Feeding continued until the entire portion with leaves had been removed. In contrast, *K. vaigiensis* displayed a much more 'aggressive' feeding action (consuming 13.9 ± 2.0 g per min of feeding but only dislodging 0.02 ± 0.02 g per min.). Groups of approximately ten individuals would approach and circle the *Sargassum* at a very high speed and at periodic intervals individuals would 'dart' towards the *Sargassum* and take no more than two bites before quickly rejoining the group. However, the feeding behaviour of *K. vaigiensis* was more structured than *S. canaliculatus* as bites were always taken from the top of the *Sargassum* and moved progressively towards the holdfast. This pattern may, in part, account for the smaller proportion of dislodged material despite the 'aggressive' feeding behaviour.

In addition to *S. canaliculatus* and *K. vaigiensis*, the results of the present study also recorded a second species of rabbitfish, *S. doliatus*, feeding consistently on the *Sargassum* assays in all bays. However, in comparison to *S. canaliculatus* and *K. vaigiensis*, the overall impact of *S. doliatus* in the removal of macroalgal assays was found to be limited. As noted in previous studies, *S. doliatus* represents one of the most abundant herbivores on inshore reefs of the GBR yet it has negligible impact on the removal of macroalgae over short experimental periods (Bellwood *et al.* 2006; Fox and Bellwood 2008). However, it remains a strong possibility that *S. doliatus* may play a more critical role in the removal of macroalgae on coral reefs over much longer timeframes. The relative importance of *S. doliatus* in this manner will only be identified by increasing the temporal duration of studies on herbivory and through a detailed understanding of the feeding ecology of *S. doliatus*.

To conclude, the present study has built on the techniques previously used to quantify herbivory on coral reefs and has demonstrated a technique that is capable of detecting both small and large scale spatial variation in herbivory. Furthermore, the study has shown that through the use of remote underwater video, the relative contribution of individual herbivorous fish species in the removal of macroalgal assays can be effectively quantified. Thus, the future use of this technique will provide further insight into herbivory on coral reefs, and increase our understanding of the process and the species responsible for maintaining a key process that underpins coral reef resilience.

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References

- Bellwood D.R., Hughes T.P., Folke C. and Nyström M. (2004) Confronting the coral reef crisis. *Nature* 429, 827-832.
- Bellwood D.R., Hughes T.P. and Hoey A.S. (2006) Sleeping functional group drives coral-reef recovery. *Current Biology* 16, 2434-2439.
- Birkeland C. (1977) *The importance of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits*. Proceedings of the Third International Coral Reef Symposium, Miami 1, 383-389.
- Brock R.E. (1979) An experimental study on the effects of grazing by parrotfishes and the role of refuges in benthic community structure. *Marine Biology* 51 381-388.
- Brock R.E. (1982) A critique of the visual census method for assessing coral reef fish populations. *Bulletin of Marine Science* 32, 269-276.
- Connell J.H. (1997) *Disturbance and recovery of coral assemblages*. Proceedings of the Eight International Coral Reef Symposium 1, 9-22.
- Cvitanovic C. and Bellwood D.R. (2008) Local variation in herbivore feeding activity on an inshore reef of the Great Barrier Reef. *Coral Reefs* doi 10.1007/s00338-008-0433-0.
- Done T.J. (1992) Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247, 121-132.
- Fox R.J. and Bellwood D.R. (2008) Remote video bioassays reveal the potential feeding impact of the rabbitfish *Siganus canaliculatus* (f: Siganidae) on an inner-shelf reef of the Great Barrier Reef. *Coral Reefs* 27, 605-615.
- Gardner T.A., Cote I.M., Gill J.A., Grant A. and Watkinson A.R. (2003) Long-term region-wide declines in Caribbean corals. *Science* 301, 958-960.
- Hay M.E. (1981) Herbivory, algal distribution, and the maintenance of between-habitat diversity on a tropical fringing reef. *The American Naturalist* 118(4), 520-540.
- Hay M.E. (1984) Patterns of fish and urchin grazing on Caribbean coral reefs: are previous results typical? *Ecology* 65, 446-454.
- Hemmings C.C. (1971) *Fish Behaviour*. In 'Underwater Science', eds J.D. Woods and J.N. Lythgoe, pp. 141-174. Oxford University Press: Oxford, UK.
- Hoey A.S. and Bellwood D.R. (2008) Cross-shelf variation in the role of parrotfishes on the Great Barrier Reef. *Coral Reefs* 27(1), 37-40.
- Holt R.D., Grover J. and Tilman D. (1994) Simple rules for interspecific dominance in systems with exploitative and apparent competition. *The American Naturalist* 144, 741-777.
- Hughes T.P. (1994) Catastrophes, phase-shifts and large-scale degradation of a Caribbean coral reef. *Science* 265, 1547-1551.
- Hughes T.P. and Tanner J.E. (2000) Recruitment failure, life histories, and long-term decline of Caribbean corals. *Ecology* 81, 2250-2264.
- Hughes T.P., Rodrigues M.J., Bellwood D.R., Ceccarelli D., Hoegh-Guldberg O., McCook L., Moltschanowskyj N., Pratchett M.S., Steneck R.S. and Willis B. (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology* 17, 1-6.
- Jackson J.B.C. (1997) Reefs since Columbus. *Coral Reefs* 16 (Suppl), 23-32.
- Jackson J.B.C., Kirby M.X., Berger W.H., Bjorndal K.A., Botsford L.W., Bourque B.J., Bradbury R.H., Cooke R., Erlandson J., Estes J.A., Hughes T.P., Kidwell S., Lange C.B., Lenihan H.S., Pandolfi J.M., Peterson C.H., Steneck R.S., Tegner M.J. and Warner R.R. (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293, 629-638.
- Jennings S. and Polunin N.V.C. (1995) Biased underwater visual census biomass estimates for target-species in tropical reef fisheries. *Journal of Fish Biology* 47, 733-736.

- John D.M. and Pople W. (1973) The fish grazing of rocky shore algae in the Gulf of Guinea. *Journal of Experimental Marine Biology and Ecology* 11, 81-90.
- Klumpp D.W. and Polunin N.V.C. (1989) Partitioning among grazers of food resources within damselfish territories on a coral reef. *Journal of Experimental Marine Biology and Ecology* 125, 145-169.
- Kulbicki M. (1998) How the acquired behaviour of commercial reef fishes may influence the results obtained from visual census. *Journal of Experimental Marine Biology and Ecology* 222, 11-30.
- Ledlie M.H., Graham N.A.J., Bythell J.C., Wilson S.K., Jennings S., Polunin P.V.C. and Hardcastle J. (2007) Phase shifts and the role of herbivory in the resilience of coral reefs. *Coral Reefs* 26, 641-653.
- Lewis S.M. (1986) The role of herbivorous fishes in the organization on a Caribbean reef community. *Ecological Monographs* 56(3), 183-200.
- Lewis S.M. and Wainwright P.C. (1985) Herbivore abundance and grazing intensity on a Caribbean coral reef. *Journal of Experimental Marine Biology and Ecology* 87(3), 215-228.
- Mantyka C.S. and Bellwood D.R. (2007) Direct evaluation of macroalgal removal by herbivorous coral reef fishes. *Coral Reefs* 26, 435-442.
- McClanahan T.R., McField M., Huitric M., Bergman K., Sala E., Nyström M., Nordemar I., Elfving T. and Muthiga N.A. (2001) Responses of algae, coral and fish to the reduction of macro algae in fished and unfished patch reefs of Glovers Reef Atoll, Belize. *Coral Reefs* 19, 367-379.
- McCook L.J. (1997) Effects of herbivory on zonation of Sargassum spp. within fringing reefs of the central Great Barrier Reef. *Marine Biology* 129(4), 713-722.
- Nelson S.G. and Tsutsui R.N. (1981) Browsing by herbivorous reef fishes on the agarophyte *Gracilaria edulis* (Rhodophyta) at Guam, Mariana Islands. Proceedings of the Fourth International Coral Reef Symposium, Manila 2, 503-508.
- Nyström M. and Folke C. (2001) Spatial resilience on coral reefs. *Ecosystems* 4, 406-417.
- Pandolfi J.M., Bradbury R.H., Sala E., Hughes T.P., Bjorndal K.A., Cooke R.G., McArdie D., McClenahan L., Newman M.J.H., Paredes G., Warner R.R. and Jackson J.B.C. (2003) Global trajectories on the long-term decline of coral reef ecosystems. *Science* 301, 955-958.
- Polunin N.V.C. and Klumpp D.W. (1992) Algal food supply and grazer demand in a very productive coral-reef zone. *Journal of Experimental Marine Biology and Ecology* 164(1), 1-15.
- Reinthal P.N. and Macintyre I.G. (1994) Spatial and temporal variations in grazing pressure by herbivorous fishes: Tobacco Reef, Belize. *Atoll Research Bulletin* 425, 1-11.
- Russ G.R. (2003) Grazer biomass correlates more strongly with production than with biomass of algal turfs on a coral reef. *Coral Reefs* 22(1), 63-67.
- Sale P.F. and Douglas W.A. (1981) Precision and accuracy of visual census technique for fish assemblages on coral patch reefs. *Environmental Biology of Fishes* 6, 333-339.
- Sale P.F. and Sharpe B.J. (1983) Correction of bias in visual transect censuses of coral reef fishes. *Coral Reefs* 2, 37-42.
- Sluka R.D. and Miller M.W. (2001) Herbivorous fish assemblages and herbivory pressure on Laamu Atoll, Republic of Maldives. *Coral Reefs* 20(3), 255-262.
- Steneck R.S. (1988) Herbivory on coral reefs: a synthesis. Proceedings of the Sixth International Coral Reef Symposium 1, 37-49.
- Tanner J.E. (1995) Competition between scleractinian corals and macroalgae: An experimental investigation of coral growth, survival and reproduction. *Journal of Experimental Marine Biology and Ecology* 190, 151-168.
- Tessier E., Chabanet P., Pothin K., Soria M. and Lasserre G. (2005) Visual censuses of tropical fish aggregations on artificial reefs: slate versus video recoding techniques. *Journal of Experimental Marine Biology and Ecology* 315, 17-30.
- Wilkinson C. (ed) (2002) *Status of coral reefs of the world*. Australian Institute of Marine Sciences, Townsville, Australia.

Willis T.J. (2001) Visual census methods underestimate density and diversity of cryptic reef fishes. *Journal of Fish Biology* 59, 1408-1411.

Willis T.J., Millar R.B. and Babcock R.C. (2003) Protection of exploited fish in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves. *Journal of Applied Ecology* 40, 214-227.

Developing indicators of social resilience to changes in water quality – a Townsville case study

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Introduction

This paper reports on progress during 2007/2008 of a small study within the Marine and Tropical Sciences Research Facility (MTSRF) Project 4.9.7 'Understanding and enhancing social resilience: science and management integration', which incorporates three nested scales of research focus:

- Whole of Great Barrier Reef (GBR) catchment area (CSIRO);
- Large catchment (University of Queensland); and
- Community scale (James Cook University).

Researchers at each scale are developing indicators of social resilience in relation to changing water quality. The James Cook University (JCU) team is collaborating with other MTSRF projects, researchers, planners and managers working in North Queensland to identify best practice methods for community engagement and to attempt to develop a common indicator framework that can be implemented across projects.

The case study described here is situated in Townsville, a city located in the Burdekin Dry Tropics region. Townsville is home to more than 164,000 residents, and is experiencing population growth at three percent per annum. About 8,500 Townsville residents (i.e. 5.5% of the population) identify as either Aboriginal or Torres Strait Islander, compared with 3.3% across the whole of Queensland (The New Townsville City Council 2008; Townsville City Council 2007a). In recent years, the Townsville City Council has developed a holistic approach to water management through its Creek to Coral initiative. The approach integrates engineering, environment, planning and community activities and emphasises the connectivity between waterways, wetlands and estuarine and marine areas. Creek to Coral values partnerships, co-learning and community engagement and involves council officers, non-government organisations such as Conservation Volunteers Australia and schools, through its support of strategic partnerships and community-based education and involvement (Townsville City Council 2007b). Creek to Coral is developing the Black-Ross Water Quality Improvement Plan (WQIP) for the Black and Ross River basins (which closely mirrors the local government area). This plan is one of ten being developed and implemented along the coast of Queensland with the aim of reducing the amount of nutrients and sediments entering Great Barrier Reef waters. The Plan focuses on both point sources and non-point sources of pollution, and is being developed in consultation with key stakeholders including peak body representatives, water quality experts, scientists, planners, managers, and members of the Townsville community. A key outcome will be its integration with other local, state and national planning processes, and the Burdekin Dry Tropics Regional Natural

Resource Management Plan and investment strategy. The Water Quality Improvement Plan includes a water quality monitoring and modelling program to inform reporting and future adaptive management actions and the identification of management practices such as water sensitive urban design.

It is also developing a Community-Based Social Marketing (CBSM) strategy to help improve water quality by fostering changes in community behaviour (Townsville City Council 2007b). The CBSM aims to foster sustainable behaviour by reducing the barriers and enhancing the benefits of individual actions that have positive environmental benefits (McKenzie-Mohr 2000). In this phase of the study, researchers are working with the planning team to implement and evaluate a CBSM strategy designed to encourage residents to meet some of the water quality targets identified in the plan. Indicators will be developed to measure the extent to which residents are willing and able to change their behaviour to meet the targets. The general purpose of indicators is to enhance communication, transparency, effectiveness and accountability in a natural resource management context (FAO 1999; Garcia *et al.* 1999; Segnestam 2002).

The case study began with literature and lay reviews which are now completed². Aguirre (2006 in Maguire and Hagan 2007) describes resilient communities as "... [Those] that predict and anticipate change; absorb, respond and recover from shock or disaster; and improvise and innovate in response to disaster."

In undertaking the literature review we discovered that indicators of community-scale social resilience are not well documented. In fact, we found only one framework that referred to resilient communities. Wolfenden *et al.* (2007) used four properties of socio-ecological systems to identify possible indicators to manage for resilience in irrigation communities. These properties are described in detail by Walker *et al.* (2006). Wolfenden *et al.* (2007) see a resilient community as being responsive and innovative in the face of change. They suggest that indicators measuring each of the four attributes could help to enhance or (in some circumstances erode) the resilience of a particular community. The four attributes or properties are:

- Resilience – the ability of a system to maintain essentially the same structure, function, purpose and identity;
- Adaptability – the ability of a system to respond to change;
- Transformability – the ability of a system to change its current trajectory when facing adversity; and
- Scale – the synergistic influence of systems operating at different scales.

Developing indicators that tie in with these properties could help to build a picture of a community that is resilient to changes in water quality. For example, in a resilient community, we may assume that individuals would be aware of pressures on waterways and have a shared understanding of what 'water quality' means. Community members may also understand why it is important to maintain healthy waterways; and how 'water quality' varies for different contexts and different water uses. In this hypothetical community, residents would be vigilant in monitoring water quality; develop smart solutions to water quality problems; know how to survive in a rapidly changing world; be creative, diverse and innovative; and inspire other communities. In such a community, individuals with particular values, attitudes and perceptions can become role models for others, influencing how people act and think in relation to water quality issues.

² Please see <http://www.rrrc.org.au/publications/downloads/Project-497.pdf> for a more detailed discussion.

For the case study, we used ideas and concepts from the reviewed literature to develop our conceptual framework for indicator development, which is presented in Figure 1. We expect this framework to evolve as the study progresses, and hope that it will eventually provide us with a picture of what a community that is resilient to changing water quality might look like.

In a coastal community, such as Townsville, where residents rely on water for a variety of economic and recreational activities, and where certain activities (such as mining and housing development) adversely affect water quality, social resilience to changes in water quality is highly desirable. Some water quality impacts may be controlled through legislation, but others are due to the action (or sometimes inaction) of individual residents. A measure of Townsville residents' willingness and ability to respond pro-actively to changing water quality is fundamental in managing for community-scale resilience.

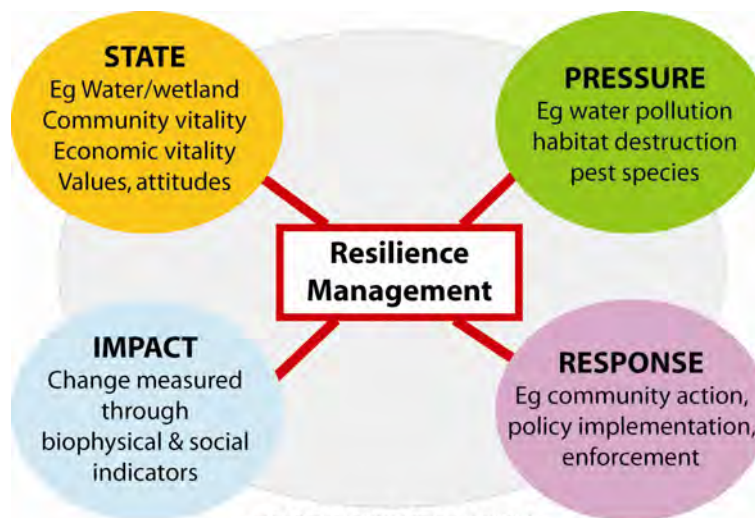


Figure 1: Evolving conceptual model for Townsville case study.

Methods

The overall aim of this phase of the study is to build the capacity of Townsville residents to change their behaviour in relation to particular water quality issues. We are concentrating on the response category of indicators, in particular the ability of individuals within a community to be proactive in the face of change. We are interested in finding out how people in Townsville might recognise and respond to changing water quality. We are also interested in how people know whether there is a water quality problem. What cues or criteria do residents use to make judgements about water quality? Are these cues or criteria different among different groups of residents? Do different groups of people use different criteria for judging water quality? Does this matter when it comes to changing the way in which people behave?

We are trying to answer some of these questions by developing and implementing three stages of research: (a) baseline data gathering; (b) an intervention strategy (CBSM); and (c) post-intervention data gathering.

(a) Baseline data gathering

Initially this will be achieved by targeting different groups of Townsville residents who attend one-day workshops organised by Council's Black-Ross WQIP planning team. We

plan to deliver an overview of the research project to the workshop participants and invite discussion from the attendees. In the same workshop session we would like participants to fill in a short written questionnaire. The aim is to identify issues of concern among different groups, including how people make judgments about water quality; on what sort of evidence they base these judgments; what specific actions/behaviours residents are willing and able to do to improve water quality; what the barriers are to doing what they would like to do; and what some benefits might be of being able to act in particular ways.

Asking residents to identify cues/criteria that they use to make judgments about water quality will help us to see whether different residents have different levels of awareness about water quality issues, and if these affect their willingness and ability to act in ways that improve water quality. Residents from the following groups will be invited to participate in the workshops:

- Scientists, planners and managers identified by the planning team;
- Three groups of residents identified through the WQIP as living in geographically distinct areas of Townsville;
- Members of the Great Barrier Reef Marine Park Authority Local Marine Advisory group;
- Indigenous residents; and
- Members of different community-based water quality monitoring groups.

As well as these workshops and surveys, we plan to gather baseline data through the inclusion of key questions in the 2008 Queensland Social Survey (QSS-2008). This will be conducted by Central Queensland University's Population Research Laboratory (PRL). This 2008 survey is the fourth in a series of annual cost-shared, omnibus surveys aimed at obtaining public opinion on a range of topics held by a random sample of Queensland residents. The survey is done by computer assisted telephone interview (CATI) and is scheduled to occur in July 2008.

The survey instrument will comprise a CATI questionnaire which will consist of three components:

- A standardised introduction;
- Questions that reflect the specific research interests of the researcher/s; and
- Demographic questions.

The questionnaire will be pilot-tested by trained interviewers on a predetermined number of randomly selected households. Interviewer comments (e.g. confusing wording, inadequate response categories, question order effect, etc.) and pre-test frequency distributions will be reviewed by the researchers before making any modifications, if necessary.

In addition to the data set, the PRL will provide frequency distributions and a technical sampling report. Included in the report will be the sampling design, the survey instrument, data collection process (including response rates, contact rates and eligibility rates), descriptions of the data, and any additional information to assist data analysis.

Through the workshops and associated written surveys, and through the results of the CATI survey, we should be able to identify a range of specific actions that residents are willing and able to take to help improve water quality in Townsville's waterways. This will form the foundation on which to build a CBSM strategy that will help enhance the benefits

and reduce the barriers to adopting particular behaviours that will help improve water quality of waterways in the Townsville area.

Once we have designed a strategy (but before strategy implementation) we will implement a stratified random survey to be mailed out to Townsville residents sometime in 2009. This will be designed to gather baseline data about residents' ability and willingness to adopt the desired behaviour(s) identified through the workshops and written questionnaires.

It may be barriers and/or benefits can be classified according to the following indicator domains, previously identified in the literature. For example:

- Social – peer pressure;
- Economic – costs, incentives;
- Human/personal – habits of mind;
- Cultural – traditions;
- Institutional – lack of policy enforcement; and
- Ecological – degree of habitat degradation.

(b) The intervention strategy (CBSM)

Depending on future funding arrangements, JCU researchers and Townsville City Council staff hope to develop a CBSM strategy that can be implemented and evaluated over a twelve-month period. This will take the form of an intervention to reduce the barriers and increase the benefits of the desired behaviour(s), so that residents are motivated to change to the desired behaviour. A pilot of the strategy will be implemented, and after modification (and funding), the strategy may be implemented across Townsville. CBSM has specific steps that we will follow including the following:

- Selecting desired behaviour and target audience – e.g. best management practices for residents;
- Identifying barriers and benefits to a behavioural change;
- Developing a strategy that uses effective 'tools';
- Piloting the strategy; and
- Evaluating the strategy once it has been implemented across a community (McKenzie-Mohr 2000).

Effective tools used to develop a strategy with CBSM include the following:

- Public commitment, e.g. sign a petition;
- Prompts – close in time and space, e.g. stickers;
- 'Norms' – peer behaviour;
- Effective messages – media – short, sharp and vivid;
- Incentives/remove external barriers – one-off reward; and
- Diffusion tools – social networking, word-of-mouth (McKenzie-Mohr 2000).

(c) Post-intervention data gathering

Finally, the baseline residential survey could be repeated (depending on time and funding), to see whether the CBSM strategy led to an increased adoption rate of the

desired behaviour. The strategy may need to be adjusted, then implemented again, and a further survey implemented (again, depending on time and funding). Thus, the survey can be modified and repeated over time to monitor changes in behaviours as well as the community's capacity to be pro-active in the face of changing water quality. It is envisaged that this ongoing survey will be integrated into the Townsville City Council's BRWQIP monitoring and reporting activities, with the information gathered to be used to inform management action adaptation strategies.

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References

- FAO (1999) *Indicators for sustainable development of marine capture fisheries*. Report No. 8, FAO Fishery Resources Division.
- Garcia S.M., Staples D.J. and Chesson J. (1999) *The FAO guidelines for the development and use of indicators for sustainable development of marine capture fisheries and an Australian example of their application*. Report No. CM 1999/P:05, International Council for the Exploration of the Sea, Bureau of Rural Sciences.
- Maguire B. and Hagan P. (2007) Disasters and communities: Understanding social resilience. *Australian Journal of Emergency Management* 22(2), 16-20.
- McKenzie-Mohr D. (2000) New Ways to Promote Pro-environmental Behavior: Promoting Sustainable Behavior: An Introduction to Community-Based Social Marketing. *Journal of Social Issues* 56(3), 543-554.
- Segnestam L. (2002) *Indicators of Environment and Sustainable Development: Theories and Practical Experience*. Paper No. 89, The World Bank Environment Department, Washington, D. C.
- The New Townsville City Council (2008) *The New Townsville City Council: a demographic profile*. First Edition. Prepared by the Social Planning Unit, Commercial Infrastructure Planning and Development Section, Townsville City Council.
- Townsville City Council (2007a) *The Townsville Region: A Social Atlas*. Fifth Edition. Prepared by the Community and Cultural Services Department, Townsville City Council. (<http://previous.townsville.qld.gov.au/atlas/default.asp>) Accessed: 20 May 2008.
- Townsville City Council (2007b) *Townsville City Council Annual Report 2006-2007*. (<http://www.townsville.qld.gov.au/resources/4.pdf>) Accessed: 20 May 2008.
- Wolfenden J., Evans M., Essaw D., Johnson F., Sanderson A., Starkey G. and Wilkinson B. (2007) *Resilience management: a guide for irrigated regions, communities and enterprises*. Technical Report No. 01/07. CRC for Irrigation Futures.

Walker B., Gunderson L., Kinzig A., Folke C., Carpenter S. and Schultz L. (2006) A handful of heuristics and some propositions for understanding resilience in social-ecological systems. *Ecology and Society* 11(1), 13. <http://www.ecologyandsociety.org/vol11/iss1/art13/>. Accessed: 5 June 2007.

Assessing the habitat quality of remnant and riparian vegetation

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Introduction

In landscapes where the majority of land is cleared for anthropogenic purposes, landholders may leave areas of remnant and riparian vegetation uncleared, either to protect against streambank erosion or due to its unsuitability for agriculture, urban or tourist development. This is the case in many of the agricultural and urbanising landscapes of the Wet Tropics region. Therefore, forest remnants in the Wet Tropics are a biased subset of the original forest cover (Laurance and Goosem 2008). Remnants frequently persist in steep areas, on poorer soils, in scenic reserves and on partially inundated lands such as paperbark swamps and mangrove forests, as well as along some streambanks. However, such remnant and riparian vegetation may provide habitat as well as connectivity for fauna and flora in the otherwise fragmented landscape.

Species richness of many groups of flora and fauna is often positively correlated with fragment size (Laurance and Goosem 2008). Forest fragments and riparian strips have fewer species in a given area than the same area of continuous forest (Ferraz *et al.* 2003; Laurance 1990; Lawson *et al.* 2008; Warburton 1997), particularly if non-rainforest species that sometimes invade forest fragments are excluded from consideration. Some of this loss of species can be attributed to a suite of alterations in biophysical conditions near abrupt artificial forest margins, termed 'edge effects'. Microclimate, vegetation floristics and structure, and consequently the species composition of fauna inhabiting the forest edge, can all be affected (Goosem 2000; Laurance *et al.* 2002; Pohlman 2006; Pohlman *et al.* 2007). The result is a reduction in the quality of habitat for native species and often the ingress of species from other habitats and invasions by exotics. Loss of species can also be related to the degree of isolation of forest remnants (Bennett 1990; Saunders and Hobbs 1991).

Rainforests can be considered especially vulnerable to fragmentation. With such an extreme habitat contrast between the forest and surrounding cleared matrix, even relatively small clearings can prevent or reduce movements by some rainforest species. Many rainforest species also avoid edge-affected habitat (Dawe and Goosem 2007; Goosem and Marsh 1997; Goosem 2000, 2001, 2002; Laurance *et al.* 2002; Laurance and Gomez 2005). Many species are therefore unable to traverse cleared landscapes lacking closed canopy habitat.

Provision of connectivity of habitat for native species that allows movements through cleared landscapes is a major goal for conservation outside protected areas. Connectivity can reduce the deleterious effects of population isolation on forest-dependent flora and fauna (Laurance and Laurance 2003). Linear strips of vegetation along streams (from ten to two hundred metres in width) can form habitat and movement routes for many forest bird and mammal species (Crome *et al.* 1994; Laurance 1991; Laurance and Laurance 1999; Lawson *et al.* 2008). Small (<20 ha) forest fragments linked to large forest tracts by such corridors sustain a greater diversity of arboreal marsupials than nearby, isolated fragments of comparable area (Laurance 1990). Similarly, restoration of a linkage along a stream can increase

movements and gene flow for some forest vertebrates and plants (Janzen 2005; Tucker 2000).

Breeding activity and stable home ranges of many birds, mammals, and amphibians in tropical corridors suggest that they can provide useful wildlife habitat (Crome *et al.* 1994; Laurance and Laurance 1999; Lima and Gascon 1999).

However, all but the widest corridors suffer significant edge effects and are likely to be selective filters, facilitating movements of some species but not forest-interior specialists, which are often the most vulnerable to fragmentation (Laurance and Goosem 2008). In contrast, for species that suffer greater predation along edges, corridors may increase the vulnerability of nearby populations in fragments. Corridors could also increase the spread of pathogens among fragments (Simberloff and Cox 1987). Therefore, although corridors may be effective for many species, there may be no simple way to counter the negative effects of fragmentation on highly vulnerable species (Laurance and Goosem 2008).

These connectivity principles guided a habitat quality assessment of riparian vegetation undertaken in the Douglas Shire south of the Daintree River in 2005 and 2006. The study used a quick and reliable remote sensing technique that created an index incorporating canopy cover and forest width and was 88% effective in predicting field-assessed habitat quality (Lawson *et al.* 2008). Field habitat quality was determined using rapid assessments of vegetation and replicated bird observations (Lawson *et al.* 2007, 2008). Riparian areas were then prioritised for restoration according to feasibility and cost, with highest priority subjectively assigned to riparian sections which provided habitat connectivity along streams to large forest areas that could provide a source of rainforest species. These sections were judged feasible and cost-effective to restore if they revegetated a narrow gap in connectivity of generally less than fifty metres in length or alternatively strengthened a narrow riparian section to potentially allow more specialised species to move into the riparian forests.

Method

In August 2007, a stakeholder workshop considered regional priorities for similar rapid habitat quality assessment, focusing on current pressures in sections of the Wet Tropics. Stakeholders present included Terrain NRM Ltd, Wet Tropics Management Authority, Barron River Catchment Management Group, Queensland Department of Main Roads, Conservation Volunteers and researchers from other projects. The highest priority after consideration of a range of factors was given to the Mission Beach region due to the high pressures for development and the current habitat network action planning exercise for the region. The Mission Beach area was subsequently divided into six priorities based on current pressures and importance of habitat connectivity. Highest priority was assigned to the fast developing area along the coastal strip between Bingil Bay and Hull Heads (Figure 1).

Results

It must be emphasised that results in this paper are only in draft form due to the requirement for ground-truthing of the remotely sensed data, which will be undertaken over the next seven months.

Post-Cyclone Larry aerial photography (Figure 2a) taken in late 2006 was purchased and remote sensing assessment commenced in October 2007. We allocated canopy cover classes using a novel technique which relies on the creation of a digital stereo anaglyph to allow interpretation of percentage canopy cover on the computer screen rather than using a manual stereoscope (Figure 2b). The expected canopy cover class prior to the cyclone for the vegetation type of each polygon was then determined from Wet Tropics Management Authority vegetation mapping (WTMA, in prep.) by grouping vegetation types that usually

possess closed canopy (Figure 2c). Similarly, open forest types, woodland types and open woodland types were grouped according to expected percentage canopy cover (McDonald *et al.* 1990). A canopy cover index was created, ranging from 5 where there was little canopy damage, to 1 where post-cyclone canopy cover was very poor in comparison to that shown in previous vegetation mapping (Figure 2d). A class of 1 implied either extreme damage from Cyclone Larry or that vegetation had been severely (but not completely) cleared. A separate category showed completely cleared areas under agricultural and urban land-uses.

The rectified aerial photography was then used to create a remnant vegetation layer (i.e. all remaining native vegetation). The vegetated polygons were buffered by a range of distances (Figure 3a) relating to the distance of penetration of edge effects as determined in fragments and riparian vegetation and along linear clearings in the Wet Tropics (Goosem 2001; Goosem and Marsh 1997; Laurance 1991; Laurance and Laurance 2003; Pohlman 2006; Pohlman *et al.* 2007; Siegenthaler and Turton 2000; Siegenthaler *et al.* 2000; Turton and Freiburger 1997). Remnant vegetation polygons containing core area after buffering by the largest distance (200 m) were assigned a high vegetation shape index of 5, whilst polygons that contained no core area using the smallest buffer (five metres) were assigned the lowest vegetation shape index of 1 (Figure 3b), with each index values relating to a buffer distance. Remotely sensed vegetation quality was then determined by summing the two indices (canopy cover/vegetation type and vegetation shape) and assigning each consecutive pair of scores to a class from very poor to excellent (Figure 3c). Figure 4 shows a flow diagram of the methodology used.

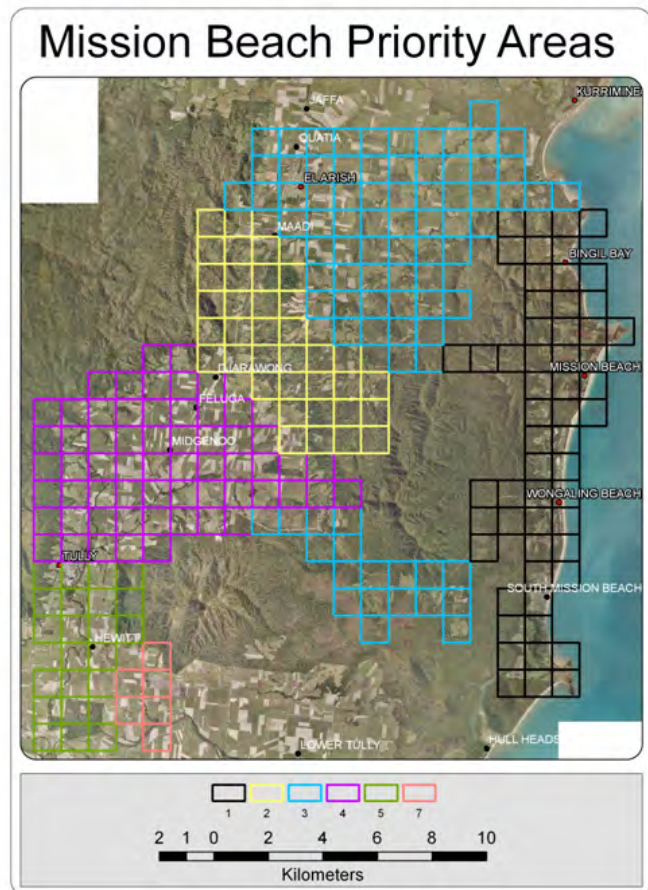


Figure 1: Priorities for assessment within Mission Beach region: (1) Urbanising coastal strip; (2) Range connecting uplands with lowlands; (3) Areas to north and south of main protected areas; and (4) Feluga to Tully area.

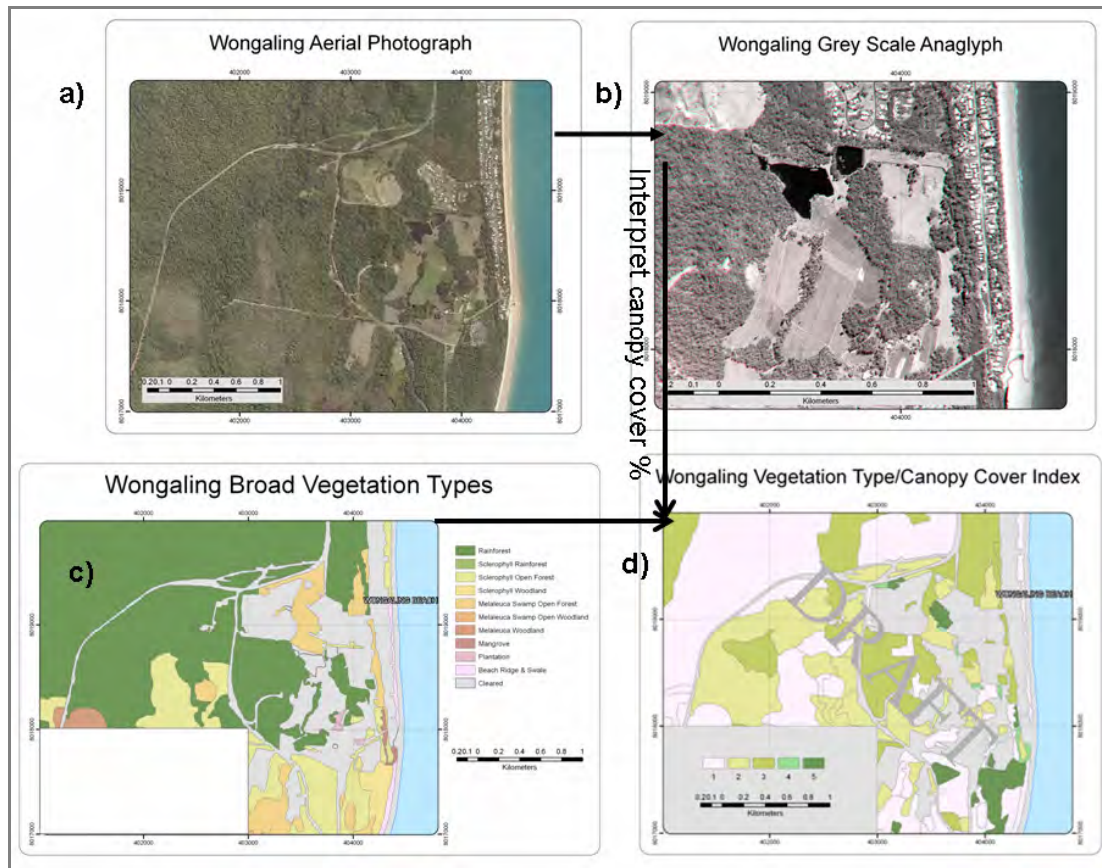


Figure 2: Remotely sensed habitat quality still to be ground-truthed using field surveys. Examples from Wongaling section of Mission Beach region post Tropical Cyclone Larry, showing (a) remnant vegetation polygons buffered by variety of distances relating to edge effect penetration; (b) vegetation shape index assigned from presence of core area in polygon when buffered; (c) vegetation type / canopy cover index (see Figure 2); and (d) remotely sensed habitat quality index.

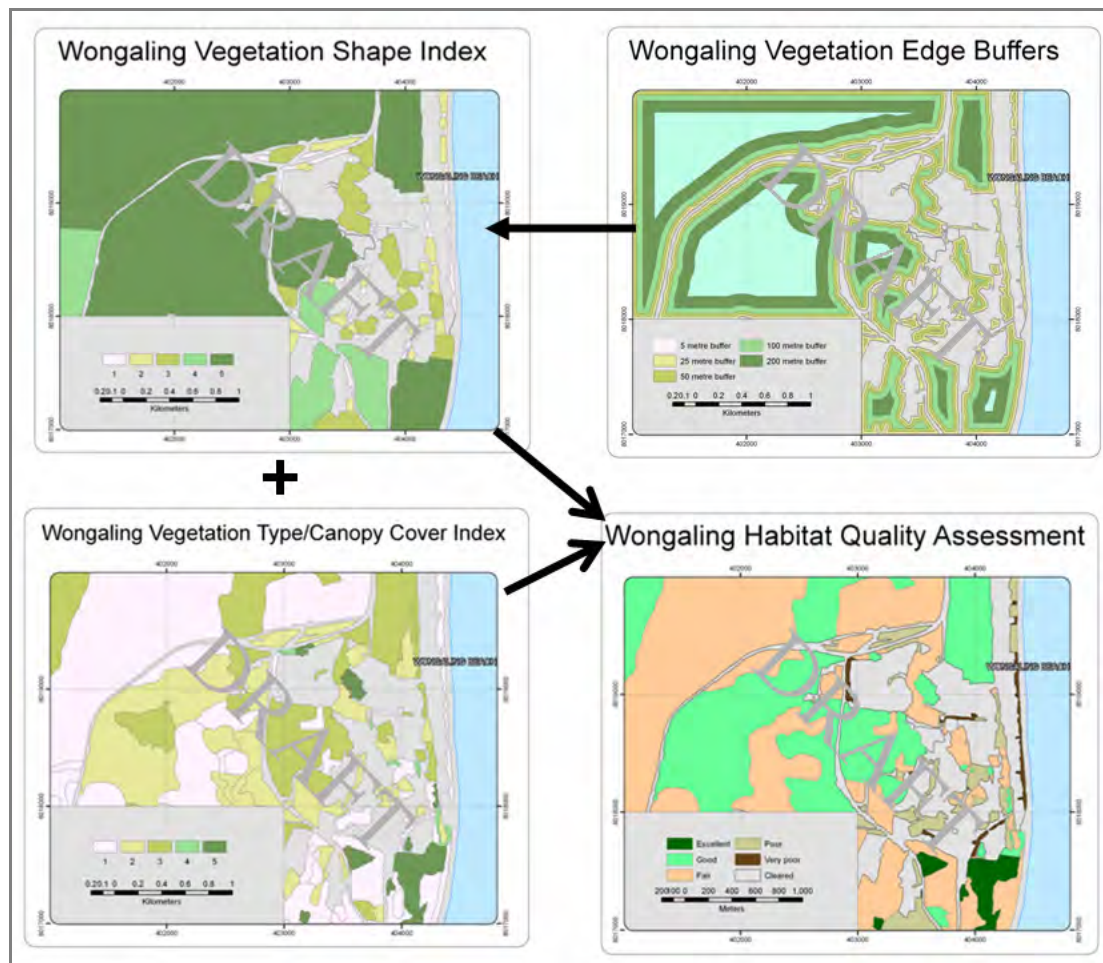


Figure 3: Remotely sensed habitat quality still to be ground-truthed using field surveys. Examples from Wongaling section of Mission Beach region, showing (a) remnant vegetation polygons buffered by variety of distances relating to edge effect penetration; (b) vegetation shape index assigned from presence of core area in polygon when buffered; (c) vegetation type / canopy cover index (see Figure 2); and (d) remotely sensed habitat quality index.

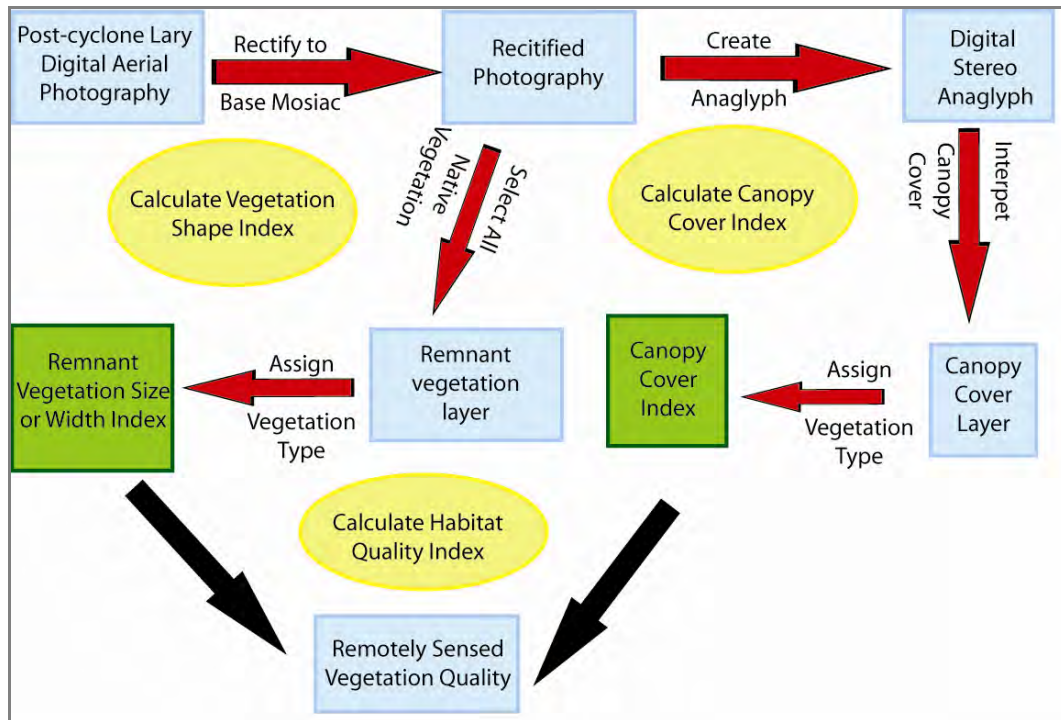


Figure 4: Flow chart of methodology for remote sensing of habitat quality in the Mission Beach region.

Project continuation

Ground-truthing of the remotely sensed vegetation quality will be undertaken between May and December 2008, together with microclimate measurements and bird observations. More than forty sites will be chosen to represent all remotely sensed vegetation qualities and to incorporate both remnant patches and riparian strips, with control sites also chosen in continuous forest near the test sites. All three field observation types will use a modification of the transect technique from MTSRF Project 4.9.5 Vegetation Monitoring Toolkit (Kanowski and Catterall 2006). This involves recording woody debris along a fifty metre transect (Figure 5). Three 10 x 10 m quadrats along the transect are used for measurement of canopy cover, canopy height, the abundance of large trees (>10 cm diameter) and their structural damage as well as the presence of special life forms including lianas and weeds. Within half of each 10 x 10 m quadrat, the abundance and structural damage of smaller trees is quantified, whilst a 1 m x 1 m quadrat at the centre of the larger quadrats will be used to assess percentage groundcover of parameters such as bare soil, leaf litter, seedlings and woody debris. Microclimate parameters including light intensity (PAR), air temperature, vapour pressure deficit, soil moisture and soil temperature will be measured at five metre intervals along the transect. Bird observations will incorporate the transect but extend ten metres either end of it to a distance of fifteen metres either side and be undertaken over a set length of time for each transect, replicated in morning and evening on different days and on two field sampling occasions, with a minimum of two kilometres between sampled transects during any one period.

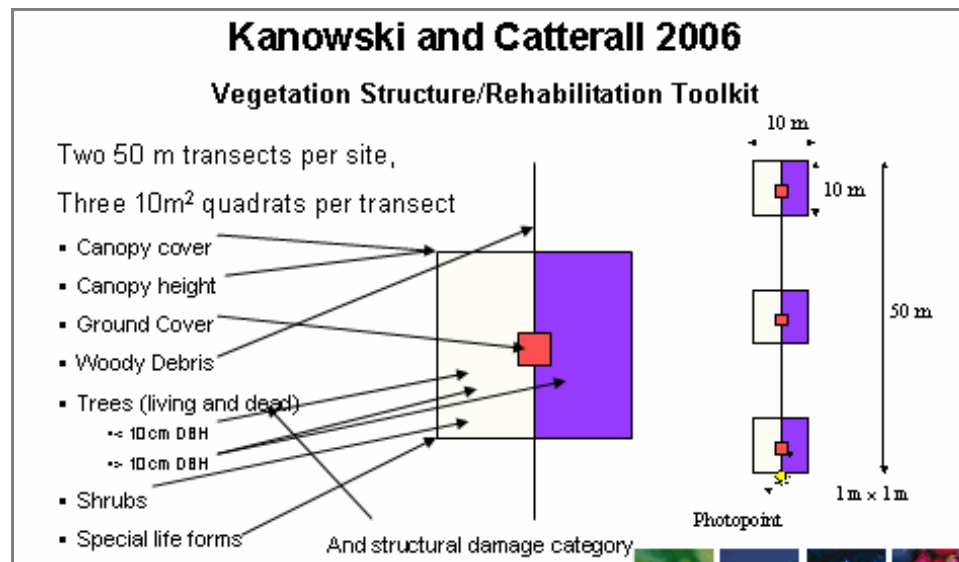


Figure 5: Vegetation field assessment ground-truthing methodology from Kanowski and Catterall 2006.

References

- Bennett A.F. (1990) *Habitat Corridors: Their Role in Wildlife Management and Conservation*. Department of Conservation and Environment, Melbourne.
- Crome F.H.J., Isaacs J. and Moore L. (1994) The utility to birds and mammals of remnant riparian vegetation and associated windbreaks in the tropical Queensland uplands. *Pacific Conservation Biology* 1, 328-343.
- Dawe G. and Goosem M. (2007) Noise Disturbance Along Highways; Kuranda Range Road Upgrade Project. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Ltd, Cairns (http://www.rrrc.org.au/publications/noise_disturbance.html)
- Ferraz G., Russell G.J., Stouffer P.C., Bierregaard R.O., Pimm S.L. and Lovejoy T.E. (2003) Rates of species loss from Amazonian forest fragments. *Proceedings of the National Academy of Sciences of the United States of America* 100, 14069-14073.
- Goosem M.W. (2000) Effects of tropical rainforest roads on small mammals: edge changes in community composition. *Wildlife Research* 27, 151-163.
- Goosem M. (2001) Effects of tropical rainforest roads on small mammals: inhibition of crossing movements. *Wildlife Research* 28, 351-364.
- Goosem M. (2002) Effects of tropical rainforest roads on small mammals: fragmentation, edge effects and traffic disturbance. *Wildlife Research* 29, 277-289.
- Goosem M.W. and Marsh H. (1997) Fragmentation of a small-mammal community by a powerline corridor through tropical rainforest. *Wildlife Research* 24, 613-629.
- Janzen A. (2005) Avian use of restoration plantings along a creek linking rainforest patches on the Atherton Tablelands, North Queensland. *Restoration Ecology* 2, 275-283.
- Kanowski J. and Catterall C. (2006) *Monitoring revegetation projects for biodiversity in rainforest landscapes. Toolkit Version 1*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns.
- Laurance W.F. (1990) Comparative responses of five arboreal marsupials to tropical forest fragmentation. *Journal of Mammalogy* 71, 641-653.
- Laurance W.F. (1991b) Ecological correlates of extinction proneness in Australian tropical rainforest mammals. *Conservation Biology* 5, 79-89.

- Laurance S.G. and Gomez M. (2005) Clearing width and movements of understory rain forest birds. *Biotropica* 37, 149-152.
- Laurance W.F. and Goosem M. (2008) *Impacts of habitat fragmentation and linear clearings on Australian rainforest biota*. In 'Living in a dynamic tropical forest landscape' eds. N. Stork and S. Turton, pp 295–306. Blackwell Publishing: Oxford, UK.
- Laurance S.G. and Laurance W.F. (1999) Tropical wildlife corridors: Use of linear rainforest remnants in arboreal mammals. *Biological Conservation* 91, 231-239.
- Laurance S.G. and Laurance W.F. (2003) *Bandages for wounded landscapes: Faunal corridors and their roles in wildlife conservation in the Americas*. In 'How Landscapes Change: Human Disturbance and Ecosystem Fragmentation in the Americas' eds G. Bradshaw and P. Marquet, pp. 313–325. Springer: New York, USA.
- Laurance W.F., Lovejoy T., Vasconcelos H., Bruna E., Didham R., Stouffer P., Gascon C., Bierregaard R., Laurance S. and Sampaio E. (2002) Ecosystem decay of Amazonian forest fragments: A 22-year investigation. *Conservation Biology* 16, 605-618.
- Lawson T., Gillieson M. and Goosem M. (2007) Assessment of riparian rainforest vegetation change for management and restoration. *Geographical Research* 45, 387-397.
- Lawson T., Goosem M. and Gillieson D. (2008) Rapid assessment of habitat quality in riparian rainforest vegetation. *Pacific Conservation Biology* (in press).
- Lima M.G. and Gascon C. (1999) The conservation value of linear forest remnants in central Amazonia. *Biological Conservation* 91, 241-247.
- McDonald R.C., Isbell R.F., Speight J.G., Walker J. and Hopkins M.S. (1990) *Australian Soil and Land Survey Field Handbook 2nd Edition*. Inkata Press: Melbourne, Australia.
- Pohlman C. (2006) Internal fragmentation in the rainforest: Edge effects of highways, powerlines and watercourses on tropical rainforest understorey microclimate, vegetation structure and composition, physical disturbance and seedling regeneration. PhD thesis, James Cook University, Cairns, Australia.
- Pohlman C., Turton S. and Goosem M. (2007) Edge effects of linear canopy openings on tropical rainforest understory microclimate. *Biotropica* 39, 62-71.
- Saunders D.S. and Hobbs R.J. eds. (1991) *Nature Conservation 2: The Role of Corridors*. Surrey Beatty: Chipping Norton, Australia.
- Siegenthaler S., Jackes B., Turton S. and Goosem M. (2000) *Edge effects of roads and powerline clearings on rainforest vegetation*. In 'Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area' eds M.W. Goosem and S.M. Turton, pp. 46-64. Rainforest CRC: Cairns, Australia.
- Siegenthaler S. and Turton S. (2000) *Edge effects of roads and powerline clearings on microclimate*. In 'Impacts of Roads and Powerlines on the Wet Tropics World Heritage Area' eds M.W. Goosem and S.M. Turton, pp. 20-43. Rainforest CRC: Cairns, Australia.
- Simberloff, D. and Cox, J. (1987) Consequences and costs of conservation corridors. *Conservation Biology* 1, 63-71.
- Tucker N.I.J. (2000) Linkage restoration: Interpreting fragmentation theory for the design of a rainforest linkage in the humid Wet Tropics of north-eastern Queensland. *Ecological Management and Restoration* 1, 35-41.
- Turton S.M. and Freiburger H. (1997) *Edge and aspect effects on the microclimate of a small tropical forest remnant on the Atherton Tableland, Northeastern Australia*. In 'Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities' eds W.F. Laurance and R.O. Bierregaard, pp. 45–54. University of Chicago Press: Chicago, USA.
- Warburton N.H. (1997) *Structure and conservation of forest avifauna in isolated rainforest remnants in tropical Australia*. In 'Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities,' eds W.F. Laurance, R.O. Bierregaard, pp. 190-206. University of Chicago Press: Chicago.
- Wet Tropics Management Authority (in prep). Vegetation of the Wet Tropics bioregion. Based on reports and 1:25,000 data provided by J. P. and D. J. Stanton (1997-2005). Wet Tropics Management Authority, Cairns.

Community monitoring of Great Barrier Reef coral reefs

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What is Reef Check Australia?

Reef Check is something people can do to participate in coral reef conservation and management. Our mission is to promote healthy local coral reefs through scientific research, community education and marine conservation.

Reef Check Australia was set up in 2001 by a passionate group of Australians dedicated to helping conserve Australia's coral reefs. We are part of an international network of volunteers who help to protect coral reefs by monitoring their health. Australian teams monitor the health of a number of reefs both on and outside the Great Barrier Reef (GBR).

Reef Check is UN-endorsed and teams are active in more than ninety countries, making Reef Check the largest coral reef monitoring effort around the world. Reef Check was established in 1997 to answer the question, "What is the health of the world's coral reefs?" because scientists acknowledged a deficit of information around the world at that time. The first two years of surveys helped to bring coral reefs into the global climate change debate, by illustrating a global loss of ten percent hard coral cover during the 1998 mass coral bleaching event.

How does Reef Check contribute to status and trends research on the Great Barrier Reef?

Reef Check Australia's monitoring is designed to complement and enhance existing programs such as the Australian Institute of Marine Science (AIMS) Long-term Monitoring Program, which is resourced to conduct detailed monitoring of 47 sites biannually. The AIMS program is important to maximise our level of understanding of how coral reefs are responding to threats such as crown-of-thorns outbreaks and climate change. However, due to the cost of using a professional monitoring team, the number of sites that can be visited is limited and the frequency of visits is on a biannual basis. Reef Check methods are a simplified version of the transect-based methods used by AIMS, but enable the collection of timely information from additional sites at a vastly reduced cost through a partnership with the dive tourism industry and public support. This means Reef Check can act as an early warning system for any changes in the health of our coral reefs, and helps to keep our eye on a much larger area. The Reef Check model can also be used to respond to anecdotal reports of bleaching or disease by sending out volunteers to conduct surveys for reef managers and scientists.

By involving the general community in the site selection process, Reef Check ensures its volunteers monitor sites that are important to the local community and industry, as well as providing a pathway for community participation in coral reef management issues.

As well as the AIMS long-term monitoring program, Reef Check complements other monitoring programs such as the weekly Eye on the Reef or BleachWatch reports provided

by the dive tourism industry. These reports provide a valuable source of seasonal information on presence and absence of key species and coral reef impacts. Reef Check is able to quantify and more accurately report on impacts of interest, such as algal blooms or coral bleaching.

The use of digital video and photo transects by Reef Check teams means the data can be analysed in more detail by scientists if this is required. Figure 1 illustrates the relationship between Reef Check and the other monitoring programs on the GBR.

Tasks supported by the Marine and Tropical Sciences Research Facility

The Marine and Tropical Sciences Research Facility (MTSRF) supports Reef Check Australia's 'Great Barrier Reef Project' which is also supported by the Association of Marine Park Tourism Operators and more than twenty dive operators on the GBR. The GBR project, which has been running since 2001, involves long-term monitoring³ of more than thirty key dive sites on the GBR and Osprey Reef in the Coral Sea.

Reef Check volunteers who participate are ordinary recreational divers from the Townsville, Cairns and Port Douglas region. Volunteers are trained in Reef Check monitoring methods. All volunteers pass a competency check achieving 95% in identification tests and competency in monitoring prior to joining the survey team. Surveys are led by marine biology graduates who volunteer for six-month periods during the low season for tourism (January–June). Survey expeditions are run at the weekend to enable participation of working Australians. During 2007/2008 we trained 25 new volunteers who have joined our current team of about seventy volunteers.

To ensure our collaboration with the dive industry is effective, we conducted individual meetings with nineteen dive operator managers during early 2008. We are in the process of securing formal agreements for their support and have acquired valuable feedback on planned communication and interpretation materials. All Reef Check supporting operators expressed their intent to continue to support the program.

Reef Check data reporting

A key component of Reef Check monitoring is the data reporting. The aim is to develop an 'end-user friendly' reporting system that enables the general community, industry supporters as well as researchers and managers to acquire meaningful information about the status and trends of Reef Check monitored sites.

Version 1 of the reporting system is online through Google™ Earth. Anybody with Google Earth can download the Reef Check Australia layer from our website:

www.reefcheckaustralia.org/research/data/index.cfm

The web-based data entry point and underlying database are under development. At operator meetings, 95% of dive operators ranked the Google Earth layer as the most useful type of data output. Saving paper is important to the industry. Updates from the 2008 survey season will be made after the final surveys are completed in June.

³ <http://www.reefcheckaustralia.org/research/methods/monitoring/index.cfm>

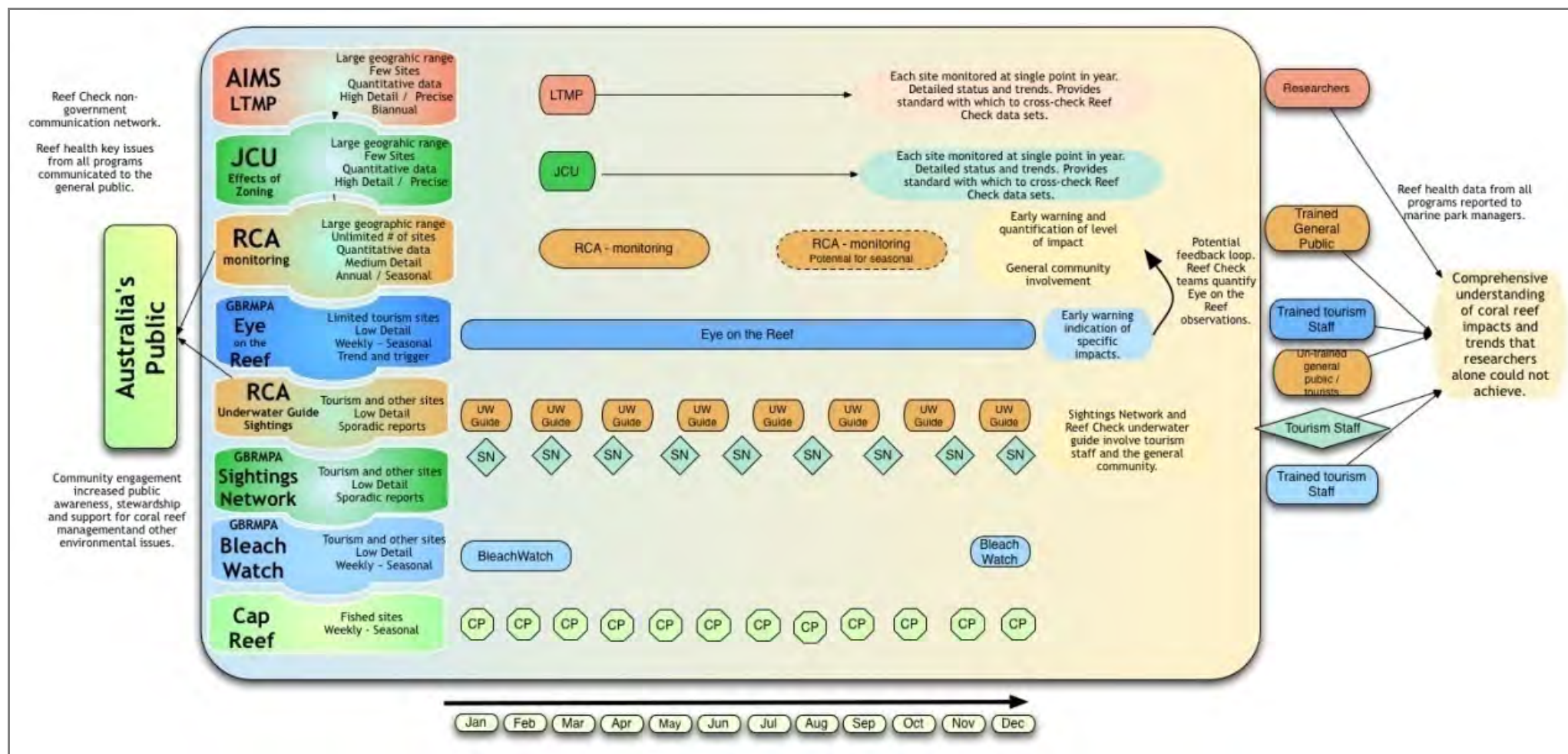


Figure 1: How Reef Check Australia (RCA) fits in with other monitoring programs on the Great Barrier Reef. AIMS LTMP = Australian Institute of Marine Science Long-term Monitoring Program; JCU = James Cook University; GBRMPA = Great Barrier Reef Marine Park Authority.

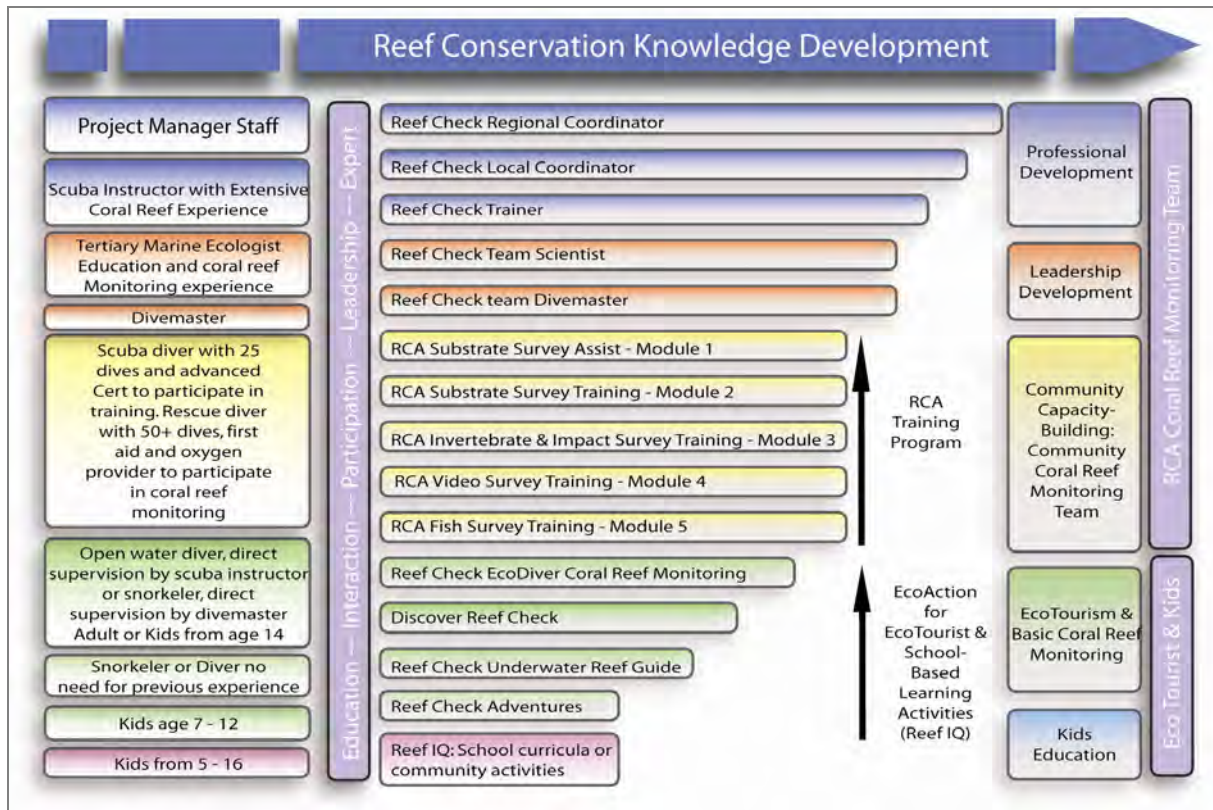


Figure 2: Reef Check Australia's 'ladder of involvement'.

How can people get involved with Reef Check Australia?

As well as our monitoring program, we have a suite of participatory programs and educational packages to suit all ages and offer different levels of involvement (Figure 2).

We believe the general community has the power to make a significant contribution towards the sustainable use of our planet's resources through active participation in conservation as well as through making sustainable lifestyle decisions. Reef Check education programs instil an ethic of stewardship towards the natural world by increasing participants' understanding of our reliance on coral reefs as a resource.

Our training and educational activities are packaged within three programs:

- Reef Check Australia training: advanced coral reef monitoring training;
- EcoAction: ecotourism and educational activities as well as basic coral reef monitoring training; and
- Reef IQ: Reef Check schools program

Reef Check Australia training course

The Reef Check Australia training course⁴ consists of five modules. Scuba divers with an advanced certification are able to participate in training. Reef Check surveyors are rescue divers with a minimum of 50 logged dives.

⁴ <http://www.reefcheckaustralia.org/education/training/rca-course-timetable-2007-08.pdf>

Reef Check Australia volunteers are trained to a higher level than Reef Check volunteers in other countries. This is to ensure the high quality of data used for the management of the Great Barrier Reef Marine Park (GBRMP).

- **Module 1:** Introduction to Reef Check, Reef Check methods overview, data entry and interpretation overview; buoyancy and methods practice; data entry, reporting and mapping.
- **Module 2:** Substrate identification training (classroom); substrate identification training (practical on a coral reef x four dives); substrate identification photo test (classroom); substrate identification and methods test (practical on a coral reef).
- **Module 3:** Invertebrate and impact training (classroom); invertebrate and impact photo test (classroom); invertebrate identification and methods test (practical on a coral reef x two dives).
- **Module 4:** Video transect methods training (classroom); video transect methods training and test (practical on a coral reef x four dives).
- **Module 5:** Fish identification training (classroom); fish identification training practical (practical on a coral reef x two dives); fish identification photo test (classroom); fish identification test and fish survey method practice (practical on a coral reef x two dives).

Reef Check Australia Trainers are scuba instructors with extensive coral reef experience. Our training program is run as a PADI, SDI or NAUI specialty course through Reef Check Australia HQ-endorsed projects.

Reef Check EcoAction program

The EcoAction program provides a range of interactive educational experiences that will stimulate active participation in coral reef conservation activities, empower dive tourists to collect reef health data, and generate additional revenues which can be used to support established Reef Check projects in Australia and around the world.

Whatever a person's age or experience level there is an EcoAction product that suits. Each product has been designed by Reef Check scientists to provide tourists with a deeper knowledge and understanding of the coral reef ecosystem. As a result, diving and snorkeling experiences are greatly enhanced.

As people progress through the EcoAction program, they will have the opportunity to participate in valuable data collection. By submitting data online, participants directly contribute to Reef Check's global coral reef conservation programs and assist Reef Check in tracking the health of Australia's coral reefs. Proceeds from the sale of EcoAction products⁵ will be used to support local coral reef conservation efforts.

Reef Check underwater reef guide

The underwater reef guide was designed as a tool to enhance tourist diving and snorkeling experiences. It can be used by anyone who wants to increase their knowledge and understanding of the fascinating coral reef fish, invertebrates, corals and algae that comprise the Indo-Pacific coral reef ecosystem. Developed by Reef Check scientists, the waterproof reef guide contains photographs and information on fifty organisms specifically chosen for their regional abundance as well as their important role in the ecosystem, allowing easy identification. It has a reusable slate attached to it which allows tourists to record what they

⁵ <http://www.reefcheckaustralia.org/conservation/ecoaction/index.cfm>

see. By submitting data online they will be helping Reef Check scientists to track global coral reef health and contributing to global coral reef status reports.

Discover Reef Check

This two-hour course allows people to gain first-hand experience in how marine biologists conduct coral reef research. The course includes a one-hour presentation, where the methods used for monitoring coral reef health will be introduced. This will be followed by a guided dive in which people can try their hands at some of the sampling techniques.

Reef Check EcoDiver

The EcoDiver course is Reef Check's international coral reef monitoring training course. It is less detailed than the Reef Check Australia course and is planned as an ecotourism activity for launch in the near future at selected tourist destinations on the GBR. People taking the EcoDiver reef monitoring course will become certified to join Reef Check survey teams around the globe and take an active role in conserving the world's coral reefs. Reef Check trainers explain the globally standardised Reef Check methodology as well as how to identify key indicator fish, invertebrates and substrates selected by Reef Check for global monitoring and conservation of coral reefs.

Partnership with the Reef Check Foundation Ltd benefits dive tourism businesses because it symbolises a long-term commitment to community-based conservation of reef resources. It will also complement ecotourism business activities in many other ways. Incorporating the EcoAction program into business is simple as it is a ready-made ecotourism solution that can be readily integrated into current reef activities.

Education

Reef Check Australia has recently begun to develop a youth education program. Products include a range of interactive learning experiences for school students and young people in order to increase their knowledge and appreciation of the value of coral reefs to humans. There are two separate courses:

Coral reefs and sustainability

This course links the sustainability of coral reefs to the sustainability of our cities. Its development has been supported by Townsville City Council's Creek to Coral program.

Classroom monitoring for management

This course teaches young people how to conduct simulated surveys of real coral reefs in the classroom using Reef Check's survey methods. Eventually school-aged children will have the opportunity to become involved in the Reef Check EcoAction program and to help collect information on the status of their local coral reefs. Through the involvement of Australia's youth, Reef Check aims to effect behaviour change within Australian families towards a more environmentally friendly lifestyle and for Australians to support initiatives to protect our coral reefs.

Reef Check communication products

Additional communication products are designed to inform the general community about opportunities to participate in Reef Check, the status and trends in condition of our coral reefs, build membership and support and, ultimately, to help encourage behaviour-change in support of a more coral reef-friendly lifestyle. Current products include:

- GBR Project Newsletter – Update on activities for supporting dive tourism industry partners;
- Reef Check Australia quarterly newsletter – Update on Reef Check activities for Reef Check Australia members;
- Brochure – General information about Reef Check programs, to be made available on-board dive tourism boats;
- Information booklet – Sixteen-page booklet which details information about Reef Check projects, why coral reefs are important and showcases the other monitoring programs with which Reef Check partners e.g. Eye on the Reef, BleachWatch, project AWARE, AIMS long-term monitoring program; will be available on-board supporting dive tourist boats;
- Promotional DVD – Fifteen-minute promotional video about Reef Check, problems facing reefs and solutions that people can become involved with; to play at tourist ticket desks or on-board;
- Operator information packs – Folder on-board supporting Reef Check tourist boats, contains information about Reef Check and a back-catalogue of Reef Check newsletters;
- Website updates – The website communicates key messages through the photography competition and information about what people can do to get involved;
- General media – Newspaper and magazine articles. Reef Check Australia attracts significant media attention. This is another tool to raise the general public's awareness about how they can help to protect coral reefs. In 2007, a total of 25 media articles were written about Reef Check Australia. So far, in 2008, six stories have been published in the media, including mainstream newspapers, two stories in Jet Star's in-flight magazine, diving and sailing networks. Jet Star listed Reef Check Australia as a 'Star Company' for green initiatives. During March 2008, we had coverage on the Channel 10 and Channel 9 news programs throughout Queensland, as well as a number of radio shows. During April 2008 our community service announcement began to play in Queensland, NSW and Victoria;
- In 2007, Reef Check's Townsville-based photo competition entitled, "What do coral reefs mean to you?" attracted more than 100 entries and was covered in local, national and international media. The 2008 national competition was launched between May 1 and June 30. The competition promotes key messages in support of Reef Check Australia partners, including the MTSRF and GBRMPA.

Cassowary conservation through adaptive, collaborative planning at Mission Beach

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Establishing local area biodiversity planning in the Wet Tropics

The distinct character of the Wet Tropics bioregion of northeast Queensland arises from its tropical climate, spectacular scenery, biological diversity, cultural values (both Aboriginal and non-Aboriginal) and economic productivity (FNQ NRM Ltd and Rainforest CRC 2004). The international significance of the region for its natural values, including contributions to global understanding of bio-evolution and geo-evolution, is recognised through World Heritage listing of both the Wet Tropics and the Great Barrier Reef. Increasing human activity threatens the region's natural environment and associated cultural values.

The Wet Tropics region has been the site of a long history of efforts and disputes focused on management of the outstanding natural and cultural values (McDonald and Lane 2000; Valentine and Hill 2008). A complex planning system has developed within the region aimed at ensuring protection of these values, and integrating international, national, state, regional and local goals, priorities and legislative requirements. The recent formulation and implementation of the Sustaining the Wet Tropics Regional Plan for Natural Resource Management 2004-2008 (Regional NRM Plan 2004-2008) has seen an unprecedented level of effort alignment (FNQ NRM Ltd and Rainforest CRC 2004).

Within this overall planning system, the Wet Tropics World Heritage Area (WTWHA) provides protection for some 900,000 ha of rainforest and associated floral communities, and is recognised as the most diverse assemblage of primitive angiosperm plant families in the world, with elements of its biota representing eight major stages of earth's evolutionary history (WTMA 1992). Biodiversity and natural areas with similar outstanding values occur outside the boundaries of the WTWHA, and many of these values are facing threats from urban and rural residential development associated with 'sea-change' and 'tree-change' movements in human population. The Regional NRM Plan 2004-2008 recognised four such areas of regional significance for priority action in relation to biodiversity management: Mission Beach, the Daintree lowlands, the southern Atherton Tableland and the Ingham lowlands (FNQ NRM Ltd and Rainforest CRC 2004). Local area planning for biodiversity was identified as the key means of enhancing the management within these priority sites.

The cassowary recovery plan (CRP) forms another important element of the Wet Tropics planning system in relation to biodiversity management and conservation. Preparation of the plan is mandated under *Environment Protection and Biodiversity Act 1999* (Commonwealth) in recognition of the 'Endangered species' status of the Southern Cassowary. The most recent CRP (Latch 2007) identifies the following eight main threats to the cassowary population:

- Habitat loss from clearing;
- Habitat fragmentation;

- Habitat degradation;
- Roads and traffic;
- Dog attacks;
- Hand feeding;
- Diseases; and
- Natural catastrophes.

The CRP recognises that while some protection was provided for cassowary habitat outside the WTWHA through the *Vegetation Management Act 1999* (Queensland), housing development still threatens local populations as supporting habitat disappears. Mission Beach was identified as a site where incremental losses to severely fragmented habitat may eventually destroy the viability of the local population, as even low density housing brings more traffic and dogs (Latch 2007). The CRP contains a recommendation for the development of cassowary conservation local area plans as the best means of implementing on-ground action and coordinated conservation, with a Mission Beach local area plan as the priority. The CRP envisages the planning process as involving all stakeholders, addressing local issues within the context of broader cassowary conservation priorities, and ensuring that the local community retains ownership of the plan through a local planning group comprising representatives from state and local government, community conservation groups, private landholders, Aboriginal groups and industry.

As part of a larger strategic regional planning research project aiming to provide a robust framework for such local area biodiversity planning, this MTSRF-supported project has the objective of developing a rigorous local area planning framework for biodiversity. Such a framework needs to incorporate values and services provided by regional ecosystems, as well as information about the threatening and beneficial processes acting on vulnerable species in the area. The framework should then be tested through a series of case studies.

Mission Beach was selected as the most appropriate locality for the implementation of a case study to develop such a local area biodiversity planning framework, reflecting the recommendations of the CRP, and following initial scoping by Weston (2006).

Two research questions were addressed through the Mission Beach case study:

- What does a rigorous local area planning framework for biodiversity look like?
- What specific tools enhance the effectiveness of local area planning?

Mission Beach context

Tropical Cyclone *Larry*, a severe Category 4 cyclone, crossed the coast near Mission Beach on 20 March 2006, causing extensive damage to forests and human infrastructure in the region. By May, hungry cassowaries were reported to be threatening people in both the Innisfail and Mission Beach areas (AAP 2006). In October 2006, the Queensland Parks and Wildlife Service (QPWS) reported that 23 cassowaries had been confirmed killed since the cyclone, most of them by struck by vehicles (QPWS 2006a).

The QPWS instigated a cassowary feeding and relocation program that proved controversial in the local community, with some people arguing that both feeding and relocation raised the level of threat to cassowaries (C4 2006; QPWS 2006b).

The post-cyclone plight of cassowaries raised public awareness of the issue of cassowary conservation in Mission Beach. Turton and Dale's (2007) assessment of the ecological and

social impacts of Cyclone *Larry* concluded that continuing to build landscape resilience was critical to reducing the impacts, and that more effective natural resource management response strategies were required.

This context highlighted the need for enhanced biodiversity conservation action, as identified through the Regional NRM Plan 2004-2008 and the CRP (Latch 2007). Most of the threats identified in the first cassowary recovery plan 2001-2005 (QPWS 2002) appear to have intensified in the five years prior to Cyclone *Larry*, particularly in the Mission Beach area. Historical analysis is required to determine the extent of this intensification. However, limitations in the implementation of key cassowary conservation measures can be traced which must be related to ongoing intensification of threatening processes.

For example, a Mission Beach coastal area development control plan (DCP) was completed jointly between Cardwell and Johnstone Shire councils in 1997. The plan was completed under the *Local Government Planning and Environment Act 1990*, which has now been replaced by the *Integrated Planning Act 1997*, and the DCP has lapsed. This plan established a vision that development would not be allowed in habitat strips along the road between the development nodes identified in 1997 – an intent which has clearly been breached. The Far North Queensland Regional Plan 2010 also established a Mission Beach case study, described in some detail by Weston (2006). The case study developed clear objectives and tasks focused on cassowary conservation, but most of these were never implemented. Key actions in the case study, including the rolling fund to buy land and the system of devolved grants, did not occur as financial resources were not made available to the project. Latch's (2007) review of the cassowary recovery plan also identified lack of implementation of key actions.

Strengths and weaknesses of local area planning

The concept of local area planning is aligned with a recognised paradigm shift in both natural resource management and protected area management globally. Borrini-Feyerabend *et al.* (2004a) argue that the policy paradigm shift is from protected areas as islands, managed reactively with a narrow focus on conservation and control of the activities of local people, to protected areas as elements of a network, managed adaptively with a broader focus on socio-economic and cultural objectives, and established and run together with local people. Collaborative management at the local scale has emerged as a key means of overcoming the tension between local people and protected areas (see Beltrán 2000; Borrini-Feyerabend *et al.* 2004b; Worboys *et al.* 2001). In the field of natural resource management, a move to adaptive management, combined with a landscape-scale approach, is seen as a 'paradigm shift' away from the traditional 'command and control' model of resource management (Ashby 2003; Meffe *et al.* 2002). Adaptive management is based on the general premise of learning by doing, and can occur at many different temporal and spatial scales (Stankey *et al.* 2005). The local scale is captured in the concept of adaptive co-management systems as flexible community-based systems of resource management tailored to specific places and situations, supported by and working with various organisations at different levels (Folke *et al.* 2002; Ollson *et al.* 2004).

Local-scale strengths in planning are identified as employment, experiential knowledge, greater responsiveness to local context and priorities, and provision of greater efficiencies through recruitment of local people in implementation (Lane and Corbett 2005). The collaborative nature of local-scale planning provides the opportunity to use deliberative democracy planning techniques to build community ownership and long-term commitment (Healey 1996).

Conservation is recognised as an activity that happens on the ground through local action (Borrini-Feyerabend *et al.* 2004b). The Locally Managed Marine Area Network has found

local planning approaches and participatory tools such as mapping, root cause analysis, priority matrices and ranking to be highly effective (Govan *et al.* 2008). Planning at the local scale is widely supported by governments and stakeholders in the Wet Tropics region as the most appropriate means to achieve integration, effort alignment and coordination between the multiplicity of planning instruments and agencies (Weston 2006).

However, the local scale also generates a number of risks to achieving equitable natural resource management and protection of the identified natural and cultural values. Localism can increase the marginalisation of indigenous people in conservation management, replicating existing power asymmetries and entrenched local racial tensions (Cheng and Mattor 2006; Lane and Corbett 2005; Smyth *et al.* 2004; Young 2001). Agrawal and Gibson (1999) highlight the limitations at the local scale arising from the conceptualisation of 'community' as a small spatial unit of people/place, with homogeneous social structure, and a shared set of understandings and social norms. Lane and McDonald (2005) identify a similar concern, and additionally point to problems of inequality, lack of capacity, lack of knowledge diversity and parochialism in local-scale, community-based environmental planning. Local-scale planning also risks jeopardising natural resource management outcomes through processes such as elite capture and interest heterogeneity undermining collective action, and jeopardising internal institution building and resultant outcomes for sustainability (Tai 2007). Rather than a means of integration and coordination, local scale plans may simply become another of the more than one hundred plans and strategies already existing within the Wet Tropics region, diverting resources away from much needed on-ground action. The lack of a clear intellectual framework (or legislative mandate) for local area biodiversity planning is in itself a risk.

In the Mission Beach context, an examination of the institutional arrangements highlights the challenges (Coggan *et al.* 2007). All three levels of Eckersley's (2003) framework for institutional failure are implicated in the limitations of cassowary conservation at Mission Beach:

- First-order limitations in policy instruments, such as in the failure to implement the plans as discussed above, and in the weak regulatory instruments to protect cassowary habitat from clearing;
- Second-order limitations in policy goals, with key national, state and local agencies having different goals, and the decision-making authority residing primarily with those agencies that give greater priority to development; and
- Third-order limitations in policy paradigm or the hierarchy of goals behind the policy setting, with a relatively low priority for the cassowary conservation goal in the hierarchy of goals of both Queensland and national governments reflected in low levels of funding for voluntary measures and a weak regulatory regime.

Clearly, local area biodiversity planning at Mission Beach will not provide protection for cassowaries or other biodiversity if it is conceived simply as an exercise in localism – a multi-scale approach is required. Successful outcomes at the local scale are associated with realistic approaches that recognise the multiple interests and actors within all communities, and how these actors exercise influence in both the internal and external institutions that shape the decision-making process (Brook *et al.* 2006; Sayer and Campbell 2004).

The local area biodiversity planning framework

The local area biodiversity planning framework developed for Mission Beach aims to build on the strengths and overcome the potential weaknesses of action and planning at the local scale through:

- Collaboration to build strong community ownership;
- Rigorous science and co-research to overcome risks such as capture by local elites;
- Integration across planning scales to include actors in external institutions through brokering and nesting;
- Explicit recognition of the local planning process as part of an overall ongoing planning system, not a plan; and
- On-ground actions from the beginning of the local area planning process to ensure the resources are not diverted away from this important component.

It is called the Mission Beach Habitat Network Action Plan to emphasise its ongoing action component. For example, grants for restoration projects in the Mission Beach area were made available by Terrain NRM during early 2007. The local area biodiversity planning framework being implemented through the action plan includes three elements:

- An adaptive collaborative management framework (Figure 1);
- A regional hierarchical nesting framework (Figure 2); and
- A planning systems brokering framework (Figure 3).

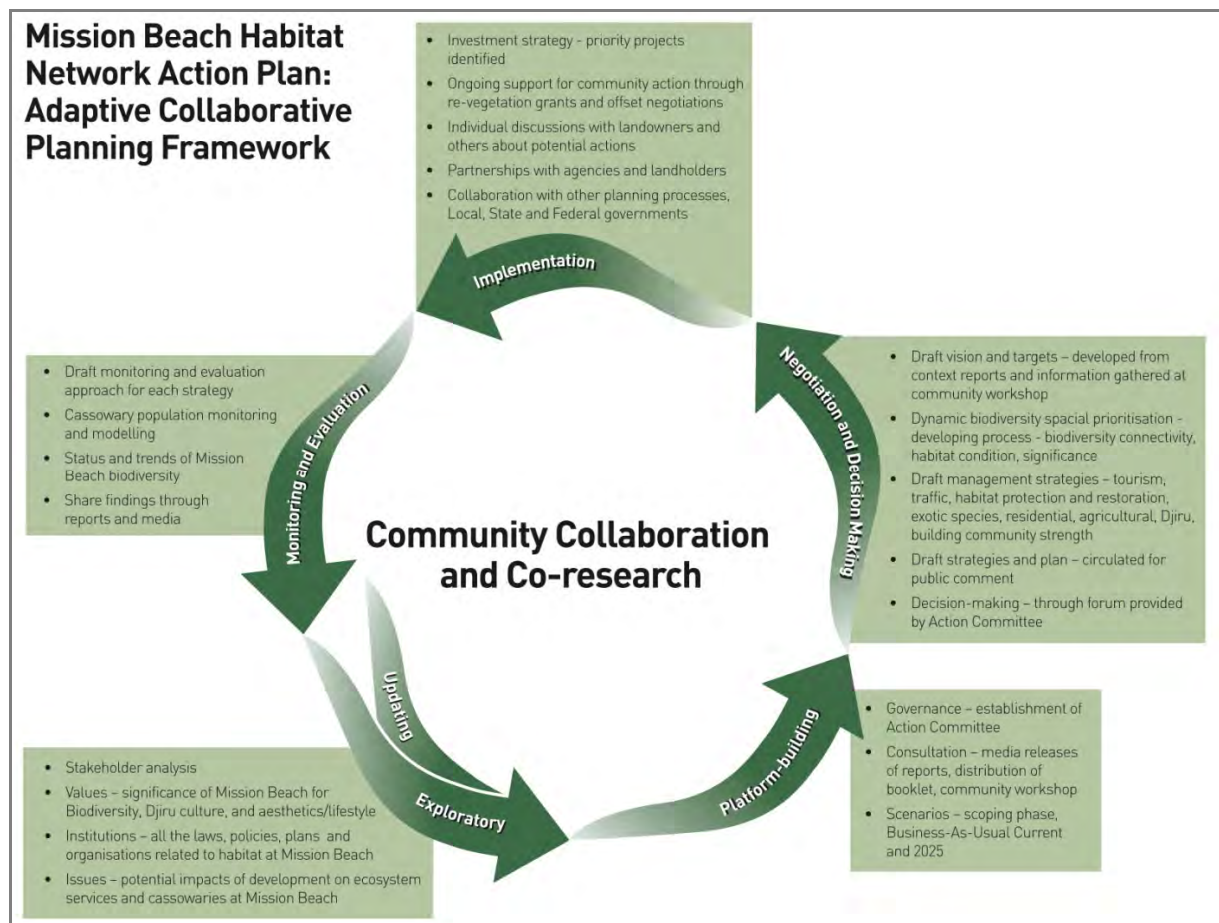


Figure 1: Adaptive Collaborative Management Framework.

The adaptive collaborative management framework essentially builds community collaboration through co-research in five phases of an adaptive management cycle: exploratory; platform-building; negotiation and decision making; implementation and monitoring; and evaluation. Adaptive management systemises social learning through an explicit, deliberative approach to framing questions and problems, experimenting, analysing results, and changing behaviour to improve management, based on indicators, interventions and monitoring (Ashby 2003; Stankey *et al.* 2005). Biodiversity science knowledge is brought into the planning process through these social learning processes. The community, conceptualised broadly as all the people and agencies in the local area, is placed at the centre of this adaptive collaborative cycle.

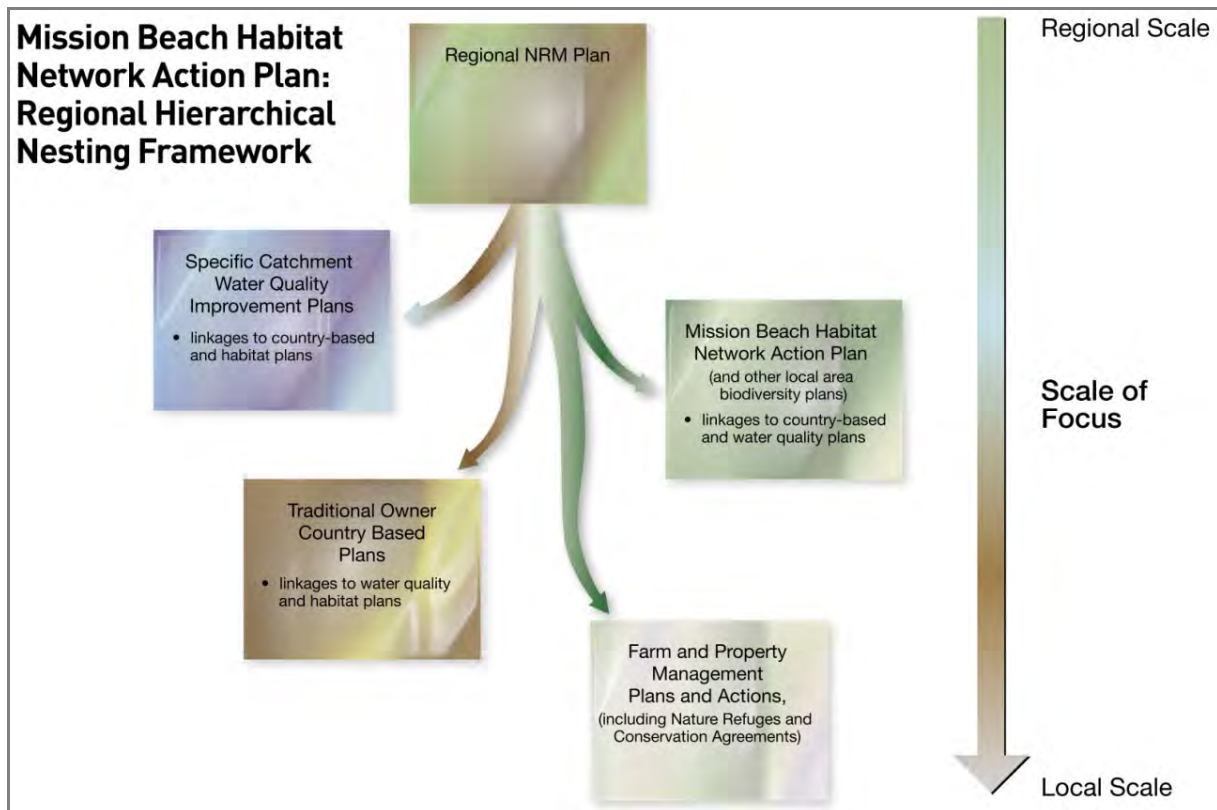


Figure 2: Regional Hierarchical Nesting Framework.

The regional hierarchical nesting framework recognises that this particular adaptive collaborative cycle occurs within a special jurisdiction – the regional natural resource management system established by the Australian Government, which sets out a framework for aspirational targets (goals), resource condition targets, management action targets and management actions (FNQ NRM Ltd and Rainforest CRC 2004). Clear nesting of the local area biodiversity plan within this jurisdiction requires the adoption of this format for the targets in the plan. However, a view has emerged through community engagement processes that this format is not suitable for or comprehensible by the non-technical audience, who form the majority of people living and working in Mission Beach. A simpler, strategy-based approach and language is therefore being adopted to develop the targets, alongside the technical NRM format.

The third and possibly most critical aspect of the local planning approach is the brokering framework. NRM planning is only one aspect of the broad environmental planning system that affects biodiversity at Mission Beach.

Brokering across the planning system is an effective way of ensuring that actions at the site and local neighbourhood scale (e.g. a few suburban blocks) appropriately reflect strategic national and regional laws, policies and plans, and vice-versa. For example, the aim of brokering information and outcomes from the Mission Beach habitat network action plan into the emerging Far North Queensland (statutory) regional plan is to reduce potential negative impacts of the urban footprint design on nationally significant biodiversity, such as occurred in south east Queensland (Peterson *et al.* 2007). 'Effort alignment' is a key concept underpinning this approach to brokering. The local area planning officer's role is critical in undertaking this brokering – without this resource, the local area plan would undoubtedly become further duplication, rather than a means of integration.

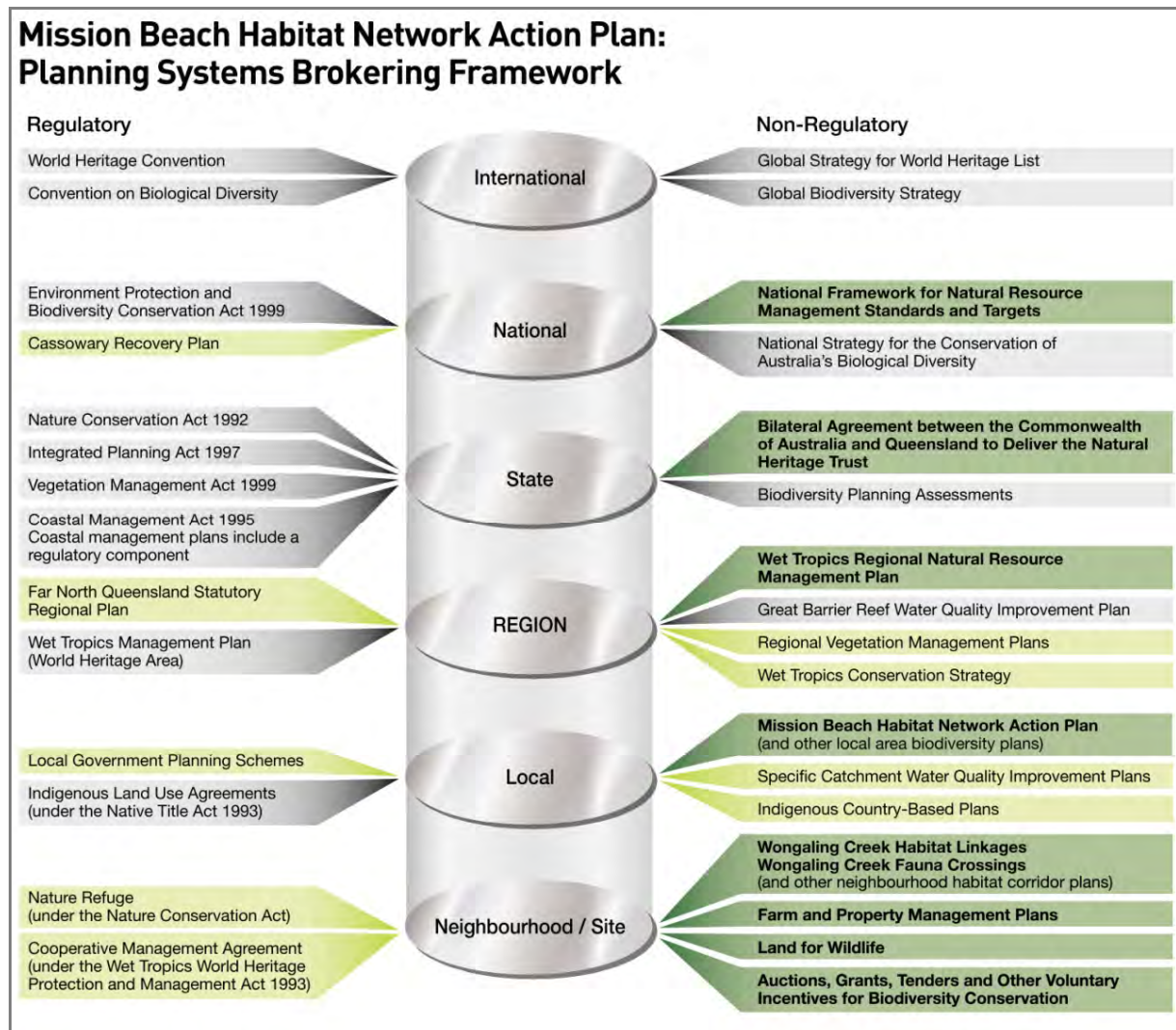


Figure 3: Planning systems brokering framework. Darker and lighter shades of green represent spheres of direct and indirect interest (based on Peterson *et al.* 2007).

Together, these three elements provide a framework for responding to the key directions in natural resource management and planning globally.

Effective tools in the local area biodiversity planning framework

A number of participatory and biodiversity science tools are being tested within the adaptive collaborative planning framework of the action plan (Figure 1) including:

- Action committee including government, non-government, business and Traditional Owner actors as the key means of governance of the process (see below);
- Community engagement including workshops, media, and web-based tools;
- Assessment of values and their significance as a tool to build common understanding;
- Scenarios, as an aid to vision development (Williams *et al.* 2008a, this volume);
- National Reserve System targets mapping (Williams *et al.* 2008b, this volume) as an aid to agreeing on specific targets; and
- Biodiversity attribute status and condition mapping as a means of prioritising investment.

Further information about the current status of development of these tools is available from Hill *et al.* (2008). This paper focuses on the concept of values and their significance, which underpins the 'significance assessment tool' deployed in the exploratory and platform-building phases of the adaptive cycle. Human understandings and perceptions of landscape values, changes, and what constitutes sustainability are critically important in reaching consensus in planning (Lewis 2008). While Mission Beach has been identified as an area of outstanding natural and cultural importance in a number of studies, a detailed understanding of the significance of the area was not available when planning began (FNQ NRM Ltd and Rainforest CRC 2004). Reports on the biodiversity, indigenous cultural and aesthetic/lifestyle significance of Mission Beach were commissioned to help recognise the diversity of values and perceptions that need to be addressed in the planning process (Chenoweth Environmental Planning and Landscape Architecture 2007; Falco-Mammone 2007; The Djiru Traditional Owners and Girringun Aboriginal Corporation 2007).

The outstanding lifestyle qualities of Mission Beach which were identified include the relaxed village atmosphere, low levels of development and traffic and natural landscapes. Mission Beach's plant and animal biodiversity was found to be of national significance. For example, Mission Beach contains half of Australia's remaining area of *Licuala* (fan palm) forest and the largest area of tropical lowland rainforest south of the Daintree River. The natural beauty of Mission Beach is highly significant to the Djiru traditional owners, due to their unique affinity with the rainforest that provides food, shelter and spiritual regeneration. The cassowary emerges as a highly valued component in all aspects of the significance assessment of Mission Beach.

The biodiversity, indigenous cultural, and aesthetic/lifestyle significance reports were released at a local community function on 27 October 2007 and posted on the internet. A leaflet summarising the identified values and inviting people to become involved in the planning process was distributed to the Mission Beach local community by mail⁶. In this way the wide array of understandings and perceptions held about the values and meanings of the biodiversity at Mission Beach were acknowledged as the starting point of the planning process.

Emerging outcomes

At this stage of the implementation of the local area biodiversity planning framework, it is not possible to evaluate its full impact. Nevertheless, several outcomes are encouraging:

⁶ http://www.terrain.org.au/index.php?option=com_content&task=view&id=80&Itemid=52

- A high level of commonality in the vision and strategies developed through the community workshop, which attracted a strong degree of community interest and participation;
- Interest expressed by a number of private landholders in establishing long-term conservation arrangements on their properties;
- Adoption of measures in the draft FNQ 2025 that protect substantial parts of Mission Beach from sub-division (statutory regional plan under the *Integrated Planning Act 1997* Queensland);
- A strong level of participation by government agencies in the Mission Beach habitat network action committee, providing better coordination; and
- Ongoing participation by Djiru Traditional Owners in the process, including development of a Traditional Owner management strategy.

The commonality of purpose which arose through the community workshop in December 2007 is particularly encouraging. Action committee members worked with Terrain NRM staff to identify suitable participants from across the stakeholder groups, and more than fifty people participated in the workshop. However, only one Djiru Traditional Owner was present and a subsequent workshop with a group of Djiru people was held in May 2008. Several members of the action committee took on roles as facilitators of small group workshop discussions during the day, together with Terrain NRM and CSIRO staff.

The workshop gathered information in response to two key focus areas:

1. Our goal is to develop a habitat network that is ecologically viable and protects the identified community values. Imagine that by 2025 we have achieved our goal. What does Mission Beach look like then? How does it differ from the business-as-usual 2025 scenario?
2. Again imagine that by 2025 we have achieved our goal of an ecologically viable habitat network that protects the identified community values. What were the prime issues we needed to address in each of the eight key areas (traffic management, tourism management, residential management, agricultural management, management by traditional owners, habitat protection and restoration (see below), exotic species management, building community strength)? What steps did we take to address these issues?

A summary of the responses was presented to the action committee and subsequently posted on the Terrain NRM website.

The overall vision emerging from the responses to the first question at the community workshop was one in which the business-as-usual scenario does not come to fruition. Key aspects of the desired future include:

- The entire area is a sanctuary, which maintains an environmentally focused way of life;
- The defining feature is a strong community – this will ensure that values are protected; and
- Mission Beach will be different and better managed than other environmentally significant coastal regions.

The vision and steps to achieve it were developed in some detail, with many steps suggested in several key areas:

- Traffic – public transport, bicycles, development design, road design including cassowary overpasses, underpasses, traffic calming, roadside vegetation, canopy cover, fencing;
- Tourism – facilities, environmental focus, threat management;
- Residential and infrastructure – tropical architecture, semi-natural landscapes, density management, waste management;
- Agricultural – crop diversity, sustaining production, managing impacts;
- Management by Traditional Owners—Indigenous people's values respected and included;
- Habitat protection and restoration – habitat network, corridors, net ecological gain, cassowary population secured, increased, water quality protected;
- Protection and restoration toolkit – protected areas expanded, incentives for conservation, management of conservation areas, corridors, protected species and invasive species;
- Exotic species management – domestic animal management, weed and pest management;
- Economic viability – economic diversity, business support mechanisms (leadership, resources), healthy environment needed for businesses to be sustainable/logical development, employment opportunities;
- Planning and institution-building – regulatory action, local government, town plan, regional and other plans; and
- Building community strength – strong community that is vibrant, diverse and bigger, facilities, community values and opportunities, community events and networks.

The second question, which asked people to consider which issues would be encountered when trying to achieve their vision, and steps to address these, elicited a set of very useful and innovative ideas which is now being developed into specific projects.

Conclusion

Local area biodiversity planning in the Wet Tropics region is emerging as a key means of achieving conservation of cassowary and other important biodiversity. This project has identified a number of inherent strengths in a local area planning approach, such as the opportunity to build community commitment and coordination between the many agencies and instruments involved within the overall natural resource planning system of the Wet Tropics. However, a number of potential inherent weaknesses have also been identified, including the risk of replicating power asymmetries, and of different interests and elite capture undermining outcomes (Tai 2007).

An intellectual framework has been developed to ensure that local area biodiversity planning builds on inherent strengths and overcomes potential weaknesses. It recognises that local area planning is not an exercise in localism, but a multi-scale approach. The key elements of the framework are adaptive collaborative management, nesting, and cross-scale brokering. Within this overarching framework, a number of tools are being tested. A values and significance tool is proving effective in building understanding of different perspectives between stakeholders. A number of other tools are also being tested, such as the use of scenarios. The planning research and development to date confirm that substantial investment is required to ensure survival of the cassowary on the 'Cassowary Coast', particularly at Mission Beach.

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References

- AAP (2006) Hungry cassowaries menacing Innisfail. Sydney: Sydney Morning Herald, Thursday 25 May. Online Available from: <http://www.smh.com.au/news/NATIONAL/Hungry-cassowaries-menacing-Innisfail/2006/05/25/1148524811025.html>. Accessed: 20 April 2008.
- Agrawal A. and Gibson C.C. (1999) Enchantment and Disenchantment: The Role of Community in Natural Resource Conservation. *World Development* 27(4), 629-649.
- Ashby J. (2003) *Introduction: Uniting Science and Participation in the Process of Innovation – Research for Development*. In 'Managing Natural Resources for Sustainable Livelihoods', eds B. Pound, S. Snapp, C. McDougall and A. Braun, pp1-19. Earthscan Publications: London.
- Beltrán J. (2000) *Indigenous and Traditional Peoples and Protected Areas: Principles, Guidelines and Case Studies*. IUCN-The World Conservation Union and WWF International: Gland, Switzerland and Cambridge, UK.
- Borrini-Feyerabend G., Kothari A. and Oviedo G. (2004a) *Indigenous and Local Communities and Protected Areas: Towards Equity and Enhanced Conservation*. Gland, Switzerland and Cambridge, UK: IUCN. World Commission on Protected Areas. Best Practice Protected Area Guideline Series No. 11.
- Borrini-Feyerabend G., Pimbert M., Farvar M.T., Kothari A. and Renard Y. (2004b) *Sharing Power. Learning by doing in co-management of natural resources throughout the world*. IIED: Tehran and IUCN/CEESP/CMWG: Cenesa.
- Brook B.W., Bowman D.M.J.S., Bradshaw C.J.A., Campbell B.M. and Whitehead P. J. (2006) Managing an Endangered Asian Bovid in an Australian National Park; the Role and Limitations of Ecological-Economic Models in Decision-Making. *Environmental Management* 38(3), 463-469.
- C4 (2006) *Assessment of the QPWS 'Cassowary Feeding Strategy'*. Community for Coastal and Cassowary Conservation Inc. report to the Queensland Parks and Wildlife Service.
- Cheng A.S. and Mattor K.M. (2006) Why Won't They Come? Stakeholder Perspectives on Collaborative National Forest Planning by Participation Level. *Environmental Management* 38, 545-561.
- Chenoweth Environmental Planning and Landscape Architecture (2007) *Biodiversity Significance of Mission Beach*. A Report to Terrain Natural Resource Management Ltd, Brisbane.
- Coggan A., Hill R., Whitten S. and Harmon B. (2007) *Market Based Instruments, Ecosystem Services and Development in Mission Beach, Far North Queensland. Background Report 3: Institutions and structures currently in place for the management of development and the cassowary — what do they do, what are the gaps, and what does this mean?* Draft Report to the Marine and Tropical Science Research Facility. Reef and Rainforest Research Centre Ltd, Cairns.
- Eckersley R. (2003) *Politics and Policy*. In 'Managing Australia's Environment', eds S. Dovers and S. Wild-River, pp 485–500. The Federation Press: Sydney.
- Falco-Mammone F. (2007) *The Aesthetic and Lifestyle Significance of Mission Beach*. Focus on Research, Cairns.
- FNQ NRM Ltd and Rainforest CRC (2004) *Sustaining the Wet Tropics: a Regional Plan for Natural Resource Management 2004-2008*. FNQNRM Ltd, Innisfail.
- Folke C., Carpenter S., Elmqvist T., Gunderson L., Holling C.S. and Walker B. (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31, 437-440.
- Govan H., Aalbersberg W., Tawake A. and Parks J. (2008) *Locally-Managed Marine Areas: a Guide for Practitioners*. The Locally-Managed Marine Area Network, Suva.

- Healey P. (1996) The Communicative Turn in Planning Theory and its Implications for Spatial Strategy Formation. *Environment and Planning B: Planning and Design* 23, 217-234.
- Hill, R., K.J. Williams, and P.L. Pert. (2008) *Local Area Biodiversity Planning in the Wet Tropics Bioregion. Mid-Project Draft Synthesis Milestone Report Mission Beach Habitat Network Action Plan*. Cairns: Report to the Marine and Tropical Research Facility from CSIRO Sustainable Ecosystems.
- Lane M.B. and Corbett R. (2005) The Tyranny of Localism: Indigenous Participation in Community-Based Environmental Management. *Journal of Environmental Policy and Planning* 7(2), 141-159.
- Lane M.B. and McDonald G. (2005) Community-based Environmental Planning: Operational Dilemmas, Planning Principles and Possible Remedies. *Journal of Environmental Planning and Management* 48(5), 709-731.
- Latch P. (2007) *Recovery Plan for the Southern Cassowary Casuarus casuarus johnsonii 2007-2011*. Report to Department of the Environment and Heritage by Queensland Parks and Wildlife Service, Brisbane.
- McDonald G. and Lane M. (2000) *Securing the Wet Tropics?* In 'Securing the Wet Tropics?', eds G. McDonald and M. Lane, pp 219-232. The Federation Press: Annandale, NSW.
- Meffe G.K., Nielsen L.A., Knight R.L. and Schenborn D.A. (2002) *Ecosystem Management Adaptive, Community-Based Conservation*. Island Press: Washington DC.
- Peterson A., McAlpine C.A., Ward D. and Rayner S. (2007) New Regionalism and Nature Conservation: Lessons from South East Queensland, Australia. *Landscape and Urban Planning* 82, 132-144.
- QPWS (2002) *Recovery plan for the Southern Cassowary Casuarus casuarus johnsonii 2001-2005*. Queensland Parks and Wildlife Service, Environmental Protection Agency, Brisbane.
- QPWS (2006a) *Post-cyclone Larry cassowary supplementary feeding program update*. Unpublished report from the Queensland Parks and Wildlife Service to the Cassowary Advisory Committee, Cairns 13 October 2006.
- QPWS (2006b) *Cassowary Feeding Strategy*. Environmental Protection Agency, Cairns. Queensland Parks and Wildlife Service brochure.
- Sayer J. and Campbell B. (2004) *The Science of Sustainable Development: Local Livelihoods and the Global Environment*. Cambridge University Press: Cambridge, UK.
- Smyth D.M., Szabo S., and George M. (2004) *Case Studies in Indigenous Engagement in Natural Resource Management in Australia*. Australian Government Department of Environment and Heritage, Canberra.
- Stankey G.H., Clark R.N. and Bormann B.T. (2005) *Adaptive Management of Natural Resources: Theory, Concepts and Management Institutions*. United States Department of Agriculture, Forest Service, Pacific Northwest Research Station: Seattle, USA.
- Tai Hsing-Sheng (2007) Development through Conservation: an Institutional Analysis of Indigenous Community-based Conservation in Taiwan. *World Development* 35(7), 1186-1203.
- The Djiru Traditional Owners in conjunction with Girringun Aboriginal Corporation (2007) *Indigenous Cultural Significance Assessment Mission Beach*. Report to CSIRO from P. Pentecost for Bilyana Archaeological Consultancies, Tully.
- Turton S.M. and Dale A. (2007) *A preliminary assessment of the environmental impacts of Cyclone Larry on the forest landscapes of northeast Queensland, with reference to responses to natural resource management issues in the aftermath*. Report to the Bureau of Meteorology.
- Valentine P.S. and Hill R. (2008) *The Establishment of a World Heritage Area*. In 'Living in a Dynamic Tropical Forest Landscape', eds N.E. Stork and S.M. Turton, pp 81-93. Blackwell Publishing: Oxford.
- Weston N. (2006) *Local Area Planning Approach to Mission Beach Cassowary Conservation Stage 1: Framework*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns.

Williams K.J., Hill R., Pert P., Harding E.K. and O'Malley T. (2008a) *Current, pre-clearing and 2025 scenarios of vegetation cover and cassowary habitat in Mission Beach and surrounds*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Annual Conference, 28 April – 1 May, Cairns'. Long, S. and Taylor, R. (eds). Reef and Rainforest Research Centre Ltd, Cairns.

Williams K.J., Faith D.P., Ferrier S., Hill R. and Pert P. (2008) *Potential gaps in the complementary representation of regional ecosystems within protected areas of the Wet Tropics Natural Resource Management planning region*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Annual Conference, 28 April – 1 May, Cairns'. Long, S. and Taylor, R. (eds). Reef and Rainforest Research Centre Ltd, Cairns.

Worboys G., Lockwood M. and De Lacy T. (2001) *Protected Area Management Principles and Practices*. Oxford University Press: Melbourne.

WTMA (1992) *Wet Tropics Plan: Strategic Directions*. Wet Tropics Management Authority: Cairns.

Young I.M. (2001) Activist challenges to deliberative democracy. *Political Theory* 29(5), 670-690.

An assessment of wetland connectivity in the Tully-Murray floodplain using a hydrodynamic model

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Introduction

The Tully-Murray catchment was chosen for the first phase of this research because of its environmental significance, and to aid in sustainable water management for the protection of important wetlands in this region (Veitch and Sawynok 2005). Wetlands on floodplains provide a range of habitats for aquatic biota, as well as ecosystem goods and services, in addition to their ability to improve water quality (Junk *et al.* 1989). The habitat quality and ecological condition of a floodplain wetland depends on many factors, but a key determinant is how the wetland is connected to other wetlands, streams, rivers and the ocean over time (Paterson and Whitfield 2000; Bunn and Arthington 2002). Connectivity in this project is defined as the extent to which fish and other fully aquatic biota can move between different habitat types. It has major consequences for wetlands of different types and the habitats and biodiversity each type can support. The level of connectivity depends on the period of time water flows between wetlands and/or streams. In the Wet Tropics, permanent flows are often present in rivers and larger creeks to provide continuous connectivity; however, off-stream wetlands may be isolated for long periods (Veitch and Sawynok 2005). Wetland connectivity is driven by the hydrology of the floodplain, which determines both the ambient (non-flood) flow and associated connectivity, and the inundation regime and connectivity under flood flow conditions.

A recent study by the Great Barrier Reef Marine Park Authority (GBRMPA) identified the wetlands of the Tully-Murray floodplain as among the highest value from a fishery perspective (Veitch and Sawynok 2005). However, the connectivity of the wetlands in this catchment is yet to be explored. This study provides a preliminary assessment of connectivity between wetlands and main waterways under extreme flow conditions.

Study area and wetlands

The Tully-Murray catchment is located in the southern part of the Wet Tropics, with an area of 2,072 square kilometres (Wallace *et al.* 2008). The area has a mean annual rainfall of 2,000 to more than 4,000 mm, depending on the location in the catchment. Most of the rainfall (60–80%) occurs during a distinct wet season (December to April). The Tully and Murray Rivers are the two main waterways that connect wetlands in this catchment directly or indirectly. The wetlands in these catchments may be permanent, semi-permanent or ephemeral. Flooding is very common on the Tully-Murray floodplain, with the rivers going overbank several times a year on average (Wallace *et al.* 2008). Since the topography of the

Tully-Murray floodplain is very flat and the rivers are quite close, floodwaters often merge and connect the majority of the wetlands between the two rivers.

In this study, wetlands were identified using three metre grid LiDAR (Light Detection and Ranging) data. Figure 1 shows locations and area extents of the selected wetlands along with LiDAR data boundaries. The area in blue represents water bodies (e.g. lagoon, river and stream) and the black colour shows the roads and highway. A total of ten wetlands with a surface area in the range of 5,000 to 60,000 square metres were selected for connectivity assessment. Kyambul, Bunta and Zamora lagoons are permanent wetlands and the remainder is semi-permanent wetlands.

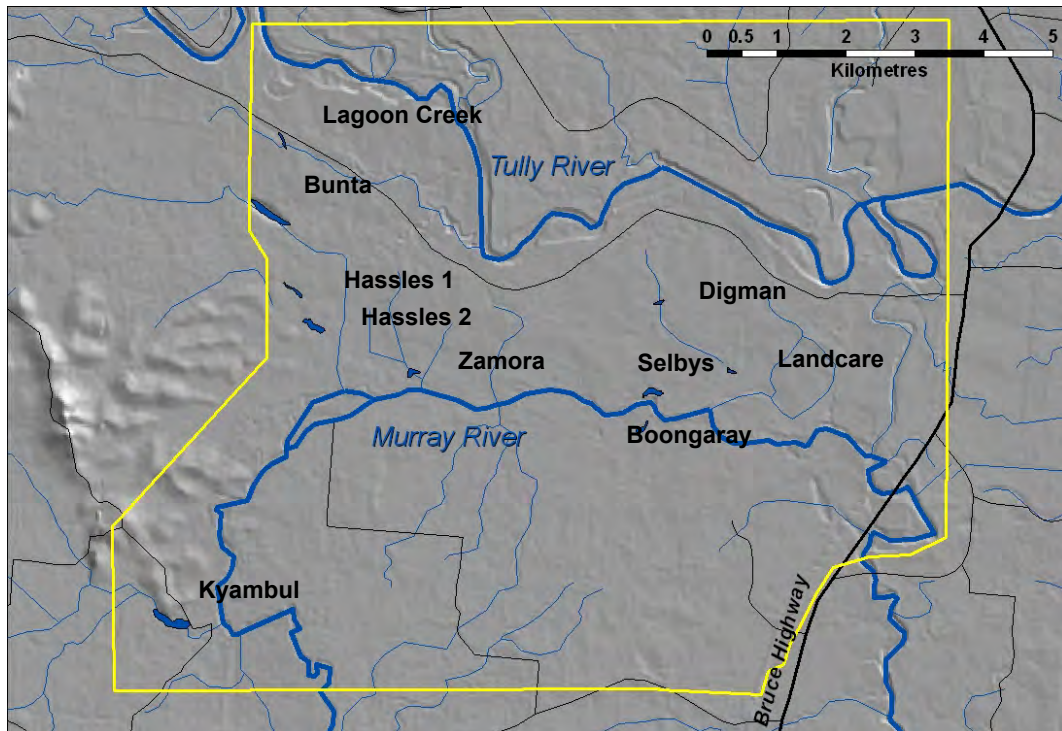


Figure 1: Location of wetlands, main rivers (blue) and road networks (black) on the Tully-Murray floodplain.

Methods

The study first computed spatial and temporal water depth information for selected hydrological events using a hydrodynamic model. This gave the temporal history of water depths at each wetland and along the intervening pathways, from which the timing and duration of connection with surrounding water bodies and/or with main streams were estimated. The hydrodynamic model setup and the techniques of connectivity analyses are briefly outlined in the following sections.

Hydrodynamic flow simulation

A two-dimensional hydrodynamic model was set up using MIKE 21 model (DHI 2008). The initial setup of the model was based on Connell Wagner's Tully-Murray flood study model (Connell Wagner 2006). The main inputs to the model were topography, surface roughness, runoff source/sink information and boundary conditions. The computational domain for the present setup covered 720 km² of the floodplain (30 km × 24 km). The domain was divided into 800,000 computational grids (30 m × 30 m) to track water movement over time. In the present model setup, runoff due to rainfall was the only source of water within the computational domain. Runoff for 66 sub-catchments within this model domain was

calculated using a rainfall-runoff model. These modelled runoffs (time varying flow rates) were incorporated into the hydrodynamic model as a source point at the outlet of each sub-catchment. Runoff from the upper catchment to the hydrodynamic domain was incorporated by introducing time-varying boundary sources at two locations (corresponding to the points where the Tully and Murray Rivers enter the hydrodynamic model domain). For each hydrological condition (flood event), the simulation was carried out for twelve consecutive days with a six-second time step. The outputs from the hydrodynamic model were water height, water depth, flow per unit width and velocity. The model was run for two flood events of one-year recurrence interval (ARI 1) and twenty-year recurrence interval (ARI 20).

The flood event of 19 February to 1 March 2007 had a return period of one year, so rainfalls measured during that period were used to estimate the flooding extent of an ARI 1 event. Probabilistic rainfalls based on depth-duration-frequency analyses were used to simulate an ARI 20 event.

Connectivity analyses

In this study we considered connectivity of wetlands in terms of, (1) connectivity to a surrounding waterbody due to overbank flow conditions, and (2) connectivity to the main rivers via floodplain pathways. Connectivity was analysed using time series of water depths across the floodplain and within individual wetlands. A wetland was considered connected with other water bodies when it started receiving water from other sources by overbank flow, and considered disconnected when water receded below its bank level. Connection time of a particular wetland to the river system was based on time series water depth grids. To do this, an algorithm was developed to uniquely identify areas of contiguous water during each time step, and then tag all waterbodies and river sections which were contiguous with a given waterbody in that time step. A threshold water depth of thirty centimetres was used to distinguish between connected and non-connected waterbodies.

Results and discussion

The calculation of connectivity is graphically illustrated in Figure 2 using water depth information at Digman Lagoon (Figure 1). Digman Lagoon is a semi-permanent wetland that connects the Tully and Murray Rivers during wet season floods. The zero initial water depth at this lagoon implies a non-permanent wetland. The results shown are for the flood events of ARI 1 and ARI 20. Durations of connection for these two flood events are shown in Figure 2. It can be seen that the start and ending of connections are different for floods of different magnitudes. As expected, the larger flood produced an earlier and longer connection time.

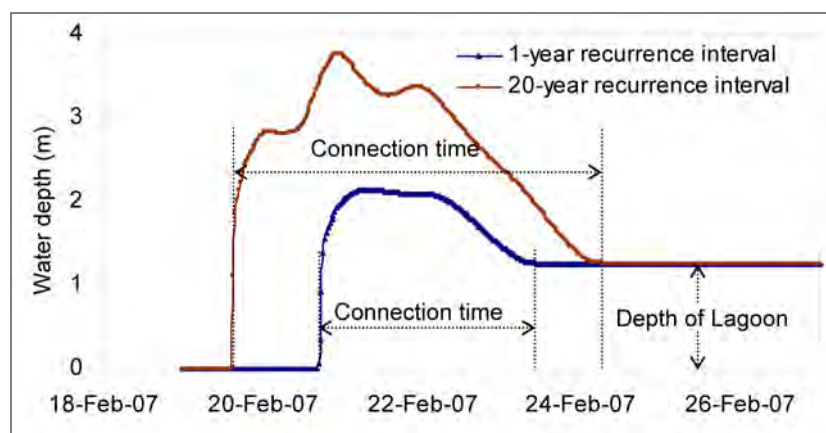


Figure 2: Schematic view of connectivity analysis based on water depth information at Digman Lagoon.

In this preliminary investigation we assessed the connectivity of the wetlands to the Tully and Murray Rivers only. An example of this type of connectivity analysis is shown in Figure 3. Each colour in this figure represents the areas of contiguous water at that particular time step. For example, 106 hours after the start of a flood with a return period of 1 year (ARI 1), the wetlands within the rectangular block were connected with each other and with the Murray River but not connected with the Tully River. Other wetlands were not connected with either river. In terms of watershed connection, an ARI 20 flood event produced a 1½ times larger flooding area, and so larger contiguous waterbodies, compared with an ARI 1 event. The duration of connection increases with the increase in flood magnitude, irrespective of wetland size and location.

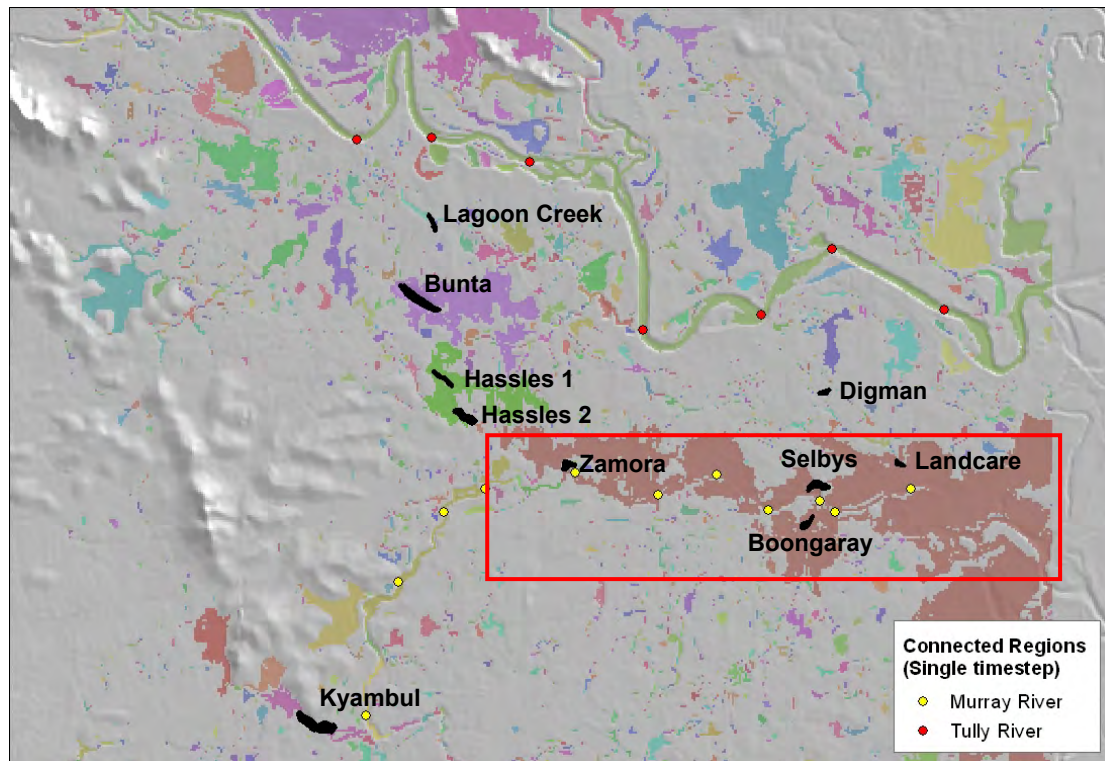


Figure 3: Connectivity analysis based on water depth grids. Each colour shows contiguous water during a particular time step. In this analysis, Zamora, Selbys, Landcare and Boongaray Lagoons are connected to the Murray River [ARI 1 event].

A brief summary of connection time and duration of connection of the wetlands to the Tully and Murray Rivers is shown in Figure 4 for the flood events of (a) ARI 1 and (b) ARI 20. It can be seen that Lagoon Creek was not connected to either river for the flood with an ARI of 1 but was connected to both for the flood with an ARI of 20. This is because Lagoon Creek is relatively elevated and flood water only reaches it during a large flood. For individual wetlands, it is noticeable that the duration of connection to the Murray River is longer than that to the Tully River. The main reason is the low bank elevation of the Murray River compared to the Tully river bank. It is interesting to note the simultaneous cut-offs to the Tully River for most of the wetlands. The reason behind this pattern is the connection and disconnection of a large body of flood water to the Tully River via a single drainage line. The results also show that Boongaray and Landcare lagoons retain their connection to the Murray River even after the flooding period. These are the examples where overbank flow conditions (due to the low banks of the Murray) have maintained a much longer connectivity to nearby lagoons. It can be seen that the duration of connection to the Murray River for Selbys and Boongaray Lagoons is less for the larger flood (ARI 20) than the smaller flood (ARI 1), which

is not typical of floodplain connectivity behaviour. However, it might happen if the spatial rainfall distributions for the floods were very different. For example, we used observed rainfall for February 2007 to simulate the ARI 1 flood. In contrast, probabilistic rainfall data was used for the flood with an ARI of 20. We will explore different scenarios of rainfall pattern during the next phase of this study. For the 10 selected wetlands, the duration of wetland connectivity ranges from one to ten days for floods with an ARI of one year, to three to twelve days for floods with an ARI of twenty years.

(a) Flood magnitude of ARI 1:

Connected to Tully River

Lagoon	Duration (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Lagoon Creek Lagoon	0										
Bunta Lagoon	32										
Hassles1	32										
Hassles2	32										
Kyambul Lagoon	32										
Zamoras Lagoon	32										
Selbys Lagoon	32										
Boongaray Lagoon	32										
Landcare Lagoon	32										
Digmans Lagoon	30										

Connected to Murray River

Lagoon	Duration (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Lagoon Creek Lagoon	0										
Bunta Lagoon	68										
Hassles1	86										
Hassles2	86										
Kyambul Lagoon	78										
Zamoras Lagoon	94										
Selbys Lagoon	158										
Boongaray Lagoon	230										
Landcare Lagoon	226										
Digmans Lagoon	52										

(b) Flood magnitude of ARI 20:

Connected to Tully River

Lagoon	Duration (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11
Lagoon Creek Lagoon	38											
Bunta Lagoon	84											
Hassles1	84											
Hassles2	84											
Kyambul Lagoon	80											
Zamoras Lagoon	84											
Selbys Lagoon	84											
Boongaray Lagoon	84											
Landcare Lagoon	84											
Digmans Lagoon	84											

Connected to Murray River

Lagoon	Duration (hrs)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11
Lagoon Creek Lagoon	38											
Bunta Lagoon	112											
Hassles1	112											
Hassles2	114											
Kyambul Lagoon	90											
Zamoras Lagoon	114											
Selbys Lagoon	132											
Boongaray Lagoon	172											
Landcare Lagoon	276											
Digmans Lagoon	100											

Figure 4: Summary of wetland connectivity to the Tully and Murray Rivers for the flood events of (a) ARI 1 and (b) ARI 20.

Conclusions

In this exploratory study of floodplain hydro-ecological processes we have demonstrated how the connectivity of different wetlands can be quantified using hydrodynamic modeling. Using this technique we found that the majority of the large wetlands on the Tully-Murray floodplain are connected with each other and/or with the main river channels during floods with ARIs between one and twenty years. However, connection time and the duration of connectivity of each wetland differ according to its location and/or proximity to streams. For the ten selected wetlands, the duration of wetland connectivity ranges from one to ten days for floods with an ARI of one year, to three to twelve days for floods with an ARI of twenty years. Connection time of individual wetlands varies with location in the floodplain and flood magnitude.

Some wetlands appear to be connected only during large floods. We also found that wetlands on the Tully-Murray floodplain are connected to the Murray River for longer periods than they are to the Tully River.

The above results should be regarded as preliminary since the hydrodynamic simulations are based on relatively coarse topographic data (30 m horizontal and 0.7 m vertical). In future, high resolution LiDAR data will be incorporated to improve topographic refinement and model results. In this preliminary study, the wetlands were identified using LiDAR data; however, these wetland details have yet to be included within the hydrodynamic model. This will require a flexible mesh (triangular and/or rectangular with variable mesh size) hydrodynamic model setup. Increasing resolution has the potential to significantly change the connectivity results for smaller drainage systems such as creeks and cane drains. Results will be of significance to the potential movement patterns of aquatic biota during and after flood events, to the habitat and water quality of individual wetlands over time, and to the potential for wetland processes to influence downstream water quality.

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References

- Bunn S.E. and Arthington A.H. (2002) Basic principles and consequences of altered hydrological regimes for aquatic biodiversity. *Environmental Management* 30, 492-507.
- Connell Wagner (2006) *Tully-Murray Rivers Flood Study Calibration Phase Report*. Prepared for Department of Main Roads, Department of Natural Resources and Mines and Queensland Rail.
- DHI (2008) MIKE by DHI (Danish Hydraulic Institute), MIKE 21 Flow Model, Scientific Documentation, p60.
- Junk W.J., Bayley P.B. and Sparks R.E. (1989) The flood pulse concept in river-floodplain systems. *Canadian Special Publication of Fisheries and Aquatic Sciences* 106, 110-127.
- Paterson A.W. and Whitfield A.K. (2000) Do shallow-water habitats function as refugia for juvenile fishes? *Estuarine, Coastal and Shelf Science* 51, 359-364.
- Veitch V. and Sawynok B. (2005) *Freshwater Wetlands and Fish*, Sunfish Queensland Inc. Report No: SQ200401, p136.

Wallace J.S., Stewart L.S., Hawdon A. and Keen R. (2008) *The impact of floods on sediment and nutrient fluxes from the Tully-Murray catchments to the GBR lagoon*. Report to Terrain NRM and the Marine and Tropical Sciences Research Facility for input to the Water Quality Improvement Planning process. CSIRO Science Report Y/07, p56.

Just a bunch of pretty trees? Rainforest tourism in the Wet Tropics World Heritage Area

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Introduction

While there have been a number of studies of tourist patterns in the Wet Tropics rainforest, they have been undertaken on an ad-hoc basis and lack a longitudinal framework that allows for the identification of trends and seasonal variations. A multi-site monthly survey seeking to rectify these deficiencies commenced in November 2006. The aim of this study was to develop a longitudinal survey framework that reported on a range of visitor characteristics including socio-demographic profiles, motivations, satisfaction, behaviours and visitor dispersal. Quantitative surveys were adopted as the primary methodology. In the reporting period (January to December 2007) a total of 1,408 visitors were surveyed at six key sites throughout the region. This paper explores the importance of visiting the rainforest for visitors, along with the importance of World Heritage branding and interest in various rainforest walking activities. This information cumulatively is important for both management agencies as well as the commercial tourism sector.

Methodology

The key methodology used for this research was structured surveys. The survey instrument was piloted before the commencement of the annual surveying program and was developed through a rigorous consultative process with representatives from industry, government and university. Most tourists visit rainforest locations in the region either on tour buses/coaches or as independent travellers using a private or rented vehicle. To ensure coverage of each mode of transport, surveys were distributed by employees of tour bus operators, accommodation facilities, attractions and visitor information centres, as well as by trained JCU survey staff at key rainforest locations. Throughout the year, support was offered from three large and one small tour operator, one small accommodation facility, three tourism attractions and three visitor information centres. The two most significant Wet Tropics locations that attract high visitor numbers are Mossman Gorge and Marddja Boardwalk (and later on, Daintree Discovery Centre), so these were targeted by the James Cook University research team for surveying, with an eighty percent return rate. The survey was only distributed in English, potentially causing a strong bias towards Eurocentric visitors and thus care must be exercised when generalising results.

Results

Almost 66% of respondents were first-time visitors to the region. Of the remaining repeat visitors (34.2%), 75.4% had visited the region up to three times. The majority of respondents were travelling as a couple (55.8%), followed by those travelling with friends (13.8%), as a family with children (13.6%) or with relatives (6.7%). Table 1 shows the demographic make up of respondents at key locations, while Figure 1 compares mean values of importance of visiting the rainforest (on a scale of 1 to 5 where 5 was 'very important') and the gender, origin and age of respondents. The overall mean from the entire sample was 4.32.

Overall, 66.7% of respondents were aware before their visit that the Wet Tropics rainforest was World Heritage listed. Just over eighty percent of Australians were aware, compared with 46.3% of international visitors; 88.6% of respondents agreed that they would still have visited the rainforest even if it did not have the listing. Figure 2 compares the gender, origin and age of respondents with their World Heritage knowledge.

The survey also identified visitor interest in participating in rainforest walks (gauged on a scale of 1 to 4, where 4 was 'very interested'). A short rainforest walk (3.54) attained the most interest, followed by a self-drive along a rainforest road (3.08), one-day unguided hike (2.41), one-day guided hike (2.25), overnight guided hike (1.82) and overnight unguided hike (1.68). Figure 3 compares the interest in these rainforest walking activities with the gender and origin of respondents.

Table 1: Characteristics of respondents at key Wet Tropics rainforest locations, 2007.

Gender (%)		Female		Male	
		52.7		47.3	
Origin (%)		Age (%)		Occupation (%)	
Australia	59.8	20-29 yrs	21.1	Professional	28.2
UK and Ireland	14.0	30-39 yrs	20.1	Retired	17.4
North America	8.9	50-59 yrs	19.5	Student	8.1
Europe	7.6	40-49 yrs	17.3	Self-employed	9.4
Germany	3.4	Over 65 yrs	9.6	Management	7.1
New Zealand	2.2	60-65 yrs	8.5	Office/clerical	6.1
Scandinavia	1.7	Under 20 yrs	3.9	Public service	5.4
Asia	1.6			Other	5.3

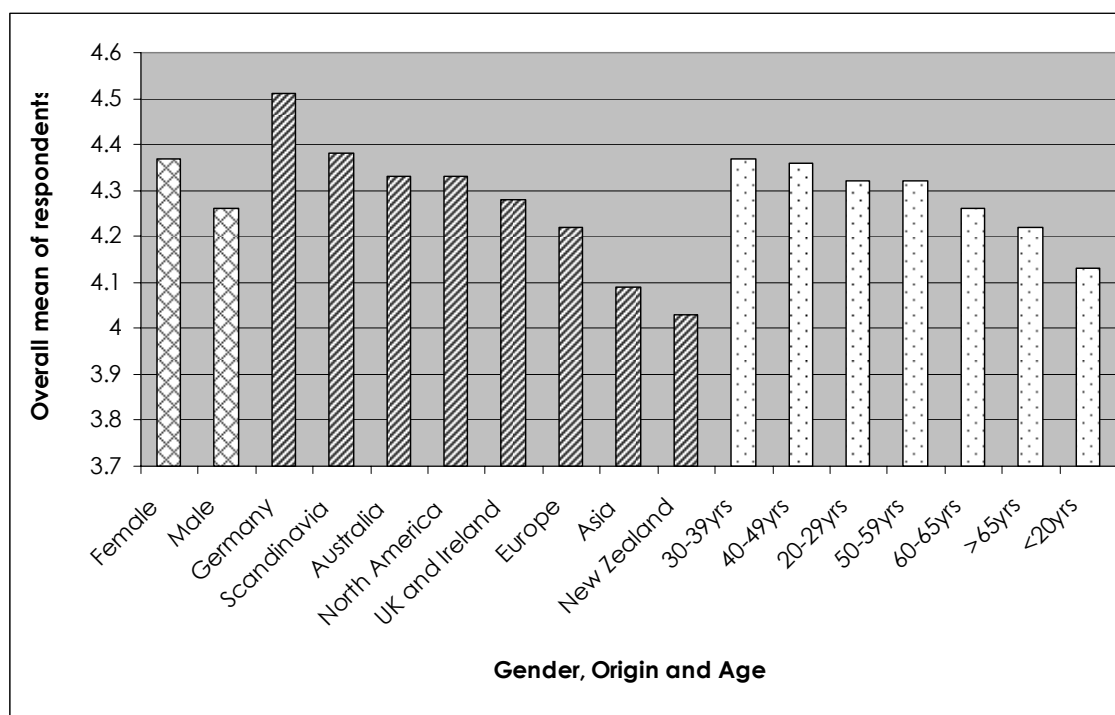


Figure 1: Comparing respondent gender, origin and age with the importance of visiting the Wet Tropics rainforest (expressed as an average mean value, 2007).

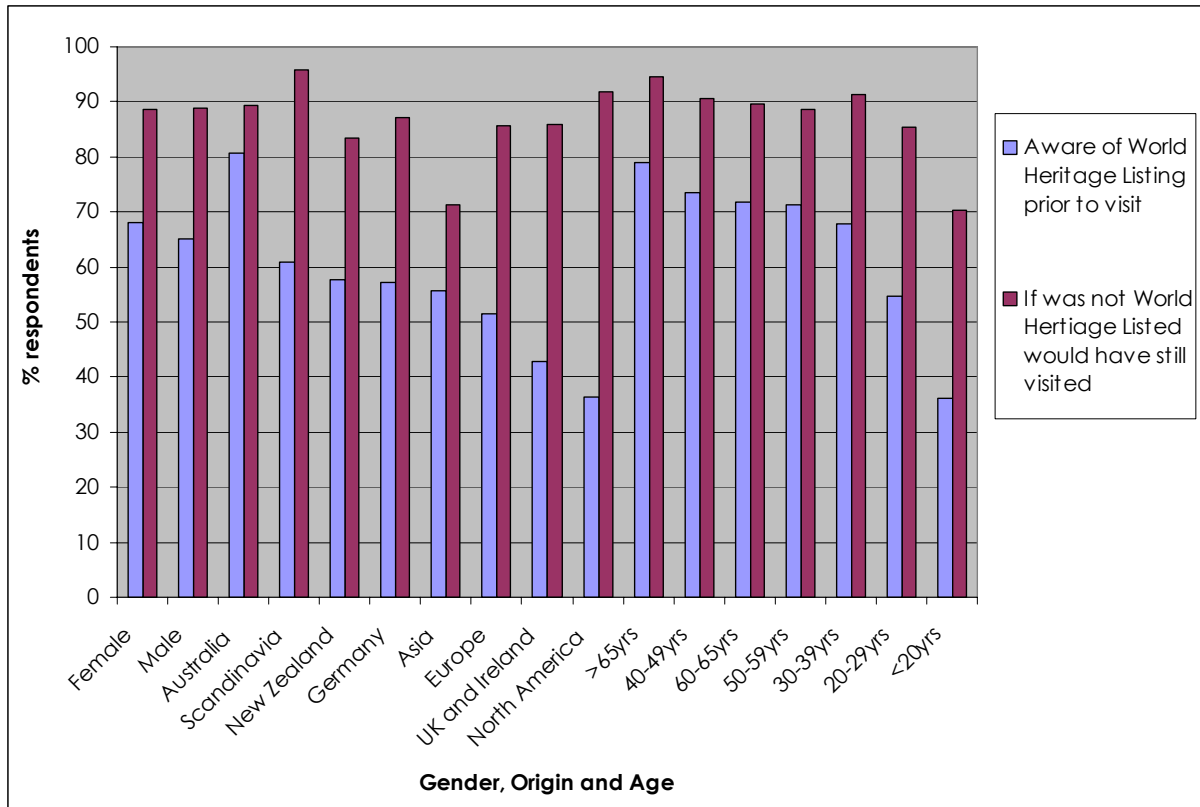


Figure 2: Comparing respondent gender, origin and age with the importance of visiting the Wet Tropics rainforest (expressed as overall percentage, 2007).

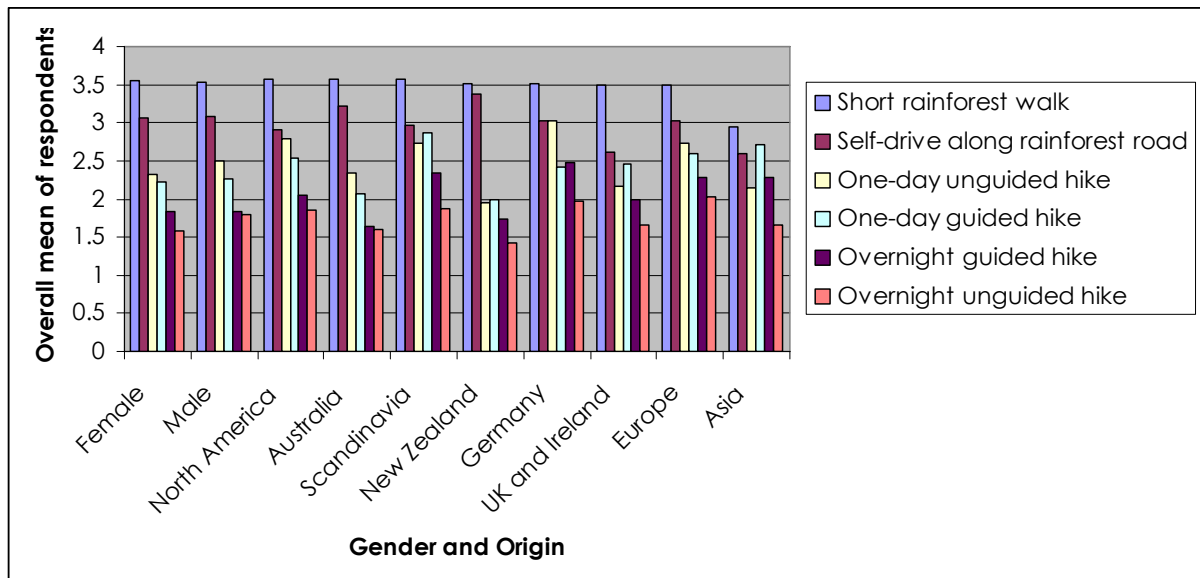


Figure 3: Rainforest walking – interest of respondents according to gender and origin (expressed as average mean value, 2007).

Conclusions

This study confirms the importance of both the rainforest and rainforest walking activities as tourism attractions within the regional destination. The findings identified particular respondent interest in short rainforest walks and drives along rainforest roads. Longer rainforest hikes were preferred by younger, European travellers. Given the current lack of trails of this nature there appears to be a case for further investment in short rainforest trails (up to half a day) near the larger population centres of Cairns, Port Douglas, Atherton or Innisfail. In terms of addressing emerging market segments, management agencies may well be interested in developing longer hiking trails (up to one day), as well as assisting the tourism industry in developing sustainable overnight rainforest tours.

Acknowledgments

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Managing scientific knowledge as a basis for management of the Great Barrier Reef Marine Park

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What is knowledge management?

“Knowledge management comprises a range of practices used by organisations to identify, create, represent, and distribute knowledge” (Wikipedia). Taking the broadest definition, this includes all aspects of the Great Barrier Reef Marine Park Authority’s (‘the GBRMPA’ or ‘the Authority’) operations. Knowledge management should be integrated with the objectives of an organisation or group – this provides the context.

Here the discussion extends beyond the GBRMPA to the Queensland Government, research agencies and other organisations with a role in management of the Great Barrier Reef Marine Park, but the focus of this paper is on science-based knowledge management, rather than the administrative aspects such as contract management and in-house system development to share ‘intelligence’ across the range of agency agendas.

This knowledge is available in many different forms; as research outputs in scientific publications; policy papers, the media; reference material in libraries and ‘thinking/delivery tools’ such as GIS, the Internet and Google™ Earth.

The Great Barrier Reef contributes an overall gross product exceeding \$5 billion annually to the Australian economy. Managing this resource for ecological sustainability must ensure maintenance of the region’s natural and cultural values while enabling reasonable use. The Great Barrier Reef is in good condition but under pressure from a range of sources, including (in rough order of importance):

- Climate change effects, especially elevated temperatures and ocean acidification;
- Downstream effects of land use (declining water quality);
- Fishing effort and impacts of some types of fishing gear on the environment;
- Increasing rate and extent of coastal developments;
- Shipping and pollution incidents; and
- Tourism and increasing recreational use of the Marine Park. Figure 1 details the steady increase in the number of recreational boats registered adjacent to the Great Barrier Reef between 2002 and 2008.

Managing the reef for ecological sustainability

The regulatory and monitoring part of management of the sustainability of the Great Barrier Reef is driven principally by government regulations (Australian, Queensland and local) but also assisted by voluntary work of community and industry groups (Eye on the Reef, CapReef, Seagrass Watch, Bleach Watch, Reef Check, and others). In the past it was normal to focus only on your own sectoral interest, whether it is commercial, recreational,

government, indigenous. Now there is more awareness of cross sectoral cooperation and a focus on our shared responsibility for the stewardship of the Great Barrier Reef.

The variety of management tools used in a multi-use marine park include legislation (see the Australian Government's Great Barrier Reef Marine Park Act, amended 2007 and 2008, and its regulations); best environmental codes of practice; relationships with key stakeholders, such as eco-certification of commercial operators (in reef tourism we call them 'high standard operators'), traditional use of marine resources agreements with traditional owners, and Reef Guardian councils; and education, through schemes such as ReefEd (www.reefed.edu.au), the Townsville Reef HQ Aquarium and Reef Guardian schools.

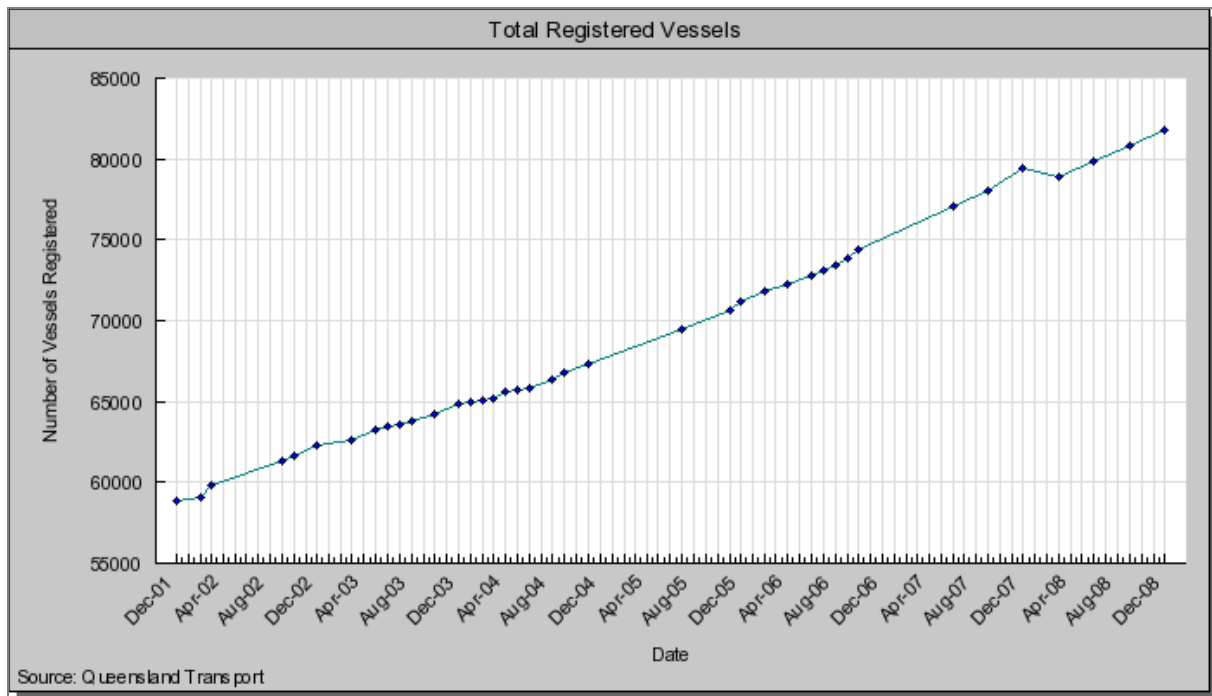


Figure 1: Total number of registered recreational vessels.

The Great Barrier Reef Marine Park Authority has the long term ecological sustainability of the Great Barrier Reef as its primary goal.

The GBRMPA works cooperatively with the Queensland Government through long standing arrangements for joint management of the Reef. In addition to GBRMPA, there are a number of Commonwealth Government departments (particularly the Department of the Environment Water, Heritage and the Arts or 'DEWHA') which also carry out roles in environmental management in the Great Barrier Reef. As well as the Commonwealth government responsibilities handled by the GBRMPA, DEWHA and the Australian Maritime Safety Authority, the reef is managed by state government regulations – the Queensland Environmental Protection Agency, the Department of Primary Industries and Fisheries, Maritime Safety Queensland, the Department of Natural Resources and Water and Local Government Authority approvals.

All of these agencies need a strong scientific basis for developing and implementing policies, programs and regulations for management. Through the Commonwealth Government's Marine and Tropical Sciences Research Facility, implemented in North Queensland by the

Reef and Rainforest Research Centre Ltd (RRRC), the GBRMPA has connections to the fifteen research organisations coordinated by the RRRC.

Highlighting the importance the GBRMPA places on education programs and community links, we have more than 150 Reef Guardian schools and councils and eleven Local Marine Advisory Committees. The GBRMPA also receives advice from four Reef Advisory Committees (water quality; conservation and indigenous; fisheries; and tourism).

Science informing reef management

Where does scientific research enter the world of reef managers? What do these managers need to know to permit reasonable and ecologically sustainable use? The Great Barrier Reef is a complex ecosystem and it needs to have scientifically based management systems to match.

Research needs to be targeted at answering the relevant questions, such as, “What will make the reef more resilient to climate change impacts?” It is better to have an approximate answer to the right question than a precise answer to the wrong question (an observation by statistician John Tukey, ca. 1963).

Useful information will be spatially explicit (‘Where is it?’) and able to link to many databases (‘What do we need to know about this area?’).

Information systems that incorporate the results of scientific research must be sufficiently flexible so that management specialists can access the information for a range of purposes:

- (a) Strategic decision making, such as regional planning, demands aggregate statistics and information about large areas and the broad trends which are updated periodically; plus finer scale information for application of planning rules on local scales – such as planning for new vessel moorings.
- (b) Tactical management decisions, such as responding to a short term emergency or short notice permit request, requires more detailed information in real time or near real time.

Information about the effects of zoning by region (Figure 2) is an example of research that is relevant, spatial and adaptable and the results can be used to help manage the reef sustainably.

Some Key Performance Indicators for knowledge management

The UK Government has conducted a review that gives us some guidance on how to improve science linkages with policy making. The conclusions are strongly relevant to improving links between science and natural resource management. The UK study, as reported by Holmes and Clark (2008) concluded that the following was needed:

- “A cultural change with a new mindset towards policymaking;
- “Policy makers to become more intelligent customers, better able to define questions to science and reflect uncertainties appropriately in policy formulation;
- “Improvements in the ability of researchers to communicate findings to policy makers in a useful form and more incentives to do so; and
- More time, resources and analytical capacity to enable the science–policy interface to work more effectively.”

Some questions about how to evaluate research programs follow from these broad conclusions.

Is the right question being asked in the research project?

It doesn't matter how good the science is, if you have failed to ask the right question, the research output will not generate the information that is required by the user of the research results. Sometimes, failed communication is to blame – the researcher didn't understand the question or conversely management didn't explain the problem, or perhaps didn't understand the answer.

Are you pursuing an idea that is no longer relevant?

Another problem is the case of many different answers to the one question which may be due to the problem not having been articulated well. It may also be that the researcher is pursuing their own interest and being diverted away from the problem posed by the end-user. This is a choice which is made by the researcher and the end-user. There is a powerful place for less applicable 'discovery' research.

Another cause of this problem is when researchers are so enamoured of a theory that they become blind to strong evidence refuting it.

"You should hold your hypothesis in the tips of your fingers, so the lightest breath of evidence will blow it away." I think it was a Richard Feynman quote.

The relevance of a line of research should be answered by strong dialogue between the researchers and the users of the results. In the MTSRF process this is supported by the researchers' statements on 'path to impact'.

In the UK paper by Holmes and Clark (op cit) this relationship features strongly – they say studies point to:

"The need for sustained engagement between researchers, policy 'customers' and other relevant stakeholders from the question framing stage, through the research process itself to the interpretation and uptake of the research results. They recommend that researchers develop a more 'rounded' appreciation of the problem, which enhances the relevance and quality of the research and leads to better policy-making and learning." [p. 705, Holmes and Clark, 2008]

Will the raw data and background knowledge you have built be captured and saved?

Sometimes research fails to contribute to the 'pool' of knowledge because the information never escapes the researchers' offices or institutions. The hard won data sets and interpretations are lost owing to poorly documented data sets or 'knowledge-hoarding'. Many of our research institutions are not set up to capture data and look after it for the long term. Universities have a particular challenge in this regard.

Is the research product credible?

The value of research outputs can be diminished in a number of ways by loss of credibility. The most useful research products are those that pass normal scientific review, don't over-claim significance and which have a clear pathway for use (= impact) outside the science community.

Research may not be credible when it receives a poor third-party review, is seen to lack quality assurance or when the researcher has a visible conflict of interest.

Recent advances – What's going right?

In a number of areas the development of science for management of the GBR is headed in the right direction:

- The MTSRF research management strategy, as delivered by the Reef and Rainforest Research Centre, is based on transparency and accountability following a clear set of procedures to plan, fund, deliver/publish and evaluate research.
- The Risk, Resilience and Response Atlas – now in development – offers prospects of a powerful tool which will be linked to the Google™ Earth (and Google™ Ocean) interface. It is an example of a research product that has a fast path to adoption if it is successfully implemented.
- The GBR Ocean Observing System is a strategic investment in the tools and infrastructure needed for long-term management of the Great Barrier Reef.
- Creative Commons Intellectual Property – Queensland Spatial Information Council, Australia New Zealand Land Information Council. Increasing adoption of intellectual property arrangements encouraging information sharing and recognition of owners is a very positive step.
- Australian Maritime Identification System is a terrestrial-based radio system for accurately plotting location and vector for large ships operating inside the GBR and elsewhere in the Exclusive Economic Zone (EEZ). Its rapid polling rate and potential for 'smart' communication of collision risks suggest that perhaps other commercial and recreational vessels should be using it.
- The GBRMPA's new knowledge management plan is still under development but will be outcome-oriented, open access and enhance public accountability; it will integrate in-house information with shared systems held by science agencies and other government bodies.

Wish list

Although a number of things are going right, there is, of course, still more that we would like to do, including the following:

1. A knowledge management system for sustainability of the Great Barrier Reef with transparent access to all reef-related data for researchers, managers and other users of the GBR; one of its first products could be a Reef ATLAS which is not only an internal tool but also available to public and industry – one that is both easy to use and easy to contribute information – and its development should be accelerated. Improved sharing of information across Queensland and Commonwealth governments – including ecological, physical, social and economic data.
2. Improved capacity in reef management agencies (including GBRMPA) to identify strategic directions and, in collaboration with end users and scientists, articulate those strategic priorities to improve the impact of existing investment in research.
3. A reef sustainability think tank. This would be something beyond a steering committee that would consider risk assessment, knowledge gap analysis, industrial and "all source" environmental intelligence and information analysis – like an Office of National Assessments for the GBR.

Acknowledgements

I thank the Reef and Rainforest Research Centre, Commonwealth Department of the Environment, Water, Heritage and the Arts, and all MTSRF partners – both the industry end users, such as tourism associations, and the research providers. The MTSRF is critically important for reef management and already some great results have been delivered. I am grateful for the opportunity afforded to the GBRMPA by engagement with the MTSRF at many levels – steering committee, operations committee and project levels.

References

Holmes, J and R Clark (2008) Enhancing the use of science in environmental policy-making and regulation. *Environmental Science and Policy* 11: 702-711.

***Symbiodinium* diversity on the Great Barrier Reef**

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Introduction

Many reef invertebrates live in an obligate symbiotic relationship with dinoflagellate protists (genus *Symbiodinium*), also referred to as 'zooxanthellae'. The symbiotic dinoflagellates reside within the endodermal layers of their host and provide an important proportion of their daily energy requirement (Muscatine 1990). The range of hosts that harbour *Symbiodinium* includes reef building corals, anemones, soft corals, gorgonians, sponges, clams, hydroids, and even other protists such as foraminiferans and ciliates (e.g. LaJeunesse *et al.* 2003; Pochon *et al.* 2006; van Oppen *et al.* 2001). Certain environmental conditions, such as increased sea surface temperature, increased irradiance or salinity changes, disrupt the finely balanced symbiosis whereupon the dinoflagellate symbionts are lost from the host tissue (e.g. Egana and Di Salvo 1982; Lesser *et al.* 1990; Glynn and D'Croz 1990). Sea surface temperature anomalies have been indicated as the predominant factor causing the loss of symbionts from their hosts. Increased sea surface temperatures have been directly linked to the occurrence of coral bleaching on a global scale (Hoegh-Guldberg 1999) and have caused significant mortality of reef invertebrates over the last two decades. Coral bleaching is predicted to increase in occurrence and severity over the coming decades and is now regarded as one of the primary threats to the persistence of corals reefs (Hughes *et al.* 2003; Pandolfi *et al.* 2003). As a result, research has focused on how symbionts can influence the capacity of the host to respond to a range of environmental conditions (Baker 2003; Baker *et al.* 2004; Berkelmans and van Oppen 2006; Jones *et al.* 2008; LaJeunesse *et al.* 2007; Rowan 2004; Warner *et al.* 2006).

General knowledge on tolerance ranges of specific host-symbiont combinations is crucial to understanding the response of these important reef builders to changes in environmental conditions. It is expected that corals containing more tolerant symbionts will resist the effects of environmental changes for longer than corals harboring less tolerant symbionts. It has been shown that the presence of more thermally tolerant symbionts may be beneficial in terms of surviving bleaching events (Berkelmans and van Oppen 2006; Jones *et al.* 2008) but may incur physiological trade-offs. For example, while corals hosting clade D were more heat tolerant than con-specifics hosting clade C, the clade D symbiosis was accompanied by a decrease in host growth rates (Little *et al.* 2004). Besides decreased growth rates, the extent to which corals can cope with environmental stress may be hampered by the current rates of environmental change (Hoegh-Guldberg *et al.* 2002) and tolerance ranges may in fact be limited. Furthermore, mortality of hosts with more sensitive symbionts leads to a decrease in biodiversity of both the host and symbiont, which will have long-term effects on reef resilience and community composition (Sampayo *et al.* 2008). Thus, *Symbiodinium* identity and geographical distributions may limit the environmental range in which the host can occur. After compiling what is currently known about *Symbiodinium* diversity on the GBR we conclude that relatively little is known about the distribution of *Symbiodinium* across the huge diversity of host species present along the GBR. Assessing how the environment

influences the host symbiont association and mapping the tolerance ranges of each association is integral to our understanding of how current and future reefs are shaped. Understanding abundance and tolerance ranges across host species at different sites, each with distinct environmental conditions is important for management strategies designed to minimise climate impacts by targeting specific areas of importance for maintaining diversity.

Materials and methods

Database of existing literature

A database was compiled of all existing literature on symbiont diversity on the GBR up to October 2007. Each sampled individual was annotated with site, GPS position, host identity (order, family, genus, species), depth of collection, date of collection and symbiont identity (all samples have a cladal designation; subcladal symbiont designations were only partially available). This dataset served to obtain preliminary data on what is presently known about *Symbiodinium* diversity on the GBR as well as to identify possible gaps in our current state of knowledge.

Novel collections

A total of 720 samples were collected within the Cairns section of the GBR, including Lizard Island (mid-shelf), Yonge and Day reefs (both outer reefs). The sampling design was targeted to encompass a wide range of species spanning various classes of organisms (Anthozoa, Hydrozoa and Mollusca) that host symbiotic dinoflagellates of the genus *Symbiodinium*. Up to four individuals were sampled from each species at each site. Samples were preserved in 20% DMSO buffered saline (Seutin *et al.* 1991) and stored at -20°C until further processing. The DNA of each sample was extracted using the Wizard DNA extraction protocol cf. LaJeunesse *et al.* (2003). To determine symbiont identity the internal transcribed spacer region 2 (ITS2) of the ribosomal genes was PCR amplified and amplicons were screened for polymorphisms using denaturing gradient gel electrophoresis (DGGE) (cf. LaJeunesse *et al.* 2003; Sampayo *et al.* 2007). Here, we report on the preliminary data of these recent soft coral collections. The data is used as an example of how additional information significantly contributes to the current state of knowledge about *Symbiodinium* diversity on the GBR by showing added benefit of additional collection sites as well as the identification of symbionts on the subcladal level.

Results and discussion

***Symbiodinium* database**

The *Symbiodinium* diversity database comprises about 1,500 entries of samples collected by a number of researchers (LaJeunesse *et al.* 2003; Rodriguez-Lanetty *et al.* 2003; Rodriguez-Lanetty and Hoegh-Guldberg 2003; Ulstrup and van Oppen 2003; Fabricius *et al.* 2004; LaJeunesse *et al.* 2004; van Oppen *et al.* 2005a, 2005b; Ulstrup *et al.* 2006). Information was included from 46 collection sites of which 8, 29 and 9 sites are situated in the Cairns, Central and Capricorn sections of the GBR respectively (Figure 1a). Sections were further subdivided into in-shore, mid-shelf and outer reefs. The inshore and outer reef areas, in particular, have received little attention in sampling efforts to date (Figure 1a).

The type of sampled hosts across the GBR consisted mainly of reef-building corals (Scleractinia) and soft corals (Alcyonacea), although a limited number of other organisms such as anemones, fire corals, hydroids and giant clams were also sampled (Figure 1b). The largest proportion of all samples was obtained from thirteen different families of reef-building corals (Scleractinia) with 87%, 97% and 94% of all samples collected in the Cairns, Central and Capricorn sections of the GBR respectively belonging to this host group. Other

organisms besides Scleractinians were only sampled on the mid-shelf reefs within each section, again showing that collections within specific areas need to be expanded.

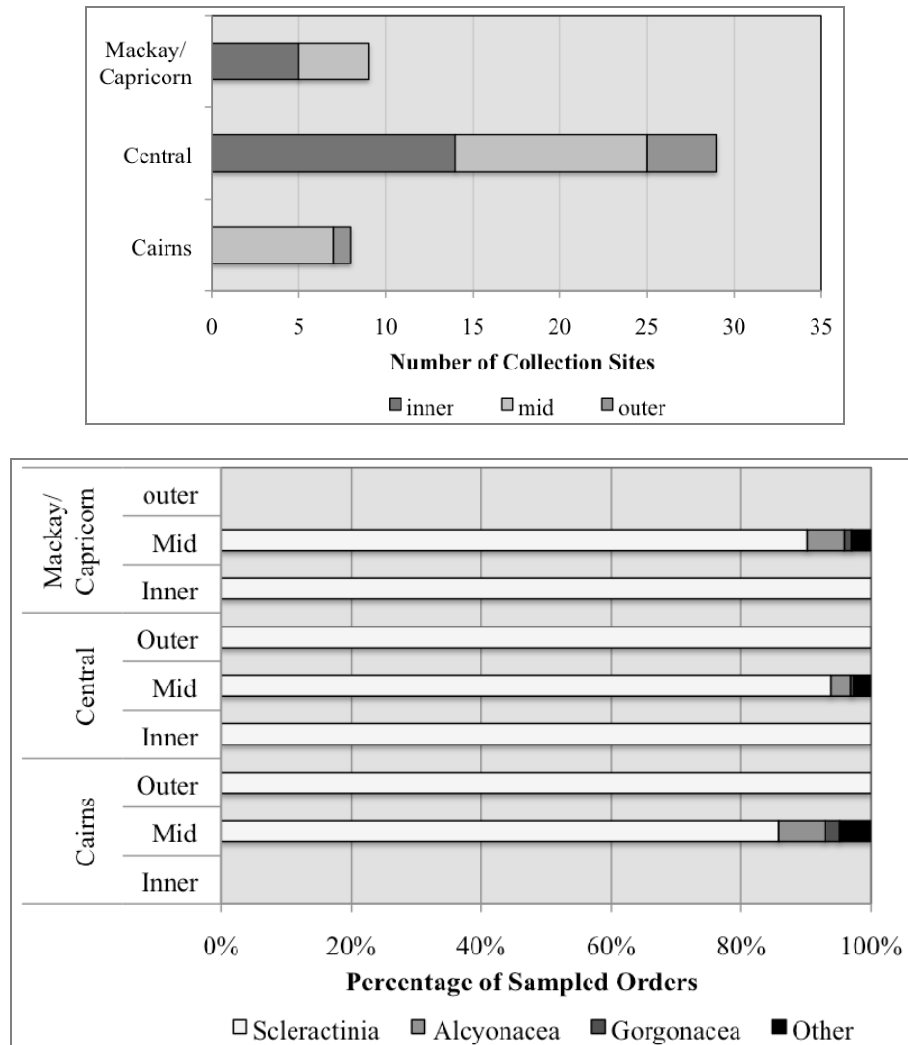


Figure 1: (Top) Number of sites collected to investigate *Symbiodinium* diversity in different sections of the Great Barrier Reef (the Cairns, Central and Capricorn/Mackay sections as outlined by the Great Barrier Reef Marine Park Authority). Sites collected in each section were further subdivided as being an outer, mid-shelf or inner (inshore) reef site. The data highlights that sampling efforts are limited in the Mackay and Cairns sections of the GBR and that data from outer and inshore reef sites respectively is lacking from these sections. (Bottom) Number of individuals collected from different host taxa for identification of *Symbiodinium* diversity. Collections represented Scleractinians, Alcyonids, Gorgonians and other organisms (hydroids, anemones, fire corals, zoanthids, corallimorphs, giant clams) but only the mid-shelf reefs contained representatives from each of the four groups.

Across the different sections of the GBR and the range of host taxa residing in them, the database showed the presence of five different *Symbiodinium* clades (clade A, B, C, D, G, Table 1). The vast majority of sampled hosts (97%) contained clade C *Symbiodinium*, while only 2.4% contained clade D and less than 1% harbored clade A, B or G. The majority of sampled species were found to contain only a single detectable symbiont (although types below a relative abundance of 5-10% could not be detected with the methods we used). Only

12% of all sampled individuals contained *Symbiodinium* from two different clades and 97% of these mixed associations belonged to clade C and D. The distribution of cladal types was partially driven by host identity. Clade B was only found in Alcyonid hosts, clade G was found in Alcyonids and Gorgonians only and clade A was identified in fire corals and two specific acroporid species only (*Acropora longicyathus* and *Acropora millepora*). Another factor which is likely to be driving symbiont distribution is the environment. While clade C is distributed evenly over the different regions, the relative abundance of clade D seems to increase in more inshore locations (Table 1). This has previously been suggested to result from the relatively lower light levels of inshore reefs (Berkelmans and van Oppen 2006; Ulstrup *et al.* 2006). However, these results could be influenced by limited sampling at these locations (Figure 1, Table 1) or by limited sampling of specific hosts (due to symbiont specificity). Full comparisons between reefs on longitudinal and latitudinal gradients would be significantly strengthened by inclusion of additional sampling information from targeted locations.

Table 1: The percentage of different *Symbiodinium* clades found in organisms from inshore, mid-shelf and outer reef positions on the GBR.

GBR Section		Clade (%)				
		A	B	C	D	G
Mackay / Capricorn	inner	0	0	96.4	3.6	0
	mid	1.6	1.1	95.7	1.6	0
	outer	–	–	–	–	–
Central	inner	0	0	96.5	3.5	0
	mid	0.5	0	99.2	0.3	0
	outer	0	0	100	0	0
Cairns	inner	–	–	–	–	–
	mid	0	0	98.8	1.2	0
	outer	0	0	100	0	0

Information from previous publications highlighted the fact that some taxa and areas have received little attention and would benefit from increased efforts to accurately estimate levels of *Symbiodinium* diversity. Inshore regions of the GBR, the far northern section of the GBR and outer reefs in the Capricorn section in particular have received little attention. It is expected that complementing the existing database will allow for analyses on a multi-scalar approach. This more complete dataset will significantly improve our ability to estimate how changes in the environment may affect reef community composition.

Symbiont diversity from novel collections

To initiate additional collections for inclusion in the database, a wide range of invertebrate hosts was sampled from Lizard Island and Yonge and Day reefs in the northern end of the Cairns section of the GBR. The 720 individuals sampled included thirteen different orders and seventy genera. Of these samples, 72% were reef-building corals with representatives of 38 different genera, with a further 17% of samples belonging to the Alcyonidae and Gorgonidae (at least fifteen genera).

The remaining samples were obtained from a range of organisms, including hydroids, fire corals, zoanthids and giant clams. Preliminary results obtained from analysis of soft corals and gorgonians showed that these organisms contained a wide range of symbionts. Across the fifteen genera, at least fourteen symbiont types were identified, of which eighty percent were members of clade C while the remainder belonged to clade B. Analysis of symbionts on the subcladal level showed that distinct symbiont types were highly specific to the host genus

from which they were isolated. Although some closely related host genera such as *Lobophyton*, *Sarcophyton* and *Sinularia* shared symbionts, all other host genera analysed associated with different subcladal symbionts.

The level of diversity and dominance of members of clade C *Symbiodinium* that resulted from the Lizard Island, Yonge and Day reefs collection, mirrors the diversity and distributions of *Symbiodinium* previously found in other locations on the GBR. Host specificity is generally high, although some generalist symbiont types occur across a wide range of hosts (e.g. van Oppen *et al.* 2001; LaJeunesse *et al.* 2003; Fabricius *et al.* 2004; Goulet 2007; Sampayo *et al.* 2007). The abundance and host-specificity of the subcladal symbiont types we identified in soft corals suggests that identification of symbionts at the lowest possible taxonomic level, with use of current methodologies, is indeed ecologically relevant. Identification of symbionts at this level showed that specific symbionts occur in conjunction with specific host genera. Moreover, it has previously been shown that specific symbionts are ecologically distinct (Iglesias-Prieto *et al.* 2004; Warner *et al.* 2006; Sampayo *et al.* 2007; Frade *et al.* 2008). Using this level of resolution is, therefore, expected to increase our understanding of the complex responses displayed by each distinct host-symbiont combination. The additional collections around Lizard Island showed that the currently available information on *Symbiodinium* diversity of soft corals can be doubled with relatively little effort. Many host species associate with specific symbiont types on the GBR (e.g. van Oppen *et al.* 2001; LaJeunesse *et al.* 2003) and the preliminary data obtained here shows that distinct soft coral genera also associate with specific symbiont types (on the subcladal level).

A limitation of the compiled database is that, at present, full analyses are only possible at the cladal level due to the use of different genetic markers or missing data. The distinct role of different subcladal types could therefore not be compared across sampled sites on the GBR. Given that subcladal symbiont types are likely to have distinct characteristics that affect their host, the first step to understanding how symbiont diversity changes as a factor of environmental parameters is to establish a database that includes multiple levels of taxonomic diversity of symbionts present within hosts on the GBR. Future efforts should be made to not only cross-correlate the information from different markers but, more importantly, to expand sampling locations across the GBR. An important point highlighted by the establishment of our database is that certain regions and hosts have received little attention in sampling efforts so far and it is likely that the full complexity of symbiont diversity is underestimated. The ability to compare multiple hosts and symbiont types in relation to a wide range of environmental parameters and reef systems present across the GBR will help to increase our ability to accurately predict sensitivity of particular reef areas as a result of climatic changes.

References

- Baker A.C. (2003) Flexibility and specificity in coral-algal symbiosis: Diversity, ecology, and biogeography of *Symbiodinium*. *Annual Review of Ecology Evolution and Systematics* 34, 661-689.
- Baker A.C., Starger C.J., McClanahan T.R. and Glynn P.W. (2004) Corals' adaptive response to climate change. *Nature* 430, 741.
- Berkelmans R. and van Oppen M.J.H. (2006) The role of zooxanthellae in the thermal tolerance of corals: a 'nugget of hope' for coral reefs in an era of climate change. *Proceedings of the Royal Society Series B* 273, 2305-2312.
- Egana A.C. and Disalvo L.H. (1982) Mass expulsion of zooxanthellae by Easter Island corals. *Pacific Science* 36, 61-63.
- Fabricius K.E., Mieog J.C., Colin P.L., Idip D. and Van Oppen M.J.H. (2004) Identity and diversity of coral endosymbionts (zooxanthellae) from three Palauan reefs with contrasting bleaching, temperature and shading histories. *Molecular Ecology* 13, 2445-2458.

- Frade P.R., De Jongh F., Vermeulen F., Van Bleijswijk J. and Bak R.P.M. (2008) Variation in symbiont distribution between closely related coral species over large depth ranges. *Molecular Ecology* 17, 691-703.
- Glynn P.W. and D'Croz L. (1990) Experimental evidence for high-temperature stress as the cause of El Nino coincident coral mortality. *Coral Reefs* 8, 181-191.
- Goulet T.L. (2007) Most scleractinian corals and octocorals host a single symbiotic zooxanthella clade. *Marine Ecology Progress Series* 335, 243-248.
- Hoegh-Guldberg O. (1999) Climate change, coral bleaching and the future of the world's coral reefs. *Marine and Freshwater Research* 50, 839-866.
- Hoegh-Guldberg O., Jones R.J., Ward S. and Loh W.K. (2002) Is coral bleaching really adaptive? *Nature* 415, 601-602.
- Hughes T.P., Baird A.H., Bellwood D.R., Card M., Connolly S.R., Folke C., Grosberg R., Hoegh-Guldberg O., Jackson J.B.C., Kleypas J., Lough J.M., Marshall P., Nystrom M., Palumbi S.R., Pandolfi J.M., Rosen B. and Roughgarden J. (2003) Climate change, human impacts, and the resilience of coral reefs. *Science* 301, 929-933.
- Iglesias-Prieto R., Beltran V.H., LaJeunesse T.C., Reyes-Bonilla H. and Thome P.E. (2004) Different algal symbionts explain the vertical distribution of dominant reef corals in the eastern Pacific. *Proceedings of the Royal Society of London Series B* 271, 1757-1763.
- Jones A.M., Berkelmans R., van Oppen M.J.H., Mieog J.C. and Sinclair W. (2008) A community change in the algal endosymbionts of a scleractinian coral following a natural bleaching event: field evidence of acclimatization. *Proceedings of the Royal Society B* 275, 1359-1365.
- LaJeunesse T.C., Loh W.K.W., van Woesik R., Hoegh-Guldberg O., Schmidt G.W. and Fitt W.K. (2003) Low symbiont diversity in southern Great Barrier Reef corals, relative to those of the Caribbean. *Limnology and Oceanography* 48: 2046-2054
- LaJeunesse T.C., Bhagooli R., Hidaka M., DeVantier L., Done T., Schmidt G.W., Fitt W.K. and Hoegh-Guldberg O. (2004) Closely related *Symbiodinium* spp. differ in relative dominance in coral reef host communities across environmental, latitudinal and biogeographic gradients. *Marine Ecology Progress Series* 284, 147-161.
- LaJeunesse T.C., Reyes-Bonilla H., Warner M.E. (2007) Spring "bleaching" among Pocillopora in the Sea of Cortez, eastern Pacific. *Coral Reefs* 26, 265-270.
- Lesser M.P., Stochaj W.R., Tapley D.W. and Shick J.M. (1990) Bleaching in coral-reef Anthozoans – effects of irradiance, ultraviolet-radiation, and temperature on the activities of protective enzymes against active oxygen. *Coral Reefs* 8, 225-232.
- Little A.F., van Oppen M.J.H. and Willis B.L. (2004) Flexibility in algal endosymbioses shapes growth in reef corals. *Science* 304, 1492-1494.
- Muscantine L. (1990) The role of symbiotic algae in carbon and energy flux in reef corals. *Coral Reefs* 25, 1-29.
- Pandolfi J.M., Bradbury R.H., Sala E., Hughes T.P., Bjorndal K.A., Cooke R.G., McArdle D., McClenahan L., Newman M.J.H., Paredes G., Warner R.R. and Jackson J.B.C. (2003) Global trajectories of the long-term decline of coral reef ecosystems. *Science* 301, 955-958.
- Pochon X., Montoya-Burgos J.I., Stadelmann B. and Pawlowski J. (2006) Molecular phylogeny, evolutionary rates, and divergence timing of the symbiotic dinoflagellate genus *Symbiodinium*. *Molecular Phylogenetics and Evolution* 38, 20-30.
- Rodriguez-Lanetty M. and Hoegh-Guldberg O. (2003) Symbiont diversity within the widespread scleractinian coral *Plesiastrea versipora*, across the northwestern Pacific. *Marine Biology* 143, 501-509.
- Rodriguez-Lanetty M., Chang S.J. and Song J.I. (2003) Specificity of two temperate dinoflagellate-anthozoan associations from the north-western Pacific Ocean. *Marine Biology* 143, 1193-1199.
- Rowan R. (2004) Coral bleaching – Thermal adaptation in reef coral symbionts. *Nature* 430, 742.

- Sampayo E.M., Franceschinis L., Hoegh-Guldberg O. and Dove S. (2007) Niche partitioning of closely related symbiotic dinoflagellates. *Molecular Ecology* 16, 3721-3733.
- Sampayo E.M., Ridgway T., Bongaerts P. and Hoegh-Guldberg O. (2008) Bleaching susceptibility and mortality of corals is determined by fine-scale differences in symbiont type. *Proceedings of the National Academy of Sciences USA*, in press.
- Seutin G., White B.N. and Boag P.T. (1991) Preservation of avian blood and tissue samples for DNA analyses. *Canadian Journal of Zoology* 69, 82-90.
- Ulstrup K.E. and Van Oppen M.J.H. (2003) Geographic and habitat partitioning of genetically distinct zooxanthellae (*Symbiodinium*) in *Acropora* corals on the Great Barrier Reef. *Molecular Ecology* 12, 3477-3484.
- Ulstrup K.E., Berkelmans R., Ralph P.J. and van Oppen M.J.H. (2006) Variation in bleaching sensitivity of two coral species across a latitudinal gradient on the Great Barrier Reef: the role of zooxanthellae. *Marine Ecology Progress Series* 314, 135-148.
- van Oppen M.J.H., Palstra F.P., Piquet A.M.T. and Miller D.J. (2001) Patterns of coral-dinoflagellate associations in *Acropora*: significance of local availability and physiology of *Symbiodinium* strains and host-symbiont selectivity. *Proceedings of the Royal Society of London Series B* 268, 2617-2617.
- van Oppen M.J.H., Mahiny A.J. and Done T.J. (2005a) Geographic distribution of zooxanthella types in three coral species on the Great Barrier Reef sampled after the 2002 bleaching event. *Coral Reefs* 24, 482-487.
- Van Oppen M.J.H., Mieog J.C., Sanchez C.A. and Fabricius K.E. (2005b) Diversity of algal endosymbionts (zooxanthellae) in octocorals: the roles of geography and host relationships. *Molecular Ecology* 14, 2403-2417.
- Warner M.E., LaJeunesse T.C., Robison J.D. and Thur R.M. (2006) The ecological distribution and comparative photobiology of symbiotic dinoflagellates from reef corals in Belize: Potential implications for coral bleaching. *Limnology and Oceanography* 51, 1887-1897.

Climate change projections for the tropical rainforest region of North Queensland

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Introduction

A previous study (Suppiah *et al.* 2007) presented projections of temperature and rainfall changes for the 21st Century for a larger region, north of 25°S and east of 140°E, and three sub-regions: north, south and the Marine and Tropical Sciences Research Facility (MTSRF) region. The projections included ranges of likely change derived from simulations of fifteen global climate models (GCMs), which were selected from 23 models on the basis of their simulations of the present average Australian climate for the 1961-1990 period. Since the publication of the report, CSIRO has developed new climate change projections for Australia using a probabilistic method that involves weighting the output of all 23 GCMs according to simulation of climate averages for the period from 1961 to 1990 (CSIRO and Australian Bureau of Meteorology 2007). This paper summarises the results of probability based annual temperature and rainfall projections for the MTSRF region and projected changes in tropical cyclone characteristics and sea level presented at the 2008 MTSRF Annual Conference. Preliminary temperature and rainfall changes simulated by the CSIRO high resolution regional climate model, the Conformal Cubic Atmospheric Model (CCAM) (see McGregor and Dix 2001 and McGregor 2005) were also presented and are included here.

Firstly, a brief description on the new method of generating probabilistic projections is given. Secondly, projected changes in annual average temperature and rainfall are given for the tropical rainforest region of north Queensland. Thirdly, projected changes in tropical cyclones and sea level will be given. Finally, changes in mean, maximum and minimum air temperature and rainfall by 2070 simulated by CCAM are discussed.

Method for generating probabilistic climate change projections

This paper presents probabilistic projections of average temperature and rainfall totals for 2030 and 2070 as changes relative to averages for the twenty-year period (1980-1999) drawn from the most up-to-date assessment of climate change in Australia (CSIRO and Bureau of Meteorology 2007). The changes refer to the climate of the periods around 2030 and 2070 and individual years will show some variation from these average conditions. The changes were derived from the output of the most recent generation of climate models using a method described in detail by Watterson (2008). Three main sources of uncertainty were accounted for:

- Uncertainty in the future evolution of greenhouse gas and sulphate aerosol emissions;
- Uncertainty in how much the global average surface temperature will respond to increases in atmospheric greenhouse gas concentrations and changes in sulphate aerosol emissions; and

- Uncertainty in how the climate of Australia will respond to an increase in global average surface temperature.

The first uncertainty was addressed by considering six different scenarios for the future evolution of greenhouse gas and sulphate aerosol emissions described by the Special Report on Emissions Scenarios (SRES) (Nakićenović and Swart 2000) of the Intergovernmental Panel on Climate Change (IPCC). These emission scenarios are illustrated in Figure 1. Each of these SRES scenarios, denoted A1B, A1FI, A1T, A2, B1 and B2, is based on a plausible storyline of future global demographic, economic and technological change in the 21st Century.

The second uncertainty was addressed by considering information on the response of the global average surface temperature to the emissions scenarios from multiple climate models and the IPCC's Fourth Assessment Report (Meehl *et al.* 2007b). The third uncertainty was addressed by considering the response of the climate of Australia to global warming in 23 climate models. Model output from the Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (see Meehl *et al.* 2007a) of the World Climate Research Programme (WCRP) was processed using the pattern scaling technique described by Mitchell *et al.* (1999), Mitchell (2003) and Whetton *et al.* (2005). Each climate model was given a score based on its ability to simulate average patterns of temperature, precipitation and mean sea level pressure in the Australian region for the 1961-1990 period. Models with higher scores were given greater emphasis in the projections.

The uncertainty in future changes in a given climate variable by a given year for a given emissions scenario and location in Australia was represented by a probability distribution comprising a set of probabilities assigned to the numerous plausible values of change. The probability distributions were used to derive the ranges of uncertainty and central values of changes given in the CSIRO and Australian Bureau of Meteorology assessment of climate change in Australia and in this report. The 10th and 90th percentile changes of the distributions provided ranges of uncertainty while the 50th percentile changes provided best estimate values of changes.

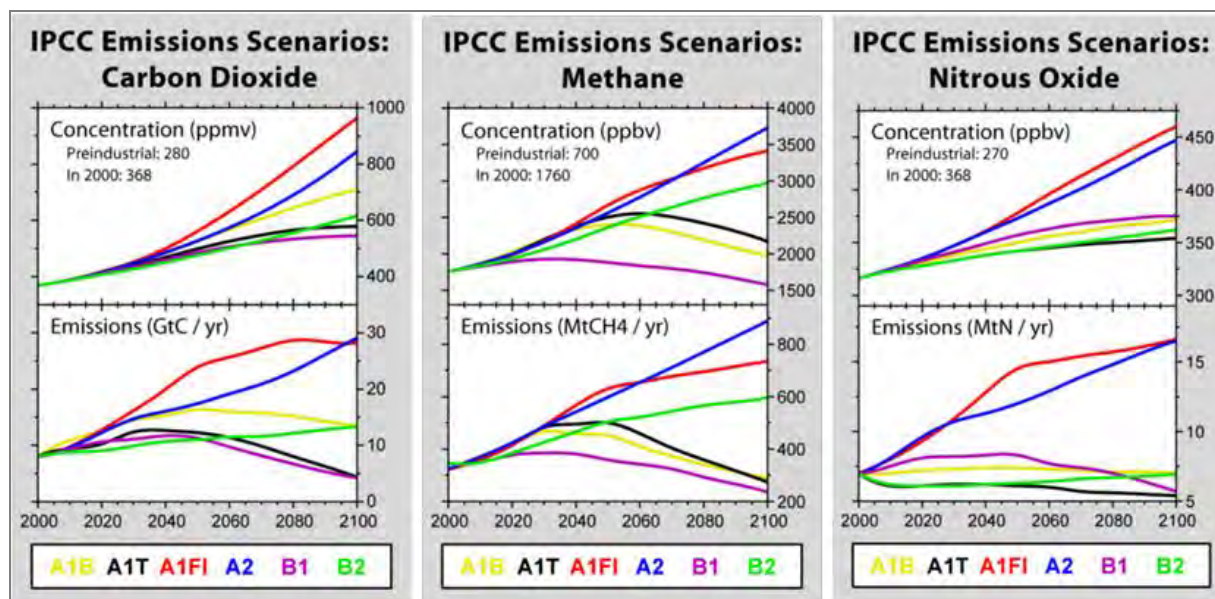


Figure 1: Anthropogenic concentrations and emissions of carbon dioxide, methane and nitrous oxide for the six SRES scenarios (IPCC 2007).

Results

Projected global average surface temperatures

Figure 2 shows the IPCC Fourth Assessment Report (Meehl *et al.* 2007b) estimates of the likely warming of global average surface air temperatures for the 21st Century for the six SRES scenarios. Warming of between 0.5 and 1.6°C by 2030 and between 1.1 and 6.4°C by 2100 are suggested.

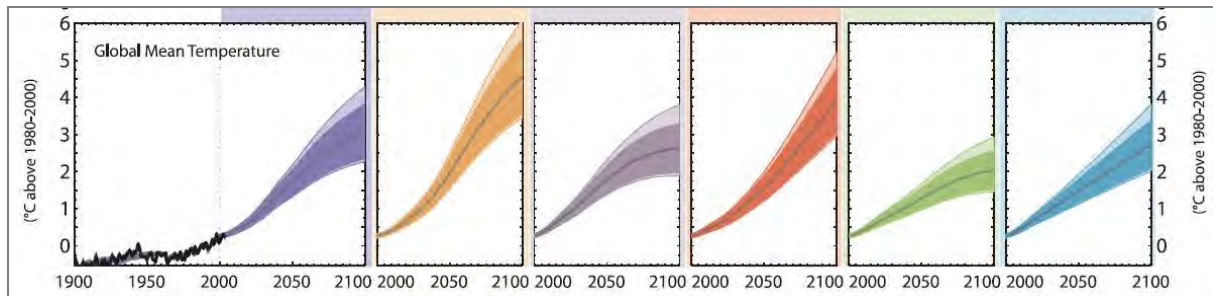


Figure 2: Changes, relative to the average for the 1980-2000 period, in global average surface temperature for the 21st Century for the A1B, A1FI, A1T, A2, B1 and B2 SRES emissions scenarios. The dark shaded areas represent uncertainties in changes based on the consideration of the response of nineteen climate models to the emissions scenarios. The light shaded areas represent uncertainties in changes based on the consideration of the response of the models to the emissions scenarios and uncertainty in carbon cycle feedbacks in the climate system. The coloured lines indicate changes based on the mean average response of the models and mid-range assumptions about carbon cycle feedbacks. The black line indicates changes recorded during the 20th Century (Meehl *et al.* 2007b).

Projected changes in annual average temperature and rainfall

Figures 3 and 4 show projected changes in annual average surface air temperature and rainfall by 2030 and 2070 for the MTSRF region. Projected average temperature and rainfall values provided in this paper were calculated from a large area (10-20°S, 142-148°E). Changes for this broader region are summarised in Table 1.

Projected changes in mean annual and seasonal temperature and rainfall for the entire region and sub-regions are given in the forthcoming report for the MTSRF project (Suppiah *et al.* 2008). Changes by 2030 do not vary greatly between different emissions scenarios. Changes by 2070 are heavily dependent on the future evolution of greenhouse gas concentrations in the atmosphere. Hence, changes for 2070 are presented for both low (B1) and high (A1FI) emissions scenarios. The best estimate of temperature change by 2030 is 1.0°C, with an uncertainty range of 0.7 to 1.3°C. The best estimate of rainfall change by 2030 is -2%, with an uncertainty range of -9 to +6%. Changes by 2070 could be triple those by 2030 if a high emissions scenario eventuates.

The projected warming is large in inland areas. The warming in coastal areas is moderated by the relatively slow rate of warming of the ocean (annual average sea surface temperatures along the MTSRF coast are projected to increase by 0.7°C by 2030, with an uncertainty range of 0.4 to 1.0°C, and by 1.3°C by 2070, with an uncertainty range of 0.6 to 2.0°C). However, even the relatively moderate coastal warming will have a marked effect on the frequency of extreme temperatures. On average, Cairns currently experiences about four days a year on which the temperature exceeds 35°C. The projected warming will increase the average annual number of days above 35°C per year, from the current 3.8 days to between 5 and 9 by 2030 and to between 8 and 96 by 2070, with a likely range between 19 and 96.

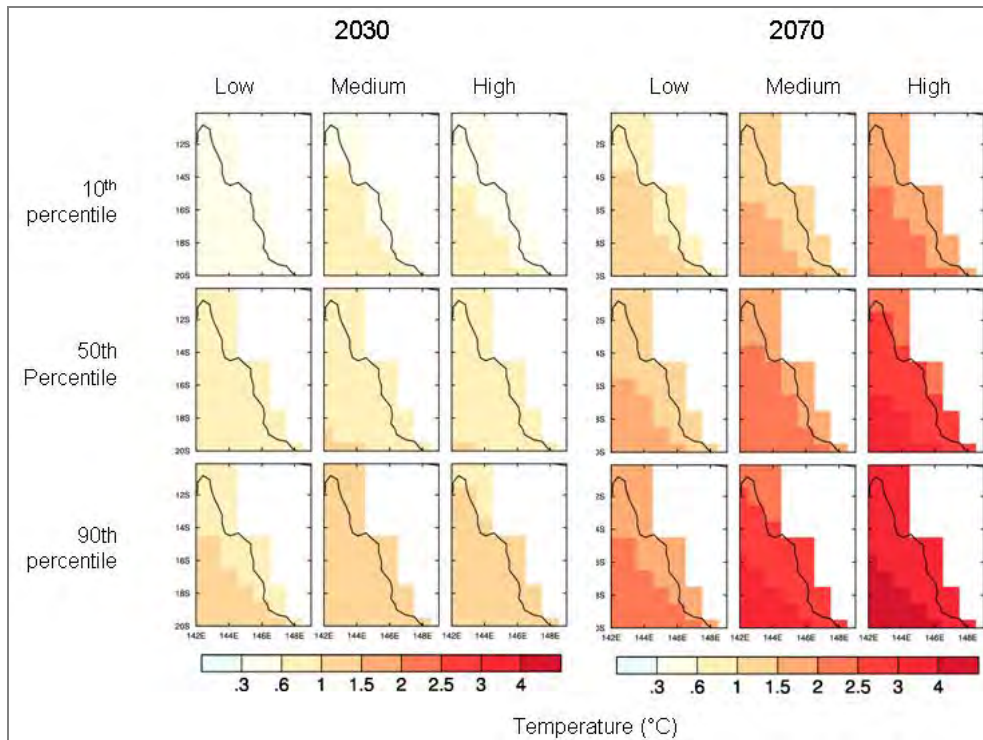


Figure 3: Projected 10th, 50th and 90th percentile values of annual average temperature changes for low (B1), medium (A1B) and high (A1FI) emission scenarios by 2030 and 2070. Temperature changes are in degrees Celsius and are relative to averages for the twenty-year (1980-1999) period.

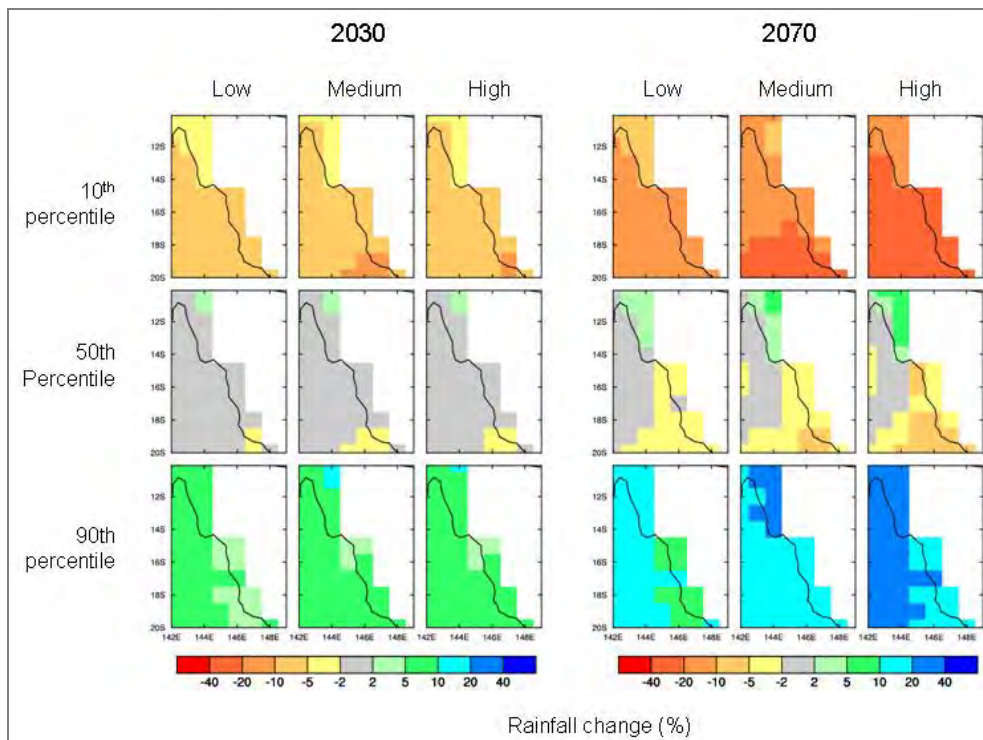


Figure 4: Projected 10th, 50th and 90th percentile values of annual average rainfall changes for low (B1), medium (A1B) and high (A1FI) emission scenarios by 2030 and 2070. Rainfall changes are percentages relative to averages for the twenty-year (1980-1999) period.

Table 1: Projected changes in annual average temperature and rainfall for the region between 10-20°S, 142-146°E by 2030 and 2070. Changes are relative to averages for the 1980-1999 period. Uncertainty ranges are given in brackets.

	2030	2070 (low emissions scenario)	2070 (high emissions scenario)
Temperature change	1.0°C (0.7 to 1.3°C)	1.6°C (1.1 to 2.2°C)	3.1°C (2.1 to 4.3°C)
Rainfall change	-2% (-9 to +6 %)	-3% (-15 to +11%)	-5% (-29 to +20%)

Projected changes in tropical cyclone activity and sea level

Three recent studies have produced projections for tropical-cyclone changes in the Australian region. Two, by Walsh *et al.* (2004) and Leslie *et al.* (2007), suggest that there will be no significant change in the frequency of tropical cyclones off the east coast of Australia to the middle of the 21st Century. The third, Abbs *et al.* (2006), shows a significant decrease in the frequency of cyclones in the Australian region. However, by 2070 longer-lived cyclones off the east coast of Australia result in an increase in the frequency of cyclone days (defined as days on which a cyclone resides in a two-degree latitude by two-degree longitude box) across the MTSRF region.

Each of the three studies finds a marked increase in the frequency of Category 3-5 cyclones in the Australian region. Abbs *et al.* (2006) show a significant decrease in the overall frequency of cyclones in the region, but estimated increases of 60% and 140% in the frequency of Category 3-5 cyclones for 2030 and 2070 respectively, although these changes are for a small number of storms. Walsh *et al.* (2004) and Leslie *et al.* (2007) found increases of 56% and 22% respectively in the frequency of Category 3-5 cyclones by 2050. These results suggest the likelihood of increasing cyclone intensity in the MTSRF region.

Sea surface temperature along the MTSRF coast is projected to increase by 0.7°C by 2030 with a range between 0.4 and 1.0°C and by 1.3°C by 2070 with a range between 0.6 to 2.0°C (CSIRO and Bureau of Meteorology 2007).

Global mean sea level is expected to rise between 13 and 20 cm by 2030 and between 49 and 89 cm by 2070, relative to 1990 (Horton *et al.* 2008). Significant uncertainty remains about the rate at which polar ice will melt. This melting rate will be an important determinant of sea level rise. Ocean acidity is predicted to increase but the rate of increase is unclear.

A combination of higher mean sea levels, larger storm surges and an increase in the intensity of extreme rainfall events means that the potential for flooding in the MTSRF region will increase markedly in future.

For example, McInnes *et al.* (2003) showed that higher mean sea levels and increasing cyclone intensity by 2050 could increase the areal extent of flooding as a result of the most extreme storm tides from approximately 32 km² to 71 km², and would encompass much of downtown Cairns.

High resolution climate model simulations

To assess the potential regional scale response for a climate change projection, it is necessary to apply downscaling techniques to the GCM output. In the case of dynamic downscaling, regional climate models (RCMs) are used to simulate atmospheric dynamics and physics using modelling techniques that are similar to those used in GCMs, but with enhancements for simulating meso-scale and local-scale meteorology. To account for surface forcings that influence the local climate, RCMs employ higher resolution surface data sets (e.g. orography, land-use, albedo, etc). Most RCMs also assimilate some features of the large-scale synoptic weather patterns and global warming trends from the host GCM into their simulations. In this way, RCMs are designed to dynamically respond to changes in climate, like GCMs, while providing much higher spatial resolution for regional climate projections.

The global climate was simulated using Mk3.0 at approximately two hundred kilometre resolution and then dynamically downscaled to fifteen kilometre resolution using CSIRO's Cubic Conformal Atmospheric Model (CCAM). Regional climate projections for the average daily maximum (screen) temperature, average daily minimum (screen) temperature and average daily rainfall are made for each season relative to the results of the previous CCAM control run (Thatcher *et al.* 2007). Detailed projections are given by Thatcher and McGregor (2008). The resulting regional climate projection datasets can be used to study various climate change impacts, such as the implications for hydrology.

Daily minimum temperatures are predicted to rise between 1.4 and 2.4°C and daily maximum temperature between 1.6 and 2.6°C on average, depending on the location. There is a tendency for the average increase in minimum temperature to be smaller towards the northern part of the study domain compared to the south. Greater increases in temperature can be expected for transitional season 1 (November to December) and the dry season (August to October), compared to transitional season 2 (April to July) and the wet season (January to March) (see Suppiah *et al.* 2007 for seasonal demarcation). All changes in average temperature are statistically significant at the 95% confidence level, relative to the simulated climate variability. However, the shapes of minimum and maximum temperature probability distribution functions (PDFs) are not predicted to change between 1970-2000 and 2060-2090 under SRES A2 emission scenario (i.e. the temperature PDFs are simply shifted towards higher temperatures).

No statistically significant changes in average rainfall are predicted by the CCAM simulations at the 95% confidence level, although the simulation results do suggest a possible decrease in the wet season rainfall around the Cape York Peninsula at the fifty percent confidence level.

Conclusions

This paper summarises results presented at the 2008 MTSRF Annual Conference. Projected changes in annual average temperature and rainfall were produced for the MTSRF region using the latest CSIRO method. The method takes into account uncertainties associated with future greenhouse gas emissions and differences between climate models. In producing the projections, results from different climate models were weighted according to the quality of their reproduction of the current climate of Australia.

By 2030, annual average temperature is projected to increase by 1.0°C, with an uncertainty range of 0.7 to 1.3°C. Annual average rainfall is expected to change by -2% by 2030, with an uncertainty range of -9 to +6%. By 2070, tropical cyclones will occur with increased frequency and intensity across the MTSRF region.

A combination of higher mean sea levels, larger storm surges and an increase in the intensity of extreme rainfall events means that the potential for flooding in the MTSRF region will be markedly increased in the future.

High resolution climate model (CCAM) simulations indicate increases in temperature under enhanced greenhouse conditions but do not predict any statistically significant change in rainfall by 2070. CCAM simulations also show detailed spatial patterns of temperature and rainfall changes where topography and land use play important roles. Data from these simulations are available for impact studies.

In another development, models were processed using the pattern scaling technique described by Mitchell *et al.* (1999), Mitchell (2003) and Whetton *et al.* (2005). This method allows the spatial patterns of climate variation under climate change predicted by models, to be compared directly. A new version of CSIRO's tool, OzClim utilises the latest models and incorporates information to allow researchers to focus on the MTSRF region of interest.

Acknowledgements

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References

- Abbs D.J., Aryal S., Campbell E., McGregor J. L., Nguyen K., Palmer M., Rafter T., Watterson I. and Bates B. (2006) *Projections of Extreme Rainfall and Cyclones*. A CSIRO report to the Australian Greenhouse Office, Canberra, Australia. 97 pp.
- CSIRO and Bureau of Meteorology (2007) *Climate change in Australia*. Technical Report, 140 pp. Available from: <http://www.climatechangeinaustralia.com.au/resources.php>. Accessed: 14 July 2008.
- Horton R., Herweijer C., Rosenzweig C., Liu J., Gornitz V. and Ruane A.C. (2008) Sea level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters* 35 L02715, doi:10. 1029/2007GL032496.
- IPCC 2007. Climate Change (2007) *The Physical Science – Summary for Policymakers*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 17pp.
- Leslie L.M., Karoly D.J., Leplastrier M. and Buckley B.W. (2007) Variability of tropical cyclones over the southwest Pacific Ocean using a high resolution climate model. *Meteorology and Atmospheric Physics* (Special Issue on Tropical Cyclones) 97, 171-180.
- McGregor J.L. and Dix M.R. (2001) *The CSIRO conformal-cubic atmospheric GCM*. In 'IUTAM Symposium on Advances in Mathematical Modelling of Atmosphere and Ocean Dynamics', Ed. P.F. Hodnett, pp. 197–202. Kluwer: Dordrecht.
- McGregor, J.L. (2005) C-CAM: Geometric Aspects and Dynamical Formulation. CSIRO Atmospheric Research Technical Paper No. 70, 43 pp. Available from: http://www.cmar.csiro.au/e-print/open/mcgregor_2005a.pdf. Accessed: 14 July 2008.
- McInnes K.L., Walsh K.J.E., Hubbert G.D. and Beer T. (2003) Impact of sea-level rise and storm surges on a coastal community. *Natural Hazards*, 30 187-207.
- Meehl G.A., Covey C., Delworth T., Latif M., McAvaney B., Mitchell J.F.B., Stouffer R.J. and Taylor K.E. (2007a) The WCRP CMIP3 multimodel dataset: A new era in climate change research. *Bulletin of the American Meteorological Society* 88, 1383-1394.

Meehl G.A., Stocker T.F., Collins W.D., Friedlingstein P., Gaye A.T., Gregory J.M., Kitoh A., Knutti R., Murphy J.M., Noda A., Raper S.C.B., Watterson I.G., Weaver A.J. and Zhao Z.-C. (2007b) *Global Climate Projections*. In 'Climate Change 2007: The Physical Science Basis',

Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press: Cambridge, United Kingdom and New York, USA.

Mitchell T.D. (2003) Pattern scaling: An examination of the accuracy of the technique for describing future climates. *Climatic Change* 60, 217-242.

Mitchell J.F.B., Johns T.C., Eagles M., Ingram W.J. and Davis R.A. (1999) Towards the construction of climate change scenarios. *Climatic Change* 41, 547-581.

Nakićenović N. and Swart R. (Eds.) (2000) *Special Report on Emissions Scenarios*. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, United Kingdom and New York, USA, 599 pp.

Suppiah R., Macadam I and Whetton P.H. (2007) *Climate Change Projections for the Tropical Rainforest Region of North Queensland*. A CSIRO report to the Marine and Tropical Sciences Research Facility. Available from: <http://www.rrrc.com.au/publications/downloads/25ii1-Climate-Projections.pdf>. Accessed: 14 July 2008

Suppiah R., Macadam I., Page C. and Whetton P.H. (2008) *Climate change projections for the MTSRF region using probability density functions*. A CSIRO report to the Marine and Tropical Sciences Research Facility.

Thatcher M., McGregor J.L. and Nguyen K. (2007) *Regional climate downscaling for the Marine and Tropical Sciences Research Facility (MTSRF) between 1971-2000*. CSIRO, Marine and Atmospheric Research Report. Available from: http://www.rrrc.org.au/mtsrf/theme_2/program_5ii.html. Accessed: 14 July 2008.

Thatcher M. and McGregor J.L. (2008) *Dynamically downscaled Mk3.0 climate projection for the Marine and Tropical Sciences Research Facility (MTSRF) from 2060 to 2090*. CSIRO, Marine and Atmospheric Research Report. Available from: http://www.cmar.csiro.au/e-print/open/2008/thatchermj_b.pdf. Accessed: 14 July 2008.

Walsh K.J.E., Nguyen K.C. and McGregor J.L. (2004) Finer-resolution regional climate model simulations of the impact of climate change on tropical cyclones near Australia. *Climate Dynamics* 22, 47-56.

Watterson I.G. (2008) Calculation of probability density functions for temperature and precipitation change under global warming. *Journal of Geophysical Research* 113, D12106, doi:10.1029/2007JD009254.

Whetton P.H., McInnes K.L., Jones R.N., Hennessy K.J., Suppiah R., Page C.M., Bathols J. and Durack P.J. (2005) *Australian climate change projections for impact assessment and policy application: A Review*. CSIRO, Marine and Atmospheric Research Paper 001, Aspendale, 34pp.

Attitudes of recreational fishers to the rezoning of the Great Barrier Reef Marine Park

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Introduction

The Great Barrier Reef Marine Park (GBRMP) is one of the largest marine parks in the world, covering an area of roughly 345,000 sq km, and extending approximately 2,300 km along the north-east coast of Queensland. The Great Barrier Reef Marine Park Authority (GBRMPA) manages the park with the primary goal of preserving and protecting the ecosystem while allowing for various activities in the area.

In July 2004, GBRMPA implemented a new zoning plan for the park, increasing no-take areas from 5% to 33% of the total park area. The rezoning was aimed at increasing the level of protection for marine life in the park. Prior to implementation, a consultation process allowed the public to have input into the size and location of new zones and to comment on draft zoning plans. As part of this process, about 360 public meetings were held and more than 31,000 written submissions were received by GBRMPA.

Recreational fishing is a popular activity in the park. With more than 180,000 active recreational fishers within easy access of the park, the recreational fishing community could be seen as the largest group likely to suffer any negative impacts arising from the increase in no-take areas. However, should the new no-take areas lead to healthier fish stocks, recreational fishers are also the group most likely to benefit.

Prior to implementation of the plan, anecdotal evidence from the public media, the recreational fishing media, and comments made at public meetings, suggested that there was a high level of opposition among recreational fishers towards the concept of the rezoning and towards the Zoning Plan itself. However, no effort was made to confirm or deny this perception by surveying a representative sample of GBR recreational fishers.

Comments by recreational fishers in the media since the rezoning suggest that many are unhappy with the outcomes thus far.

This study was the first aimed at objectively quantifying the attitudes and perceptions of recreational fishers regarding the 2004 Zoning Plan, the rezoning process, and the costs and benefits of the plan to the recreational angling community. This information will allow for a more accurate assessment of the costs and benefits of the 2004 Zoning Plan, and will help facilitate better engagement of the recreational fishing community in future marine park development and management, both in the Great Barrier Reef and elsewhere in Australia.

Recognising the need for information about social impacts of rezoning the Great Barrier Reef, the Marine and Tropical Sciences Research Facility provided funding for the study (formerly funded by the CRC Reef). GBRMPA and the recreational angling community (through Sunfish Queensland and CapReef) also lent support and advice.

Methods

Data were collected using both telephone and mail surveys. To get a good sample, 13,435 households within fifty kilometres of the GBRMP were randomly called in February 2007.

Only people who were aged over 15 years and had fished in the park in the previous twelve months were interviewed. From the telephone survey, 1,532 active Great Barrier Reef fishers were identified and sent a follow-up mail survey. Fishers were questioned about how often they fished yearly, the number of years of experience they had, how familiar they were with the 2004 Zoning Plan, and their opinions about the effects of the zoning plan on their fishing activity and the sustainability of the Great Barrier Reef. The fishers were also asked their opinions about how effective the consultation process had been at considering the concerns of recreational fishers. Eight hundred completed mail surveys were returned.

Results

Profiling recreational fishers

Most of the recreational fishers interviewed were male, between the ages of 31 and 60, with an average age of 43 years. The most common annual household income category was between \$30,000 and \$59,000.

Total fishing experience covered a broad range, from 1 to 74 years with Great Barrier Reef fishing experience ranging from 1 to 69 years. On average, recreational fishers had approximately 29 years of fishing experience in total and 23 years fishing experience in the GBRMP.

A majority of fishers reported that fishing is their first or second most important outdoor activity and 67% said that fishing is their most important activity in the GBRMP. Most fishers surveyed averaged 20 days of fishing in total and 14 days in the GBRMP over the previous year and 73% of fishers reported being either moderately or very satisfied with fishing in the GBRMP.

What fishers thought about the 2004 Zoning Plan

When asked, “In general, do you think the rezoning of the GBRMP was a good idea, a bad idea or neither?” most recreational fishers said they thought that the rezoning was a good idea (Figure 1). Only 17% believed that it was a bad idea. When asked about their level of support for the plan that was implemented in 2004, almost 60% of fishers said they supported it, whereas just 30% were opposed to it (Figure 2).

Fishers were also asked to give their opinions about the size of each of the zones in the areas where they fish. Many (47%) believed that there was too much green (no take) zone, 43% believed that there was just enough yellow (limited fishing – one hook and line only) zone, 42% believed there was just enough olive (buffer, limited fishing – trolling only) zone and 40% believed that there was just enough pink (preservation – no entry) zone. Just a little under half of those fishers surveyed also believed that there was not enough dark blue (habitat protection – no trawling) zone.

The area covered by yellow zones was increased within the GBRMP as part of the 2004 zoning plan. The nature of yellow zones severely limits commercial fishing (i.e. no netting or trawling, limited crabbing, only one line and one hook, and only one dory permitted) while still allowing access to recreational fishers so long as no more than one line and one hook is used per fisher.

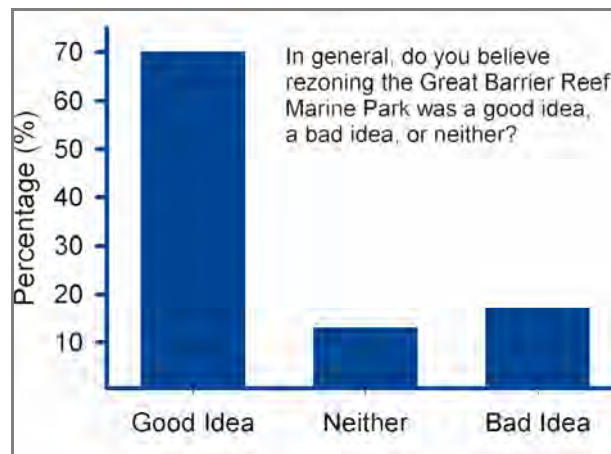


Figure 1: Recreational fishers' attitudes to the rezoning of the Great Barrier Reef Marine Park.

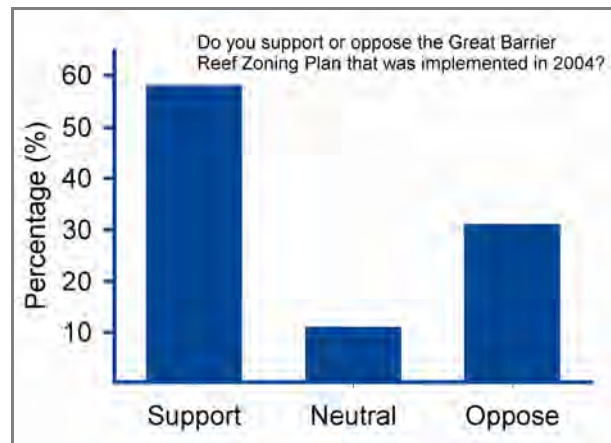


Figure 2: Recreational fishers' support for the 2004 rezoning of the Great Barrier Reef Marine Park.

To find out how recreational fishers felt about these zones in particular, we asked a series of questions specifically about yellow zones. Most fishers believe that, generally, yellow zones are a good idea, and also stated that less than 25% of their GBRMP fishing activity over the previous year occurred in yellow zones.

A majority of fishers believe that yellow zones will result in better recreational fishing in the GBRMP. They also believe that the benefits of restricted commercial fishing in yellow zones outweigh the costs to recreational fishers. Interestingly, 41% of fishers believe that yellow zones have also reduced the impact of recreational fishing on the Great Barrier Reef. Very few fishers believe that yellow zones are too restrictive – for recreational or commercial fishers.

Perceived effects of the Zoning Plan

Fishers were asked a series of questions about the effects the 2004 zoning plan on their recreational fishing activities and the quality of their fishing experiences.

When asked about the overall effects of the new zoning plan on their recreational fishing activity, 73% of fishers said that it had either no effect or a positive effect.

When asked about specific impacts of the plan on their fishing activity, a majority (68%) said that there was no effect on the number of times they went fishing, the amount of time they spent fishing (67%), size of the fish caught (57%) or the cost of going fishing (55%). A large proportion (47%) also believed that the zoning plan had no effect on the number of fish they now catch and were, overall, still happy about fishing.

Sixty-six per cent of the fishers surveyed agreed that the new plan has increased the protection of marine life in the park and for 52%, their level of knowledge about the marine park also increased. However, they also believe that the new plan has increased the number of people fishing in the remaining open areas and that their access to the best fishing areas in the park is now limited.

A question of management

Recreational fishers were asked how they felt about the 2004 zoning plan and the management of the GBRMP. Not surprisingly, results show that recreational fishers are generally very environmentally conscious. For example, 77% of fishers agreed that protecting the diversity of marine life is the most important goal of managing the Great Barrier Reef. Fifty-nine per cent also agreed that the plan will help ensure the survival of the Great Barrier Reef and is necessary to maintain it in a healthy condition. Additionally, almost two-thirds of fishers agreed that the plan would ensure sustainable fisheries in the Great Barrier Reef, while 54% of respondents also felt that recreational fishers did not need to be compensated for any lost areas.

Despite the general support for the plan and positive beliefs about its impacts on GBR sustainability, a substantial number (44%) of recreational fishers disagreed that they were adequately consulted about the plan and do not trust GBRMPA to consider the concerns of recreational fishers when managing the park. Many recreational fishers (64%) also felt that they did not receive fair treatment compared to other groups during the 2004 rezoning process.

Public consultation programs

Research undertaken by the Fishing and Fisheries Research Centre in 2006 revealed that public consultation programs may not adequately represent the views of the recreational fisher population. So, to find out how fishers could be better engaged in the management process, we asked them how they felt about public consultation and specific consultation techniques.

Almost all (97%) of those fishers surveyed believed that government agencies should consult the public about fisheries and marine park decisions. When asked which aspects or outcomes of public consultation programs were most important to them, three-quarters of the respondents said that consultation programs should follow a process easily understood by everyone; result in the best outcome for the marine environment and should not allow one group too much influence in decision making – thus allowing everyone a genuine opportunity to influence decisions. Three-quarters of fishers also believed that citizens should be allowed to express their opinions to resource managers and that their local concerns should be incorporated into decisions.

As for techniques that fishers rated as being very useful during public consultation: a large majority believed that public information displays, educational brochures and pamphlets and engagement of recreational fishers in research were all very useful.

Were some fishers more affected by the zoning plan than others?

To understand whether some fishers were more affected by the rezoning than others, we broke the fisher population down according to two variables. First, we examined whether the impacts experienced by fishers for whom fishing is a very important part of their lifestyle differed from the impacts experienced by 'average' GBR fishers. Second, we looked at whether fishers from different regions (i.e. Rockhampton, Mackay, Townsville and Cairns) experienced different impacts.

Nineteen per cent of fishers surveyed rated fishing as a very or extremely important part of their lifestyle. These highly committed fishers are those who spend the most money on fishing tackle, spend the most time out fishing, and catch the most fish. Highly committed fishers were more likely than other fishers to say: a) the zoning plan has had an overall negative effect on their fishing activity (48% of committed fishers v. 27% of 'average' fishers); b) the zoning plan has reduced the number of fish they catch (52% committed; 37% average); c) their satisfaction with fishing has decreased (55% committed, 34% average); and d) the zoning plan has reduced their ability to access quality fishing areas in the park (66% committed; 51% average). Committed fishers were also more likely than average fishers to say that the cost of fishing and the number of people fishing in the remaining open areas on the GBRMP has increased since the 2004 zoning plan was implemented.

Consequently, committed fishers were more likely to believe that the zoning plan was unnecessary, and were less likely to believe that it would reduce the impact of fishing on the Great Barrier Reef. They were also more likely to believe that GBRMPA was not doing a good job of managing the Great Barrier Reef and did not consider the concerns of recreational fishers, consult them adequately, or treat them fairly during decision making processes. A high proportion of these committed fishers also reported losing more locations on average than other fishers and were more likely to compensate by fishing more frequently at their usual locations.

In general, support for the zoning plan was lowest among Cairns fishers (48%) and highest among fishers in Rockhampton (66%) and Mackay (60%). Fishers in Cairns were also the most likely to say that the zoning plan had a negative effect on their fishing activity; most notably the numbers of fish caught, satisfaction gained from fishing and the amount of time spent fishing. Cairns fishers were also the ones most likely to have lost at least one regular fishing area to the 2004 zoning plan, with 65% affirming this in their survey responses.

Conclusions

The survey showed that there is consensus among recreational fishers about the need to protect and conserve the Great Barrier Reef and that many recreational fishers are strong supporters of marine park management. However, many fishers reported experiencing at least some negative effects as a result of the 2004 zoning plan; effects which must be considered when evaluating the overall costs and benefits of the plan.

It is also clear that some groups of recreational fishers perceive the costs and benefits of the 2004 zoning plan in a different way to the majority. In particular, fishers in Cairns and those who consider fishing an important part of their lifestyle had the least positive attitudes towards the plan and reported the greatest impacts on their fishing activity. These results are significant because they demonstrate that some important groups were affected more than others, and that these differences are less evident if we focus only on the impacts on the 'average' recreational fisher.

The survey also demonstrated that the rezoning process and the 2004 zoning plan have resulted in a reduced level of trust in GBRMPA amongst recreational fishers. It is likely that

dissatisfaction towards the rezoning and consultation process is the reason why some fishers still publicly express negative attitudes towards the plan and GBRMPA. This reduced trust may be a problem for resource managers when attempting to build and maintain a productive relationship with the recreational fishing community.

Ultimately, the results of this survey underline the need to continue monitoring recreational fishers' attitudes and perceptions in order to fully understand their views on the zoning plan and Great Barrier Reef management over time. It is also obvious that maintaining a strong and productive relationship between resource managers and the recreational angling community is extremely important, as is ensuring that all recreational fishers are allowed to meaningfully participate and communicate during the management process.

Update on the status of reefs of the Great Barrier Reef from the AIMS Long-term Monitoring Program: Status Report # 8

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Introduction to the AIMS Long-term Monitoring Program

The Australian Institute of Marine Science (AIMS) Long-term Monitoring (LTM) Program grew out of a program to survey reefs of the Great Barrier Reef (GBR) for the crown-of-thorns starfish, *Acanthaster planci*, which began in the early 1980s and provided the first broad-scale picture of the distribution of *A. planci*. In 1992 the program was modified to include surveys of benthic organisms and reef fishes on marked sites in a standard habitat on 52 reefs as well as surveys for *A. planci*. These reefs were located to span the major gradients in reef communities in the GBR: from north to south (in six bands of latitude) and from the Coral Sea to the coast (three cross-shelf zones). The program remained largely unchanged until late 2005. After 2005, the LTM surveys were continued but in odd-numbered years, while surveys in alternate years aimed to assess the effects of the rezoning of the Great Barrier Reef Marine Park (GBRMP) in 2004 on biodiversity. This new program involved surveys of pairs of reefs, matched by size, distance from shore and angle of reef slope. Both the reefs in each pair were open to fishing prior to rezoning in 2004, but while one reef remained open to fishing, the other was rezoned as a no-take area in the new zoning plan. Sets of six reef pairs were chosen near major centres of population: Cairns, Townsville, Mackay, the Swain Reefs and the Capricorn-Bunker reefs. The same LTM survey techniques were used, and eight of the reefs from the program were included in reef pairs for the effects of rezoning surveys.

The program has produced status reports at two to three year intervals. The latest report, No. 7, was published in 2005. Status Report No. 8 covers surveys to June 2007.

Summary of the report's findings

Trends in crown-of-thorns starfish outbreaks

In the central section of the GBR, outbreaks of crown-of-thorns starfish occur in waves that appear to originate on reefs north of Cairns and then spread south as larvae are carried from reef to reef by the prevailing currents. The third recorded wave of outbreaks has now reached reefs in the Whitsunday and Pompey sectors (Figure 1). Outbreaks in the Townsville and Cape Upstart sectors have subsided. Timing of outbreaks of *A. planci* in the Swains sector is independent from the waves of outbreaks seen on reefs in the central section of the GBRMP. Outbreaks have been recorded on reefs in the Swains sector each year since surveys began in the 1980s, up until 2007. In 2007, persistent outbreaks on some reefs died out and no new outbreaks were recorded. While low numbers of *A. planci* were found on some survey reefs in 2007, there were no active or incipient outbreaks in the Swains sector for the first time since AIMS surveys began.

Crown-of-thorns starfish early-warning surveys

At the request of the reef tourism industry, the AIMS long-term monitoring program has made extensive surveys of reefs between Cairns and Cooktown, which is thought to be the region in which starfish numbers initially build up to initiate the waves of outbreaks that then pass southwards through the central GBR as starfish larvae are carried from reef to reef by the southerly currents. These waves have occurred at approximately fifteen-year intervals since the 1960s. The current third recorded wave was first detected in 1994, so history suggests that another wave may occur soon.

Early detection of any build-up in adult starfish numbers that might initiate a new wave of outbreaks would allow the tourism operators in the Cairns and Port Douglas regions to plan for eradication programs around their high-value sites. The perimeters of 41 reefs in the region were surveyed in 2006, but only four starfish were seen in total, each one on a different reef. This represents background population densities and means that there was no indication of an impending wave of outbreaks. These surveys will be repeated in 2008-09.

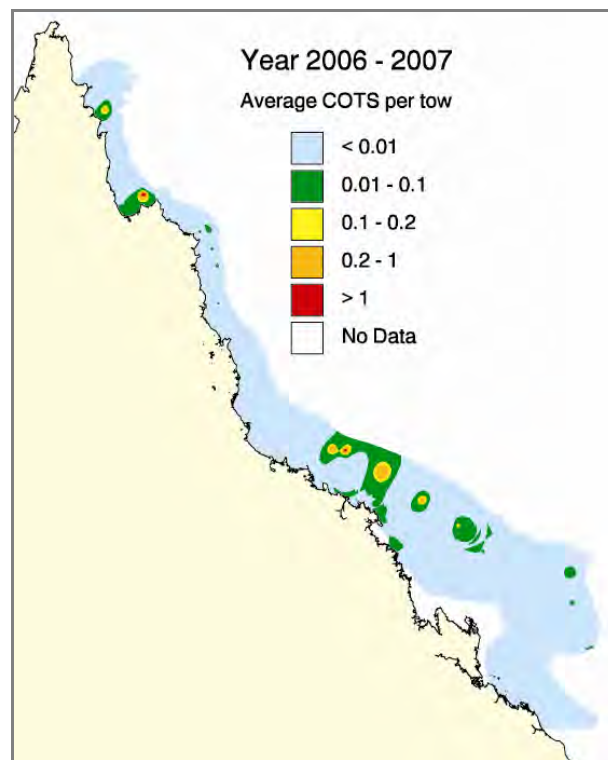


Figure 1: Distribution of crown-of-thorns starfish, *Acanthaster planci*, on the Great Barrier Reef in the 2006/2007 survey year. Starfish densities are expressed as starfish per tow, with 0.22 starfish per tow judged to be a sufficient density (incipient outbreak density) to reduce coral cover on an average reef. The numbers of starfish seen in the Swain reefs was a twenty-year low.

A scientific benefit of this sub-project should be the identification of the true site of origin of outbreaks. The area of the GBR between Cairns and Cooktown has been implicated, based on the rate of spread of outbreaks. Mid-shelf, and even offshore, reefs in the area between Cairns and Cooktown are frequently bathed in floodwaters from rivers of the Wet Tropics;

leading to the suggestion that agricultural runoff may facilitate the initiation of waves of outbreaks, though no primary outbreak has ever actually been recorded on the GBR.

The first evidence of the third (current) wave of outbreaks in AIMS' surveys was seen in the Lizard Island region (i.e. north of Cooktown) well north of the supposed initiation zone. To date, the relationship between runoff and *A. planci* outbreaks on the GBR remains speculative; identifying the location of primary outbreaks could be a critical piece of information.

Trends in corals and other benthic organisms

The salient changes on the Great Barrier Reef over the fifteen years to 2007 reflect the impact of *A. planci* and cyclones and, to a lesser extent, bleaching and disease on reef communities and the subsequent recovery of the communities from such disturbances. This has been particularly noticeable on outer reefs in the Cooktown – Lizard Island sector and the Capricorn-Bunker sector, which recovered strongly from storm damage in the late 1980s or early 1990s to have high coral cover by 2000. There have been few cyclones and limited bleaching in the 2006 and 2007 survey years, indicating a period of recovery and growth. As an example, hard coral cover on the permanent survey sites in the inner regions of the Cairns sector declined in the late 1990s due to coral bleaching, storms and *A. planci*, but have shown slow but steady increases in recent surveys (Figure 2). An intense cyclone (Tropical Cyclone *Larry*) moved quickly across a region of the reef near Innisfail where the coral cover was already low following extensive *A. planci* outbreaks about six to eight years ago.

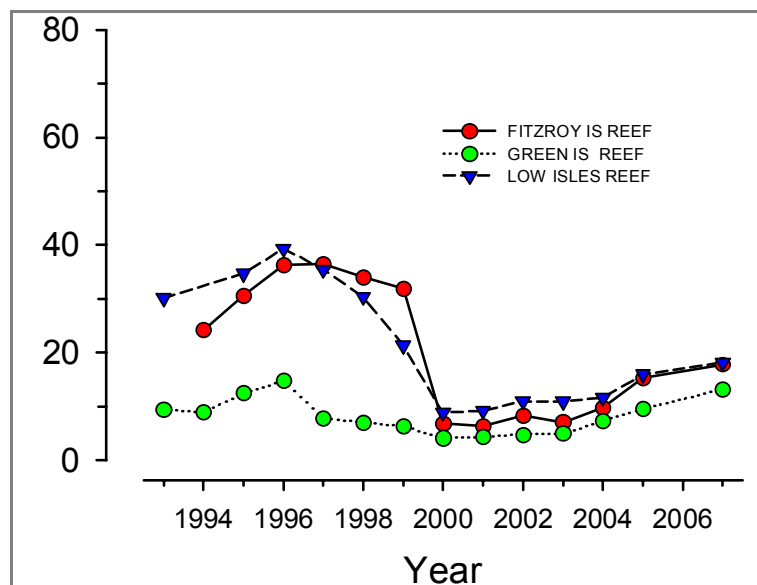


Figure 2: Cover of hard coral on three inshore reefs in the Cairns section, showing gradual recovery after bleaching and crown-of-thorns starfish damage in the late 1990s.

An exception to this pattern of limited disturbance is the increase in reports of coral disease, particularly in regions with high coral cover. Storms greatly reduced the coral cover on the outer shelf reefs in the northern Cooktown–Lizard Island sector in 1990. The fronts of these reefs are dominated by tabulate *Acropora* species which grow rapidly and coral cover returned to very high levels by the year 2000. After a period of stability, coral cover has halved since 2004, at least in part due to the effects of coral disease (Figure 3).

Substantial numbers of colonies with white syndrome have been recorded on these reefs each year since 2002 and the cumulative result has been noticeable coral mortality. Tabulate *Acropora* species are particularly susceptible to white syndrome, especially at high densities. This is unusual, because it means that the reefs with high coral cover (that are often considered to be healthy) are at risk.

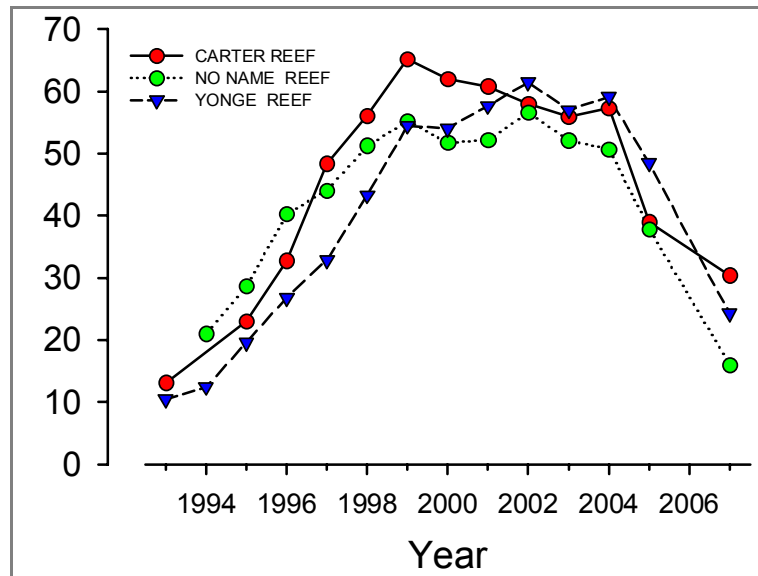


Figure 3: Cover of hard corals on three outer-shelf reefs in the Cooktown–Lizard Island sector, showing rapid recovery to very high cover levels after storm damage (Tropical Cyclone Ivor) in 1990 and rapid decline in recent years due, in part, to a consistent and relatively high incidence of the coral disease white syndrome on these reefs.

Trends in abundance of coral reef fishes

While abundance of several groups of fishes showed significant long-term and short-term trends in various regions, there were only a few instances where a majority of groups in a region showed a consistent trend. These were usually related to changes in coral cover. For instance the majority of larger, more mobile fish families, and damselfish genera, increased in abundance over the thirteen years of surveys in the Capricorn-Bunker sector. Coral cover increased greatly in this region from very low levels recorded in 1989 and the changes in fish assemblages reflect this. Several groups, such as surgeonfishes, butterflyfishes, parrotfishes, wrasses and coral-associated damselfishes, continued to increase in 2006 and 2007, even though coral cover has not increased and may even have declined.

In other sectors, most families of larger mobile fishes showed little net change in abundance over the fifteen years of surveys. Most families also did not change in abundance over the last two surveys.

Monitoring the effects of rezoning the Great Barrier Reef Marine Park

The objective of rezoning the GBRMP was to conserve biodiversity by ensuring that a proportion of each habitat type was protected from exploitation. The effects of protection from exploitation should be most rapidly evident as changes in the abundance and size structure of the target species of reef fisheries.

Surveys of the selected reef pairs in 2006 found that the abundance of coral trout (*Plectropomus* spp.), the main target of the commercial reef line fishery on the GBR, was 54% higher on average on no-take reefs than on reefs that were open to fishing and there was a consistent positive difference between no-take and open reefs in all five regions. The surveys were made 1½ to 2 years after the rezoning, so this is a surprisingly rapid response.

Conclusion: The GBR in 2008

Status Report 8 summarises data from a period of relatively low disturbance on the GBR. The major cause of losses of coral, *A. planci*, was at low levels and coral bleaching and cyclones affected only limited areas of the GBR. While this allowed coral recovery in some regions, significant loss of coral to coral disease was evident for the first time on the GBR.

Ecological impacts of tropical cyclones on terrestrial ecosystems of the Wet Tropics region: Insights from Tropical Cyclone *Larry*

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Abstract

Tropical Cyclone *Larry* (Category 4) was the most severe tropical cyclone to impact on the Wet Tropics bioregion since the devastating 1918 Innisfail cyclone. Based on an analysis of earlier cyclones impacting on this region over the period 1856-2006, it was determined that Cyclone *Larry* was a one-in-fifty-year event. This significant disturbance event provided researchers with a unique opportunity to examine the ecological impacts and recovery of continuous and fragmented forests along a gradient from the coastal plain south of Cairns through to the Atherton Tablelands. Under the auspices of the James Cook University (JCU) and CSIRO Tropical Landscapes Joint Venture, an integrated program of research was undertaken following the cyclone with many projects linked to the Marine and Tropical Sciences Research Facility (MTSRF) portfolio of research. Most researchers had extensive pre-cyclone data for these landscapes, providing opportunities to quantify impacts at species, community and ecosystem levels and to put in place long-term studies of recovery. Outcomes of this program of research were published in a special issue of *Austral Ecology* in June 2008. This paper provides an overview of the major findings and insights of the 'Cyclone Larry' research program and what we have learnt from this significant environmental event. It also discusses the implications of the 'lessons from Larry' for future management and conservation of our wet tropics landscapes, particularly in relation to future climate and land use change scenarios.

Introduction

The role of tropical cyclones in ecosystem dynamics in the Wet Tropics of northeastern Australia has been long recognised since the pioneering work of Dr Len Webb following Tropical Cyclone *Agnes* (Webb 1958). The influences of tropical cyclones on the structural and floristic composition of tropical lowland and foothill rainforests were eloquently described by Webb (1958). He noted that local topographic effects, as well as the frequency and intensity of cyclones, were important determinants of wind damage at various scales. Areas frequently impacted suffered canopy lowering and compositional changes, including vine towers and weed invasion. Webb (1958) also noted the increased fuel load after cyclones, the fire risk depending on subsequent rainfall. He concluded that the catastrophic effect of cyclones on rainforests overrides the usual ecological factors, and in such areas, even without human interference, a stable forest is not attained. Similar observations were also made by Unwin *et al.* (1988) following Cyclone *Winifred* that impacted the same region in February 1986.

Tropical cyclones are therefore significant natural disturbance phenomena for forest ecosystems in the Wet Tropics of northeast Australia, especially for forests near the coast (Turton and Stork 2008). For this reason, even continuous forests in the region have been described as hyper-disturbed ecosystems with patches of damaged forest constantly

recovering from previous cyclonic events, often in concert with floods, droughts and fires. Cyclones are part of the ecosystem dynamics of these forested landscapes and recovery of canopy cover following such events is often remarkably rapid, although forest structure and composition may take many decades to recover. The same cannot be said for fragmented forests in the Wet Tropics, located within either an agricultural, urban, linear infrastructure or grassland matrix. These forest fragments are particularly vulnerable to impacts of tropical cyclones and their associated strong winds, largely due to their high forest edge to area ratios (Laurance and Goosem 2008).

The occurrence of two severe cyclones in northern Australia during the late summer of 2006 (Cyclones *Larry* and *Monica*) reminded ecologists of their important role in ecosystem dynamics, and provided the stimulus for a recent special issue of *Austral Ecology* (Volume 33(4), 2008). Many of the studies reported in the special issue were able to capitalise on long-term ecological data sets from the tropical landscapes affected by these two major cyclonic events, affording unique opportunities to quantify impact and recovery. In this context, impact may be considered as a neutral term, as there are clearly positive and negative impacts on ecosystems following a severe cyclonic event. Lugo (2008) goes further, suggesting that ecologists should consider 'effects' of hurricanes on ecosystems rather than 'impacts' and 'trajectories of response' rather than 'recovery'.

Severe Tropical Cyclone *Larry*, with maximum wind gusts near 240 km h^{-1} , crossed the coast near Innisfail, Queensland, Australia as a Category 4 system on 20 March 2006, causing extensive damage to human communities, primary industries, infrastructure and ecosystems across a one hundred kilometre strip of coastal lowlands and adjacent uplands (Bureau of Meteorology 2007). The system was moving at 25 km h^{-1} when it crossed the coast and was still a Category 3 system when it crossed over the Atherton Tablelands some sixty kilometres from the coast. Cyclone *Larry* produced numerous tornado-type features within the system's eyewall and feeder bands that have been linked to patches of catastrophic forest damage. *Larry* was a very 'compact' system with its radius of maximum winds extending only thirty kilometres from the centre (Bureau of Meteorology 2007).

This paper examines the following research questions:

1. How unusual was Tropical Cyclone *Larry* compared with other westward moving cyclones that have affected the Wet Tropics bioregion since records began in 1858?
2. What were the ecological effects of Cyclone *Larry* on the ecosystems and biota of the areas along the path of the system?
3. What are the implications of climate change for tropical cyclones in the Wet Tropics bioregion, and how might any changes in frequency and intensity affect our forest ecosystems?
4. What were the key natural resource management issues in the aftermath of Cyclone *Larry* and what lessons have been learnt that may be applied to building more cyclone resilient landscapes for the future?

How unusual was Tropical Cyclone Larry?

Utilising a historical data base, Turton (2008) examined tropical cyclones impacting the east coast of Australia between 1858 and 2006. Cyclones crossing the coast from east to west between Cooktown and Ingham (the so-called 'wet tropical coast' of Queensland) were identified and classified according to the Australian Cyclone Severity Scale (see Table 1). The data shows that a weak cyclone (Australian System: Categories 1-2) is likely to cross the wet tropical coast with a frequency interval of about five years, compared with a frequency of about fifteen years for a moderate to severe cyclone (Category 3), and about fifty years for a very severe cyclone (Categories 4-5). Based on the historical record, it would therefore be

reasonable to consider Cyclone *Larry* to be a one-in-fifty-year event for the Wet Tropics bioregion.

Table 1: Frequency and intensity of tropical cyclones that have made east to west landfall along the wet tropical coast of Queensland, Australia (Cooktown to Ingham) over the period 1858 to 2006 (Turton 2008).

Australian Cyclone Severity Scale	Peak Gusts (km h ⁻¹)	Central Pressure (hPa)	Frequency (number recorded)	Return interval (years) [#]
Category 1	90-124	986-995	18	5
Category 2	125-169	971-985	11	9
Category 3	170-224	956-970	10	15
Category 4 and 5	≥ 225	≤ 955	2	50

[#] Estimated using a quadratic function.

Tropical Landscapes Joint Venture 'Cyclone Larry' Research Program

In the aftermath of Cyclone *Larry* the JCU/CSIRO Tropical Landscapes Joint Venture committed resources to undertake:

- Local rapid assessments of the ecological impacts of the cyclone;
- Regional assessments of cyclone impacts, utilising aerial surveys and satellite imagery;
- Monitoring of recovery of terrestrial ecosystems; and
- Provision of scientific input to government and industry with respect immediate and long-term community development and natural resource management issues.

Ecological effects of Cyclone Larry on the ecosystems and biota of the Wet Tropics bioregion

The primary scientific findings from the 'Cyclone Larry' research program were published in a special issue of *Austral Ecology* in June 2008. The principal ecological effects of the cyclone on fragmented and intact forests of the Wet Tropics bioregion are summarised in Table 2.

Climate change and tropical cyclones in the Wet Tropics region

Global warming is predicted to increase the intensities of tropical cyclones by ten to twenty percent by the end of the 21st century, while cyclone frequency is predicted to remain unchanged (Henderson-Sellers *et al.* 1998). Two factors that contribute to more intense tropical cyclones, ocean heat content and water vapour, have both increased over the past several decades. Emanuel (2005) has produced some evidence for a substantial increase in the power of tropical cyclones (denoted by the integral of the cube of the maximum winds over time) during the last fifty years. This result is supported by the findings of Webster *et al.* (2005) that there has been a substantial global increase (nearly 100%) in the proportion of the most severe tropical cyclones (Category 4 and 5 on the Saffir-Simpson scale), from the period from 1970 to 1995, which has been accompanied by a similar decrease in weaker systems (Categories 1-3, same scale). The findings from both studies correlate with the rise in sea surface temperatures in regions where tropical cyclones typically originate, including the oceans around Australia. However, according to Nyberg *et al.* (2007), the phase of enhanced hurricane activity since 1995 is not unusual compared with other periods of high hurricane activity in the (270 year historical) record and thus appears to represent a recovery

to normal hurricane activity, rather than a direct response to increasing sea surface temperature.

What are the implications of more intense cyclones for our tropical rainforests? Will biodiversity decline? Will forest structure change over time? Given that cyclones are a significant disturbance agent for the forests of the Wet Tropics region (Webb 1958), there is a plausible link between periodic cyclonic disturbance and forest composition and structure at the landscape scale. The Intermediate Disturbance Hypothesis proposes that biodiversity is highest when ecosystem disturbance is neither too rare nor too frequent (Connell 1978). With low disturbance, competitive exclusion by dominant species arises, while with high disturbance, only species tolerant of the stress agent can persist. A shift in the severity spectrum of tropical cyclones will tend to favour species more resistant to strong winds, such as palms, and those more tolerant of post-disturbance environmental stresses, such as pioneers, vines and weeds (Lugo and Scatena 1996; Metcalfe *et al.* 2008; Murphy *et al.* 2008). Increases in cyclone intensity, even with cyclone frequency remaining stable, may lead to shifts in forest succession direction, higher rates of species turnover, and hence opportunities for species change in tropical forests (Dale *et al.* 2001). Such changes will be in concert with other ecological and physiological effects of global warming on forest biota and ecosystem.

Table 2: How Tropical Cyclone *Larry* affected fragmented and intact forests in the Wet Tropics Bioregion.

Main Findings from the Tropical Landscapes Joint Venture Research Project
Forest structure, measured up to six months after Tropical Cyclone <i>Larry</i> , did not differ between small (<40 ha) fragments and larger forested areas; the severity of effects in both was dictated by proximity to the cyclone's eye (Catterall <i>et al.</i> 2008).
Forest structure was not different between small linear fragments and edges and interiors of larger forest tracts – a year after the cyclone its main effect was increased local spatial variability in all forests (Grimbacher <i>et al.</i> 2008).
A surprising finding was that secondary vegetation that developed along two artificial edges created during forest fragmentation (a road and a power line lane) may have buffered forest interiors against changes in understorey moisture and light more effectively than a long-standing natural edge along a stream course (Pohlman <i>et al.</i> 2008).
Thirty-five percent of cassowary populations were killed directly during Cyclone <i>Larry</i> but those that survived and ventured beyond the fragments suffered even higher mortality – struck by motor vehicles or attacked by dogs (Moore and Moore, unpublished).
There were no reductions in populations of five species of folivorous marsupials, measured six to eight months after the cyclone, in fragmented forests within pastoral landscapes compared with pre-cyclone estimates (Kanowski <i>et al.</i> 2008b, Wilson <i>et al.</i> 2008).
Numbers of frugivorous birds were much reduced two weeks after Cyclone <i>Larry</i> in severely-affected forest fragments but were at pre-cyclone levels by seven months after the cyclone (Freeman <i>et al.</i> 2008).
Before Cyclone <i>Larry</i> , the regional population of the flying fox <i>Pteropus conspicillatus</i> roosted in large camps but afterwards altered its roosting behaviour so that there were many small camps, presumably in response to food limitation (Shilton <i>et al.</i> 2008).
Non-native plant species germinated in the rainforest in the first six to nine months after cyclone disturbance but little since (Murphy <i>et al.</i> 2008). They concluded these species were ephemeral and unlikely to persist during forest recovery.
In coastal areas, planted trees in riparian sites were more severely damaged by the cyclone than trees in nearby forest fragments (Bruce <i>et al.</i> 2008). However, on the Atherton Tableland where wind speeds were lower, planted rainforest trees were not severely damaged (Kanowski <i>et al.</i> 2008a).
Trees with high woody density in rainforests affected by Cyclone <i>Larry</i> showed greater resistance (Curran <i>et al.</i> 2008).
The abrupt decrease in wind speeds away from the eye of Cyclone <i>Larry</i> (Turton 2008) meant that damage to widespread tree species could be assessed across a gradient of wind severity, and most showed consistent responses (Metcalfe <i>et al.</i> 2008).

Lessons from Cyclone Larry for the Wet Tropics region

The landscape-scale impact of Cyclone *Larry* had implications far wider than the impact on forested areas. A very wide range of natural resource assets and processes were affected. An opportunity for a level of integrated response to this impact was provided through the Queensland Government's Industry Recovery Action Planning process. Within this process, Terrain NRM Ltd, the region's designated regional Natural Resource Management body, undertook North Queensland-wide ranging consultation with affected communities, industry and interest groups. Terrain NRM Ltd carried out this work in the context of its role in representing the Wet Tropics community on natural resource issues. The early response issues arising from this consultation were articulated in a Natural Resources Management Recovery Plan. The details of such proposed and actual responses are outlined in Turton and Dale (2007).

Additionally, several months after the cyclone, a broad community forum was held to determine the longer term 'Lessons from *Larry*' with respect to a wide range of natural resource management considerations. A summary of some of the more substantive cyclone response lessons and recommendations are outlined in Turton and Dale (2007).

Through these processes, perhaps the most striking natural resource management learning from *Larry* was that a more resilient landscape has a better chance of withstanding cyclone impacts and recovering more quickly. Securing landscape resilience to cyclonic events in the Wet Tropics bioregion means focusing future natural resource management investments in the six areas outlined in Table 3.

Table 3: Recommendations for future Natural Resource Management investments in the Wet Tropics Bioregion (Turton and Dale 2007).

Landscape connectivity Cassowaries, mahogany gliders and tree kangaroos are examples of iconic species in the Wet Tropics bioregion. The rainforests of the coastal plain and tablelands are critical habitats to them and many other rare and/ or regionally endemic species. These forests are already fragmented and fragments in particular were badly damaged by Cyclone <i>Larry</i>. While areas of forest with a critical mass will recover well, a lack of effective corridors meant these rare animals had fewer recovery options.
River repair Healthy rivers and streams in the Wet Tropics bioregion reduce erosion and crop damage on-farm and contribute to the health of the Great Barrier Reef. One way to achieve this is through restoring healthy native vegetation along the region's rivers. Thin riparian vegetation was prone to serious degradation by Cyclone <i>Larry</i>, exacerbating water quality and erosion risks in post cyclonic flooding.
Protecting coastal assets The region's unique coastal zone provides a significant natural buffer to cyclonic and storm surge events. Additionally, increasing urban development in recent years has boxed coastal ecosystems between the sea and urban landscapes, leaving these ecosystems very much at risk in the even of storm surges. Despite this, there is still inadequate effort going towards coastal protection.
Cyclone resilient farms The adoption of sound management practices on farm (e.g. grassed inter-rows in banana plantations) and grants to landholders enable significant land repair and critical on-farm changes. This will ensure greater resilience against future climatic threats.
Education for the future Community resilience comes from community knowledge of how to manage for a cyclone resilient landscape. Investing in education is about making an investment in the capacity of future generations to sustainability manage the region's natural resources.
Avoiding climate change Climate change scenarios suggest an increasing frequency of high intensity cyclones in far northern Queensland. This means the region has to play its part in reducing Greenhouse gas emissions.

References

- Bruce C., Kroon F., Sydes D. *et al.* (2008) Cyclone damage sustained by riparian revegetation sites in the Tully-Murray floodplain, Queensland Australia. *Austral Ecol.* 33, 516-524.
- Bureau of Meteorology (2007) *Severe Tropical Cyclone Larry*. Bureau of Meteorology, Commonwealth of Australia, Brisbane.
- Catterall C. P., McKenna S. and Kanowski J. (2008) Do cyclones and forest fragmentation have synergistic effects? A before–after study of rainforest structure at multiple sites. *Austral Ecol.* 33, 571-584.
- Connell J. H. (1978) Diversity in tropical rain forests and coral reefs. *Science*. 199, 1302-1310.
- Curran T. J., Gersbach L. N., Edwards W. and Krockenberger A. K. (2008) Wood density predicts plant damage and vegetative recovery rates caused by cyclone disturbance in tropical rainforest tree species of North Queensland, Australia. *Austral Ecol.* 33, 442-450.
- Dale V. H., Joyce L. A., McNulty S. *et al.* (2001) Climate change and forest disturbances. *Bioscience*. 51, 723-734.
- Emanuel K. (2005) Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*. 436, 686-688.
- Everham E. M. and Brokaw N. V. L. (1996) Forest damage and recovery from catastrophic wind. *Bot. Rev.* 62, 113-173.
- Freeman A.N.D., Pias K. and Vinson M. F. (2008) The impact of Tropical Cyclone Larry on bird communities in fragments of the endangered rainforest type 5b. *Austral Ecol.* 33, 532-540.
- Grimbacher P. S., Catterall C. P. & Stork N. E. (2008) Do edge effects increase the susceptibility of rainforest fragments to structural damage resulting from a severe tropical cyclone? *Austral Ecol.* 33, 525-531.
- Henderson-Sellers A., Zhang H., Berz G. *et al.* (1998) Tropical Cyclones and global climate change: a Post-IPCC assessment. *B. Am. Meteorol. Soc.* 79, 19-38.
- Kanowski J., Catterall C. P., McKenna S. G. *et al.* (2008a) Impacts of Cyclone Larry on monoculture and mixed species timber plantations, restoration plantings and upland rainforests of the Australian wet tropics. *Austral Ecol.* 33, 485-494.
- Kanowski J., Winter J.W. and Catterall C. P. (2008b) Impacts of Cyclone Larry on arboreal folivorous mammals endemic to upland rainforests of the Atherton Tableland, Australia. *Austral Ecol.* 33, 485-494.
- Laurance, W.F. and Goosem, M. (2008) Impacts of forest fragmentation and linear clearings on Australian rainforest biota, pp. 295-306. In: Stork, N.E. and Turton, S.M. (eds.) (2008) *Living in a Dynamic Tropical Forest Landscape*. Blackwell Publishing, Oxford, UK.
- Lugo A. E. (2008) Visible and invisible effects of hurricanes on forest ecosystems: an international review. *Austral Ecol.* 33, 368-398.
- Lugo A. E. & Scatena F.N. (1996) Background and catastrophic tree mortality in tropical moist, wet, rain forests. *Biotropica* 28, 585-599.
- Metcalfe D. J., Bradford M. G. and Ford A. J. (2008) Cyclone damage to tropical rain forests: species- and community level impacts. *Austral Ecol.* 33, 432-441.
- Murphy H. T., Metcalfe D. J., Bradford M. G. *et al.* (2008) Recruitment dynamics of invasive species in rainforest habitats following Cyclone Larry. *Austral Ecol.* 33, 495-502.
- Nyberg J., Malmgren B. A., Winter A. *et al.* (2007) Low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years. *Nature* 447, 698-701.
- Pohlman C. L., Goosem M. & Turton S. M. (2008) Effects of Severe Tropical Cyclone Larry on rainforest vegetation and understorey microclimate near roads, powerlines, and streams. *Austral Ecol.* 33, 503-515.

- Shilton L. A., Latch P. J., McKeown A. *et al.* (2008) Landscape scale redistribution of a highly mobile threatened species, *Pteropus conspicillatus* (Chiroptera, Pteropodidae), in response to Tropical Cyclone Larry. *Austral Ecol.* 33, 549-561.
- Turton S. M. (2008) Landscape-scale impacts of Cyclone Larry on the forests of northeast Australia including comparisons with previous cyclones impacting the region between 1858 and 2006. *Austral Ecol.* 33, 409-416.
- Turton, S.M. and Stork, N.E. (2008) Impacts of tropical cyclones on forests of the Wet Tropics of Australia, pp. 47-58. In: Stork, N.E. and Turton, S.M. (eds.) (2008) *Living in a Dynamic Tropical Forest Landscape*. Blackwell Publishing, Oxford, UK.
- Turton S. and Dale A. (2007) *An assessment of the environmental impacts of Cyclone Larry on the forest landscapes of northeast Queensland, with reference to responses to natural resource management issues in the aftermath*. JCU/CSIRO Tropical Landscapes Joint Venture, Australian Tropical Forest Institute and Terrain NRM Ltd. Report submitted to Bureau of Meteorology, Brisbane. 24p.
- Unwin G. L., Applegate G. B., Stocker G. C. and Nicholson D. I. (1988) Initial effects of tropical cyclone 'Winifred' on forests in north Queensland. *Proc. Ecol. Soc. Australia* 15, 283-296.
- Webb L. J. (1958) Cyclones as an ecological factor in tropical lowland rainforest, north Queensland. *Aust. J. Bot.* 6 (3), 220-228.
- Webster P. J., Holland G. J., Curry J. A. and Chang H. R. (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*. 309, 1844-1846.
- Wilson R. E., Goosem M.W. and Wilson G.W. (2008) Resilience of arboreal folivores to habitat damage by a severe tropical cyclone. *Aust. Ecol.* 33, 573-579.

The impacts of climate change on above-ground productivity in the Australian Wet Tropics

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Introduction

Net primary productivity (NPP) is defined as the difference between total photosynthesis and total plant respiration in an ecosystem (Clark *et al.* 2001). NPP is an important component of terrestrial carbon fixation and carbon budgets; it helps make better predictions of potential changes in forest ecosystems and is a key determinant for biodiversity by limiting patterns of abundance and assemblage structure. In order to maximise our adaptive management potential in the face of climate change, an understanding of the links between productivity and biodiversity is important in the highly productive and diverse forests of the tropics. Despite its significance, direct measurements of productivity are lacking in most tropical ecosystems, including an overall estimate for the whole Australian Wet Tropics, due to cost and measurement complexity. Complete records of the distribution of NPP in the Wet Tropics will help us to better understand local biodiversity distribution, and to more accurately predict more accurately the impacts of climate change on the biota of the region.

Methods

On-site productivity was estimated over a sixteen-month period (June 2006 to October 2007) from 265 leaf litter traps located throughout six sites in an altitudinal and latitudinal gradient in the Wet Tropics bioregion (Figure 1). For each site, 1-km long transects were located at every two hundred metres in altitude. In every transect, ten leaf litter traps, each 0.25m², were set up, along with a weather station recording humidity, soil and air moisture, and soil and air temperature at fifteen-minute intervals.

A regional NPP was also estimated using two separate techniques: climate surrogates as proxies for NPP and vegetation indices from satellite imagery. Climate surrogate equations from the literature were used to estimate monthly and annual NPP values from temperature, rainfall, solar radiation and evapotranspiration climate layers (Bioclim and Esoclim at eighty metres resolution) using ESRI ArcGIS 9.2 software (Rosenzweig 1968, Monteith 1970; Lieth 1973, 1975; Schuur 2003). The second technique consisted of monthly images for the year 2005, prior to damage from Cyclone Larry to the area, using the enhanced vegetation index (EVI) (sixteen-day composites with 250 m resolution) from the MODIS satellite. These NPP estimates were compared against climate data (from the climate layers and the local weather stations) and a species richness layer created at a resolution of eighty metres.

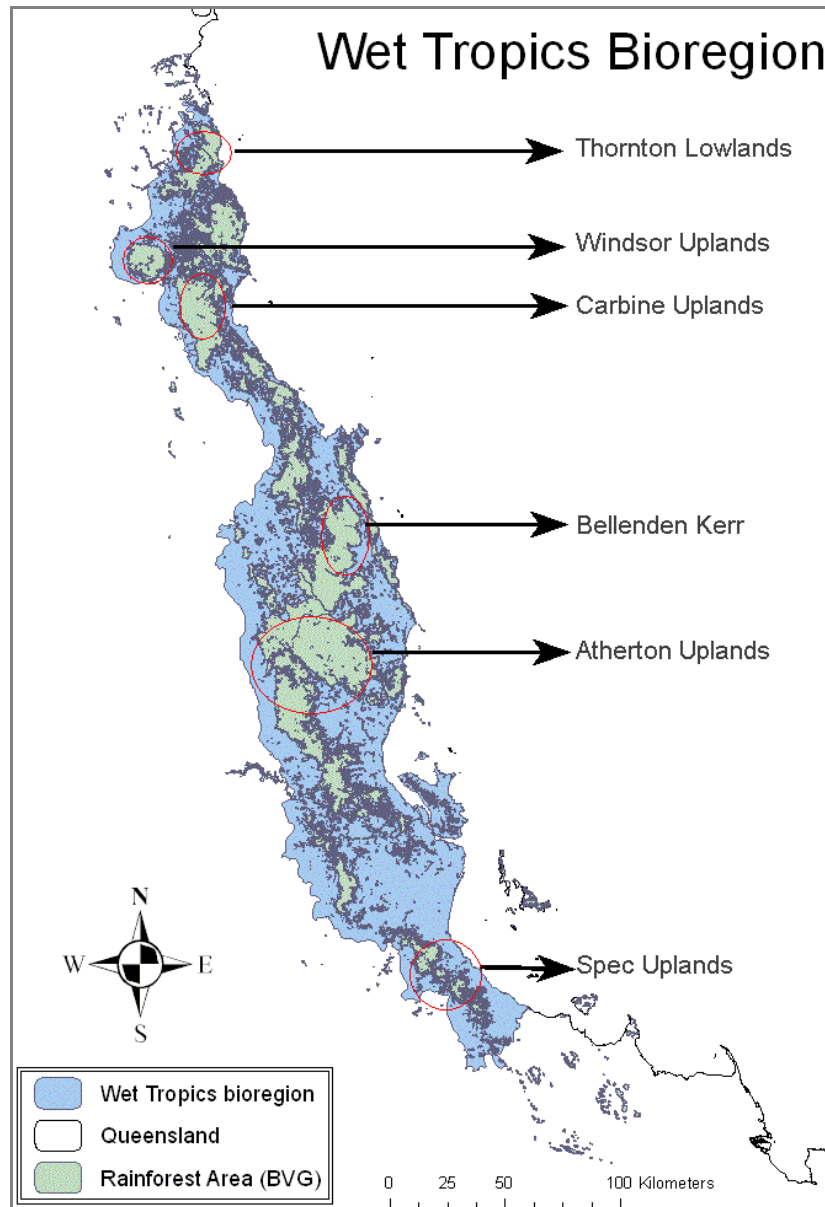


Figure 1: Study sites throughout the Wet Tropics Bioregion.

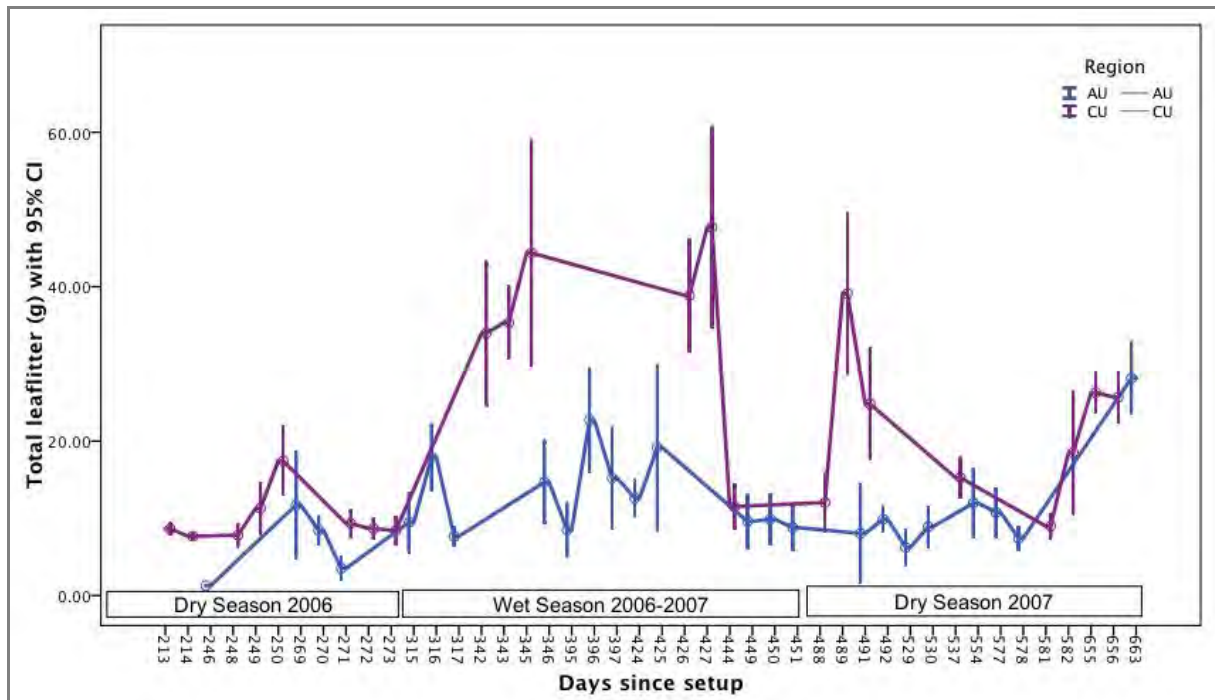
Results

Leaf litter traps

The average leaf litter for the region is 504.91 g/m^2 per year with a maximum in the Spec lowlands (919.41 g/m^2 per year) and a minimum in the Bellenden Kerr uplands (51.51 g/m^2 per year). For the period sampled, litterfall turnover between regions was significantly different (ANOVA, $F_{(5,8146.53)}=38.26$, $p<0.01$). There was also a clear wet season effect where there is more leaf litter turnover, and a bottleneck of resources during the dry season. The leaves make the highest leaf litter proportion (66.97%), followed by the woody (20.28%) and fruit/flower (7.08%) portions.

There is no apparent pattern in the timing or quantity of these components, but there is a clear peak in flower/fruit proportion at the beginning of the wet season. Altitude has a significant effect on the total amount of leaf litter (ANOVA, $F_{(13,2690.36)}=12.41$, $p<0.01$). This effect is especially apparent when all regions are compared against the Atherton Tablelands,

which has a significantly lower proportion of leaf litter at all altitudes due to the impact of Cyclone Larry in March 2006. Comparing the Atherton Tablelands with regions that were not affected by this natural disturbance demonstrates the negative effect cyclones have on local productivity, even after 18 months (Figure 2). Finally, it is imperative for future studies to determine the conditions and the variables that are limiting productivity to allow more accurate methodologies to estimate NPP in tropical forests.



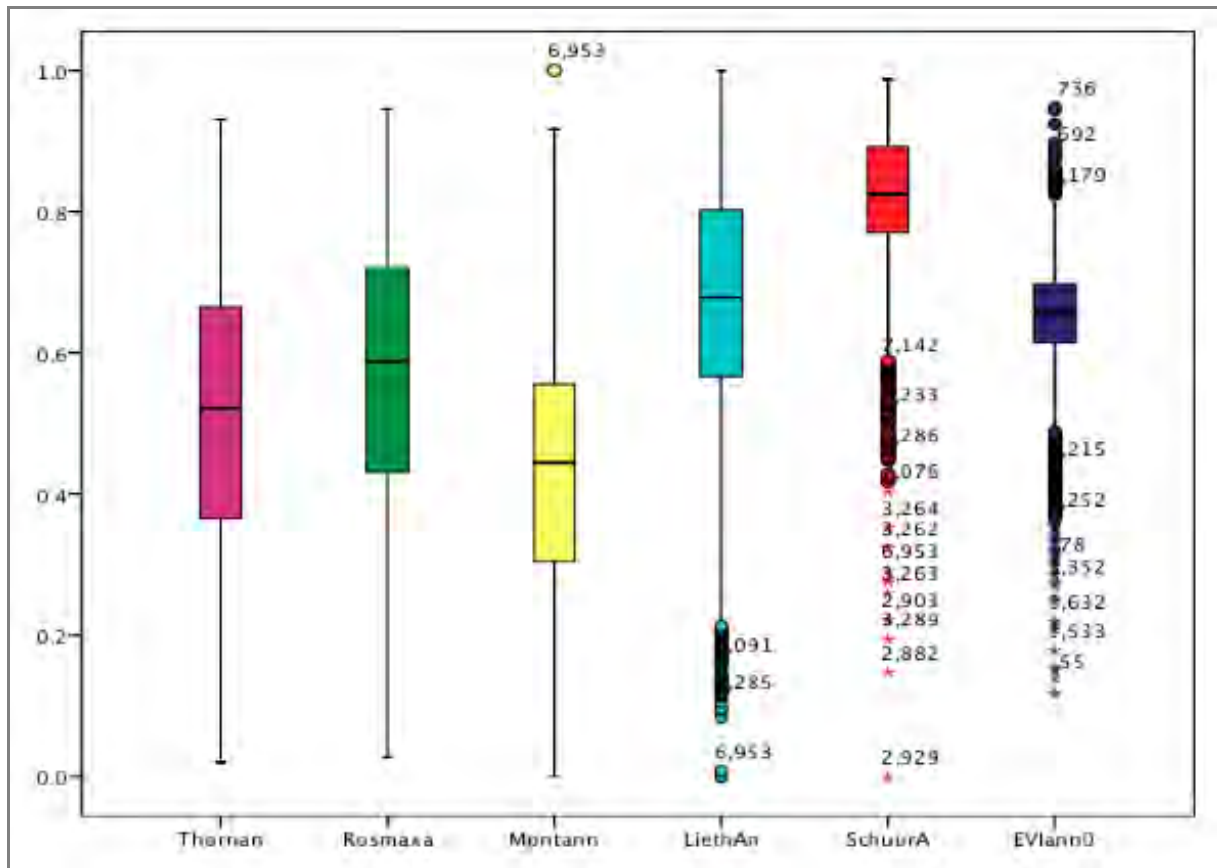


Figure 3: Mean annual NNP according to climate surrogate and methodology used. Productivity values are a ratio from 0 to 1.

Discussion and conclusion

The diversity in methodologies shows the great difference (under- or over-estimate) of primary productivity in the region. The annual average litterfall coincided with previous measurements for the area with Spain (1984) reporting an annual litterfall range between 728 and 1053 g/m² per year in northeastern Queensland. The results of the study reported here also show a significant difference between regions, altitudes and seasons, with higher productivity in the Carbine and Spec lowlands followed by sites at 1000 m a.s.l. in Windsor, Atherton and Carbine. Due to the impact of Tropical Cyclone *Larry*, litterfall in the Atherton Uplands is significantly lower than in other regions. Rainforests have a significant interannual variability and distinct seasonality reflected in leaf litter and overall primary productivity. Leaf litter peaked between the latter part of the dry season and early wet season with eaves making the biggest proportion of leaf litter.

When using climate surrogates and satellite imagery to estimate NPP it is important to remember that there are significant differences amongst methodologies. It is therefore crucial to calibrate with field estimates and choose datasets that relate in time and space.

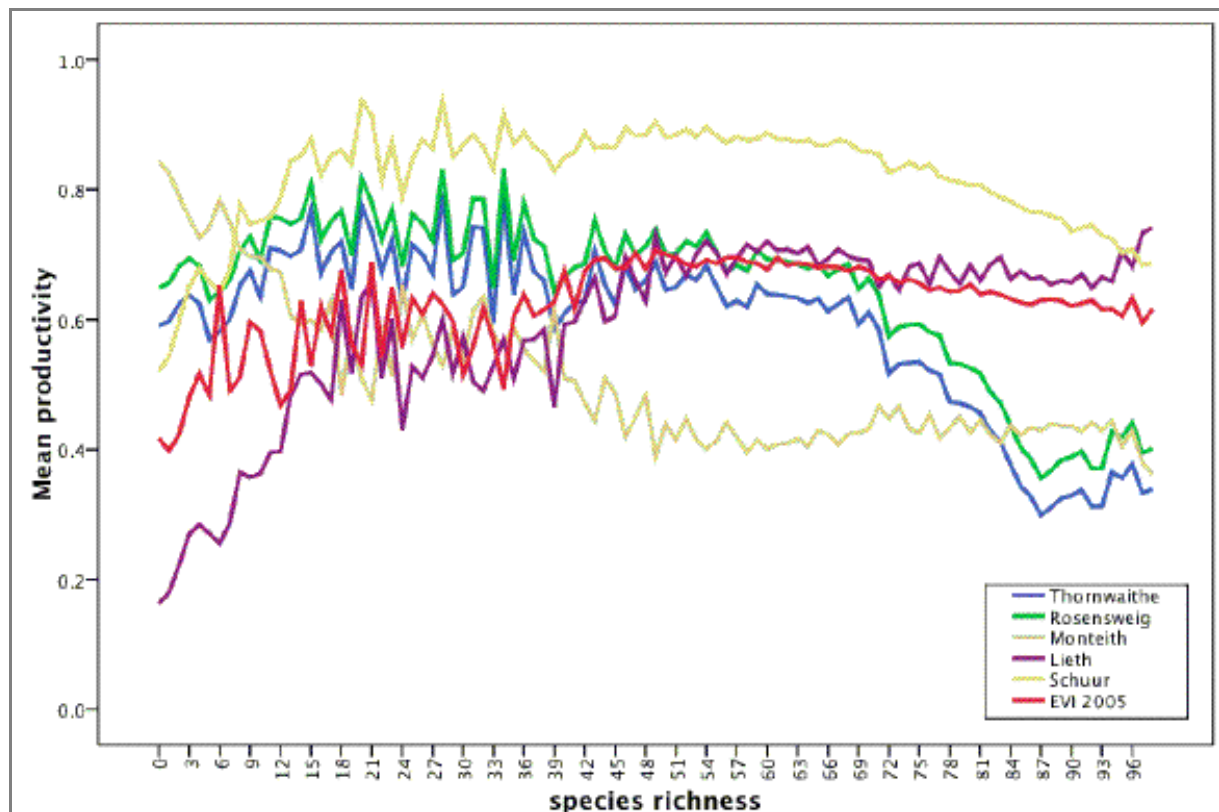


Figure 4: Mean productivity according to total species richness for vertebrate rainforest obligates.

References

- Clark D.A., Brown S., Kicklighter D.W., Chambers J.Q., Thomlinson J.R. and Ni J. (2001) Measuring net primary production in forests: concepts and field methods. *Ecological Applications* 11, 356-370.
- Lieth H. (1973.) Primary production: terrestrial ecosystems. *Human Ecology* 1, 303-332.
- Lieth H. (1975) *Modeling the primary productivity of the world*. In 'Primary Productivity of the Biosphere' eds H. Lieth and R.H. Whittaker, pp. 237-263. Springer-Verlag: New York.
- Monteith J.L. (1970) *Solar radiation and productivity in tropical ecosystems*. In 'Meeting on productivity of tropical ecosystems' pp. 747-766. IBP/UNESCO, Makerere University, Uganda.
- Rosenzweig M.L. 1968. Net primary productivity of terrestrial communities: prediction from climatological data. *The American Naturalist* 102, 67-74.
- Schuur E.A.G. (2003) Productivity and global climate revisited: the sensitivity of tropical forest growth to precipitation. *Ecology* 84, 1165-1170.
- Spain A.V. (1984) Litterfall and the standing crop of litter in three tropical Australian rainforests. *Journal of Ecology* 72, 947-961.

Assessing the cost-effectiveness of market-based instruments for water quality improvement in linked terrestrial and marine ecosystems using a spatial environmental-economic modelling approach

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Introduction

Agricultural development in coastal catchments along the Great Barrier Reef (GBR) region of Australia has lead to a substantial increase in the export of diffuse-source water pollutants (sediments and nutrients) into the GBR lagoon over the past 150 years (Furnas 2003). There is concern that the associated elevated levels of sediment and nutrient concentrations in the GBR lagoon are one of the biggest potential causes of reef degradation (Fabricius 2005; Rogers 1990) and, consequently, may affect the economic sectors that rely on the GBR for their income generation (Roebeling 2006).

Sustainable economic development of coastal regions requires balancing of marginal benefits from terrestrial (agricultural) water pollution on the one hand and marginal costs from associated marine resource degradation on the other (Gustavson and Huber 2000; Hodgson and Dixon 1988; Roebeling 2006; Ruitenbeek *et al.* 1999). Terrestrial (agricultural) water pollution from GBR catchments is, however, considered an externality and, consequently, market-based instruments (like taxes and subsidies) can be used to internalize it, in which case market behaviour could lead to cost-efficient, social welfare maximizing outcomes (Shortle *et al.* 1998; Perman *et al.* 1999). In this paper we assess the cost-effectiveness of various market-based instruments for promoting industry adoption of management practices for water quality improvement (the terms water quality, water pollution and water quality improvement refer to delivery of water pollutants to the coast). To this end we employ the Environmental Economic Spatial Investment Prioritization (EESIP) model (Roebeling *et al.* 2006, 2007b), that integrates a land use and value chain model (Smith *et al.* 2005) with a hydrological model (see Bartley *et al.* 2004) and, thus, relates management practice choice and water pollutant delivery to land use location, distance to the market and agri-industrial processing options. A case study is given for dissolved inorganic nitrogen (DIN) water pollution by the sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment (Queensland, Australia). The market-based instruments assessed include a DIN delivery abatement subsidy, a DIN delivery tax, a DIN supply tax and a nitrogen (N) fertiliser tax.

Approach for assessment of market-based instruments for water quality improvement

To relate land use and management practice location to economic opportunities and environmental consequences we used the EESIP model – a spatial environmental-economic modelling approach which relates management practice choice and water pollutant delivery

to land use location, distance to the market and agri-industrial processing options (see Roebeling *et al.* 2006, 2007b).

This approach recognises that, (a) bio-physical characteristics of the land vary widely according to location and, in turn, determine agricultural production potentials; (b) climatic and geomorphologic conditions differ according to location and, in combination with land use and management practice, determine diffuse source water pollutant delivery to the coast; and (c) farmers make use of existing (non-straight line) infrastructure to transport their produce to the processing plant or market. Moreover, differences in fixed and variable costs and potential benefits from alternative agri-industrial processing options are considered. Land use and management practices are allocated at the regional scale on the basis of which land use and management practice on a particular land unit contributes most to regional agricultural income, where regional agricultural income is estimated as total production value (based on final products) less corresponding fixed and variable production, transport and processing costs. For further details on the EESIP modelling approach, please refer to Roebeling *et al.* (2006, 2007b).

Cost-effectiveness of market-based instruments for water quality improvement in the Tully-Murray catchment

A case study is provided for dissolved inorganic nitrogen (DIN) water pollution by the sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment. The EESIP model is parameterised and calibrated using constant 2005 input prices and average 2003 to 2005 output prices as well as detailed input-output figures for production systems and management practices in sugarcane, horticulture, grazing and forestry production (Roebeling *et al.* 2007a), in combination with elevation (QLUMP 2004), soil class (Murtha and Smith 1994) and rail and road distance (Roebeling *et al.* 2006) information. The analysis includes 576 sugarcane, 54 horticulture, 660 grazing and six forestry management practice combinations (see Roebeling *et al.* 2007a). The following sub-sections provide an overview of the baseline and market-based instrument simulation scenario results.

Baseline scenario

Baseline model results per industry and associated management practice arrangements in the Tully-Murray catchment are shown in Table 1. Total agricultural land use in the Tully-Murray catchment equals just over 72,000 ha, with sugarcane and grazing the dominant land uses covering about 50% and 30% of the agricultural area, and horticulture and forestry accounting for 12% and 8%, respectively.

From an economic perspective, however, sugarcane and horticulture are the most important industries in the Tully-Murray catchment. The sugarcane and horticulture industries account for, respectively, about 50% and 40% of regional agricultural income, while grazing and forestry account for 7% and 3%. Total regional agricultural income in the Tully-Murray catchment equals about \$125 million per year. Rates of DIN water pollution from sugarcane, horticulture, grazing and forestry production are, roughly proportional to the relative land use distribution for each of the industries in the Tully-Murray catchment. Total DIN delivery equals almost 650 t/yr, with sugarcane and horticulture production contributing up to 20% more to DIN delivery compared to their relative land share.

Market-based instrument simulation scenarios

We used the EESIP model to assess the cost-effectiveness of various market-based instruments (taxes and subsidies) to promote industry adoption of management practices to achieve DIN water quality improvement. The market-based instruments assessed include a DIN delivery abatement subsidy (i.e. a payment for the achieved reduction in net delivery of DIN to the coast), a DIN delivery tax (i.e. a price on the net delivery of DIN to the coast), a

DIN supply tax (i.e. a price on the gross supply of DIN to waterways) and a nitrogen (N) fertiliser tax (i.e. an increase in the price of N fertiliser).

To assess the cost-effectiveness of the DIN supply tax and the N-fertiliser tax relative to the (cost-efficient) DIN delivery tax, tax levels were adjusted so that they lead to the same DIN delivery as obtained by the DIN delivery tax (i.e. a decrease in delivery from 644 t DIN to 368 t DIN).

Table 1: Baseline and market-based instrument simulation results per industry for dissolved inorganic nitrogen (DIN) delivery abatement.

Scenario	Indicator	Sugarcane	Horticulture	Grazing	Forestry	Total
Base	Land use (ha)	36,548	8064	22,964	5784	73,360
	Reg. Agr. Inc. (\$m)	65	48	8	5	127
	DIN delivery (t)	371	86	177	11	644
DIN delivery	Land use (ha)	36,548	8064	17,576	5784	67,972
abatement subsidy	Reg. Agr. Inc. (\$m)	74	48	10	5	137
(\$40/kg NID)	DIN delivery (t)	156	86	116	11	368
DIN delivery tax	Land use (ha)	36,548	8064	17,576	5784	67,972
(\$40/kg DIN)	Reg. Agr. Inc. (\$m)	59	48	3	4	111
	DIN delivery (t)	156	86	116	11	368
DIN supply tax	Land use (ha)	36,548	7762	11,052	4667	60,029
(\$11/kg DIN)	Reg. Agr. Inc. (\$m)	47	35	6	3	91
	DIN delivery (t)	212	49	101	6	368
N-fertiliser tax	Land use (ha)	36,548	8064	17,608	5784	68,005
(+160%)	Reg. Agr. Inc. (\$m)	57	41	4	4	105
	DIN delivery (t)	149	86	123	11	368

If downstream costs from DIN water pollution delivery to the coast are \$40/kg DIN, a DIN delivery abatement subsidy and a DIN delivery tax of \$40/kg DIN are likely to lead to identical and cost-efficient industry adoption of management practices at locations in the Tully-Murray catchment that result in social welfare maximising rates of water pollution (see Roebeling 2007b) – implying a reduction in DIN delivery of about 45%. Industries in the Tully-Murray catchment respond differently to the DIN delivery tax and the DIN delivery abatement subsidy of \$40/kg DIN. In sugarcane production DIN delivery is reduced by almost 60% due to industry adoption of win-win management practices (economic optimum rates of fertiliser application, nitrogen replacement and split nitrogen application) as well as adoption of some lose-win management practices (rates of fertiliser application below the economic optimum). In beef production, DIN delivery is reduced by about 35% through a reduction in the grazing area as well as a reduction in the nitrogen application rate. Finally, in horticulture and forestry production, DIN delivery is not reduced as neither the DIN delivery tax nor the DIN delivery abatement subsidy provide a sufficiently large incentive to change land use and/or management practice. The DIN delivery abatement subsidy and the DIN delivery tax lead, respectively, to an 8% increase and a 12% decrease in regional agricultural income and, consequently, the costs involved are carried by either the government or the relevant industries.

The DIN supply tax is charged on the (gross) supply of DIN to waterways, which ignores the fact that DIN delivery is time and spatially dependent (Prosser *et al.* 2001; Shortle *et al.* 1998). A DIN supply tax of \$11/kg DIN is likely to lead to industry adoption of management practices that result in rates of DIN water pollution similar to those obtained by the DIN delivery tax (i.e. a decrease in delivery from 644 t DIN to 368 t DIN). Industry response to the DIN supply tax of \$11/kg DIN is fairly strong. While the sugarcane area remains unchanged, the area of grazing, forestry and horticulture production is reduced by about 50%, 20% and 5%, respectively.

DIN delivery in sugarcane production is reduced through industry adoption of lose-win management practices (fertiliser application rates below the economic optimum application rate), while DIN delivery in grazing and horticulture production is reduced through industry adoption of lose-win management practices (reduced stocking rates and/or fertiliser application rates) in combination with a reduction in the production area. DIN delivery in forestry production is reduced through a reduction in the production area only. The costs associated with the DIN supply tax are fairly large (\$36 m/year or almost 30% of regional agricultural income) and carried by the involved industries. At an average DIN delivery reduction cost of \$0.13m/t DIN for the supply tax versus \$0.06m/t DIN for the delivery tax, the DIN supply tax is about 130% less cost-effective in reducing DIN delivery to the coast. In line with environmental-economic theory (Perman *et al.* 1999), it can thus be concluded that the DIN supply tax is less cost-effective than the (cost-efficient) DIN delivery tax as management practices are adopted throughout the catchment independent of their actual effectiveness in reducing DIN delivery.

The nitrogen fertiliser tax is charged on the gross input of inorganic nitrogen and thus, like the DIN supply tax, ignores the fact that DIN delivery is time and spatially dependent. The nitrogen fertiliser tax of 160% is likely to lead to industry adoption of management practices that result in rates of DIN water pollution similar to those obtained by the DIN delivery tax, implying a reduction in DIN delivery of about 45%. Industry response to the 160% N-fertiliser tax varies widely. While the horticulture and forestry industries are not likely to respond to the tax, in sugarcane production DIN delivery is reduced by about 60% due to industry adoption of win-win management practices (economic optimum rates of fertiliser application, nitrogen replacement and split nitrogen application) and in beef production DIN delivery is reduced by almost 30% due to a reduction in grazing area and nitrogen application rate. The costs involved in the N-fertiliser tax are carried by the industries involved and amount to about \$22m/year (about 15% of regional agricultural income). At an average DIN delivery reduction cost of \$0.08m/t DIN for the N-fertiliser tax versus \$0.06m/t DIN for the delivery tax, we see that the N-fertiliser tax is almost 40% less cost-effective in reducing DIN delivery to the coast. Like the DIN supply tax, the N-fertiliser tax is less cost-effective than the (cost-efficient) DIN delivery tax as management practices are adopted throughout the catchment independent of their actual effectiveness in reducing DIN delivery.

Conclusions and discussion

Among the wide range of pollution control instruments available, market-based instruments can be used to value externalities associated with terrestrial (agricultural) water pollution from GBR catchments (Perman *et al.* 1999). In this paper we employ a spatial environmental-economic modelling approach (EESIP) to assess the cost effectiveness of various market-based instruments in promoting industry adoption of management practices for water quality improvement. The EESIP model (Roebeling *et al.* 2006, 2007b) integrates a land use and value chain model (Smith *et al.* 2005) with the water quality model SedNet/ANNEX (see Bartley *et al.* 2004), thus relating management practice choice and water pollutant delivery to land use location, distance to the market and agri-industrial processing options. The approach differs from other spatially explicit explorative approaches in agricultural and environmental economics that relate land use and management practice

location to economic opportunities and environmental consequences (Hajkowicz *et al.* 2005; Jansen *et al.* 2005; Khanna *et al.* 2003; Nelson 2002; Rounsevell *et al.* 2003), as the approach is spatially explicit from an economic as well as an environmental point of view.

For a case study of dissolved inorganic nitrogen (DIN) water pollution by the sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment (Queensland, Australia), we show that a water pollutant delivery tax as well as a water pollutant delivery abatement subsidy provide cost-efficient incentives for water quality improvement, although associated costs need to be carried by the involved industries (in case of the tax) or the government (in case of the subsidy). A water pollutant supply tax and a N-fertiliser tax, on the other hand, provide non-cost-efficient incentives for water quality improvement because management practices are adopted throughout the catchment independent of their actual effectiveness in reducing water pollution (i.e. water pollutant delivery to the coast). Compared to the (cost-efficient) DIN delivery tax, the DIN supply tax is almost 150% less cost-effective and the N-fertiliser tax is almost 50% less cost-effective in reducing DIN delivery to the coast.

A number of caveats need to be mentioned. First, land use and management practice arrangements in the catchment are allocated on the basis of the social planner's perspective and, thus, do not necessarily reflect short-term farm response to the assessed market-based instruments (Shortle *et al.* 1998; Bouman *et al.* 2000). Second, market-based instrument policy recommendations should be based on total costs (i.e. abatement and transaction costs), as transaction costs associated with the implementation of different market-based instruments vary widely between instruments (Horan and Ribaudo 1999; Kampas and White, 2002). The inability to measure emissions and, to a minor extent, emission proxies at a reasonable cost would, therefore, argue in favour of an input tax (Horan and Ribaudo 1999). Finally, it is argued that stochasticity in diffuse source water pollution may affect the cost-effectiveness ranking of market-based instruments for water pollution control (Kampas and White 2004).

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References

- Bartley R., Henderson A., Baker G., Bormans M. and Wilkinson S. (2004) *Patterns of erosion and sediment nutrient transport in the Douglas Shire catchments (Daintree, Saltwater, Mossman and Mowbray), Queensland*. CSIRO Land and Water Client Report, Atherton, Australia. 61pp.
- Bouman B.A.M., Jansen H.G.P., Schipper R.A., Hengsdijk H. and Nieuwenhuyse A. (eds) (2000) *Tools for land use analysis on different scales: With case studies for Costa Rica*. Kluwer Academic Publishers: Dordrecht, The Netherlands. 274 pp.
- Fabricius K.E. (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50(2), 125-146.
- Furnas M. (2003) *Catchments and Corals: Terrestrial Runoff to the Great Barrier Reef*. Australian Institute of Marine Science, Townsville, Australia.

- Gustavson K. and Huber R.M. (2000) *Ecological Economic Decision Support Modelling for the Integrated Coastal Zone Management of Coral Reefs*. In 'Collected Essays on the Economics of Coral Reefs,' ed. H.S.J. Cesar, pp. 183-202. CORDIO, Dept. for Biology and Environ. Science, Kalmar University, Kalmar.
- Hajkowicz S., Perraud J.M., Daves W. and DeRose R. (2005) The strategic investment model: a tool for mapping optimal environmental expenditure. *Environmental Modelling and Software* 20, 1251-1262.
- Hodgson G. and Dixon J.A. (1988) *Logging versus fisheries and tourism in Palawan*. East-West Environment Institute (EAPI) Occasional Paper 7, Hawaii, USA.
- Horan R.D. and Ribaudo M.O. (1999) Policy objectives and economic incentives for controlling agricultural sources of nonpoint pollution. *Journal of the American Water Resources Association* 35(5), 1023-1035.
- Jansen H.G.P., Bouman B.A.M., Schipper R.A., Hengsdijk H. and Nieuwenhuysse A. (2005) An interdisciplinary approach to regional land use analysis using GIS, with application to the Atlantic Zone of Costa Rica. *Agricultural Economics* 32(1), 87-104.
- Kampas A. and White B. (2002) Emission versus input taxes for diffuse nitrate pollution control in the presence of transaction costs. *Journal of Environmental Planning and Management* 45(1), 129-139.
- Khanna M., Yang W., Farnsworth R. and Onal H. (2003) Cost-effective targeting of land retirement to improve water quality with endogenous sediment deposition coefficients. *American Journal of Agricultural Economics* 85(3), 538-553.
- Murtha G.G. and Smith C.D. (1994) *Key to the soils and land suitability of the wet tropical coast: Cardwell – Cape Tribulation*. CSIRO Division of Soils and Queensland Department of Primary Industries.
- Nelson G.C. (2002) Introduction to the special issue on spatial analysis for agricultural economists. *Agricultural Economics* 27, 197-200.
- Perman R., Ma Y., McGilvray J. and Common M. (1999) *Natural resource and environmental economics, 2nd edition*. Pearson Education Limited: Harlow, UK. 564 pp.
- Prosser I., Hughes A., Rustonji P. and Moran C. (2001) *Predictions of the sediment regime of Australian rivers*. In 'Proceedings of the Third Australian Stream Management Conference' eds I. Rutherford, G. Brierley, S. Bunn, F. Sheldon and C. Kenyon, pp. 529-533. Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.
- QLUMP (2004) *Queensland Land Use Mapping Program*. Queensland Department of Natural Resources and Mines, Brisbane, Australia.
- Roebeling P.C. (2006) Efficiency in Great Barrier Reef water pollution control: a case study for the Douglas Shire. *Natural Resource Modeling* 19(4), 539-556.
- Roebeling P.C., Smith D.M. and van Grieken M.E. (2006) *Exploring environmental-economic benefits from agri-industrial diversification in the sugar industry: an integrated land use and value chain approach*. Contributed paper prepared for presentation at the 26th Conference of the International Association of Agricultural Economists (IAAE), Gold Coast, Australia, 12-18 August, 2006.
- Roebeling P.C., Webster A.J., Biggs J. and Thorburn P. (2007a) *Financial-economic analysis of current best management practices for sugarcane, horticulture, grazing and forestry industries in the Tully-Murray catchment*. Report to MTSRF and FNQ NRM Ltd, CSIRO Sustainable Ecosystems, Townsville, Australia. 48 pp.
- Roebeling P.C., van Grieken M.E. and Webster A.J. (2007b) *Environmental-economic analysis for exploration of efficient land use and land management arrangements, water quality improvement targets and incentives for best management practice adoption in the Tully-Murray catchment*. Report to FNQ-NRM Ltd, CSIRO Sustainable Ecosystems, Townsville.
- Rogers C.S. (1990) Responses of Coral Reefs and Reef Organisms to Sedimentation. *Marine Ecology Progress Series* 62, 185-202.
- Rounsevell M.D.A., Annetts J.E., Audsley E., Mayr T. and Reginster I. (2003) Modelling the spatial distribution of agricultural land use at the regional scale. *Agriculture, Ecosystems and Environment* 95, 465-479.

Ruitenbeek J., Ridgley M., Dollar S. and Huber R. (1999) *Optimisation of Economic Policies and Investment Projects using a Fuzzy logic based cost-effectiveness model of coral reef quality: Empirical results for Montego Bay, Jamaica*. World Bank Project RPO# 680-08, Washington, DC, 85 pp. plus Appendices.

Shortle J.S., Horan R.D. and Abler D.G. (1998) Research issues in nonpoint pollution control. *Environmental and Resource Economics* 11(3-4), 571-585.

Smith D.M., Roebeling P.C, Parker T., Webster A.J., Williams K.J. and Antony G. (2005) *Financial assessment of CAPS at regional scale: A case study for Tully*. Report prepared for the Bio-industries Alliance of North Queensland (BioNQ), CSIRO-Sustainable Ecosystems, Townsville, Australia, 23pp.

Sediment and nutrient export from the Tully and Murray catchments during floods

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Introduction

Concern over anthropogenically-enhanced loads of sediment and nutrients to the Great Barrier Reef lagoon has led to the development of 'water quality improvement plans' (WQIPs) for a number of catchments adjacent to the Coral Sea, including the Tully and Murray catchments (Kroon 2007). These plans identify the current status of constituent loads along with a set of management practices to reduce them. In the Tully and Murray catchments the current sources and annual average loads of sediment and nutrient have been estimated using flow and concentration data (Furnas 2003) and the SedNet model (Brodie *et al.* 2003; Armour *et al.* 2007). Table 1 shows the high variability in the results of these studies, with the latest modelling study by Armour *et al.* 2007 estimating that 119,000 tonnes of sediment, 2,318 tonnes of nitrogen and 244 tonnes of phosphorus are transported to the GBR lagoon annually.

Table 1: Estimates of sediment (TSS), nitrogen (N) and Phosphorus (P) loads from the Tully and Murray catchments and a comparison with floodborne loads in 2006 and 2007. Also shown are the loads of nitrogen species; dissolved inorganic (DIN), dissolved organic (DON) and particulate (PN) and phosphorus species; filterable reactive (FRP), dissolved organic (DOP) and particulate (PP). **All measurements in tonnes.**

	DIN	DON	PN	Total N	FRP	DOP	PP	Total P	TSS
A. Tully + Murray annual average ¹	744	346	632	1722	18	25	139	182	170000
B. Tully + Murray annual average ²	1192	870	656	2718	24	56	212	292	245000
C. Tully + Murray SedNet estimates³	1159	529	630	2318	54	31	159	244	119000
D. Flood 1: March 2006 (Post Tropical Cyclone Larry)	71	294	125	491	10	15	37	61	15700
E. Flood 2: January – February 2007	475	524	241	1239	27	23	48	98	46722
F. Flood 3: February 2007	129	237	68	436	6	9	13	28	12117
G. Flood 4: March 2007	41	87	32	160	1	2	7	10	5886
2007 Total	645	848	341	1835	34	35	68	136	64725
Annual average: channelised river flow	574	268	487	1329	14	19	107	141	130868
Annual average: over bank flood flow	242	559	203	1003	16	19	38	73	32176
Annual average (this study): Total	815	827	690	2332	31	38	145	214	163044

¹ From Furnas 2003 (Table 32)

² From Brodie *et al.* 2003 (Table 8.24)

³ From Armour *et al.* 2007

Both the above model (Brodie *et al.* 2003; Armour *et al.* 2007) and measurement (Furnas 2003) estimates are annual averages that would be delivered to the ocean by flows from the Tully and Murray rivers. However, these two catchments are subject to frequent flooding, when the water that runs over the bank can bypass the river gauges. During floods, therefore, the Tully and Murray River gauges do not record the total catchment discharge very well. For example, this study has shown that during the 2007 floods the Tully river gauge at Euramo only recorded 70-90% of the flood discharge and the Upper Murray only recorded 10-30% of the flood discharge. Clearly, during over bank floods large amounts of water may leave the Tully and Murray catchments that are not recorded by the catchment river gauges. Furthermore, current 'measured' ocean sediment and nutrient loads are based on concentrations measured within the rivers (Furnas, 2003), yet it is not known what the sediment and nutrient concentrations are in over bank flood waters. This paper addresses these issues by presenting the results of flood discharge estimates and water quality measurements made during four flood events that occurred in the Tully and Murray catchments during 2006 and 2007. The results are presented in more detail in a CSIRO Land and Water Report (Wallace *et al.* 2008).

Results and discussion

Combining the data from the 2006 flood (reported by Wallace *et al.* 2007) and the 2007 flood data (Wallace *et al.* 2008) gives the sediment, nitrogen and phosphorus loads shown in Table 1. This clearly demonstrates the important contribution that flood events make to the ocean loads. For example, during the 2007 wet season the three flood events alone carried total sediment and nutrient loads that were a large fraction (50-80%) of the annual average riverborne loads. Since much of the flood discharge is not measured by the river gauges, a substantial amount of this flood load will be additional to the currently estimated annual riverine load.

Combining the water quality data for the four floods in 2006 and 2007 with long-term flow records (1972-2007) for the Tully and Murray rivers allows estimates of the annual average ocean loads that include flood discharge (Table 1). The sediment (TSS) loads derived in this way are similar to those reported by Furnas (2003), with an average of 20% delivered in over bank flood flow. However, these sediment loads are about forty percent greater than those reported by Armour *et al.* 2007. Taking account of flood flows gives total nitrogen (TN) and phosphorus (TP) loads that fall within the fairly wide range of previously published values. However, our analysis also demonstrates that 43% of TN and 34% of TP are delivered as over bank flow during floods.

A second important feature emerges from the flood water quality data. The largest fraction of the nitrogen load in flood waters (see Table 1) is in the form of dissolved organic nitrogen (DON). This contrasts markedly with the nitrogen species reported for river waters, where dissolved inorganic nitrogen (DIN) is the dominant form. Annual average DON loads estimated using the flood water quality data are 1.6 to 2.4 times those estimated by Armour *et al.* and Furnas (Table 1). It is believed that the main source of DIN is from agricultural land, whereas the main source of DON is likely to be from upper catchment rainforest.

Current WQIP recommendations focus on how to reduce DIN loads and implicitly assume that either the DON loads to the ocean have not changed or that DON is not biologically available, so cannot contribute to marine eutrophication. However, there is some evidence that runoff to the GBR lagoon may have increased due to land drainage (e.g. McCulloch 2006), so there may be an enhanced DON load to the ocean. Furthermore, this extra DON may be directly assimilated by macrophytes, seagrasses and algae; albeit at lower (10-20%) rates than DIN is assimilated (see Wallace *et al.* 2007).

Consequently, the biologically available nitrogen load to the ocean may also have been enhanced by elevated DON loads arising from the upper catchment rainforest.

Implications for water quality targets and monitoring

The implications of the flood water quality studies in the Tully and Murray catchments, and potentially for other Wet Tropics WQIPs, are as follows:

- Over bank floods make a large contribution to the marine load of sediment and nutrients and much of this load is not recorded by standard river gauges.
- Current marine load estimates of sediment and nutrients (based on gauged flows, measured river concentrations and SedNet modelling) from Wet Tropics catchments with frequent flooding may be too low, by up to about sixty percent, depending on estimation method and constituent.
- The size of this underestimate in any year will depend on the number and size of over bank flood events in that year. This will make the monitoring of any trends in ocean loads difficult unless they are made over long enough periods to remove inter-annual variability.
- Monitoring of marine loads will take a significant number of samples of both river and flood flows (in time and space) – otherwise the large uncertainties in mean loads may be misleading and it may be difficult to detect any load reductions.
- The cause of the above underestimate in loads is mainly due to the poor recording of flood (over bank) discharges by river gauges, but also to differences in flood water and river water quality concentrations.
- Flood waters carry more dissolved organic nitrogen (DON) than dissolved inorganic nitrogen (DIN), which is the opposite of their concentrations in river water. Consequently DON loads to the ocean may be nearly twice those previously estimated from riverine data.
- Actions in water quality improvement plans that focus on farm interventions in agriculture will potentially reduce DIN loads.
- Reductions in DON (and sediment) loads that arise outside the floodplain require different interventions to those used in agriculture to reduce DIN; i.e. off farm measures that slow down and reduce drainage.
- An important advance made in the Tully-Murray WQIP (see Kroon 2007) is that it addresses the reduction of both DIN and DON, e.g., via on farm interventions and the introduction and/or rehabilitation of riparian zones and wetlands.

Conclusions

The inaugural flood water quality data collected in the Tully and Murray catchments has demonstrated the importance of obtaining observations from the key processes that control the marine loads that are of concern. In the Wet Tropics, in addition to channelised flow, over bank flooding is a primary material transport mechanism and it is very difficult to adequately capture this process in monitoring and/or modelling schemes that are entirely river based.

However, the results of the current study are limited to only four floods in two catchments. To make allowances for a greater range of flood magnitudes it is recommended that further measurements of flood water quality be made in the Tully and Murray catchments. To account for flood loads in other Wet Tropics catchments it is recommended that flood water quality sampling is repeated in a number of other catchments.

If this is prohibitively expensive, an interim measure may be to derive flood load correction factors based on an analysis of river flow and flood frequency data from a characteristic range of catchments in the Wet Tropics region.

References

- Armour J.D., Hateley L.R. and Pitt G.L. (2007) *Improved SedNet and Annex modelling for the Tully-Murray catchment*. A Report prepared for the Tully Water Quality Improvement Plan. Department of Natural Resources and Water, Mareeba, Queensland.
- Brodie J., Lucy A., McKergow L.A., Prosser I.O., Furnas M., Hughes A.O. and Hunter H. (2003) *Sources of Sediment and Nutrient Exports to the Great Barrier Reef World Heritage Area*. Australian Centre for Tropical Freshwater Research Report No 03/11.
- Furnas M. (2003) *Catchments and corals: terrestrial runoff to the Great Barrier Reef*. Australian Institute of Marine Science, Townsville, Australia.
- Kroon F. (2007) *Tully Water Quality Improvement Plan*. CSIRO Sustainable Ecosystems, Atherton, Queensland.
- McCulloch M. (2006) *Coral record of human impacts on land-sea interactions in the inner Great Barrier Reef*. In 'Abstracts. Catchments to Coasts. Australian Marine Sciences Association 44th Annual Conference (AMSA 2006) and The Society of Wetland Scientists 27th International Conference (SWS)', Cairns, Australia, 9-14 July 2006, p. 73.
- Wallace J.S., Hawdon A., Keen R. and Stewart L.S. (2007) *Water quality during floods and their contribution to sediment and nutrient fluxes from the Tully-Murray catchments to the GBR lagoon*. Report to FNQ NRM Ltd for their Water Quality Improvement Plan. CSIRO Science Report X/07.
- Wallace J.S., Stewart L.S., Hawdon A. and Keen R. (2008) *The impact of floods on sediment and nutrient fluxes from the Tully-Murray catchments to the GBR lagoon*. Report to Terrain NRM and MTSRF for input to the Water Quality Improvement Planning process. CSIRO Land and Water Report xx/08 (<http://www.rrrc.org.au/publications/wqpublications.html>)

Current, pre-clearing and 2025 scenarios of vegetation cover and cassowary habitat in Mission Beach and surrounds

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Introduction

Rapid growth in human population and coastal development is transforming the landscape and threatening the natural and cultural values of tropical north-eastern Australia. These contested landscapes are often characterised by community conflict and institutional weakness disrupting effective implementation of conservation plans. A new scientifically based approach to planning that more effectively engages local communities in the decision process is needed to ensure plans and actions can be sustained across whole landscapes.

Research into methods of 'local area planning' for biodiversity conservation is therefore being conducted through MTSRF Project 4.9.6b, around case studies in collaboration with Terrain NRM Ltd, who help coordinate natural resource management (NRM) strategies and activities within the Far North Queensland NRM planning region. The aim of this research is to develop a rigorous local area planning framework for biodiversity, incorporating values and ecosystem services, based on regional ecosystems, threatened species, threatening and beneficial processes provided by landholders and applied through case studies.

Our research approach to local area planning is discussed in more detail by Hill *et al.* (2008a, this volume). The envisaged outcome is a plan that coordinates conservation initiatives and supports incentive-based approaches to achieve protection of habitat at the local scale. Appropriate levels of information and rigorous biodiversity science support the development and implementation of the plan. The planning process involves social learning through community collaboration and co-research as a mechanism to achieve coordinated management of whole landscapes. The outcome is actions at the site and neighbourhood scales that appropriately reflect strategic national and regional laws, policies and plans. An additional component of our research investigates the level of detail and impact of biodiversity science in the collaborative planning process.

Mission Beach was selected as the most appropriate locality for a case study to develop the local area biodiversity planning framework, following initial scoping by Weston (2006). Mission Beach is constrained within the narrow coastal plain of the Wet Tropics Bioregion, backed by coastal ranges which give way to the elevated Atherton Tablelands and open country to the west (FNQ RPAC 2000). It is part of the newly formed Cassowary Coast Regional Council (March 2008), and incorporates the former Johnstone and Cardwell Shires.

The planning context of Mission Beach is described in more detail by Hill *et al.* (2008a, 2008b). A history of uncoordinated plans and strategies for biodiversity conservation has resulted in implementation failures.

Continuing development pressure for new residential and resort housing and the effects of Cyclone Larry (20 March 2006) highlight local impacts on the cassowary population, with escalated public concern. Despite the threats, opportunities exist to rebuild the planning process. Efforts are being aligned through formulation and implementation of the regional NRM plan Sustaining the Wet Tropics Regional Plan for Natural Resource Management 2004–2008 (FNQ NRM Ltd and Rainforest CRC 2004) with subsequent revisions (in progress, Terrain NRM Ltd.). There is proactive community interest in maintaining biodiversity, cultural, and aesthetic values, and commitment to develop a local area habitat network action plan. Supporting these initiatives, a number of MTSRF researchers have aligned their field studies to include Mission Beach (e.g. Catterall *et al.* 2008; Coggan and Whitten 2008; Goosem and Searle 2008; Hill *et al.* 2008a; Metcalfe *et al.* 2008; all this volume).

We commissioned reports on the biodiversity, indigenous cultural and aesthetic/lifestyle significance of Mission Beach to help recognise the diversity of values and perceptions that need to be addressed in the planning process (Chenoweth Environmental Planning and Landscape Architecture 2007, Falco-Mammone 2007, The Djiru Traditional Owners and Giringun Aboriginal Corporation 2007; also Hill *et al.* 2008a). Among its natural values, the Mission Beach region is recognised for its association with the most integral and widest coastal to highlands rainforest corridor remaining in the Wet Tropics and harbours Australia's highest concentration of the endangered Southern Cassowary (*Casuarus casuarus johnsonii*).

Figure 1 shows the Mission Beach study area in relation to the pattern of remnant vegetation, particularly rainforest, within the context of the wet tropics NRM planning region. Elements of biodiversity science are being compiled and integrated into relevant aspects of the local area planning process for the Mission Beach habitat network action plan (Hill *et al.* 2008a). As well as the background reports on values to support the exploratory phase, biodiversity science was used in the platform building phase through the development of land use change scenarios. This paper reports on the methods used to implement a business as usual scenario for Mission Beach and potential impacts on biodiversity values.

To support community consultation and engagement processes, we investigated spatial patterns and trends in human population and land use in the Mission Beach region over a recent five-year period and extrapolated these trends to 2025. Simple deterministic rules and assumptions for converting natural areas and agricultural land to more intensive use were developed. The spatial implications for biodiversity were interpreted in terms of cassowary habitat loss, fragmentation of forest cover, and consequent changes in the regional conservation status of species and ecosystems.

Methods

A simple approach to land use change mapping was developed to demonstrate the probable consequences of continuing the current rates of development on natural (biodiversity) values. We focused on the relationship between two key indicators – human population numbers and intensive land use – to evaluate patterns and trends over a recent five-year period for available data. The methods and data sources are described below.

Current land use and land cover (c. 2004)

In developing this approach we established a baseline map of land cover highlighting current areas of remnant and disturbed vegetation with underlying elements of land use and planning information. We compiled all applicable biophysical and planning information from a wide range of datasets. These data were integrated into a single layer using the UNION command in ESRI's software ARCGIS 9.2. The resulting spatial vector database retained

relevant fields enabling queries to be constructed that cross-referenced the different data sources.



Figure 1: Location of study area and pattern of remnant vegetation, particularly rainforest, within the context of the Wet Tropics NRM planning region and the Mission Beach study area (Source: Queensland Environmental Protection Agency, remnant 2003, broad vegetation groups).

We updated the remnant vegetation map from 2003 (QEPA 2005) with areas of recent disturbance identified on high resolution aerial photography from 2004. Approximately 16 ha of remnant vegetation was reclassified as 'disturbed' in 2004. We also incorporated potential areas of native regrowth vegetation that are not mapped as remnant vegetation.

These areas were identified by combining remote sensing of woody land cover (QDNRM 2006) with the pre-clearing vegetation type (R. Niehus pers. comm., Queensland Herbarium) where they also fell into the land use class 'residual natural cover' based on 2004 mapping (QDNRM 2006a, 2006b). The native regrowth classification was broadly validated by overlaying with aerial photography and visually assessing a sample of areas. Additional areas of 'disturbed' vegetation cover were identified from the 'dist' class in the 'RE1' field of the regional ecosystem remnant 2003 mapping (QEPA 2005). In this way, we created a base map of land use and land cover applicable to the period 2003-2004 (Figure 2).



Figure 2: Basemap for scenario modelling. Current pattern of vegetation cover (2004) in the Mission Beach study area.

The 'Business-as-usual' scenario

An initial proposal to use scenarios to support the development of a habitat network action plan at Mission Beach was presented to the first meeting of the community-based action committee, established as the primary means of governance for the planning process (Hill *et al.* 2007). The committee viewed scenarios as useful to assist in formulation of a community-based and broadly supported vision and habitat network map. However, rather than a number of scenarios, which the committee thought would be overly complicated; it endorsed the use of two scenarios:

- A scenario reflecting current conditions (current scenario); and
- A scenario modelling conditions in 2025 if current trends in land use and population continue without any specific policy interventions ('Business-as-usual' 2025 scenario).

Projecting population and land use

Spatial patterns and trends in human population and intensive land use in the Mission Beach region were investigated over a recent five-year period and extrapolated to 2025.

Data for land use were derived from systematic mapping at 1:100,000 scales in 1999 and 2004 (Jamieson *et al.* 2006, QDNRM 2003, QDNRM 2004, QDNRW 2006a, 2006b Rowland *et al.* 2002, Witte *et al.* 2006). We defined intensive land use as the Australian Land Use and Management primary classification level 5 – Intensive Uses ‘Land is subject to substantial modification, generally in association with closer residential settlement, commercial or industrial uses’ (BRS 2006).

Tabular population data were obtained from the Australian Bureau of Statistics (ABS) for the Censuses held on 7 August 2001 and 8 August 2006 by Census Collection District (CCD) (ABS 2007). Sixteen CCDs were identified as relevant to the study area, some of which covered only a portion of the area. Three sets of population data were used: usual residents, domestic visitors and overseas visitors.

The two census periods provided information about population growth rates and the land use data provide information about the amount of land under intensive uses needed to sustain the residential and tourist populations.

Because the boundaries of the population census and the study area did not match, we used the ratio of total people to area of intensive land use within each CCD to estimate the number of people in our study area (for the portion of intensive land use in each CCD). The CCD boundaries were intersected with the study area boundary and the land use data to calculate the area of intensive land use in each CCD and in the study area by CCD. In this way we were able to estimate the population of Mission Beach for the two census periods by CCD.

The population of Mission Beach was subsequently modelled using the general equation: $N = N_0 e^{rt}$, where N = population in 2025; N_0 = population in 2001; t = 24 years; e = 2.71828..., and r was calculated as the population change 2001 (N_0) – 2006 (N), separately for residents and visitors [$r = \ln(N/N_0)/t$].

The Census data demonstrated that the visitor population declined between 2001 and 2006 and the resident population decreased slightly overall, despite substantial growth rates in some CCDs (e.g. 7.8% in Mission Beach village). However, these data were collected only months after Tropical Cyclone *Larry* (20 March 2006), which had a substantial impact on the resident and visitor infrastructure, leading to a temporary population decline, and rendering the trend data unreliable (see for example, Turton and Dale 2007). Population projections to 2025 were therefore calculated using the rate of change for Census data by CCD from 2001 to 2006 and then using only positive rates for CCDs in Mission Beach study area for projections to 2025 from 2001.

The ratio of population size to area of intensive land use in 2001 was used with the estimate of population in 2025 to identify the additional requirement for land under intensive use. All calculations were conducted by CCD for residents only and for residents and visitors. Only CCDs in which there were positive rates of change in population were projected to have an impact on intensive land use in 2025. Areas of intensive land use in 2001 were assumed to remain under intensive use in 2025. The calculation steps are summarised in Box 1.

Spatial allocation of the additional intensive land use area

Spatial allocation of additional intensive land use was based on several factors:

- Local government zoning of the land;
- Land tenure classifications;
- Land suitability classifications; and
- Proximity to existing intensive land use.

Box 1: Calculations used to project population and land use for the ‘Business-as-usual’ scenario

Population for 2025 was modelled using the general equation: $r = \ln(N/N_0)/t$, where N = population at the later time period (i.e. 2025); N_0 = population at the prior time period (i.e. 2001); and t = number of years between N and N_0 (i.e. 24). R was calculated from the population changes between 2001 and 2006.

Estimates for the population where only a portion of the census collection district (CCD) was in the Mission Beach (MB) study area were calculated with the following equation:

$$N_{\text{CCDMB}} = N_{\text{CCD}} * I_{\text{CCDMB}} / I_{\text{CCD}}$$

where N_{CCDMB} is the population in the Mission Beach study area section of the CCD, N_{CCD} is the total population of the CCD, I_{CCDMB} is the area of intensive land use in the Mission Beach study area section of the CCD, and I_{CCD} is the total area of intensive land use in the CCD.

In two CCDs, data were missing from the 2001 Census. Population was therefore estimated from the 2006 data using a variant of the above equation:

$$N_{\text{CCDMB2001}} = N_{\text{CCD2006}} * I_{\text{CCDMB1999}} / I_{\text{CCD2004}}$$

where $N_{\text{CCDMB2001/6}}$ is CCD population in 2001 or 2006 respectively, $I_{\text{CCDMB1999}}$ is the area of intensive land use inside MB in 1999 and I_{CCD2004} is the total area of intensive land use in that CCD in 2004.

The additional area of intensive land use to accommodate the additional population in the Mission Beach study area was calculated by applying the following equation:

$$I_{\text{ACCDMB2025}} = N_{\text{CCDMB2025-2001}} * N_{\text{CCDMB2001}} / I_{\text{CCDMB1999}}$$

Where, $I_{\text{ACCDMB2025}}$ is the additional area of intensive land use required in that CCD within the MB study area in 2025, $N_{\text{CCDMB2025-2001}}$ is the population difference between 2025 and 2001 within the Mission Beach study area in that CCD, $N_{\text{CCDMB2001}}$ is the population of that CCD within the Mission Beach study area in 2001, and $I_{\text{CCDMB1999}}$ is the total area of intensive land use in that CCD within the Mission Beach study area.

Zoning

Local government zoning differs across Queensland but has been standardised by the Department of Local Government, Sport and Recreation. We used the draft common zoning classification field labelled ‘SGE code’ incorporated in the spatial data (QDLGSR 2006). The land use data for 1999 and 2004 reflecting actual land use was compared with the zoning intent in these SGE codes, revealing that a substantial area of intensive land use is occurring within ‘conservation’ and ‘rural’ zones at Mission Beach (Table 1). Additional intensive land use was allocated into the respective planning zone and only into other zones when there was no further land available.

Land tenure

Conversion of land was applied to freehold tenures only. Freehold land tenure derived from the digital cadastre database (QDNRW 2006c). Nature conservation areas, including freehold tenure 'nature refuges' were strictly exempt from conversion.

Table 1: Mission Beach land use in 2004 by local government planning zones for Cardwell and Johnstone Shires and proposed allocation to intensive land use by 2025.

	LGA planning scheme	Percentage Intensive land use QLUMP 2004		Allocation considering only total population 2025 intensive land use (ha)		Proposed allocation intensive land use (ha) 2025	
	SGE_CODE 2006	Cardwell	Johnstone	Cardwell	Johnstone	Cardwell	Johnstone
Non-intensive	Conservation	18.49	6.59	29	21	0	22
	Rural	19.97	56.85	32	177	0	190
Intensive	Commercial	4.98	0.00	8	0	14	0
	Rural residential	22.82	7.46	36	23	56	24
	Special purposes	0.19	0.00	0	0	6	0
	Urban	33.55	29.10	53	91	83	75
	Total			159	311	159	311

Land suitability

Areas zoned as rural under the Local Government Planning Scheme and mapped as agricultural or other non-intensive use were treated as high-quality agricultural land and not targeted for conversion to intensive land use. Similarly, areas mapped as remnant vegetation under the *Vegetation Management Act 1999* and areas of revegetation mapped by the Cardwell Shire were not targeted for conversion to intensive land use. Cleared land was targeted first, followed by regrowth and disturbed native vegetation.

Proximity to existing intensive land use

The smallest land parcels closest to the existing intensive land use were allocated first.

These allocation rules were applied by CCD until available lands were exhausted and then added to the additional lands in adjacent CCDs with nearest intensive land use.

All planned roads and infrastructure easements registered on cadastre were assumed built in 2025 and also classed as intensive use. Areas of cleared land in nature conservation areas, other than land for roads and infrastructure, were assumed revegetated by 2025. Furthermore, areas of disturbed vegetation within rural production landscapes in 2004 were assumed degraded or cleared. Additional areas of disturbed remnant vegetation due to edge effects and continuing degradation processes by 2025 were not modelled.

Evaluating potential impacts on biodiversity

Further analyses were undertaken to illustrate the biodiversity impact of land use and population change modelled for the 2025 'Business-as-usual' scenario. Specifically, we evaluated the relative impacts on cassowary habitat and threatened ecosystems.

Cassowary habitat was modelled by Kutt and King (2002, updated in Kutt *et al.* 2004) by assigning habitat suitability as 'essential', 'general' and 'rehabilitating' to regional ecosystems. This classification was applicable to an earlier version of the regional ecosystem mapping (v4.0, remnant 2001) which has no current analogy. Using a draft table for assigning remnant 2003 regional ecosystem types to cassowary habitat (S. King 2006, pers. comm., EPA unpublished data) and with reference to the previous versions of cassowary habitat mapping, we mapped indicative areas of pre-clear and remnant 2003 cassowary habitat throughout the wet tropics range of the species. In the Mission Beach study area this information was combined with the 2004 and 2025 scenarios of land cover mapping identifying the extent and relative quality of cassowary habitat. Cleared areas were assigned 'absent' for cassowary habitat and disturbed or revegetated areas were assigned 'rehabilitating'.

The 'biodiversity status' of regional ecosystems designated by the Queensland Environmental Protection Agency was used to assess the impact of the 2025 'Business-as-usual' scenario on threatened ecosystems (i.e. 'endangered' or 'of concern' due to clearing and degradation associated with land use).

Results and discussion

Land use change targets for 2025

By 2025, the resident population in the Mission Beach study area is projected to increase by 1095 people (Table 2). A slight increase in visitor numbers is also projected (additional 168 people), giving a total population of 7,415 people. The additional area of intensive land use required to sustain the resident population in 2025 is projected to be 470 ha (Table 2). Taking into account the visitors, 528 ha intensive land use is needed to sustain the total population. Therefore, the additional area of intensive land use by 2025 is estimated to be in the range 470 to 528 ha. In the current scenario (2004) there are 622 ha of land under intensive uses (excluding major connecting roads).

Land use change outcomes for 2025

The spatial allocation of land to intensive use, following the rules described in the methods, resulted in 1,624 ha by 2025. This intensive use includes new roads connecting coastal and hinterland communities, as designated in the property boundary (cadastre) database (QDNRW 2006c). The additional intensive land use required in the Mission Beach CCD (3012614 in Table 2) of 314 ha, for example, could not be fully allocated because there was not enough land available, requiring additional areas in adjacent CCDs to be allocated to meet the overall target.

Figure 3 shows the spatial pattern of population and intensive land use in 2004 and 2025. The change in land use and land cover between 2004 and 2025 is compared in Tables 3 and 4 and areas of change in 2025 are highlighted in Figure 4. An estimated 858 ha of disturbed vegetation and 397 ha intact remnant vegetation in 2004 is cleared by 2025. Some of these clearings can be attributed to new road developments, some of the disturbed vegetation is potentially cleared in the rural production landscape, but most are associated with intensive uses in coastal urbanizing zones including rural residential. There is potential revegetation of existing clearings in conservation areas (51 ha), but this is exceeded by new clearing for potential new roads or widening/realignment of existing roads (116 ha).

Table 2: Population and land use data from modelling.

Census Collector District	2001 Population Mission Beach ¹		2006 population Mission Beach ¹		2001–2006	2025 population Mission Beach ⁴		2025 Additional intensive land use required for usual residents		
	Residents	Visitors	Residents	Visitors	Residents rate of change ³	Residents	Visitors	Additional residents 2001-2025	Density 2001 pp/ha ⁵	Area intensive land use
3012606	0	0	0	0	0	0	0	0	0	0
3012607	484	37	473	58	-0.46	433	33	0	2.5	0
3012608	170	4	161	6	-1.15	129	3	0	4.3	0
3012609	335	8	277	13	-3.80	135	3	0	23.9	0
3012611	61	28	55	17	-2.13	37	17	0	7.7	0
3012612	231	625	169	401	-6.25	51	139	0	8.6	0
3012613	406	103	402	97	-0.20	387	98	0	6.4	0
3012614	227	17	336	37	7.84	1489	112	1262	4.1	311
3040102	196	8	116	6	-10.53	16	1	0	7.9	0
3040107	444	453	488	412	1.89	699	713	255	5.1	50
3040108	615	344	689	358	2.27	1061	593	446	8.8	51
3040110	495	14	237	7	-14.73	14	0	0	3.5	0
3040112	465	184	505	214	1.65	691	273	226	11.9	19
3040113 ²	177	13	192	14	1.60	260	20	83	2.1	40
3040201	0	0	0	0	0	0	0	0	0	0
3040208 ²	3	5	3	5	0.00	3	5	0	3.4	0
TOTAL	4310	1842	4103	1646		5405	2010	1095		4716

¹ Estimated from the Census data using the equation $NCCDMB = NCCD * ICCDMB / ICCD$ as described in Box 1.

² Estimated from the 2006 data using the equation $NCCDMB2001 = NCCD2006 * ICCDMB1999 / ICCD2004$ as described in Box 1.

³ Calculated for the resident population in Mission Beach using the equation $r = \ln(N/N_0)/t$ as described in Box 1, with r from the change in usual residents 2001–06 as the most reliable measure.

⁴ Calculated using the rate of change for ABS census data by CCD from 2001 to 2006 and then using only positive rates for Census Collection Districts (CCD) in Mission Beach study area for projections to 2025.

⁵ Calculated as the ratio of resident population to intensive land use using the equation: $DCCDMB2001 = NCCDMB2001 / ICCDMB1999$ as described in Box 1.

⁶ Additional intensive land use for the resident population in 2025 only is shown here. The calculation for total population (resident and visitors, not shown here) uses a different rate of change (r) and density, resulting in 528 ha additional intensive land use required in 2025.

Table 3: Land use in 2004 and 2025 in the Mission Beach study area.

	Land use	2025 scenario (area in hectares)				Total (ha)
		Conservation	Residual native cover	Rural production	Intensive uses	
Current 2004 (ha)	Conservation	8398	0	0	116	8514
	Residual native cover	0	5489	726	430	6645
	Rural production	0	5	5816	456	6276
	Intensive uses	0	0	0	662	662
Total (ha)		8398	5494	6542	1663	22,096

Table 4: Land cover (native vegetation) in 2004 and 2025 in the Mission Beach study area.

	Land cover	2025 scenario (area in hectares)			Total (ha)
		Cleared	Disturbed/ revegetation	Remnant	
Current 2004 (ha)	Cleared	6913	51	0	6964
	Disturbed / revegetation	858	380	0	1238
	Remnant	397	0	13,458	13,856
Total (ha)		8168	431	13,458	22,058

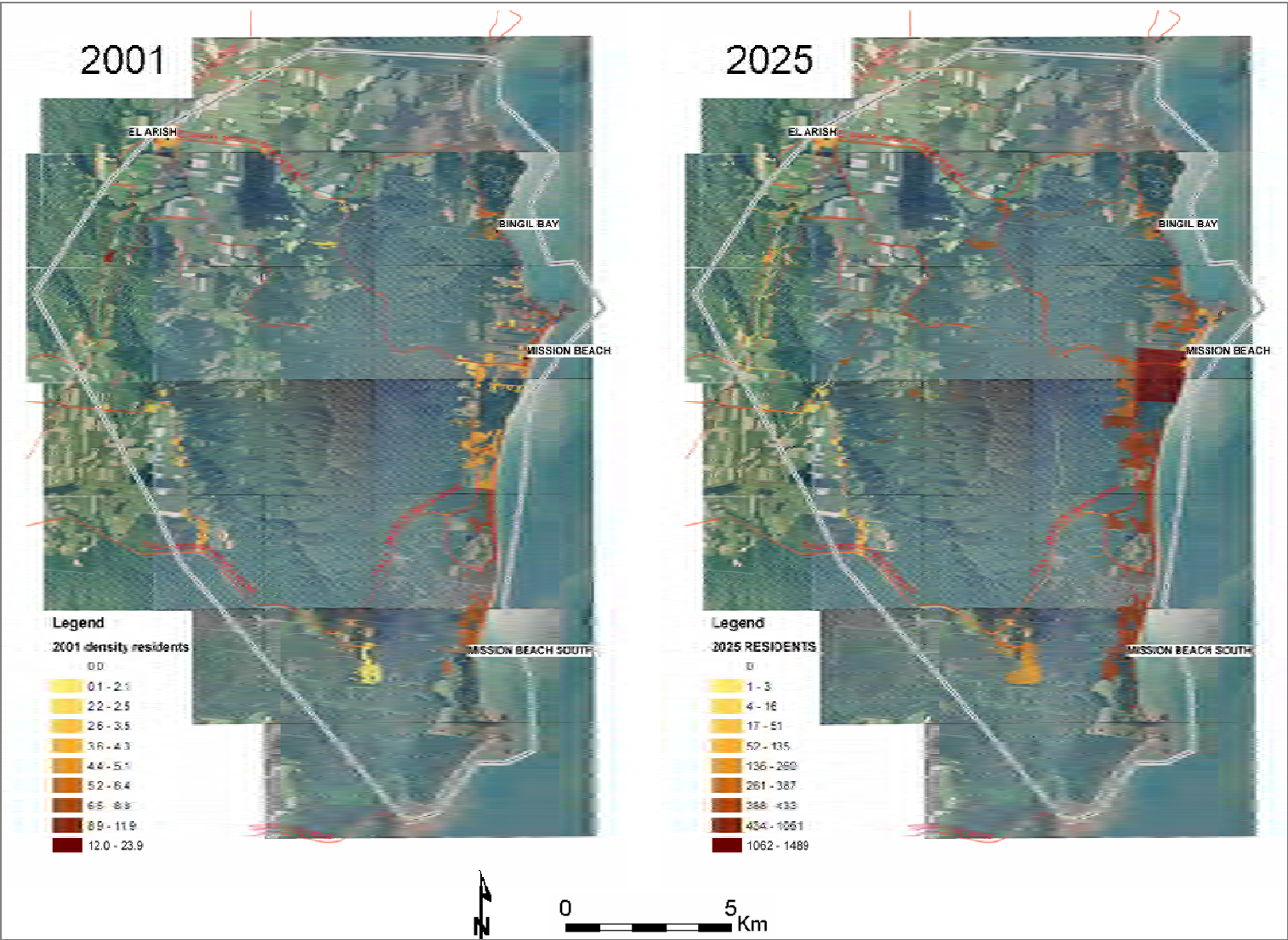


Figure 3: Spatial pattern of population and intensive land use in 2004 and 2025 in the Mission Beach study area.

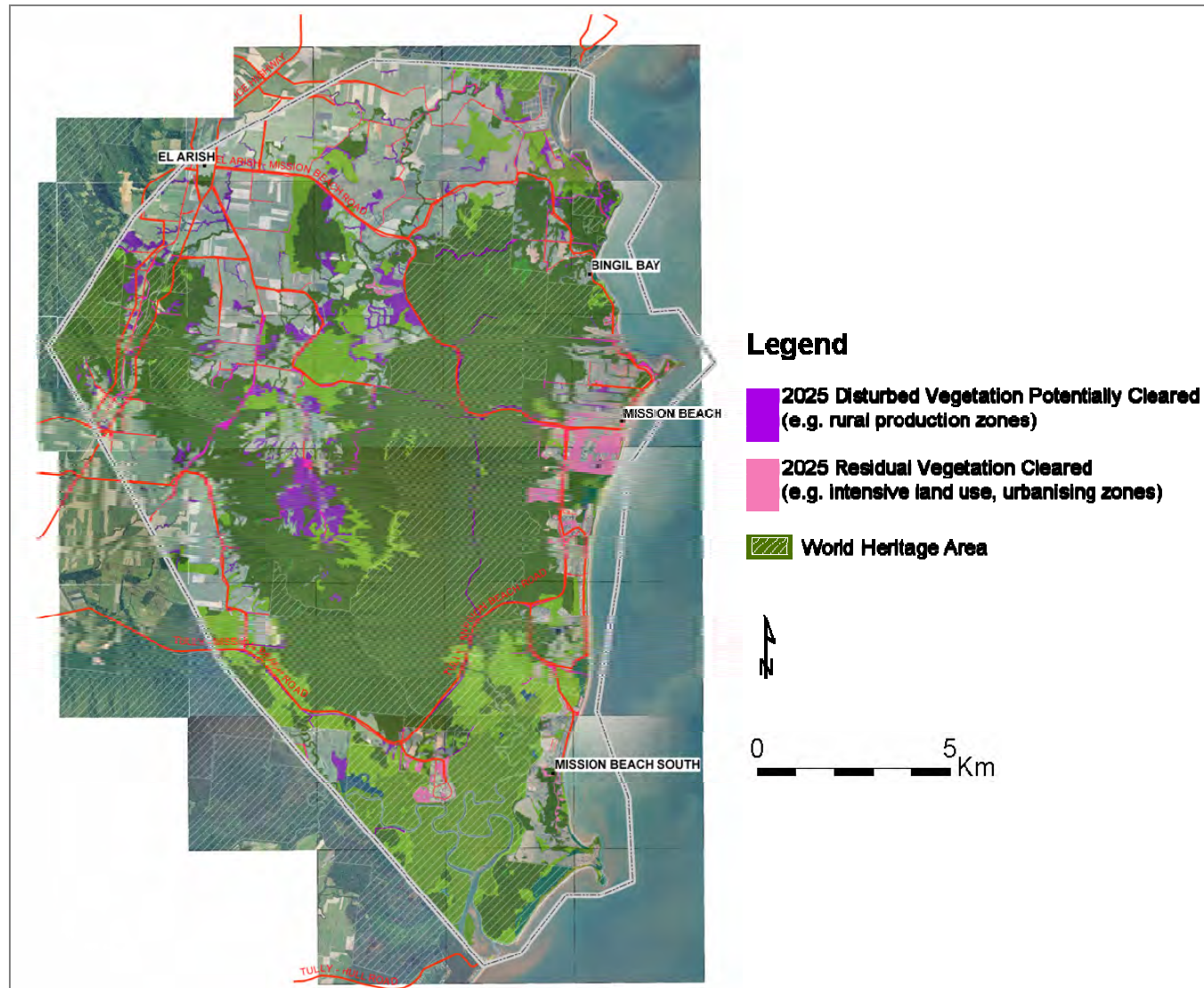


Figure 4: Spatial pattern of land conversion to intensive use and potential clearing of disturbed vegetation by 2025 under the 'Business-as-usual' scenario.

Biodiversity implications for 2025

Although an extensive area of national park will remain intact in the region, the land use requirement of residential and visitor populations projected for 2025 has implications for threatened ecosystems and cassowary habitat. Table 5 shows the change in area of regional ecosystems by their current 'biodiversity status' and Figure 5 shows where threatened ecosystems are potentially cleared. Potentially, 19 ha of 'endangered' and 190 ha of 'of concern' regional ecosystems are cleared, some of them are associated with road developments but most can be attributed to new urban or rural residential clearings.

By 2025, continuing loss of remnant and disturbed vegetation will reduce the amount of habitat available for local cassowary populations (Table 6). Figure 6 shows pre-clearing and remnant 2003 extent of cassowary habitat throughout the wet tropics and Figure 7 highlights the areas of greatest change between 2004 and 2025 in the Mission Beach study area. By 2004, clearing had reduced the extent of suitable habitat for cassowary to 66% of its former range, and by 2025 this is predicted to be 62%. Most losses are attributed to clearing or further degradation of 'disturbed' native vegetation ('rehabilitating' cassowary habitat). This has implications for local and regional connectivity of habitats between coastal and highland areas, particularly in the vicinity of Smith's Gap (see Figure 7). Additional areas of disturbed remnant vegetation due to edge effects and continuing degradation processes are likely to be evident by 2025, but were not modelled. This will likely affect the quality of habitat, resulting in a reduction of area classed as 'essential' and an increase in the areas classed as 'rehabilitating'.

Table 5: Change in area of regional ecosystems by their 'biodiversity status' associated with the 2025 'Business-as-usual' scenario in the Mission Beach study area.

Land use	Vegetation condition	EPA biodiversity status ¹ (change in area, ha)			Total
		Endangered	Of concern	Not of concern	
Conservation	Remnant	-5	-32	-60	-97
Residual native cover	Remnant	-14	-157	-140	-312
Intensive uses	Cleared	7	108	55	170
Roadway	Cleared	12	78	137	227
Rural production	Cleared	0	4	8	12
Total		19	190	200	409

¹ EPA biodiversity status is defined: http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/introduction_and_status/

Table 6: Losses of cassowary habitat in the Mission Beach study area since pre-clearing, the current (2004) scenario and 2025 'Business-as-usual' scenario.

Cassowary habitat suitability class	Pre-clearing		2004 land cover		2025 land cover	
	ha	%	ha	%	ha	%
Essential	19,617	89	12,201	55	11,828	54
General	2,407	11	1,653	7	1,629	7
Rehabilitating	0	0	720	3	193	1
Total	22,024	100	14,575	66	13,651	62

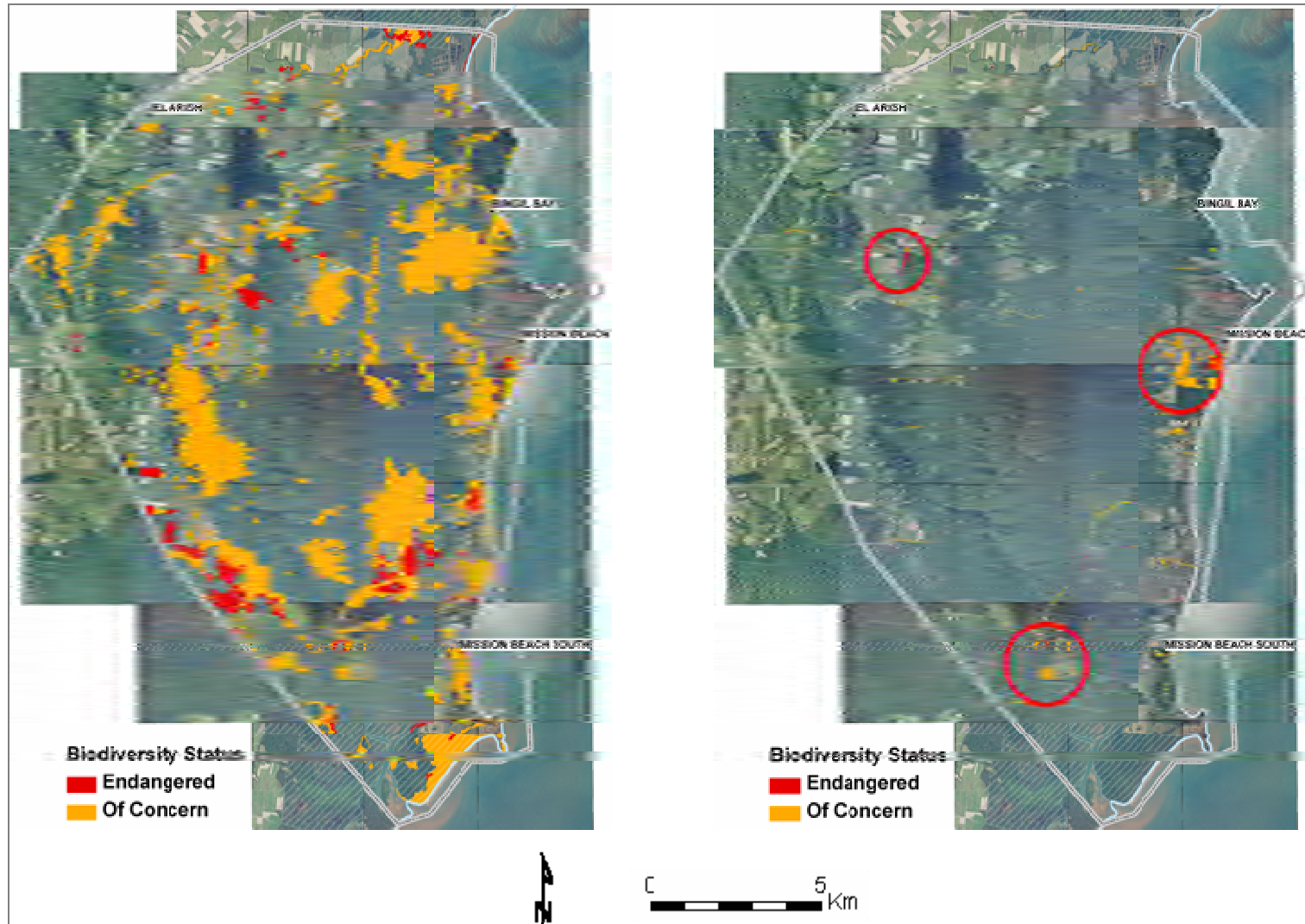


Figure 5: Potential impact of the 2025 'Business-as-usual' scenario on threatened ecosystems in the Mission Beach study area. (*Left*) The distribution of threatened regional ecosystems in 2004 (biodiversity status of 'endangered' or 'of concern'), and (*right*) locations where these ecosystems are potentially cleared (biodiversity loss) in 2025.

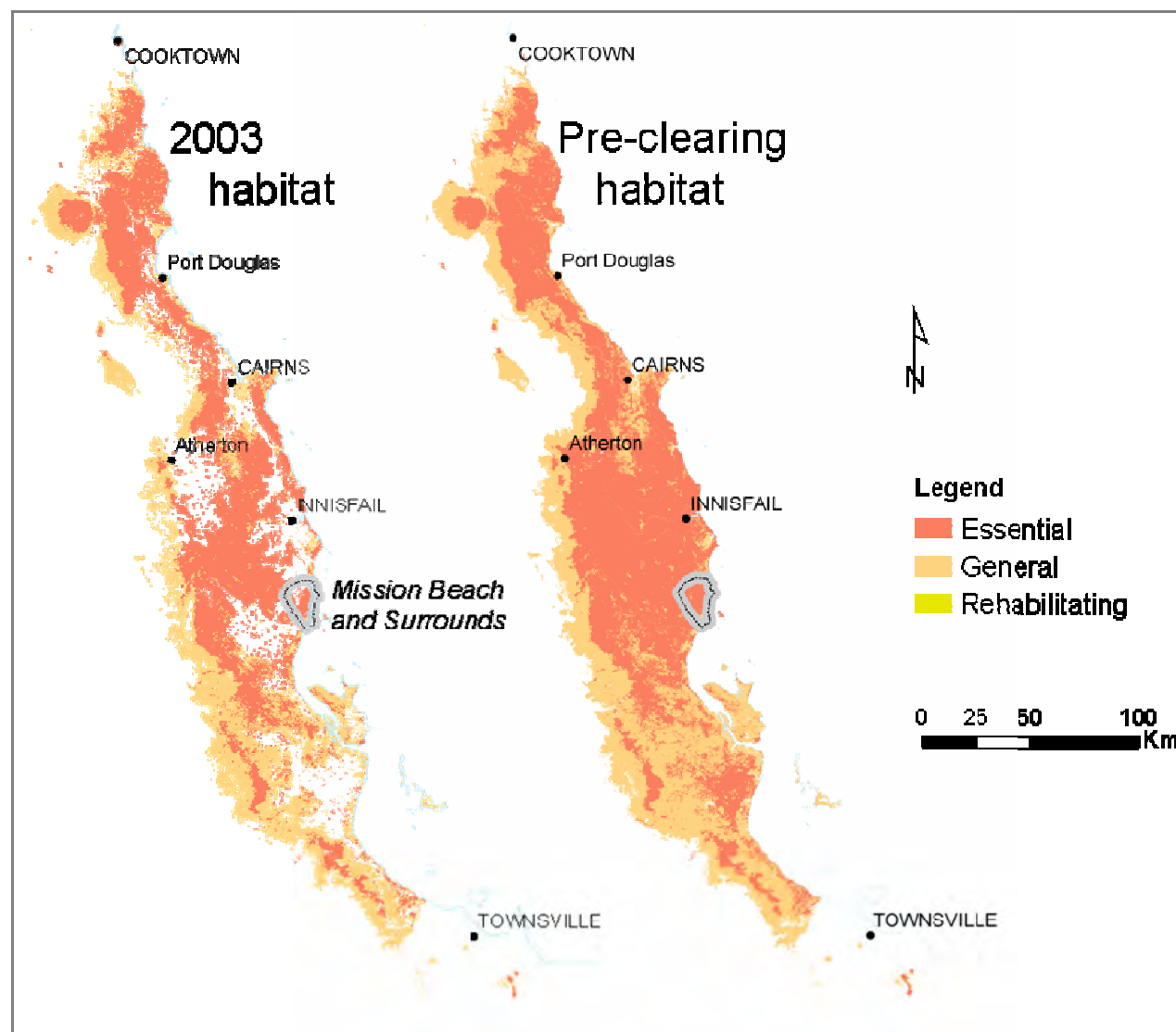


Figure 6: Historical (pre-clearing) and remnant (2003) extent of southern cassowary habitat in the Wet Tropics and context of the Mission Beach study area.

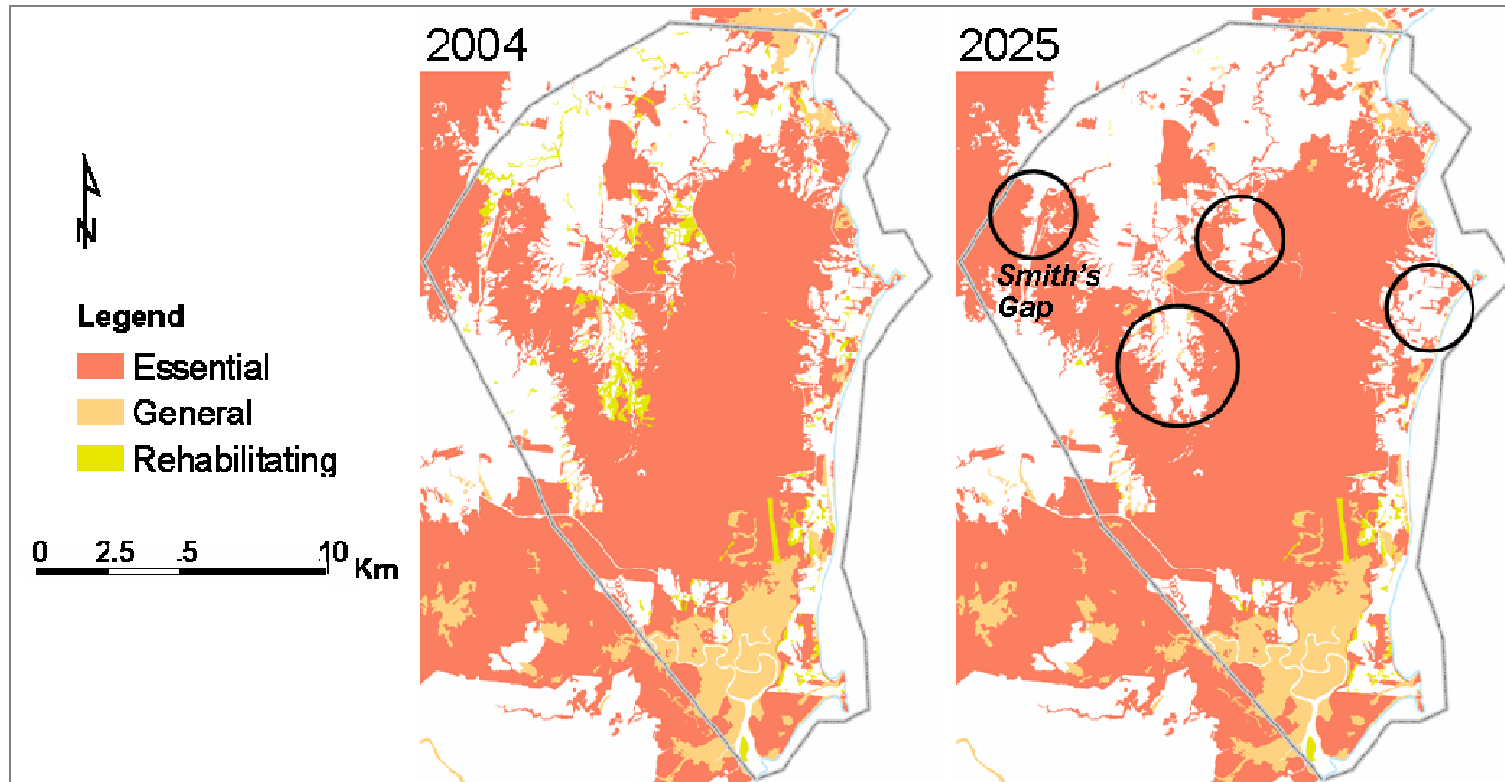


Figure 7: Loss of cassowary habitat in the Mission Beach study area between 2004 and 2025. Black circles highlight some of the locations where significant loss of connecting habitat has occurred ('rehabilitating' class).

Summary and conclusions

The 'Business-as-usual' scenario to 2025 has regional implications for some of the terrestrial biodiversity values in Mission Beach summarised by Chenoweth Environmental Planning and Landscape Architecture (2007). In particular, the scenario affects the regional significance of Mission Beach for supporting:

- The most integral and widest coastal to highlands rainforest corridor remaining in the Wet Tropics; and
- Australia's highest concentration of the endangered Southern Cassowary.

The further loss of threatened regional ecosystems (biodiversity status of 'endangered' or 'of concern') has implications for potential species extinction risk or extirpation by 2025. Continuing loss of habitat connectivity among regional east–west habitat corridors (i.e. in the vicinity of Smith's Gap), further isolates the Mission Beach cassowary population with implications for viability by 2025 (Moore 2007).

The information outlined in this paper was included in a poster series presented along with other information about cultural, social, and aesthetic values at a recent workshop with stakeholders in Mission Beach (December 2007). The scenario posters helped the community visualise the potential outcome of continuing on a business-as-usual trajectory. As a result, the community built consensus around their future vision as one in which the business-as-usual scenario does not come to fruition (Hill *et al.* 2008a, 2008b). Key aspects of their desired future included:

- Maintaining an environmentally focused way of life;
- A strong cohesive community – to ensure values are protected; and
- Mission Beach as a different and better-managed place than other environmentally significant coastal regions.

This outcome reflects on the success of the 'local area planning' process to date, which was developed within an adaptive collaborative management framework nested within a regional planning framework. The use of scenarios in platform building to assist the community to develop a common vision resulted in an unusual degree of community consensus about this future vision. This outcome reflects positively on the level of science and information that was integrated into the planning process. There was sufficient rigour in the analysis and style of presentation to support platform building within the allocated time frame for community consultation. The spatial modelling was based on simple projections using existing relationships between intensive land use and population projected to 2025 as indicative of business as usual.

We reviewed alternative ways to project population and land use, based on demographic criteria and statistical or agent-based modelling of land suitability and policy drivers, but decided that the level of sophistication required for these approaches was not warranted in our case. Our simple approach to population and land-use projection was easy for communities to comprehend and more effective for the purpose of platform building in the context of local area planning for biodiversity conservation. When evaluating land-cover change under a business-as-usual scenario with implications for biodiversity significance, we recommend a simple and transparent approach such as developed here for work with local communities.

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References

- ABS (2007) *Australian Standard Geographical Classification, July 2007*. Digital vector data. Commonwealth of Australia. Australian Bureau of Statistics: Canberra.
- BRS (2006) *Guidelines for Land Use Mapping in Australia: Principles, Procedures and Definitions*. Edition 3, Bureau of Rural Sciences: Canberra. (<http://www.affashop.gov.au/product.asp?prodid=13465> Accessed: 29 July 2007).
- Catterall C., Freebody K., Kanowski J. and Harrison D. (2008) *Restoration outcomes from government investment in rainforest revegetation*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Conference, 28 April – 1 May, Cairns'. Reef and Rainforest Research Centre Ltd, Cairns.
- Chenoweth Environmental Planning and Landscape Architecture (2007) *Biodiversity Significance of Mission Beach*. A Report to Terrain Natural Resource Management Ltd.
- Coggan A. and Whitten S. (2008) *Designing a policy package for a cassowary population objective*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Conference, 28 April – 1 May, Cairns'. Reef and Rainforest Research Centre Ltd, Cairns.
- Falco-Mammone F. (2007) *The Aesthetic and Lifestyle Significance of Mission Beach*. Focus on Research and Terrain Natural Resource Management: Cairns. (http://www.terrain.org.au/images/stories/mission_beach/The_Aesthetic___Lifestyle_Significance_of_Mission_Beach_Final.pdf Accessed: 5 March 2008)
- FNQ NRM Ltd and Rainforest CRC (2004) *Sustaining the Wet Tropics: A Regional Plan for Natural Resource Management 2004-2008*. FNQNRMLtd: Innisfail.
- FNQ RPAC (2000) *FNQ Regional Plan* (and associated supporting documents). Queensland Department of Communication and Information, Local Government, Planning and Sport, Cairns.
- Goosem M., Searle L. and Pohlman C. (2008) *Assessing the habitat quality of remnant and riparian vegetation*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Conference, 28 April – 1 May, Cairns'. Reef and Rainforest Research Centre Ltd, Cairns.
- Hill R., Bohnet I. and Butler J. (2007) *Scenario scoping paper: Mission Beach*. Report to the Marine and Tropical Sciences Research Facility and Terrain Natural Resource Management Ltd. CSIRO Sustainable Ecosystems, Cairns.
- Hill R., O'Malley T., Williams K.J., Pert P. and Harding E. (2008a) *Cassowary conservation at Mission Beach through local adaptive collaborative planning*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Conference, 28 April – 1 May, Cairns'. Reef and Rainforest Research Centre Ltd, Cairns.
- Hill R., Williams K., Pert P. and O'Malley T. with other contributions. (2008b) *Local Area Biodiversity Planning in the Wet Tropics Bioregion*. Mid-Project Draft Synthesis Milestone Report. Mission Beach Habitat Network Action Plan. Report to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Ltd, Cairns.
- Jamieson B., Pitt G., and van den Berg D. (2006). *Mapping Land Use – Land Use Change Mapping from 1999 to 2004 for the Johnstone River Catchment*; Queensland Department of Natural Resources and Water, Brisbane.

- Kutt A.S. and King S.M. (2002) *Distribution of cassowary habitat in the Wet Tropics Bioregion, Queensland*. Queensland Environment Protection Agency: Townsville.
- Kutt A.S., King S., Garnett S.T. and Latch P. (2004) *Distribution of cassowary habitat in the Wet Tropics bioregion, Queensland*. Technical Report, Queensland Environmental Protection Agency.
- Metcalfe D.J., Ford A. and Lawson T. (2008) *Predicting the biodiversity trajectory of isolated natural forest fragments based on age, size and landscape position*. In 'Proceedings of the 2008 Marine and Tropical Sciences Research Facility Conference, 28 April – 1 May, Cairns'. Reef and Rainforest Research Centre Ltd, Cairns.
- Moore L.A. (2007) Population ecology of the Southern Cassowary *Casuarius casuarius johnsonii*, Mission Beach, north Queensland. *Journal of Ornithology* 148: 357-366.
- QDLGSR (2006) *Draft common classification of local government planning schemes, SGE code, version July 2006*. Digital vector data 'plann_scheme'. The State of Queensland, Department of Local Government, Sport and Recreation, Brisbane.
- QDNRM (2003) Land Use (1999) in the Johnstone River Catchment, Queensland. Digital vector data by catchment. Queensland Department of Natural Resources and Mines, Brisbane.
- QDNRM (2004) Land Use (1999) in the Burdekin River Catchment, Queensland. Digital vector data by catchment. Queensland Department of Natural Resources and Mines, Brisbane.
- QDNRM (2006) Land cover change in Queensland 2003–2004: a Statewide Landcover and Trees Study (SLATS) Report, February 2006. Queensland Department of Natural Resources and Mines, Brisbane.
- QDNRW (2006a) Land Use (2004) in the Burdekin River Catchment, Queensland. Digital vector data by catchment. Queensland Department of Natural Resources and Water, Brisbane.
- QDNRW (2006b) Land Use (2004) in the Johnstone River Catchment, Queensland. Digital vector data by catchment. Queensland Department of Natural Resources and Water, Brisbane.
- QDNRW (2006c) Digital cadastre data (DCDB), version July 2006. Digital vector data. Queensland Department of Natural Resources and Water, Brisbane.
- QEPA (2005) Survey and Mapping of pre-clear and 2003 Remnant Vegetation Communities and Regional Ecosystems of Queensland, Version 5.0 (December 2005). Digital vector data. Queensland Herbarium, Environmental Protection Agency, Brisbane.
- QEPA (2006) Protected Areas of Queensland – Estate, version 12.4 31 December 2006. Digital vector data. Queensland Environmental Protection Agency and Queensland Parks and Wildlife Service, Brisbane.
- QEPA (2007) Nature Refuges and Coordinated Conservation Areas, gazettals up to June 2007, release version September 2007. Digital vector data. Queensland Environmental Protection Agency and Queensland Parks and Wildlife Service, Brisbane.
- QEPA (2007) Queensland Wetland Data Version 1.0 – Wetlands. Digital vector data. Queensland Environmental Protection Agency, Brisbane.
- Rowland T., O'Donnell T., Weller D and Witte C. (2002) *Catchment Scale Land Use Mapping in Queensland*. In 'Proceedings of the 11th Australasian Remote Sensing and Photogrammetry Conference, September 2-6, 2002, Brisbane, Queensland'.
- The Djiru Traditional Owners in conjunction with Girringun Aboriginal Corporation (2007) *Indigenous Cultural Significance Assessment Mission Beach*. Report to CSIRO from P. Pentecost for Bilyana Archaeological Consultancies: Tully.
- Turton S. M. and Dale A. (2007) *A preliminary assessment of the environmental impacts of Cyclone Larry on the forest landscapes of northeast Queensland, with reference to responses to natural resource management issues in the aftermath*. Report submitted to the Bureau of Meteorology.
- Weston N. (2006) *Local Area Planning Approach to Mission Beach Cassowary Conservation Stage 1: Framework*. Cooperative Research Centre for Tropical Rainforest Ecology and Management, Cairns.
- WTMA (2003) Wet Tropics Bioregion – Landscape Linkages and Rehabilitation Priorities. Digital vector data. Wet Tropics Management Authority, Cairns.

Witte C., van den Berg D., Rowland T., O'Donnell T., Denham R., Pitt G. and Simpson J. (2006) *Mapping Land Use in Queensland*. Technical Report on the 1999 Land Use Map for Queensland, Department of Natural Resources, Mines and Water, Brisbane.

Potential gaps in the complementary representation of regional ecosystems within protected areas of the Wet Tropics natural resource management planning region

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Introduction

The Convention on Biological Diversity (SCBD 2000) and Australia's response as the National Strategy for Conservation of Australia's Biological Diversity (Commonwealth of Australia 1996) consider biodiversity at three levels; genetic, species and ecosystem. The Convention on Biological Diversity aims to achieve the conservation of biodiversity and sustainable use of its components with fair and equitable sharing of the benefits arising from genetic resources. Australia's National Reserve System (NRS) is one of many actions arising from the national strategy to address the conservation of biodiversity.

The implementation framework for the NRS (NRM Ministerial Council 2005) has a foundation in systematic conservation planning (Margules and Pressey 2000) which recognises that surrogate information about the spatial patterning of biodiversity is needed in setting priorities and targets, and to monitor efficiency and progress. The NRS program aims to use 'the best available surrogates which best reflect the distribution of biodiversity in the landscape'. A comprehensive, adequate and representative (CAR) system of protected areas is a goal of the NRS through the collective efforts of the states, territories, the Commonwealth Government, and non-government organisations involved in acquisition and covenanting programs. This goal represents a framework for identifying gaps and setting priorities for the strategic acquisition of new areas to achieve:

- Samples of all ecosystems identified at an appropriate regional scale;
- Areas which are refugia or centres of species richness or endemism included;
- The ecological requirements of rare or [threatened species and rare or threatened ecological communities](#) and ecosystems considered; and
- Special groups of organisms taken into account, e.g. species with specialised habitat requirements or wide-ranging or migratory species, or species vulnerable to [threatening processes](#) that may depend on reservation for their conservation.

The NRM Ministerial Council (2005) has developed sixteen key principles to provide a strategic approach to meet this goal (reproduced in Appendix 1). Within this context, priority for funding the establishment of new protected areas is given to viable samples of ecosystems or key fauna habitats subject to high levels of threat or very low levels of protection. Where options exist, preference is given to larger areas or those that can be managed as part of a network of protected areas.

Three of the key principles – comprehensiveness, adequacy and representativeness - are commonly referred to as 'JANIS criteria' and originate from nationally agreed criteria (Commonwealth of Australia 1997). The CAR reserve design principles are:

- Comprehensiveness to sample the full range of ecological communities recognised at an appropriate scale of scientific classification;
- Adequacy to ensure the maintenance of the ecological viability and integrity of populations, species and assemblages; and
- Representativeness to ensure samples of ecological communities reflects biotic diversity of populations, species and assemblages.

As a first approximation to achieving comprehensiveness and to guide priority setting methodologies, the JANIS criteria target for the NRS is fifteen percent of the pre-1750 (pre-clearing in Queensland) extent of each bioregional ecosystem type. This has become established as a minimum guideline. Where ecosystems are rare or threatened, this baseline target is superseded by a sliding scale. The target for vulnerable ecosystems, that is, ecosystems where only about thirty percent remains intact, is sixty percent of the current area. For endangered ecosystems where about ten percent remains intact, and for rare ecosystems, the target is all that remains of the current extent (i.e. one hundred percent). A rare ecosystem is one where its geographic range is generally less than 10,000 ha, a total area of less than 1,000 ha, or patch sizes of generally less than 100 ha that do not aggregate to significant areas.

Presently the NRS incorporates more than 9,000 national parks, indigenous lands, reserves run by non-profit conservation organisations and ecosystems protected by farmers on their private working properties; comprising 89 million hectares or eleven percent of the continent (Figure 1). In 2006, 5.5% of Queensland was registered as contributing to the NRS, well below both the national average and the percentages required by the JANIS criteria.

Because priorities and strategies for meeting the NRS goal depend on how we recognise and map patterns in biodiversity across whole landscapes, it is important to continue the development and testing of ways to enhance the surrogacy value of available data. This paper considers one aspect of biodiversity surrogacy related to the comprehensiveness criterion and specifically the setting of bioregional targets for representing ecosystem pattern. We derive targets using an area-weighted formula determined on the basis of the species-area relationship (S-A-R) and a representation goal equivalent to that derived using the JANIS criteria. If we assume each ecosystem surrogate contains the same amount of biodiversity, and our goal is to capture an equal proportion of the biodiversity in each, the nature of the species-area curve means that we need to capture a higher proportion of ecosystems which occupy a smaller part of the landscape relative to ecosystems that are widespread. This is because larger areas hold proportionally fewer species than smaller areas.

The species-area relationship is regularly used in conservation planning assessments, for example to estimate species loss in response to habitat loss and degradation (e.g. Faith *et al.* 2008, May *et al.* 1995, Ney-Nifle and Mangel 2000, Pimm and Raven 2000, Sala *et al.* 2000,), to set baseline targets for priority setting (Desmet and Cowling 2004, Ferrier *et al.* 2004; Gole *et al.* 2005; Williams *et al.* 2006) and as a benefit-function in conservation decision software (e.g. Arponen *et al.* 2006).

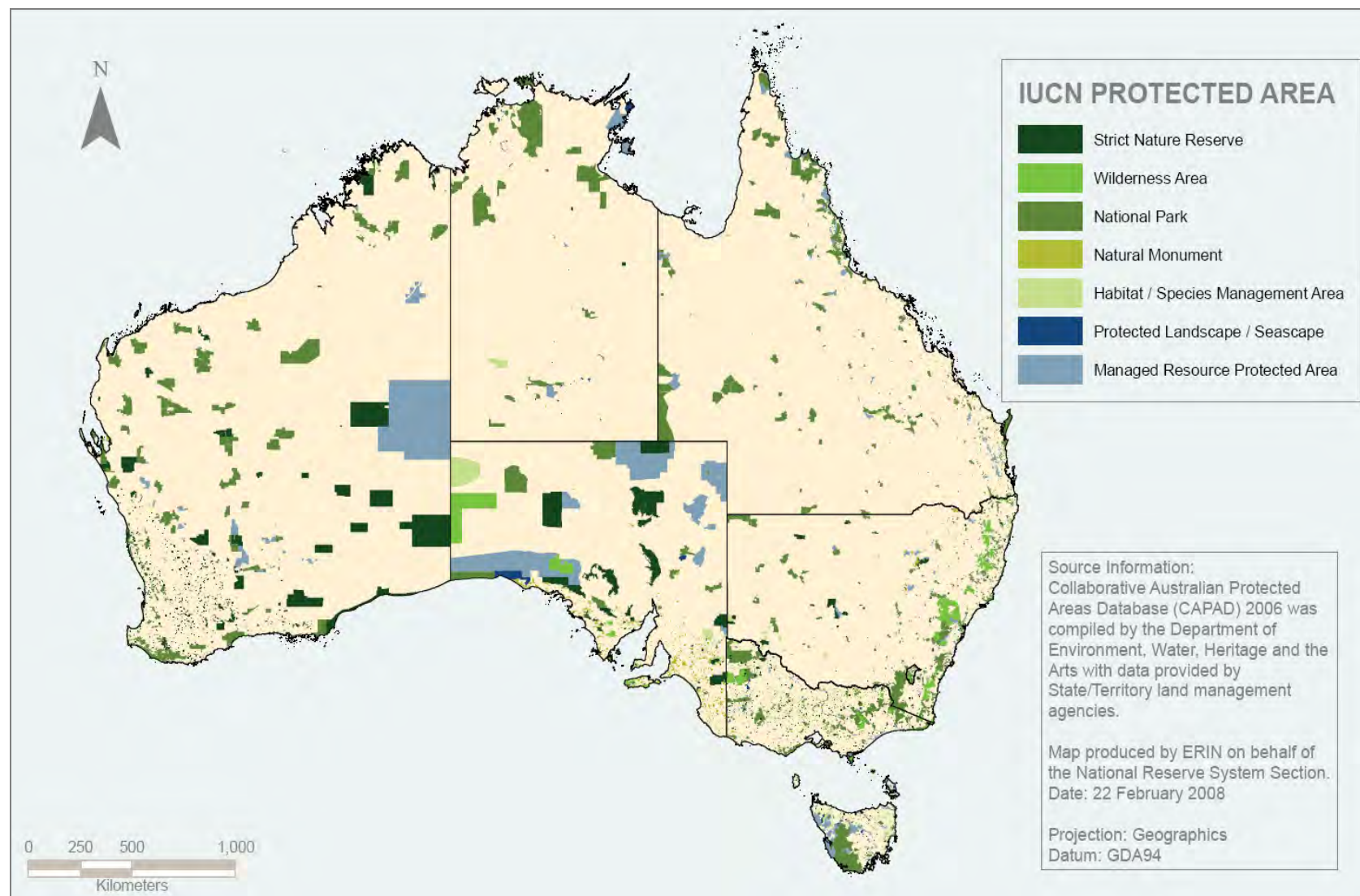


Figure 1: The IUCN protected areas status of the National Reserve System as at 2006
(Source: Collaborative Australian protected areas database: <http://www.environment.gov.au/parks/nrs/science/capad/index.html>)

Although different formulae have been proposed (e.g. Williams 1995, Veech 2000), the power relationship is the most commonly used and robust form of the species-area curve (Martin and Goldenfeld 2006): $S = C A^z$, where S = number of species (richness per ecosystem), A = area (of ecosystem), C is a scaling factor that relates to the sample size used and z is a parameter defining the rate at which species are encountered in a system. The power model is a straight line in log–log space ($\log_{10} S = \log_{10} C + z \log_{10} A$) in which C is the intercept and z is the slope of the log-transformed data.

The calculation of S-A-R targets differs from the calculation of flat targets by setting the target on the 'ecosystem species richness' axis (y) rather than on the 'ecosystem area' axis (x), as shown in Figure 2. A constant target for the proportion of species richness to be captured, results in a variable target for percentage area captured. This differs from 'flat-targets' where each ecosystem target is the same percentage of its total area. For example, consider two vegetation types, 8d and 34a, comprising 9,745 ha and 98,904 ha respectively (Figure 2). If the goal is to capture an equal proportion of species richness in each ecosystem, say 75%, this results in a larger percent-area target for the smaller-area type and a smaller percent-area for the larger-area type. Every ecosystem therefore gets a different target as a percentage of its total area, reflecting the different size of ecosystems.

In the absence of specific information from biological inventory studies, we show how simple assumptions can be used with vegetation map data and the species-area relationship to derive ecosystem targets for conservation planning studies. Using the Queensland wet tropics natural resource management planning region as a case study area (henceforth the Wet Tropics plan region), we first apply the traditional model of 'fixed' targets, and also account for remnant areas and higher targets for rare and threatened ecosystems, in accordance with JANIS criteria. We then develop an equivalent approach based on the species-area relationship and compare results. We also report on the protection status of ecosystems and estimate the minimum area needed to achieve the comprehensiveness criterion.

Methods

Queensland Wet Tropics study region

The study region is defined by the jurisdiction of Terrain NRM Ltd, the peak natural resource management body responsible for the Wet Tropics regional natural resource management plan that establishes the environmental goals and targets for the Wet Tropics region (FNQ NRM Ltd and Rainforest CRC 2004). The Wet Tropics plan region covers about 2.2 million ha from the Douglas Shire in the north, to Hinchinbrook Island in the south, and extends west to include the Atherton Tableland and the Upper Herbert River catchment.

Variation in rainfall, geology, drainage and altitude in the Wet Tropics combined with the complex evolutionary and indigenous occupation history of the region has resulted in a complex spectrum of plant communities and forest types. Rainforests dominate the narrow, coastal, high rainfall zone, fringed and dissected by sclerophyll forest and woodland, mangroves and swamp communities. The Queensland Environmental Protection Agency (2005) has integrated current vegetation patterns and disturbed areas mapped at 1:50,000 by Stanton and Stanton (2005) into the classification of regional ecosystems (Neldner *et al.* 2005; Sattler and Williams 1999).

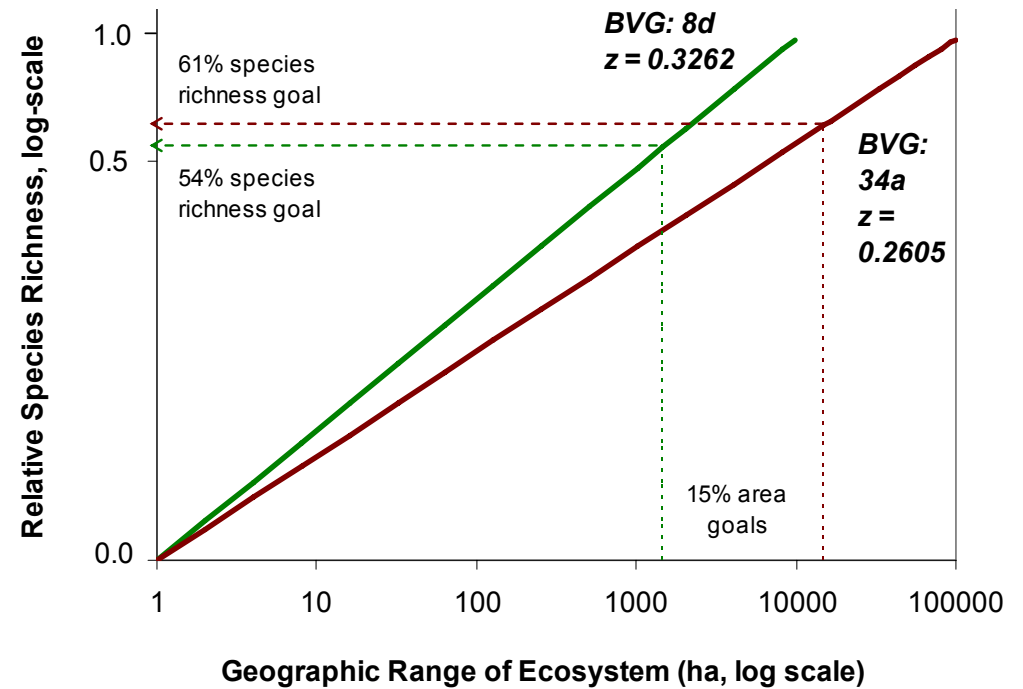
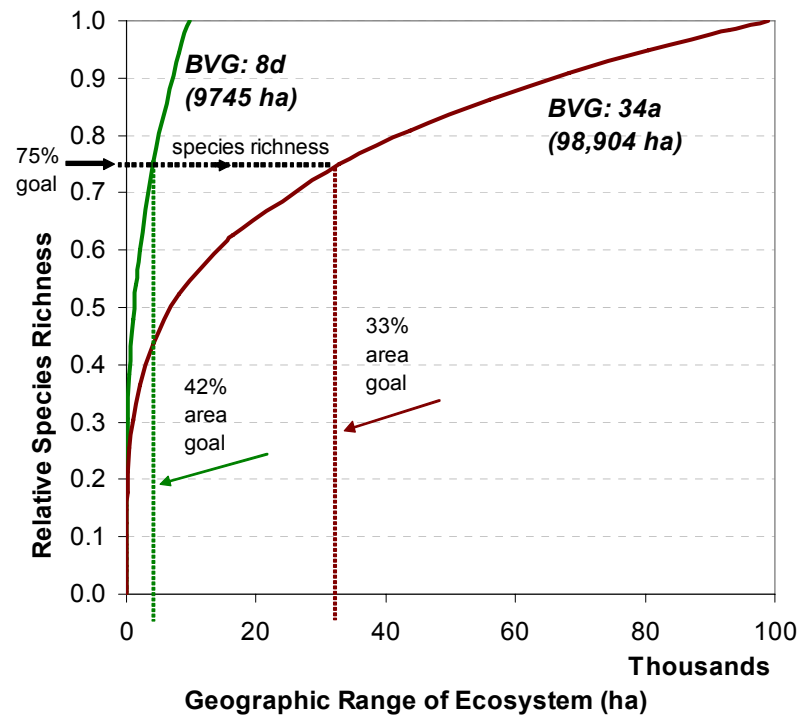


Figure 2: (Left) Hypothetical species-area curves ($S = C A^z$) for two ecosystems (types 8d and 34a) in which the total species richness is $S = 20,000$, the scaling factor C is 1,000, the area of each, A , is known, and the slope of the relationship in log-log space (z -values) can be derived. (Right) A constant proportion of species richness of 75% results in different percent area targets of 42% for the smaller-area type (8d) and 33% for the larger-area type (34a). The same % area target of 15% results in fewer species represented by the smaller-area type (54% for type 8d) compared with the larger-area type (61% for type 34a). The S-A-R method for setting targets uses a constant species richness goal resulting in variable percent area targets.

Remnant regional ecosystem mapping is updated at about two-yearly intervals from remote sensing of clearing patterns (Armston *et al.* 2004). The threat status of regional ecosystems is defined under the Queensland *Vegetation Management Act 1999* and the Commonwealth *Environmental Protection and Biodiversity Conservation Act 2000*. Subsequently, under the *Vegetation Management and Other Legislation Amendment Act 2004*, broadscale clearing of remnant vegetation ceased in December 2006.

Protected areas in Queensland are declared under the *Nature Conservation Act 1992* and managed by the Queensland Environmental Protection Agency. There are eleven types of protected area, predominantly on state land but privately-owned land may also be declared for nature conservation, where land use and wildlife conservation are compatible. Protected area maps, comprising the estate managed by the Queensland Environmental Protection Agency and privately managed nature refuges, are regularly updated and the data made available to planning and research agencies (e.g. QEPA 2006a, 2007).

Calculating JANIS criteria targets

We applied the JANIS criteria (Commonwealth of Australia 1997) for comprehensiveness to Queensland's mapping of pre-clearing and remnant regional ecosystems as at 2003 (QEPA 2005). We used the classification of regional ecosystems recognised under the *Vegetation Management Act 1999* (VMA) as described in version 5.3 of the Regional Ecosystem Description Database (QEPA 2008).

The definition of 'regional ecosystems' under the VMA applies at a classification level that ignores the postscript codes (a, b, c, etc.) which denote vegetation sub-communities or proposed new regional ecosystems (Neldner *et al.* 2005).

Many of the vegetation polygons (map units) contain more than one ecosystem in a mosaic of up to five types for which the percentage contribution of each is defined. A list of remnant and pre-clearing regional ecosystem types present within the Wet Tropics plan region was derived and used to extract the set of areas throughout Queensland representing their known geographic range (Figure 3). The pre-clearing geographic range of each regional ecosystem type was then used to define the area required to meet the fifteen percent representation target. If the area required was less than the remnant area for the ecosystem, then the target area was set to the remnant area, expressed as a percentage of the remnant extent. For example, ecosystem '7.11.12', which has a pre-clearing extent of 35,761 ha and a remnant extent of 29,990 ha in 2003 (84% of pre-clear), has a fifteen percent baseline target of 5364 ha (of pre-clearing extent). The equivalent target for remnant vegetation in 2003 is 5364 ha of 29,990 ha, which is 18%. In general terms, if the percentage of remnant vegetation exceeds the baseline percentage target, then the remnant percentage conservation target is:

$$\% \text{ remnant conservation target} = \left(\frac{(\text{baseline \% target} / 100) \times \text{pre-clear area}}{\text{remnant area}} \right) \times 100$$

The JANIS criteria established higher targets for rare and threatened ecosystems. The threat status of regional ecosystems is defined under the VMA as 'endangered' if less than 10% of the pre-clearing extent remains and 'of concern' if less than 30% remains. However, the Queensland EPA also takes into account the general condition of regional ecosystems in its classification of 'biodiversity status' (QEPA 2006b). This classification is consistent with the intent of the JANIS criteria. We therefore used the 'biodiversity status' of regional ecosystems in setting JANIS criteria targets.

The target for an 'endangered' ecosystem was set to 100% of the remnant extent (all that remains) and 60% for 'of concern' ecosystems (JANIS criteria threat status of 'vulnerable'). However, if 10-15% of a vulnerable ecosystem remains, the remnant target is less than the

baseline target of 15% pre-clear. Therefore, if the remnant extent of an ecosystem was less than 15%, the resulting target was 100% (all that remains). A 100% target on the remnant extent also applied to 'rare' ecosystems where the pre-clearing extent was less than 10,000 ha.

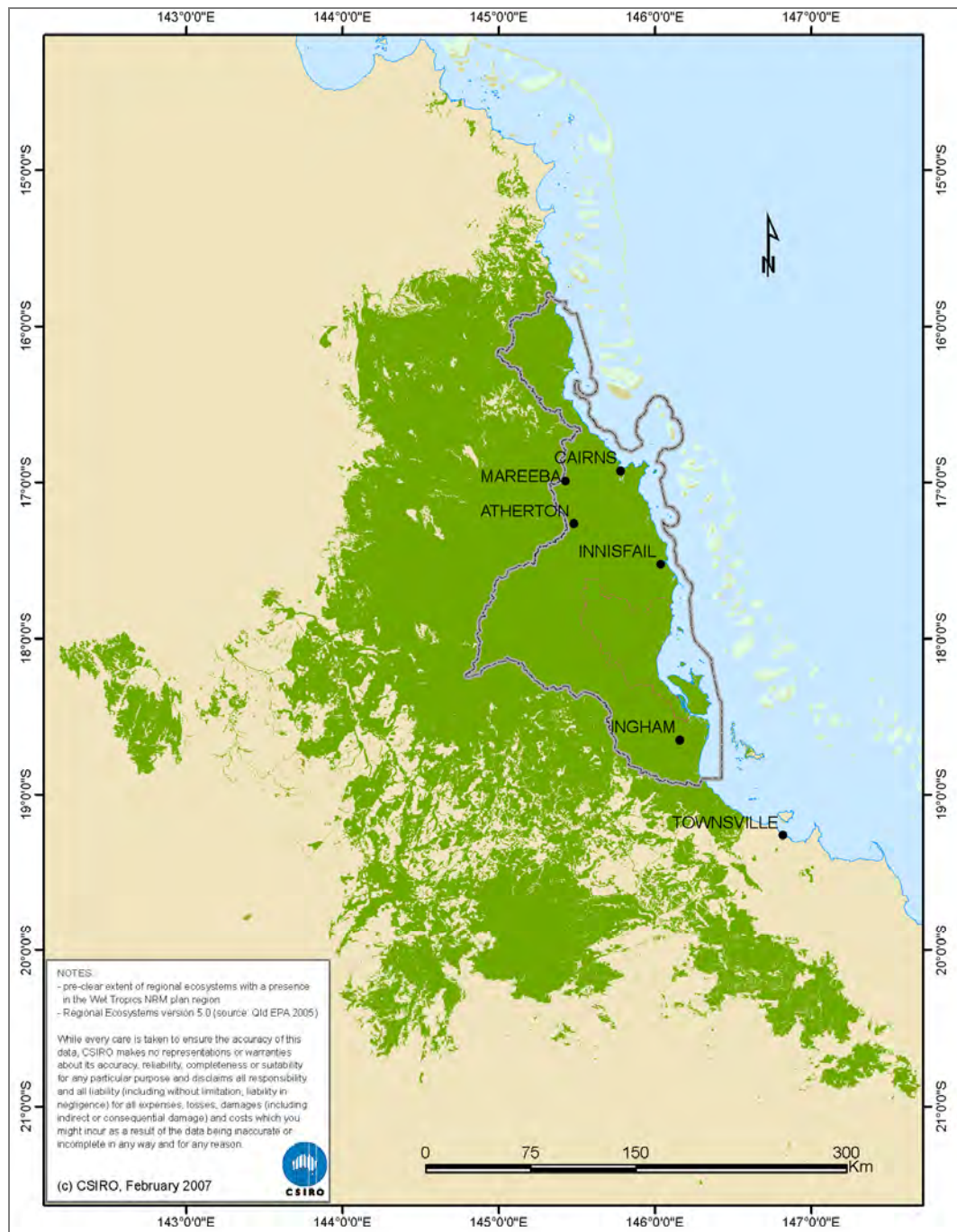


Figure 3: Queensland distribution (geographic range) of pre-clearing regional ecosystems with a presence recorded in the Wet Tropics NRM plan region (grey outline). A list of remnant and pre-clearing regional ecosystem types present within the Wet Tropics plan region was derived and used to extract the set of areas throughout Queensland representing their known geographic ranges (Data source: Queensland Herbarium).

The JANIS criteria targets for the percentage remnant of each regional ecosystem across its geographic range were applied to their respective occurrence in the Wet Tropics plan region. Because the regional ecosystems are often mapped as mosaics (up to four types may be represented within a polygon in the Wet Tropics and up to five types in some parts of Queensland), a map of targets was created as the area-weighted average of the targets for component ecosystems within a map unit. This enabled the pattern of targets to be mapped and the total remnant area applicable to the JANIS criteria for the wet tropics plan region to be assessed.

Calculating species-area relationship (S-A-R) targets

In the absence of specific information from biological inventory studies, simple assumptions can be used with vegetation map data and the species-area relationship to derive ecosystem targets for priority setting in conservation planning studies. This simplifying assumption of equal species richness between ecosystems requires that we choose a classification level at which overlap in biodiversity is minimised, or approximately equal, along a gradient of species compositional turnover. We therefore conservatively adopted the broad vegetation group classification for the wet tropics study presented here.

Broad vegetation groups (BVGs) are a higher-level grouping of vegetation units or regional ecosystems; described in Neldner *et al.* (2005). Some BVGs encompass vegetation types that are generally dominated by a single species, such as *Melaleuca viridiflora*, or a suite of species, such as *Acacia* spp. on residual substrates. Other groups are dominated by a distinct structural formation (such as tussock and closed-tussock grasslands) or by a combination of a structural formation and habitat (such as dry woodlands, primarily on coastal sandplains and dunes). Specialised habitats such as coral islands and intertidal areas form other groups.

In this application of the S-A-R to BVGs we chose an arbitrary, constant species richness of 20,000 and scaling factor C of 1,000 (this is more or less an assumption about how many species might exist in a single small plot). These parameters, along with the original (pre-clearing) extent of each ecosystem, resulted in z-values that varied within the published range of approximately 0.1 and 0.4 (Rosenzweig 1995). The z-values are sensitive to the parameter 'total species richness', but the resulting calculation of percent-area targets, is not. The S-A-R targets were determined relative to the entire pre-clearing extent of each broad vegetation group. The proportion of species richness to be captured by each ecosystem (the 'species richness goal') was varied until the sum of the target areas, adjusted for the remnant extents of each broad vegetation group within the wet tropics plan region, equalled 636,247 ha of remnant vegetation (the same extent generated by the flat targets for the JANIS criteria). This process resulted in a 'species richness goal' of 79.43% (e.g., see Figure 2). The method is easily implemented in an Excel spreadsheet, accessible to practitioners, and allows more specific knowledge of z-values to be incorporated, where information or data are available.

We mapped the BVG targets by relating these to regional ecosystems through their common link with vegetation sub-communities (data provided by Queensland Environmental Protection Agency; Wilson, B. and Niehus, R. 2008, pers. comm.). The area-weighted average of the targets for component BVGs within a map unit enabled the pattern of targets to be mapped.

Comparing JANIS criteria and S-A-R targets

The JANIS criteria targets are applicable to regional ecosystems but, in the absence of precise information, we conservatively calculated the S-A-R targets for broad vegetation groups. For the purpose of comparison we derived the equivalent JANIS criteria targets for remnant vegetation in the BVG case and, conversely, the equivalent S-A-R targets for

regional ecosystems. The BVG and regional ecosystems classifications can be related via their common relationship to vegetation sub-communities. The equivalent JANIS criteria targets for each BVG were therefore derived in proportion to the area of each vegetation sub-community nested within a regional ecosystem. The converse applies in calculating the equivalent S-A-R targets for each regional ecosystem.

Results

Study area context

As at 2003, there were 64 broad vegetation groups comprising 243 extant regional ecosystems in the Wet Tropics plan region, some of which have a minimal occurrence and are more widespread in adjacent regions. The pre-clearing and historical remnant extent (up to 2003) of these regional ecosystems (REs) in the plan region is compared with their total extent in Queensland in Table 1 (Accad *et al.* 2006). The remnant extent of native vegetation has been stable around 77% for the past five years.

Regional ecosystem conservation status is summarised in Table 2. Of the 243 ecosystems, 18 are classed as 'endangered' and 135 are 'of concern' under the Queensland Vegetation Management Act 1999. One 'critically endangered' ecological community (Mabi forest, Complex Notophyll Vine Forest 5b) is recognised under the *Environmental Protection and Biodiversity Conservation Act 2000* (EPBC Act). The Queensland EPA (2005) recognises 75 'endangered' and 106 'of concern' (vulnerable) REs, following the classification of 'biodiversity status' which further considers the disturbance condition of remnant vegetation (see QEPA 2006a). Thirty-four either 'of concern' or 'not of concern at present' ecosystems have remnant geographic extents less than 1,000 ha, and are regarded as rare under the JANIS criteria.

JANIS criteria targets

The JANIS criteria targets for the 243 remnant regional ecosystems in the Wet Tropics plan region vary from between 15% and 100% of their remnant area as at 2003 and add up to 636,247 ha or 36.7% of the plan region (Appendix 2). Taking into account existing protection recognised under the NRS, a minimum of 247,610 ha of remnant vegetation (14.3%) is needed to complement the existing set of regional ecosystems and meet the JANIS criteria targets for ecosystem representation.

Table 1: The extent of clearing 1997-2003 in the Wet Tropics natural resource management plan region (total area 2,162,199 ha) (summarised from Accad *et al.* 2006).

Pre-clearing Extent		Remnant extent				
		1997	1999	2000	2001	2003
Hectares	2,153,881	1,678,537	1,677,546	1,675,847	1,675,438	1,674,580
Percentage remnant	100	77.93	77.88	77.81	77.79	77.75

Table 2: Summary of ecosystem conservation status as defined by VMA status and EPA biodiversity status (Source: QLD EPA 2005) and interpreted for JANIS criteria, for 243 regional ecosystems with an occurrence in the Wet Tropics plan region.

VMA status	Biodiversity status	JANIS criteria status	Number of regional ecosystems	Remnant (2003) extent (ha)	Remnant (2003) in protected areas (ha)
Endangered	Endangered	Endangered	18	25,241	8960
Of Concern	Endangered	Endangered	50	74,716	38,713
Of Concern	Of Concern	Rare	34	14,565	9643
Of Concern	Of Concern	Vulnerable	51	152,442	83,090
Not of Concern	Endangered	Endangered	7	86,464	41,552
Not of Concern	Of Concern	Vulnerable	21	283,567	54,147
Not of Concern	Not of Concern at Present	Other	62	1,096,674	537,388

The spatial pattern of these JANIS criteria targets is shown in Figure 4, before protection, and Figure 5, after protection. Thirteen of the 243 regional ecosystems are not represented within any protected areas, even minimally, and 71 have met or exceeded their minimum target for comprehensiveness.

The JANIS criteria targets for regional ecosystems in the Wet Tropics plan region were equated to broad vegetation group targets (Appendix 3) through their common classification of vegetation sub-communities. The equivalent targets for broad vegetation groups in the Wet Tropics plan region were derived as the area-weighted average of component vegetation sub-communities. This enabled the JANIS criteria targets to be compared directly with the S-A-R derived targets.

S-A-R targets

The S-A-R targets for the 64 broad vegetation groups in the Wet Tropics plan region vary between 29% and 49% of their remnant area, as at 2003, and also add up to 636,247 ha or 36.7% of the plan region (Appendix 3). The equivalent S-A-R targets for regional ecosystems varied between 29% and 62% of their remnant area (Appendix 2). Figure 6a shows the relationship between the S-A-R targets and the pre-clearing extent of the 64 broad vegetation groups (based on current mapping of geographic ranges), from which the targets derive. Figure 6b shows the targets adjusted for the extent of remnant vegetation in the Wet Tropics plan region.

Using the S-A-R targets, a minimum of 109,668 ha remnant vegetation (6.3%) is needed to complement the existing set of broad vegetation groups for the equivalent area of JANIS criteria targets. The spatial pattern of these S-A-R targets is shown in Figure 7 (before protection) and Figure 8 (after protection). Six of the 64 broad vegetation types are presently not represented within protected areas and 26 have met or exceeded their minimum targets.

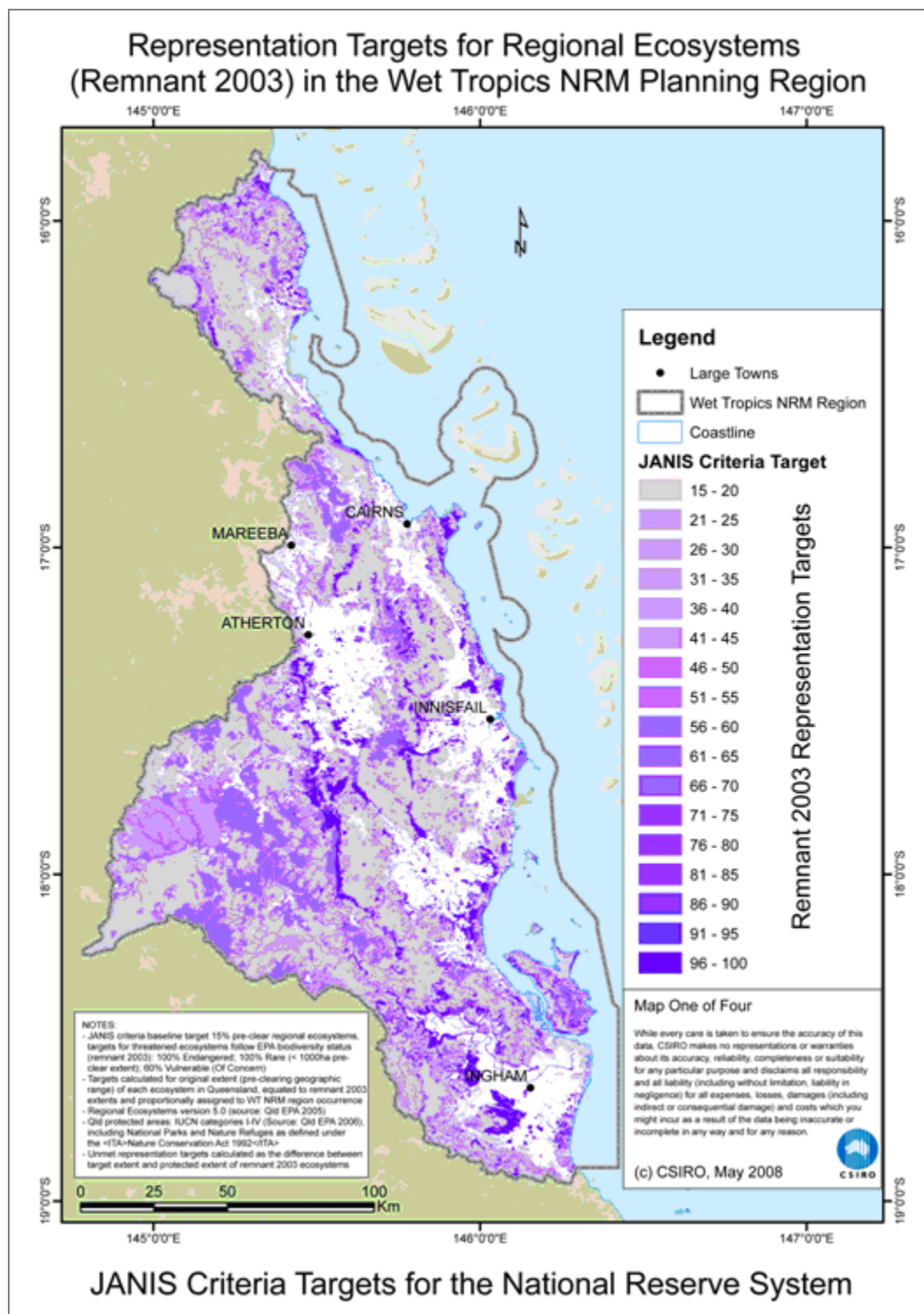


Figure 4: Spatial pattern of JANIS criteria targets for regional ecosystems in the Wet Tropics plan region (percentage of the remnant extent before protection).

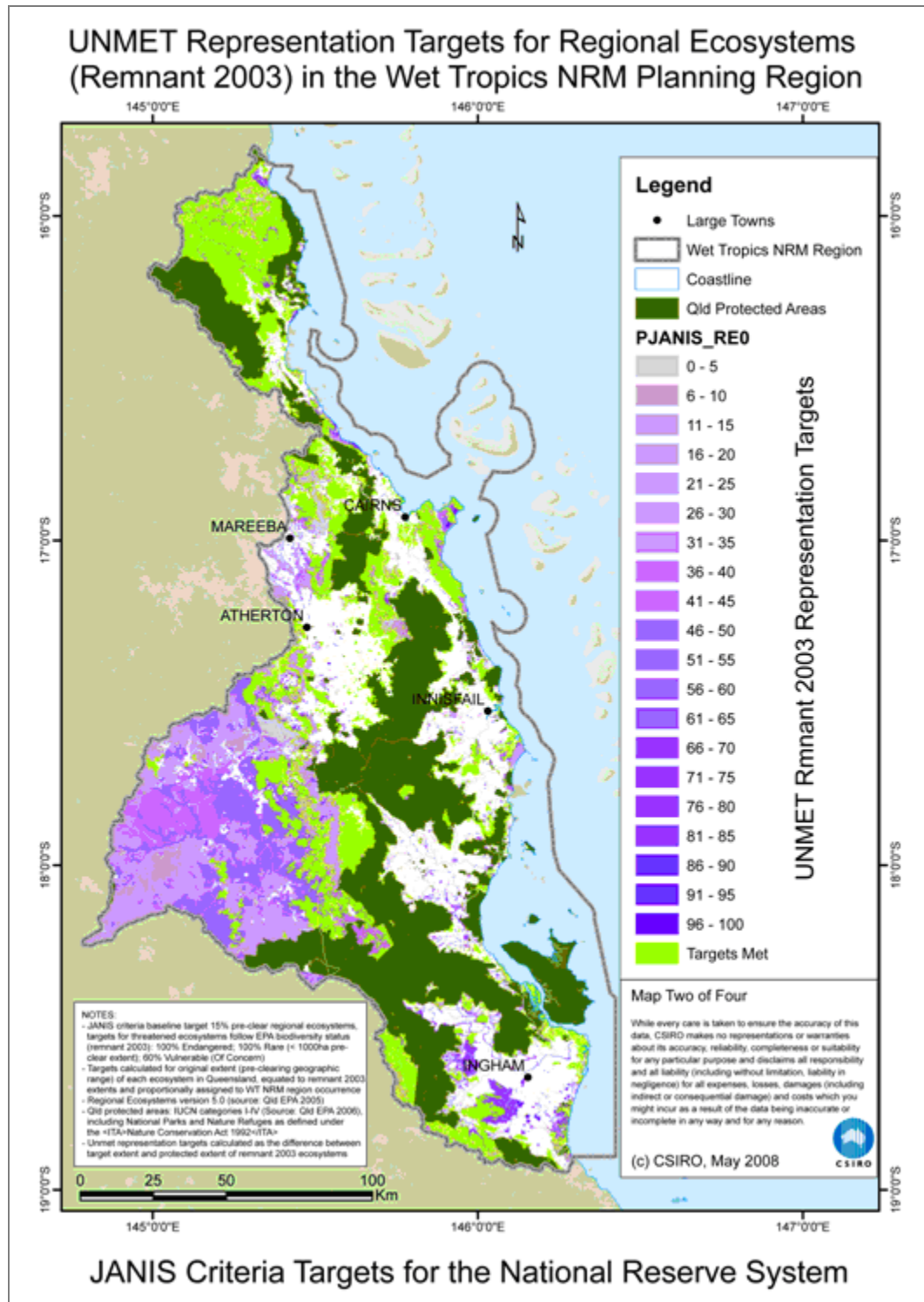


Figure 5: Spatial pattern of JANIS criteria targets for regional ecosystems in the Wet Tropics plan region (percentage of the remnant extent after protection).

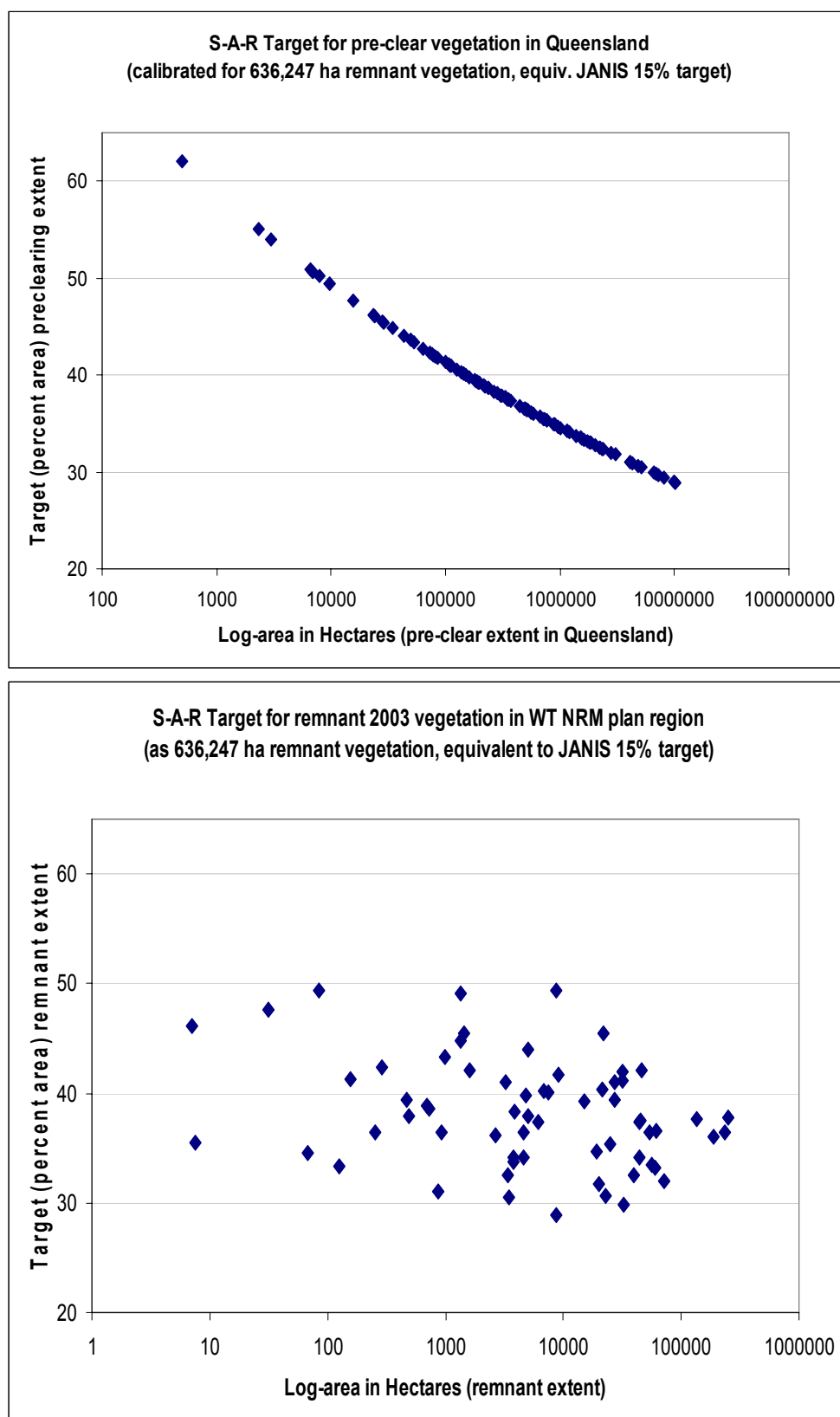


Figure 6: (Top) Relationship between the S-A-R targets and the pre-clearing extent (known geographic range) of the 64 broad vegetation groups with an occurrence in the Wet Tropics plan region; (Bottom) targets adjusted to the extent of remnant vegetation in the Wet Tropics plan region.

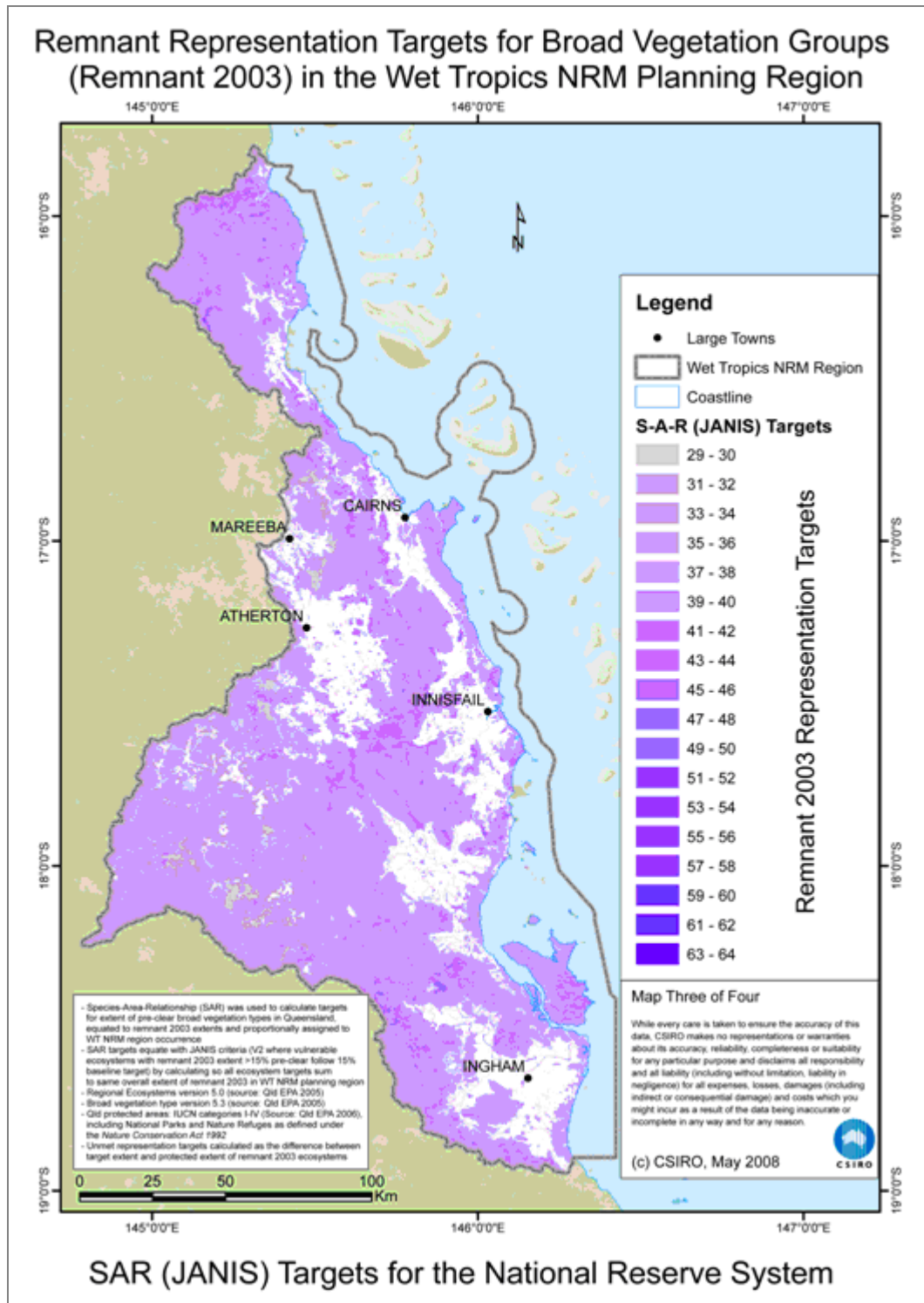


Figure 7: Spatial pattern of S-A-R targets (JANIS criteria) for broad vegetation groups in the Wet Tropics plan region (percentage of the remnant extent before protection) that meet the equivalent area of 'JANIS criteria' targets for ecosystem representation.

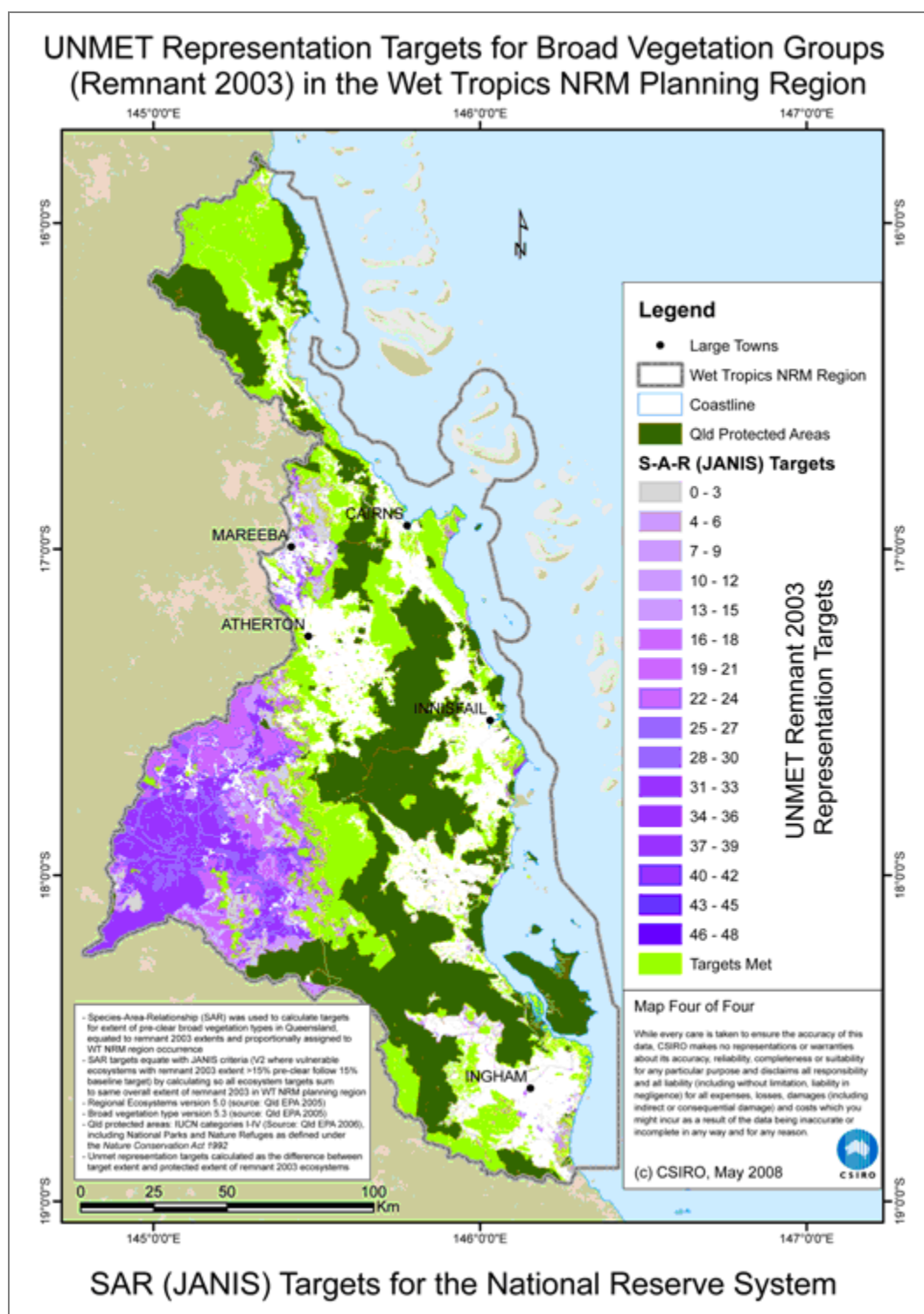


Figure 8: Spatial pattern of S-A-R targets (JANIS criteria) for broad vegetation groups in the Wet Tropics plan region (percentage of the remnant extent after protection) that meet the equivalent area of 'JANIS criteria' targets for ecosystem representation.

Comparison of JANIS criteria and S-A-R targets

Figure 9 is a graphical comparison of the JANIS criteria and S-A-R targets equated to broad vegetation types (a) and regional ecosystems (b), respectively. The JANIS criteria targets fall in three groups depending on their threat classification as 'endangered', 'vulnerable' or 'other'. Figure 10 presents these three clusters as the difference between JANIS criteria and S-A-R targets for regional ecosystems by the remnant extent.

Figure 11 shows the difference for broad vegetation groups and their threat classification implied by their respective JANIS criteria targets as 'endangered', 'vulnerable', 'near threatened' and 'other' (Appendix 3). The JANIS criteria targets were increased to account for rare and threatened ecosystems, whereas the S-A-R derived targets were not. Therefore, the JANIS criteria targets were higher for endangered and vulnerable ecosystems and the S-A-R targets were higher for other ecosystems (not considered threatened).

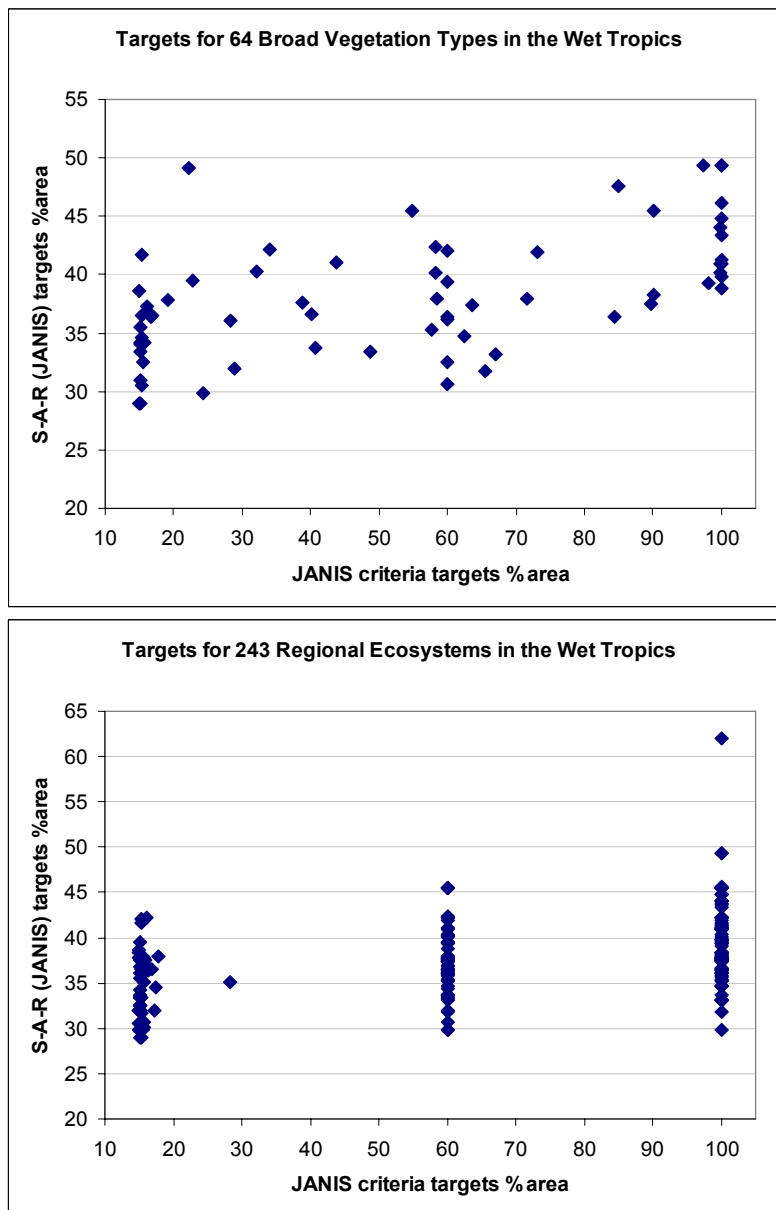


Figure 9: Comparison of JANIS criteria (x-axis) and S-A-R derived targets (y-axis) for 64 broad vegetation groups (*top*) and 243 regional ecosystems (*bottom*) in the Wet Tropics plan region.

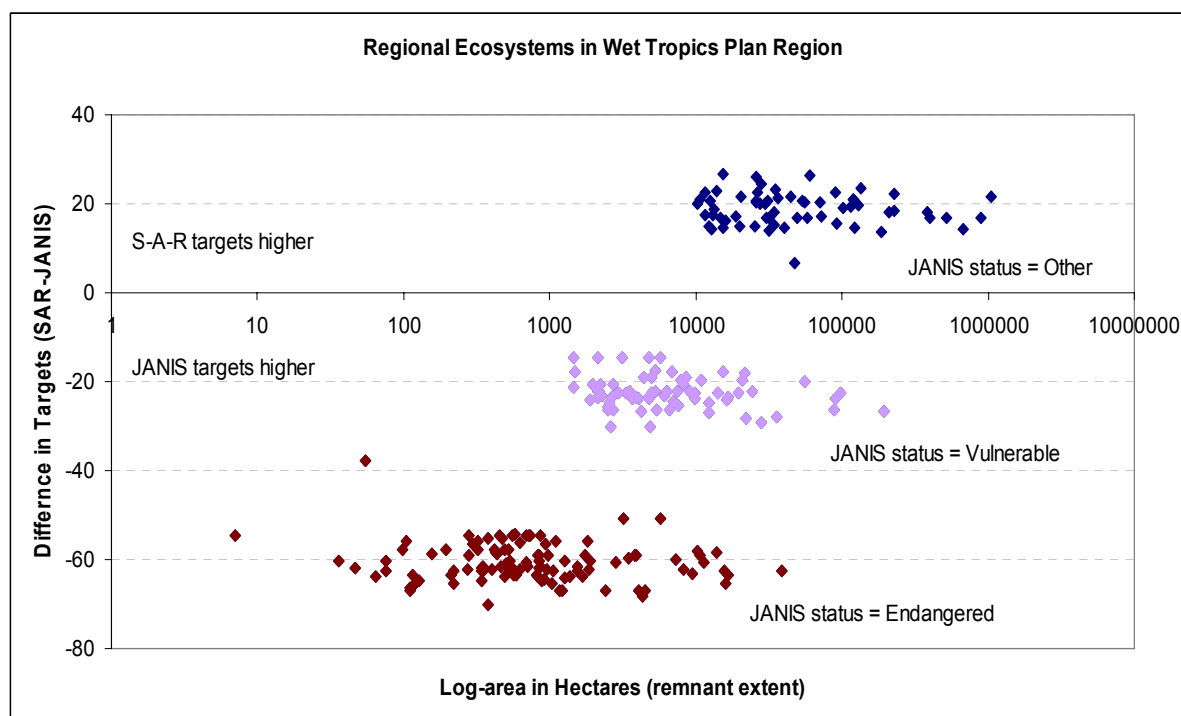


Figure 10: Difference between JANIS criteria and S-A-R derived targets for regional ecosystems in the Wet Tropics plan region. The JANIS status of regional ecosystems is shown in different colours (red = Endangered, mauve = Vulnerable, blue = other, not of concern).

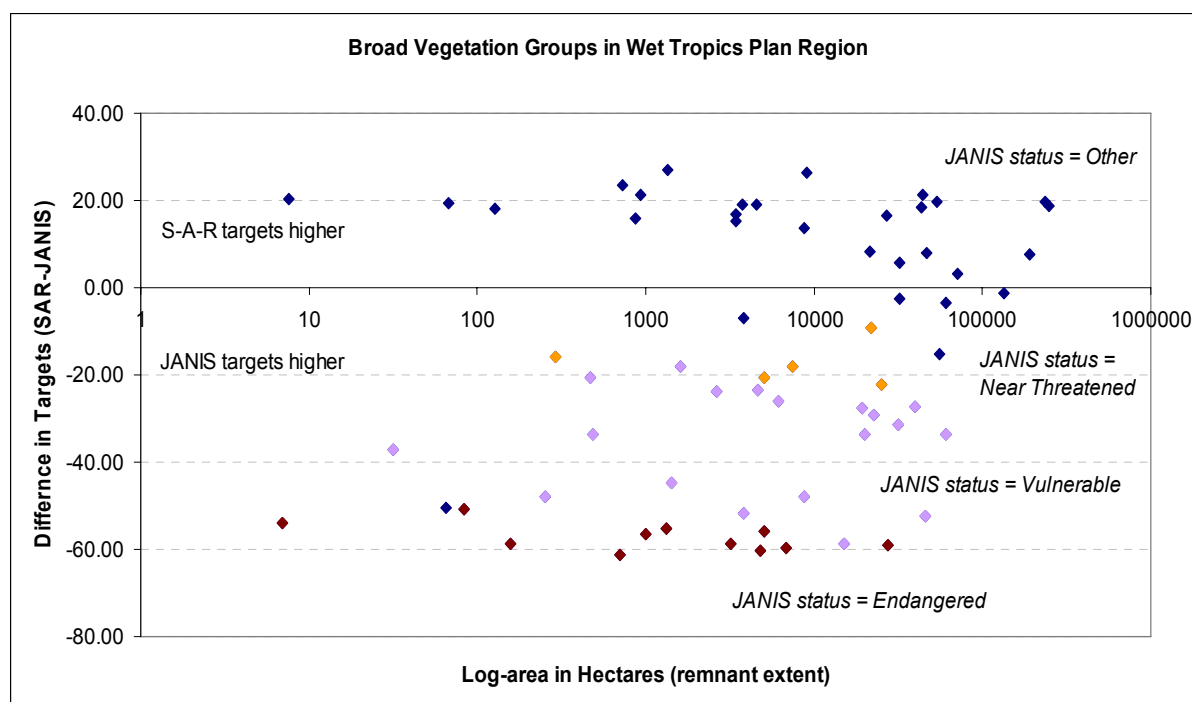


Figure 11: Difference between JANIS criteria and S-A-R derived targets for broad vegetation groups in the Wet Tropics plan region. The JANIS status of broad vegetation groups (inferred from the target level, see Appendix 3) is shown in different colours (red = Endangered, mauve = Vulnerable, orange = near threatened, blue = other, not of concern)

Discussion

The National Reserve System (NRS) program aims to use the best available surrogates to reflect the distribution of biodiversity in the landscape to set priorities and targets and to monitor progress (NRM Ministerial Council 2005). Vegetation mapping datasets, such as the Queensland regional ecosystems, are one type of surrogate. Targets for setting priorities in representing ecosystems in conservation planning studies traditionally use a constant proportion for the extent of each ecosystem to be captured. The comprehensiveness criterion for the NRS, which sets a minimum target of fifteen percent pre-clearing extent of each ecosystem, is an example. Ecosystem area, however, is a crude surrogate for the proportion of biodiversity captured. The species-area curve provides a better surrogate, and the setting of a constant target on the proportion of biodiversity to be captured is more consistent with the NRS objective to maximise biodiversity representation.

Biodiversity is multi-faceted and, therefore, so are the goals and principles of Australia's National Reserve System (Appendix 1). We explored one of sixteen principles for the NRS; that of comprehensiveness which aims to include a representative sample of all types of regional ecosystems – a corner stone of a comprehensive, adequate and representative (CAR) system of reserves. Specifically, we considered how well regional ecosystems are represented in protected areas within the Wet Tropics plan region under the jurisdiction of Terrain NRM Ltd (the natural resource management body for the Wet Tropics planning region). In doing so, we identified locations where ecosystems are well represented in parks and reserves and other places where they are partially represented or unrepresented.

Our result highlights gaps in the comprehensiveness of ecosystem representation in protected areas within the Wet Tropics plan region. Applying the JANIS criteria, a minimum 14.3% of remaining natural areas (247,610 ha) is needed to complete the sample of regional ecosystems in protected areas (Figure 6). Taking a more conservative approach and using species-area curves, we found that at least 109,668 ha remnant vegetation (6.3%) needs to be protected in the Wet Tropics plan region. These areas occur mainly in the western part of the plan region (Figure 8), but significant coastal areas are also poorly represented. While every patch of remnant vegetation potentially makes a contribution toward comprehensiveness, the higher targets indicate which ecosystems are unrepresented or poorly represented in the NRS. Thirteen of the 243 regional ecosystems and six of the 64 broad vegetation groups are not represented in national parks and other protected areas.

The NRS establishes explicit, quantitative goals for the comprehensiveness criterion. This criterion has an origin in the National Forest Policy Statement of 1992 and scientifically established and agreed criteria for reserve design, known as the 'JANIS' criteria. The JANIS criteria established fifteen percent of the pre-clearing extent of regional ecosystems as an appropriate minimum benchmark for formal protection and a sliding scale of higher targets for rare and threatened ecosystems. We developed an operational application of these criteria for Queensland's regional ecosystems based on their pre-clearing extents and adjusted these to their remnant extents. We also introduced an enhancement to the calculation of JANIS criteria targets based on notional species-area curves derived for the pre-clearing extent of broad vegetation groups. The two approaches to target-setting are naturally correlated. In some cases the JANIS criteria targets were higher (for endangered and vulnerable ecosystems) and in other cases the S-A-R targets were higher (other ecosystems, not threatened) (Figures 10 and 11).

Once the choice of targets has been confirmed by stakeholders in the planning process, the next step is to use these in conjunction with other reserve design criteria to identify the best options for additional areas, a process which could be conducted using conservation planning decision software such as TARGET (e.g. Faith and Walker 1996a, 1996b),

MARXAN (Ball and Possingham 2000; Possingham *et al.* 2000), RESNET (Garson *et al.* 2002; Sarkar *et al.* 2002) or CPLAN (Pressey *et al.* 1995; Pressey 1998).

Across whole landscapes, the National Objectives and Targets for Biodiversity Conservation identifies thirty percent as a regional goal for retention of native habitats or restoration of degraded areas (Environment Australia 2001). This goal is mirrored in the Queensland *Vegetation Management Act 1999* which established thirty percent as the threshold for classifying vegetation as 'of concern' and requiring special treatment in development planning (QDNRW 2006). This secondary goal of thirty percent vegetation cover for sustainable landscapes could be investigated in the same way as for the NRS, to identify areas that best contribute toward the representation of ecosystems, all else being equal. Such targets can be consistently and equitably calculated for any local region, nested within a framework of regional and national goals and policies.

In a review of perceived limitations, and an illustration of the benefits, of systematic conservation planning Smith *et al.* (2006) considered the misplaced perception that 'setting targets for representing conservation features is not possible', and noted there were difficulties in the target setting process. They observed that the process was less controversial when based on data-driven approaches and reflected that the setting of targets may change with increasing knowledge. Conservation planners often have to set targets on the basis of limited knowledge, but these targets may change as new information is incorporated (Pressey *et al.* 2003). Our approach to target-setting for the comprehensiveness criterion is an improvement over 'flat targets' and allows more specific knowledge to be included where data are available on species richness (e.g. Desmet and Cowling 2004).

The Wet Tropics region has some of the best biological inventory databases collected following more than a decade of systematic study (Stork and Turton 2008). These data have great potential for developing better biodiversity surrogates and thereby improving the outcome of conservation planning processes. In future studies, we aim to use biological inventory data to extend the surrogacy value of vegetation map data through predictive models of community assemblage patterns (Ferrier *et al.* 2007) and environmental diversity indices (Faith 2003). Combined with other aspects of biodiversity, these outputs will assist the process of evaluating progress and identifying new areas to include in the NRS. A well-managed, comprehensive, adequate and representative network of protected areas is increasingly urgent given the forecast rapid and dynamic change in climate, which has serious implications for the effectiveness of the NRS (Dunlop and Brown 2008).

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References

- Accad A., Neldner V.J., Wilson B.A. and Niehus R.E. (2006) *Remnant Vegetation in Queensland. Analysis of remnant vegetation 1997-1999-2000-2001-2003*, including regional ecosystem information. Queensland Herbarium, Environmental Protection Agency, Brisbane.
- Armston J.D., Danaher T.J. and Collett L.J. (2004) *A regression approach for mapping woody foliage projective cover in Queensland with Landsat data*. In 'Proceedings of the 12th Australasian Remote Sensing and Photogrammetry Conference, Fremantle, Australia, Oct 2004'. http://www.nrw.qld.gov.au/slats/pdf/armston_fpc_arspc_2004.pdf. Accessed: 5 May 2008.
- Arponen A., Kondelin H. and Moilanen A. (2006) Area-Based Refinement for Selection of Reserve Sites with the Benefit-Function Approach. *Conservation Biology*, 21(2), 527-533.
- Ball I.R. and Possingham H.P. (2000) Marxan version 1.8.3. <http://www.ecology.uq.edu.au/marxan.htm#1>
- Commonwealth of Australia (1996) *National Strategy for the Conservation of Australia's Biological Diversity*. Department of the Environment, Sport and Territories, Canberra.
- Commonwealth of Australia. (1997) *Nationally Agreed Criteria for the establishment of a Comprehensive Adequate and Representative Reserve System for Forests*. Commonwealth of Australia, Canberra.
- Desmet P. and Cowling R. (2004) Using the species–area relationship to set baseline targets for conservation. *Ecology and Society*, 9(2), 11. <http://www.ecologyandsociety.org/vol9/iss2/art11/>
- Dunlop M. and Brown P.R. (2008) *Implications of Climate Change for Australia's National Reserve System: A Preliminary Assessment*. CSIRO Sustainable Ecosystems, report to the Department of Climate Change and the Department of the Environment, Water, Heritage and the Arts, Canberra. <http://www.greenhouse.gov.au/impacts/publications/nrs-report.html>. Accessed: 5 May 2008.
- Environment Australia (2001) *National Objectives and Targets for Biodiversity Conservation 2001-2005*. Commonwealth of Australia, Canberra.
- Faith D.P. (2003) Environmental diversity (ED) as surrogate information for species-level biodiversity. *Ecography*, 26(3), 374-379.
- Faith D.P. and Ferrier S. (2002) Linking beta diversity, environmental variation, and biodiversity assessment. Science online, 22 July 2002, available at: <http://www.sciencemag.org/cgi/eletters/295/5555/636#504>
- Faith D.P., Ferrier S. and Williams K.J. (2008) Getting biodiversity intactness indices right: ensuring that "biodiversity" reflects "diversity". *Global Change Biology* 14(2), 207–217. <http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2486.2007.01500.x>.
- Faith D.P. and Walker P.A. (1996a) Integrating conservation and development: effective trade-offs between biodiversity and cost in the selection of protected areas. *Biological Conservation*, 5(4), 431-446.
- Faith D.P. and Walker P.A. (1996b) *Diversity – TD*. In *BioRap Volume 3. Tools for assessing biodiversity priority areas*, eds D.P. Faith and A.O. Nicholls, pp 63-74. The Australian BioRap Consortium, Canberra.
- Ferrier S., Manion G., Elith J. and Richardson K. (2007) Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions* 13, 252-264.
- Ferrier S., Powell G.V.N., Richardson K.S., et al. (2004) Mapping more of terrestrial biodiversity for global conservation assessment. *Bioscience* 54, 1101-1109.
- FNQ NRM Ltd and Rainforest CRC (2004) *Sustaining the Wet Tropics: A Regional Plan for Natural Resource Management 2004-2008*. FNQ NRM Ltd, Innisfail. <http://www.terrain.org.au/images/stories/publications/Volume4.pdf>
- Garson J., Aggarwal A. and Sarkar S. (2002) ResNet Ver 1.2 Manual. University of Texas Biodiversity and Biocultural Conservation Laboratory, Austin. <http://uts.cc.utexas.edu/~consbio/Cons/reports.html>

- Gole C., Burton M., Williams K.J., Clayton H., Faith D., White B., Huggett A. and Margules C. (2005) *Auction for Landscape Recovery*. Final Report for MBI project 21, October 2005, WWF Australia, Perth. <http://www.napswg.gov.au/mbi/round1/project21.html>. Accessed: 5 May 2008.
- Margules C.R. and Pressey R.L. (2000) Systematic conservation planning. *Nature* 405, 243-253.
- Martin, H.G. and Goldenfeld, N. (2006) *On the origin and robustness of power-law species–area relationships in ecology*. Proceedings of the National Academy of Science 103(27), 10310-10315.
- May R.M., Lawton J.H. and Stork N.E. (1995) *Assessing extinction rates*. In 'Extinction Rates' eds J.H. Lawton and R.M. May, pp. 1-24. Oxford University Press.
- NRMMC (2005) *Directions for the National Reserve System – A partnership Approach*. Natural Resource Management Ministerial Council, Department of the Environment and Heritage, Canberra. <http://www.environment.gov.au/parks/publications/nrs/directions/pubs/directions.pdf>.
- Neldner V.J., Wilson B.A., Thompson E.J. and Dillewaard H.A. (2005) *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland*, Version 3.1. Queensland Herbarium, Environmental Protection Agency, Brisbane.
- Ney-Nifle M. and Mangel M. (2000) Habitat loss and changes in the species-area relationship. *Conservation Biology* 14: 893-898.
- Pimm S.L. and Raven P. (2000) Biodiversity – extinction by numbers. *Nature* 403, 843-845.
- Possingham H.P., Ball I. and Andelman S. (2000) *Mathematical methods for identifying representative reserve networks*. In 'Quantitative Methods for Conservation Biology' eds S. Ferson and M. Burgman, pp 291-305. Springer-Verlag: New York.
- Pressey R.L. (1998) *Algorithms, Politics and Timber: An Example of the Role of Science in a Public Political Negotiation Process over New Conservation Areas in Production Forests*. In 'Ecology for Everyone: Communicating Ecology to Scientists, the Public and Politicians', eds R. Willis and R. Hobbs, pp. 73-87. Surrey Beatty: Sydney.
- Pressey R.L., Cowling R.M. and Rouget M. (2003) Formulating conservation targets for biodiversity pattern and process in the Cape Floristic Region, South Africa. *Biological Conservation* 112, 99-127.
- Pressey R.L., Ferrier, S., Hutchinson, C.D., Sivertsen, D.P. and Manion, G. (1995) *Planning for negotiation: using an interactive geographic information system to explore alternative protected area networks*. In 'Nature Conservation: the Role of Networks', eds. D.A. Saunders, J.L. Craig, and E.M. Matiske, pp. 23-33. Surrey Beatty and Sons: Sydney.
- QEPA (2005) *Survey and Mapping of pre-clear and 2003 Remnant Vegetation Communities and Regional Ecosystems of Queensland*, Version 5.0 (December 2005). Digital vector data. Queensland Herbarium, Environmental Protection Agency, Brisbane.
- QEPA (2006a) Protected Areas of Queensland – Estate, version 12.4 31st December 2006. Digital vector data. Environmental Protection Agency and Queensland Parks and Wildlife Service, Brisbane.
- QEPA (2006b) Regional Ecosystems: Introduction and Status. Environmental Protection Agency, Brisbane. http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/introduction_and_status/. Accessed: 5 May 2008.
- QEPA (2007) *Nature Refuges and Coordinated Conservation Areas, gazettals up to June 2007, release version September 2007*. Digital vector data. Environmental Protection Agency and Queensland Parks and Wildlife Service, Brisbane.
- QEPA (2008) Regional Ecosystem Description Database (REDD), version 5.3 March 2008. (A database describing regional ecosystems and their status). Queensland Herbarium, Environmental Protection Agency, Brisbane. http://www.epa.qld.gov.au/nature_conservation/biodiversity/regional_ecosystems/
- QDNRW (2006) State Policy for Vegetation Management. The State of Queensland, Environmental Protection Agency and Queensland Parks and Wildlife Service, Brisbane. http://www.nrw.qld.gov.au/vegetation/pdf/state_policy_nov_2006.pdf. Accessed: 5 May 2008.
- Rosenzweig M. (1995) *Species diversity in space and time*. Cambridge University Press: Cambridge, UK.

Sala O.E., Chapin F.S., Armesto J.J., Berlow E., Bloomfield J., Dirzo R., Huber-Sanwald E., Huenneke L.F., Jackson R.B., Kinzig A., Leemans R., Lodge D.M., Mooney H.A., Oesterheld M., Poff N.L., Sykes M.T., Walker B.H., Walker M. and Wall D.H. (2000) Biodiversity – global biodiversity scenarios for the year (2100). *Science* 287, 1770-1774.

Sarkar S., Aggarwal A., Garson J., Margules C.R. and Zeidler J. (2002) Place prioritization for biodiversity content. *Journal of Biosciences* 27 (Suppl. 2), 339-346.

Sattler P.S. and Williams R.D. (eds) (1999) *The Conservation Status of Queensland Bioregional Ecosystems*. Environmental Protection Agency: Brisbane.

SCBD (2000) *Sustaining life on earth: How the convention on biological diversity promotes nature and human well-being*. The Secretariat of the Convention on Biological Diversity. <http://www.cbd.int/doc/publications/cbd-sustain-en.pdf>

Smith R.J., Goodman P.S. and Matthews W.S. (2006) *Systematic conservation planning: a review of perceived limitations and an illustration of the benefits, using a case study from Maputaland, South Africa*. *Oryx*, 40, 400-410.

Stanton J.P. and Stanton D. (2005) *Vegetation of the Wet Tropics of Queensland Bioregion*. Wet Tropic Management Authority, Cairns.

Stork N. and Turton S. (eds) (2008) *Living in a Dynamic Tropical Forest Landscape*. Blackwell Publishing: Oxford, UK.

Veech J.A. (2000) Choice of Species-Area Function Affects Identification of Hotspots. *Conservation Biology*, 14 (1), 140-147.

Williams M.R. (1995) An extreme-value function of the species incidence and species-area relations. *Ecology* 76, 2607-2616.

Williams K.J., Mitchell D.K., James R., Cameron S.E., Faith D.P., Storey R., de Fretes Y., Sumantri H. and Margules C. (2006) *Milne Bay Province Terrestrial Biodiversity Conservation Outcomes: A pilot for the New Guinea Wilderness*. CSIRO and Conservation International – Melanesia CBC, Atherton.

Appendix 1: Principles underpinning the National Reserve System

The following principles have been developed to provide a strategic approach to meet the goals of the National Reserve System): <http://www.environment.gov.au/parks/publications/nrs/directions/chapter2.html>).

Regional Framework:

The *Interim Biogeographic Regionalisation for Australia* (IBRA) provides the national and regional planning framework for developing the NRS. Further investigation is needed regarding the incorporation of freshwater ecosystems within the IBRA framework.

Comprehensiveness:

The National Reserve System will aim to include the full range of regional ecosystems recognised at an appropriate scale within and across each IBRA region. Increasing the comprehensiveness of the national protected area system, particularly in those IBRA regions where biodiversity is poorly conserved in the protected area system, is the primary focus of the NRS.

Adequacy:

The NRS will aim to provide reservation of each ecosystem to the level necessary to provide ecological viability, resilience and integrity.

Representativeness:

Areas selected for inclusion in the NRS should reasonably reflect the intrinsic variability of the ecosystems they represent. One way of achieving this is to aim to represent each regional ecosystem within each IBRA subregion.

Ecosystems/Regional Ecosystems:

Ecosystem surrogates, such as vegetation units, together with environmental information mapped at appropriate scales (regional ecosystems) and species information should be the primary planning information which informs NRS planning.

Threat:

While the focus of the NRS will be on increasing comprehensiveness, the selection of priority additions to the NRS will also be based on principles of viability and [vulnerability](#) to loss. Priority will be given to the addition to the protected area system of ecosystems where there is a high risk of loss which may foreclose future options for the conservation of biodiversity within the region.

Precautionary Principle:

The absence of scientific certainty is not a reason to postpone measures to establish protected areas that contribute to a comprehensive, adequate and representative national reserve system.

Landscape Context:

The protected area system should maximise biodiversity conservation outcomes through the application of scientifically robust protected area/conservation design principles.

Highly Protected Areas:

The NRS will aim to have some highly protected areas (IUCN Categories I and II) in each IBRA region.

All appropriate protection measures should be used in regional conservation planning:

It is recognised that regional biodiversity conservation requires a mix of management strategies. These would include statutory protected areas and incentives that encourage voluntary partnerships for off-reserve conservation. Public and private protected areas would include covenanting arrangements, as well as conservation management measures and guidelines for ecologically sustainable land management.

Public land should be used first for delivering the NRS where possible:

The CAR reserve system should, where possible, be selected from public land, recognizing that key remnants of many ecosystems exist only on private lands.

Integrated decision making:

Decision making processes should effectively integrate both long-term and short-term environmental, economic, social and equity considerations.

Consultation:

The process of identification and selection of the NRS will include effective and high quality public consultation with appropriate community and interest groups to address current and future social, economic and cultural issues.

Partnerships:

The success of the NRS depends on effective partnerships between the Australian, State and Territory Governments, and between governments and non-government organisations, private landholders and indigenous landholders and organisations. These partnerships should continue to be built on to ensure the effective on-going development and management of the NRS.

Confidentiality:

Where private land is being considered for inclusion in the NRS, negotiations will take into account the owners' requirements for confidentiality.

Indigenous involvement:

The biodiversity conservation interests of Australia's indigenous peoples should be recognised and incorporated in decision making.

Appendix 2: JANIS criteria targets for regional ecosystems and S-A-R targets for regional ecosystems derived from broad vegetation group targets

JANIS criteria targets and S-A-R targets applicable to the remnant extent of regional ecosystems in the wet tropics plan region. The JANIS criteria targets were derived for regional ecosystems using a baseline target of fifteen percent extent before widespread clearing, equated to the current remnant extent (2003), with higher targets for rare and threatened ecosystems (100% for rare or endangered, 60% for vulnerable). JANIS Criteria Status: VU = Vulnerable; EN = Rare or Endangered; OT = Other. The S-A-R targets were derived from the BVG targets equated to regional ecosystems derived as the area-weighted average of component vegetation sub-communities. Further detail is given in the text.

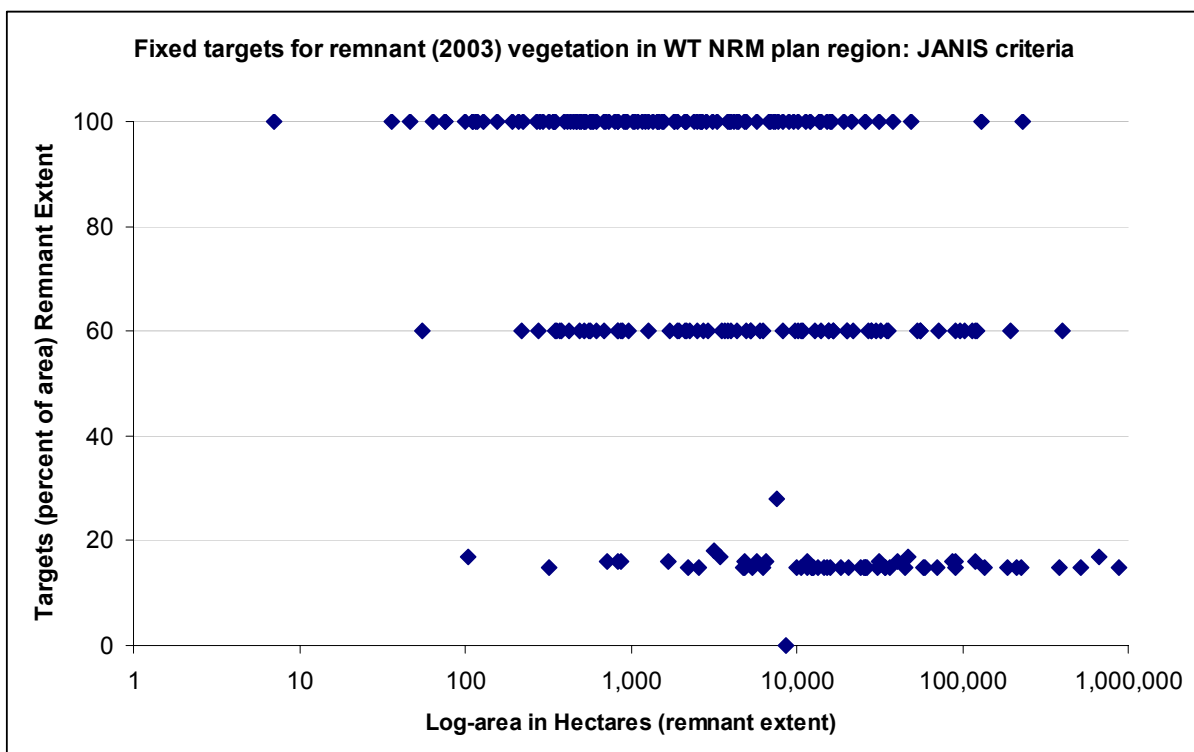


Figure: JANIS criteria targets for comprehensive sampling of regional ecosystems in the National Reserve System applicable to occurrences within the Wet Tropics plan region.

RE Label	JANIS status	Pre-clear (Wet Tropics) Ha	Remnant (Wet Tropics) Ha	JANIS Target percentage of remnant area (before protection)	JANIS Target percentage of remnant area (after protection)	S-A-R Target percentage of remnant area (before protection)
3.3.2	VU	9017.3	8602.2	60.00	48.42	40.95
3.5.23	VU	8507.9	8189.95	60.00	44.97	39.46
3.5.26	OT	11352.6	10290.8	16.55	5.94	36.56
3.8.3	EN	5587.5	3467.4	100.00	99.31	40.31
3.11.8	OT	48912	48866.3	15.01	4.30	31.93
7.1.1	OT	47109	44882	15.74	0.00	37.32
7.1.2	VU	6404	4815	60.00	31.80	36.37
7.1.3	EN	1568	1895	100.00	67.39	39.72
7.1.4	EN	241	222	100.00	77.48	37.32
7.1.5	EN	330	350	100.00	92.86	38.30
7.2.1	EN	2529	582	100.00	45.70	45.62
7.2.2	EN	1012	468	100.00	92.95	44.79
7.2.3	VU	11640	7020	60.00	23.68	35.43
7.2.4	VU	5536	2744	60.00	0.00	33.55
7.2.5	EN	555	378	100.00	46.56	44.77
7.2.6	EN	298	298	100.00	0.34	43.64
7.2.7	EN	1287	934	100.00	83.73	43.37
7.2.8	EN	2356	1562	100.00	67.35	38.30
7.2.9	EN	3655	2840	100.00	54.23	39.35
7.2.10	EN	506	506	100.00	100.00	39.08
7.2.11	VU	2506	1462	60.00	18.82	38.76
7.3.1	EN	13459	1264	100.00	91.85	39.80
7.3.2	EN	88	76	100.00	100.00	39.80
7.3.3	EN	4630	1817	100.00	43.92	44.03
7.3.4	EN	2806	1102	100.00	47.10	44.03
7.3.5	EN	25233	11369	100.00	42.70	39.30
7.3.6	EN	2465	707	100.00	98.16	38.30
7.3.7	EN	8872	1227	100.00	46.78	33.17
7.3.8	EN	38923	15908	100.00	71.92	34.67
7.3.9	EN	10988	1173	100.00	85.34	33.17
7.3.10	EN	59113	13889	100.00	49.51	41.46
7.3.12	EN	26001	4474	100.00	64.30	33.17
7.3.13	EN	989	688	100.00	91.42	39.46
7.3.14	VU	3524.85	2655.1	60.00	32.87	36.56
7.3.16	EN	37354	16489	100.00	69.27	36.56
7.3.17	EN	26319	3894	100.00	41.19	40.98
7.3.19	VU	6399	4204	60.00	0.00	33.25

RE Label	JANIS status	Pre-clear (Wet Tropics) Ha	Remnant (Wet Tropics) Ha	JANIS Target percentage of remnant area (before protection)	JANIS Target percentage of remnant area (after protection)	S-A-R Target percentage of remnant area (before protection)
7.3.20	VU	10434	6057	60.00	0.00	36.92
7.3.21	VU	5942	4035	60.00	0.00	36.04
7.3.23	EN	15701.3	3853.6	100.00	69.03	40.95
7.3.25	VU	8224	4993	60.00	27.96	37.41
7.3.26	EN	4619.4	4328.4	100.00	72.35	31.75
7.3.28	EN	7418.1	7309.3	100.00	66.83	40.14
7.3.29	EN	2035	841	100.00	87.51	39.75
7.3.30	EN	461	36	100.00	58.33	39.80
7.3.31	EN	623	534	100.00	58.61	39.80
7.3.32	EN	12300	116	100.00	89.66	36.41
7.3.33	EN	156	156	100.00	1.92	41.31
7.3.34	EN	2218	466	100.00	90.34	38.30
7.3.35	EN	1132	281	100.00	23.49	45.51
7.3.36	EN	1185	434	100.00	8.76	41.16
7.3.37	EN	744	7	100.00	100.00	45.44
7.3.38	EN	195	195	100.00	18.97	42.15
7.3.39	EN	1664	915	100.00	90.49	35.71
7.3.40	EN	15638	4045	100.00	47.96	33.17
7.3.42	EN	101	76	100.00	88.16	37.50
7.3.43	EN	3140	2430	100.00	72.84	33.17
7.3.44	EN	2448	592	100.00	44.43	36.56
7.3.45	VU	33834	12207	60.00	17.19	33.17
7.3.46	EN	7578	1730	100.00	42.20	41.09
7.3.47	EN	112	112	100.00	0.00	33.17
7.3.48	EN	238	128	100.00	86.72	35.39
7.3.49	EN	836	843	100.00	26.93	38.11
7.5.1	EN	64	64	100.00	0.00	36.11
7.5.2	VU	4414	4415	60.00	60.00	41.08
7.5.4	VU	4957	3557	60.00	41.39	37.66
7.8.1	EN	30625	10764	100.00	24.18	40.97
7.8.2	VU	51781	21421	60.00	0.00	41.95
7.8.3	EN	18934	863	100.00	41.71	45.44
7.8.4	EN	28562	10174	100.00	28.03	41.92
7.8.7	EN	1305	956	100.00	73.33	37.62
7.8.8	EN	4498	1543	100.00	69.35	37.43
7.8.10	VU	4774	1908	60.00	26.82	35.93
7.8.11	EN	552	552	100.00	4.35	45.51
7.8.12	EN	319	319	100.00	0.00	42.15

RE Label	JANIS status	Pre-clear (Wet Tropics) Ha	Remnant (Wet Tropics) Ha	JANIS Target percentage of remnant area (before protection)	JANIS Target percentage of remnant area (after protection)	S-A-R Target percentage of remnant area (before protection)
7.8.13	EN	108	99	100.00	18.18	42.15
7.8.14	EN	897	525	100.00	78.29	42.15
7.8.15	EN	517	344	100.00	62.50	37.50
7.8.16	EN	407	346	100.00	24.28	37.56
7.8.17	EN	119	119	100.00	64.71	34.63
7.8.18	EN	885	345	100.00	71.88	38.07
7.8.19	EN	8342	1849	100.00	84.91	37.66
7.11.1	OT	146035	130060	16.84	0.00	36.59
7.11.2	EN	132	104	100.00	63.46	44.03
7.11.3	VU	1489.9	1459.9	60.00	0.00	45.44
7.11.5	OT	29623	27250	16.31	0.00	36.31
7.11.6	EN	1685	1673	100.00	42.92	36.04
7.11.7	OT	27923.7	26091.7	16.05	0.00	42.15
7.11.8	EN	741	719	100.00	43.25	45.51
7.11.10	VU	2147	2120	60.00	0.00	45.51
7.11.12	OT	35761	29990	17.89	0.00	37.98
7.11.13	EN	3301	3180	100.00	11.70	49.36
7.11.14	EN	1086	1059	100.00	10.48	37.50
7.11.16	EN	1682	1272	100.00	63.60	35.85
7.11.18	VU	5653.6	2187.6	60.00	24.23	37.66
7.11.19	VU	7421	6278	60.00	2.40	37.66
7.11.20	OT	28215.8	28130.5	15.05	0.00	39.46
7.11.21	OT	13123.5	12435.5	15.83	0.00	36.56
7.11.23	EN	875	830	100.00	15.18	40.98
7.11.24	VU	5679	5722	60.00	0.00	45.51
7.11.25	VU	2317	2156	60.00	3.88	36.47
7.11.26	EN	427	427	100.00	14.99	41.58
7.11.27	EN	569	569	100.00	0.00	37.83
7.11.28	VU	1475	1475	60.00	0.00	42.15
7.11.29	EN	883	883	100.00	2.38	35.27
7.11.30	EN	489	488	100.00	23.77	42.15
7.11.31	VU	3316	3315	60.00	0.00	37.50
7.11.32	VU	2122	2116	60.00	23.89	37.89
7.11.33	VU	3021	2948	60.00	0.00	37.42
7.11.34	EN	550.2	521.4	100.00	16.28	37.99
7.11.35	VU	17921.2	16211.2	60.00	0.00	35.79
7.11.36	EN	309	278	100.00	100.00	41.09
7.11.37	VU	4965	4850	60.00	8.04	29.88

RE Label	JANIS status	Pre-clear (Wet Tropics) Ha	Remnant (Wet Tropics) Ha	JANIS Target percentage of remnant area (before protection)	JANIS Target percentage of remnant area (after protection)	S-A-R Target percentage of remnant area (before protection)
7.11.38	EN	838	838	100.00	1.31	41.09
7.11.39	EN	53	47	100.00	14.89	38.20
7.11.40	EN	626	625	100.00	79.84	43.74
7.11.41	VU	2845	2518	60.00	0.00	34.35
7.11.42	EN	380	355	100.00	9.58	37.66
7.11.43	EN	782	401	100.00	100.00	37.66
7.11.44	VU	10063	9054	60.00	0.00	37.66
7.11.46	EN	833.1	829.1	100.00	18.02	36.04
7.11.47	VU	2753.4	2711.4	60.00	0.00	39.46
7.11.48	EN	338	220	100.00	53.18	34.67
7.11.49	VU	4300	3879	60.00	34.84	36.56
7.11.50	EN	571	567	100.00	80.60	36.56
7.11.51	VU	17644.4	14040.8	60.00	0.00	37.59
7.12.1	OT	123502	119936	15.45	0.00	36.46
7.12.2	EN	322	322	100.00	6.83	44.03
7.12.4	EN	1418	1372	100.00	35.13	36.04
7.12.5	EN	11948	9503	100.00	29.44	36.71
7.12.6	EN	740	740	100.00	15.00	45.44
7.12.7	OT	15623.4	15268.8	15.35	0.00	42.13
7.12.9	VU	4843.1	4802	60.00	0.00	45.51
7.12.10	VU	1963	1962	60.00	12.80	39.35
7.12.11	VU	15483	15473	60.00	0.00	42.15
7.12.12	EN	687	696	100.00	18.68	45.51
7.12.13	EN	450	450	100.00	0.00	45.51
7.12.16	OT	240547.5	229235	15.74	0.00	37.86
7.12.17	EN	5733	5724	100.00	9.05	49.36
7.12.19	OT	13765	13761	15.00	0.00	37.83
7.12.20	VU	6324	6323	60.00	0.00	37.83
7.12.21	EN	16008.3	15733.7	100.00	13.62	37.50
7.12.22	EN	39191	38346	100.00	21.06	37.50
7.12.23	EN	8422	8275	100.00	12.59	37.66
7.12.24	OT	32006	31151	15.41	0.00	36.04
7.12.25	VU	4856	4823	60.00	0.00	36.04
7.12.26	OT	34831.5	34792.5	15.02	0.00	38.35
7.12.27	OT	26599	26271	15.19	0.00	37.58
7.12.28	OT	27156	25746	15.82	0.00	36.56
7.12.29	OT	92783.4	90965.1	15.30	0.00	37.69
7.12.30	OT	35050.4	34384.4	15.29	0.00	33.43

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7.12.33	VU	2247	2220	60.00	0.00	39.46
7.12.34	OT	54813.6	53055.4	15.50	0.00	36.04
7.12.35	VU	9947	9930	60.00	41.73	36.04
7.12.37	VU	5249	5248	60.00	0.00	42.40
7.12.39	EN	987	971	100.00	7.93	40.98
7.12.40	VU	3125	3138	60.00	0.00	45.51
7.12.41	EN	625	625	100.00	0.00	37.83
7.12.43	EN	528	528	100.00	0.00	37.83
7.12.44	EN	417	417	100.00	0.24	42.15
7.12.45	EN	272	272	100.00	36.76	37.83
7.12.47	EN	111	111	100.00	22.52	33.72
7.12.48	VU	6891	6890	60.00	0.00	42.15
7.12.49	EN	351	351	100.00	0.00	37.83
7.12.50	VU	7462	7459	60.00	0.00	37.83
7.12.51	VU	2304	2274	60.00	0.00	36.77
7.12.52	VU	9863	9763	60.00	11.50	37.50
7.12.53	OT	21354	20188	15.87	0.00	37.56
7.12.54	EN	880	871	100.00	51.32	38.44
7.12.55	VU	2172	2122	60.00	0.00	36.56
7.12.57	VU	3737	3714	60.00	36.74	36.04
7.12.58	EN	498	488	100.00	26.84	36.04
7.12.59	EN	856	805	100.00	88.94	36.56
7.12.60	EN	1272	1038	100.00	82.76	34.67
7.12.61	VU	20167	19474	60.00	0.00	37.55
7.12.62	EN	376	376	100.00	0.00	29.88
7.12.63	EN	343	342	100.00	93.27	35.28
7.12.64	VU	7822	7821	60.00	0.00	40.30
7.12.65	VU	10991	10908	60.00	24.46	40.24
7.12.66	VU	4941	4940	60.00	0.00	41.09
7.12.67	EN	55	55	100.00	0.00	62.08
7.12.68	EN	212	210	100.00	20.48	36.39
7.12.69	VU	2688	2623	60.00	39.98	29.88
9.3.3	VU	101658.3	89963.85	60.00	56.75	36.13
9.3.4	VU	7045.7	5259.5	60.00	60.00	37.90
9.3.6	OT	21115	20085.95	15.77	13.45	30.64
9.3.7	OT	11739.1	11480.6	15.34	11.68	37.90
9.3.8	VU	12482.15	12243.45	60.00	49.75	35.28
9.3.10	OT	73208.95	72080.5	15.23	3.37	32.50

RE Label	JANIS status	Pre-clear (Wet Tropics) Ha	Remnant (Wet Tropics) Ha	JANIS Target percentage of remnant area (before protection)	JANIS Target percentage of remnant area (after protection)	S-A-R Target percentage of remnant area (before protection)
9.3.11	VU	24574.6	24187.1	60.00	50.47	37.90
9.3.12	VU	56312.35	55308.85	60.00	57.83	40.14
9.3.13	VU	99024	96991	60.00	59.00	37.41
9.3.14	VU	14362.3	14094.2	60.00	50.51	37.41
9.3.15	VU	23448.3	21974	60.00	55.69	31.75
9.3.16	VU	30360	28090.5	60.00	59.03	30.64
9.3.26	VU	17074.35	16614.2	60.00	59.77	36.41
9.3.27	OT	32176.3	31983.3	15.09	5.28	28.91
9.5.2	VU	6146.7	5351.7	60.00	53.16	33.72
9.5.5	VU	202076.55	195060	60.00	54.67	33.34
9.5.6	OT	59754.35	55509.2	16.15	16.15	36.49
9.5.8	OT	46997.2	40690.65	17.32	17.20	31.93
9.5.9	OT	89094.05	47111.25	28.37	24.99	35.11
9.5.14	VU	8145	7638	60.00	60.00	34.67
9.7.1	OT	12992.2	12940.45	15.06	14.16	32.50
9.7.2	OT	34341.2	34061.4	15.12	14.85	30.48
9.7.3	OT	61415.2	60002.9	15.35	5.48	41.70
9.8.1	OT	1066681.45	1057145.95	15.14	7.68	36.80
9.8.2	VU	39340.4	20607.2	60.00	56.88	40.27
9.8.3	VU	2532	2510	60.00	0.00	33.72
9.8.4	OT	120255.75	114211.15	15.79	13.53	35.05
9.8.7	VU	87987.25	87980.95	60.00	0.00	33.72
9.8.9	OT	103633.05	102735.2	15.13	11.57	34.17
9.8.13	OT	188667.85	185744.3	15.24	10.19	28.91
9.11.2	OT	13137.3	12742.05	15.47	15.47	29.88
9.11.3	OT	894077.4	887340.55	15.11	13.10	31.93
9.11.4	OT	25424	25238.2	15.11	0.00	29.88
9.11.5	OT	386712.55	381863.5	15.19	15.02	33.34
9.11.7	OT	27938.2	25925.5	16.16	0.00	36.56
9.11.8	VU	6653.85	6597.7	60.00	52.29	33.72
9.11.10	VU	36698.8	35883	60.00	59.21	31.93
9.11.15	OT	124114.85	122942.55	15.14	15.12	29.88
9.11.22	OT	14850.6	14700.5	15.15	15.15	31.93
9.11.23	OT	72083.45	71024.45	15.22	14.61	35.48
9.11.25	OT	212658.05	211258.35	15.10	14.25	33.34
9.11.26	OT	59067.6	58348.05	15.18	12.53	31.93
9.11.27	OT	21559.55	18657.3	17.33	0.00	34.52
9.12.1	OT	705926.95	671121	15.78	15.06	30.10

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9.12.2	OT	121728.4	120224.15	15.19	0.00	36.04
9.12.3	OT	37350.7	36586.65	15.31	12.57	36.48
9.12.4	OT	229294.45	228169.8	15.07	13.26	33.52
9.12.7	OT	523711.05	519319.8	15.13	14.77	31.93
9.12.8	OT	13522.15	13459.45	15.07	1.16	33.72
9.12.17	OT	15618.3	15267.3	15.34	0.00	29.88
9.12.19	OT	12429.1	12397.9	15.04	0.00	29.88
9.12.20	OT	31084	30616.5	15.23	11.25	31.93
9.12.26	VU	2724	2570	60.00	59.30	35.28
9.12.27	OT	399391.35	398257.95	15.04	14.76	31.93
9.12.30	OT	16273.25	15947.4	15.31	0.00	31.65
9.12.31	OT	11259.3	10714.2	15.76	15.76	36.56
9.12.35	OT	31501.25	31471.35	15.01	0.00	31.93
9.12.36	OT	135196.75	134819.65	15.04	12.60	38.63
9.12.38	OT	91739.65	91611.4	15.02	0.00	30.48
9.12.40	OT	11714.8	11654.2	15.08	15.08	32.50

Appendix 3: S-A-R targets for Broad Vegetation Groups and JANIS criteria targets for BVGs derived from regional ecosystem targets

Comparison of JANIS criteria targets and S-A-R derived targets applicable to the remnant extent of broad vegetation groups in the wet tropics plan region. The JANIS criteria targets were derived for regional ecosystems and equated to targets for broad vegetation groups which could be related to regional ecosystems through the common classification of vegetation sub-communities. The equivalent targets for broad vegetation groups were subsequently derived as the area-weighted average of component vegetation sub-communities. The 'hybrid' JANIS criteria status of Broad vegetation groups is interpreted from their JANIS criteria targets (c. 100% = EN, endangered; 60-100% = VU, vulnerable; c. 60% = NT, near threatened; << 60% = NC, not of concern). Further detail is given in the text.

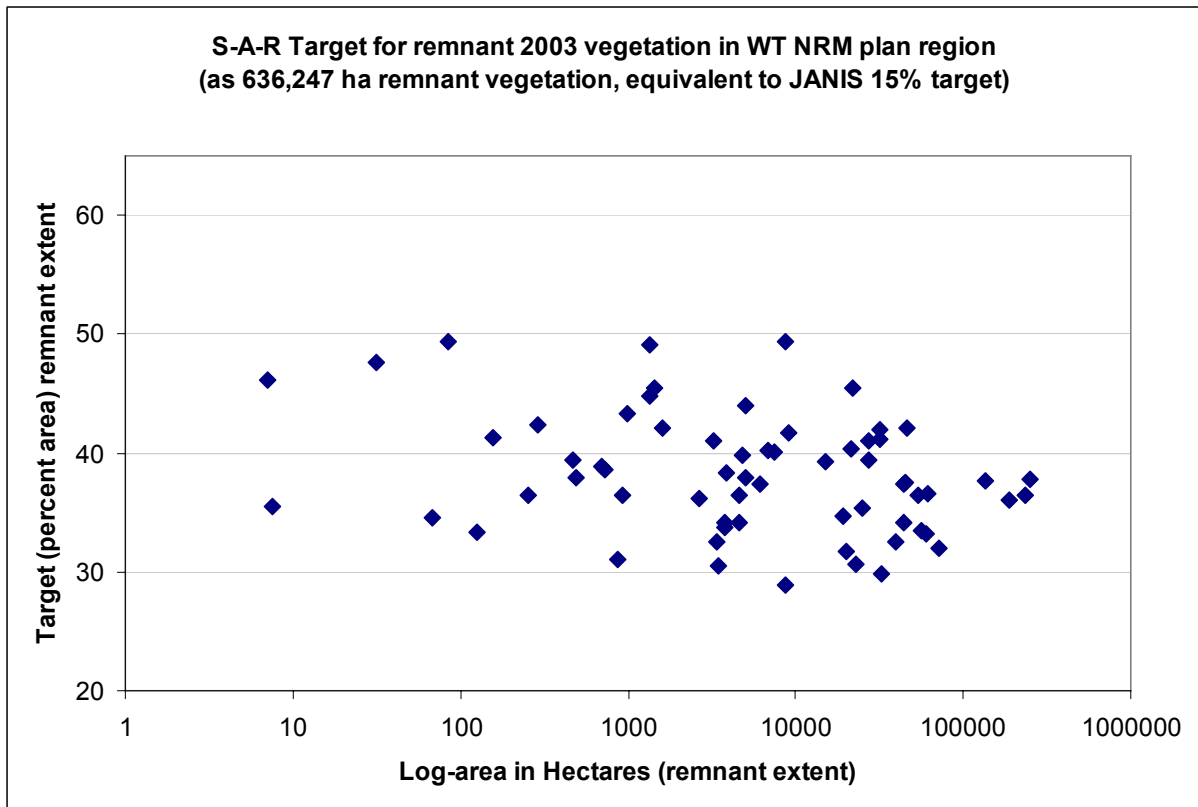


Figure: S-A-R (JANIS criteria) targets for comprehensive sampling of broad vegetation groups in the National Reserve System, applicable to occurrences within the Wet Tropics plan region.

BVG code	Description (1:5 Million class)	JANIS target percentage of remnant area (before protection)	BVG Remnant JANIS status (inferred from target)	S-A-R Target percentage of remnant area (before protection)	S-A-R Target percentage of remnant area (after protection)
10b	Coastal eucalypt woodlands to open-forests	48.71	NC	33.44	15.36
11a	Coastal eucalypt woodlands to open-forests	15.13	NC	34.18	31.71
11b	Coastal eucalypt woodlands to open-forests	15.68	NC	34.18	31.21
11c	Coastal eucalypt woodlands to open-forests	32.09	NC	40.31	33.86
12b	Coastal eucalypt woodlands to open-forests	15.35	NC	41.76	0.00
13a	Coastal eucalypt woodlands to open-forests	28.89	NC	31.94	23.01
13b	Coastal eucalypt woodlands to open-forests	15.22	NC	35.48	35.48
13c	Coastal eucalypt woodlands to open-forests	24.25	NC	29.89	1.16
13d	Coastal eucalypt woodlands to open-forests	57.64	NT	35.29	24.81

BVG code	Description (1:5 Million class)	JANIS target percentage of remnant area (before protection)	BVG Remnant JANIS status (inferred from target)	S-A-R Target percentage of remnant area (before protection)	S-A-R Target percentage of remnant area (after protection)
14b	Coastal eucalypt woodlands to open-forests	15.35	NC	34.57	34.57
14c	Coastal eucalypt woodlands to open-forests	22.84	NC	39.47	0.00
14d	Coastal eucalypt woodlands to open-forests	15.31	NC	36.48	36.48
16a	Eucalypt open-forests to woodlands on floodplains	65.48	VU	31.76	23.77
16b	Eucalypt open-forests to woodlands on floodplains	60	VU	36.14	14.62
16c	Eucalypt open-forests to woodlands on floodplains	59.97	VU	30.65	29.41
16d	Eucalypt open-forests to woodlands on floodplains	99.76	EN	40.15	8.70
17b	Eucalypt dry woodlands on inland depositional plains	15.07	NC	31.01	14.28
18b	Eucalypt dry woodlands on inland depositional plains	60	VU	32.55	30.60
18c	Eucalypt dry woodlands on inland depositional plains	16.79	NC	36.50	34.19
19d	Eucalypt low open-woodlands usually with spinifex understorey	15.17	NC	33.35	33.35
1a	Rainforests, scrubs	99.99	EN	40.99	0.00
1b	Rainforests, scrubs	73.22	VU	41.93	0.00
20a	Callitris woodland - open-forests	15.07	NC	34.10	34.10
21a	Melaleuca open-woodlands on depositional plains	62.44	VU	34.68	0.00
21b	Melaleuca open-woodlands on depositional plains	15.56	NC	32.51	18.56
22a	Melaleuca open-woodlands on depositional plains	98.2	VU	39.32	0.00
22b	Melaleuca open-woodlands on depositional plains	90.1	VU	38.31	6.41
22c	Melaleuca open-woodlands on depositional plains	63.53	VU	37.42	4.82
24a	Other acacia dominated open-forests, woodlands and shrublands	15.27	NC	30.49	14.11
27c	Mixed species woodlands - open woodlands (inland bioregions) includes wooded downs	15.04	NC	38.63	28.61
28a	Other coastal communities or heaths	100	EN	43.35	6.11
28b	Other coastal communities or heaths	60.05	VU	42.07	37.39

BVG code	Description (1:5 Million class)	JANIS target percentage of remnant area (before protection)	BVG Remnant JANIS status (inferred from target)	S-A-R Target percentage of remnant area (before protection)	S-A-R Target percentage of remnant area (after protection)
28d	Other coastal communities or heaths	100	EN	46.13	46.13
28e	Other coastal communities or heaths	43.79	NC	41.09	0.00
29a	Other coastal communities or heaths	100	EN	38.81	18.95
29b	Other coastal communities or heaths	58.25	NT	40.14	0.00
2a	Rainforests, scrubs	16.66	NC	36.40	0.00
2d	Rainforests, scrubs	90.14	VU	45.44	0.00
30b	Tussock grasslands, forblands	15.21	NC	28.92	24.46
32a	Tussock grasslands, forblands	84.37	VU	36.42	25.96
32b	Tussock grasslands, forblands	58.23	NT	42.33	26.88
34a	Wetlands (swamps and lakes)	100	EN	41.32	0.00
34c	Wetlands (swamps and lakes)	100	EN	39.80	16.87
34d	Wetlands (swamps and lakes)	58.45	NT	37.91	37.54
34f	Wetlands (swamps and lakes)	71.65	VU	37.92	0.00
35a	Mangroves and tidal saltmarshes	16.17	NC	37.33	0.00
35b	Mangroves and tidal saltmarshes	60	VU	36.37	8.22
3a	Rainforests, scrubs	100	EN	49.35	22.89
3b	Rainforests, scrubs	100	EN	44.80	0.93
4a	Rainforests, scrubs	99.81	EN	44.04	0.00
4b	Rainforests, scrubs	99.84	EN	40.95	9.81
5b	Rainforests, scrubs	60	VU	39.35	0.00
5c	Rainforests, scrubs	34.07	NC	42.16	0.00
5d	Rainforests, scrubs	54.84	NT	45.52	0.00
6b	Rainforests, scrubs	19.12	NC	37.84	0.00
7a	Rainforests, scrubs	40.67	NC	33.73	0.00
7b	Rainforests, scrubs	84.9	VU	47.61	0.00
8a	Wet eucalypt open-forests	89.8	VU	37.51	0.00
8c	Wet eucalypt open-forests	22.29	NC	49.15	0.00
8d	Wet eucalypt open-forests	97.28	VU	49.37	0.00
9b	Coastal eucalypt woodlands to open-forests	40.16	NC	36.57	0.00
9c	Coastal eucalypt woodlands to open-forests	38.86	NC	37.67	0.00
9d	Coastal eucalypt woodlands to open-forests	28.39	NC	36.05	0.00
9e	Coastal eucalypt woodlands to open-forests	66.95	VU	33.18	4.48

List of Available Conference Abstracts

Abstracts listed in alphabetical order by first author's surname.

Expanding the paradigms of thresholds for coral stress

Dr Ken Anthony, UQ

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MTSRF Project 2.5i.2

Coral reef ecosystems are under increasing pressure from an array of environmental stressors including global warming, ocean acidification and declining water quality in coastal regions. The task of identifying environmental thresholds beyond which coral reefs show declining health and function is becoming increasingly complex, yet increasingly urgent. Here we expand the conceptual framework for studying and assessing stress on coral reefs by linking responses at the level of reef organisms, populations, communities and the ecosystem. Using coral bleaching in response to thermal stress as a case study, we show that response models which build on multiple, nested layers of biological information have more power to predict bleaching severity, mortality risk, and probability of recovery than existing models. One useful metric for quantitatively linking cellular to population-level stress responses in corals is energetics, as resources for coral growth, maintenance and survival are directly affected by coral bleaching and recovery. Incorporating environmental history into an energy-balance framework allows assessment of how stress events in the recent past influence coral bleaching susceptibility and associated mortality. We show that this expanded framework for thermal thresholds provides managers with improved forecasts of bleaching-related mortality and recovery under complex environmental scenarios, and thereby proved opportunities to undertake proactive management to lessen impacts on a local scale.

The acoustic and surface behaviour of coastal dolphins in Queensland: Implications for management

Mr Alvaro Berg, JCU

Berg Soto, A and Marsh, H
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MTSRF Project 1.4.2 Objective (a)

Queensland waters support internationally significant populations of two species of coastal dolphins, (a) the Indo-Pacific humpback dolphin (*Sousa chinensis*), the Australian stocks of which may be a new species of cetacean; and (b) the Australian snubfin dolphin (*Orcaella heinsohni*), first described in 2005 and at present Australia's only endemic cetacean. Despite the importance of these populations, the scientific information required to inform their conservation management is inadequate. To develop effective tools for conserving these dolphins, it is crucial to understand their relationships with their environment, the structure of their populations, and the effects of natural and human disturbance on their communities. Gill-netting is a significant threat to coastal dolphins throughout their range, which includes Queensland waters. The Queensland Government is attempting to ameliorate this threat

using two approaches, (1) employing acoustic alarms (pingers) to reduce bycatch; and (2) equipping fishers with dolphin detection devices so they can change their behaviour in the presence of dolphins. Fisheries independent research is required to determine whether these techniques are likely to be successful and/or have unintended negative consequences for dolphin conservation. This project will use innovative technology to link video and acoustic techniques to investigate the acoustic and surface behaviours, and the responses to acoustic stimuli, of inshore dolphins in Queensland. The outcomes of this research will inform the management of, (1) Queensland Marine Parks including the Moreton Bay and Great Barrier Reef Coast Marine Parks; and (2) inshore gill net fisheries in Queensland waters.

Integrating traditional ecological knowledge into State of the Environment reporting in the Wet Tropics and Torres Strait

Dr James Butler, CSIRO

Butler, JRA and Cullen, L

CSIRO Sustainable Ecosystems and JCU/CSIRO Tropical Landscapes Joint Venture, Australian Tropical Forest Institute, James Cook University, Cairns.

MTSRF Project 1.2.1 and Project 1.3.5

Through the MTSRF research program several projects are aimed at designing and populating frameworks for reporting on the condition of natural resource assets and social-ecological systems. These are largely focused on principles and data derived from a western science perspective. However, there are numerous examples from around the world where Traditional Ecological Knowledge is integrated into such reporting and monitoring. Traditional knowledge provides a potentially valuable source of information, which has several advantages. It may be based on a longer 'time series' than western science data collection, therefore providing a more useful summary of resource trends. It also combines information of ecological and cultural value, and creates a broader social-ecological relevance of monitoring. Schemes which engage Indigenous and non-indigenous communities in delivering monitoring may also provide a source of income, diversifying livelihoods and promoting an incentive for the protection of traditional knowledge. However, there are also challenges. Traditional knowledge may be culturally heterogeneous across small spatial scales, requiring detailed and costly data collection to provide broader regional perspectives. While some traditional indicators of ecosystem health may be compatible with western approaches, others may not. Similarly, western perspectives of 'biodiversity' may not be shared by Indigenous communities, who may value species and places of little significance to the western paradigm. Finally, integrating Traditional and western indicators and data types into popular 'report cards' of regional resource condition presents a major challenge. In this paper we present provisional findings from MTSRF Project 1.2.1 *Status and trends of biodiversity and ecosystem services in the Wet Tropics* and Project 1.3.5 *Data integration and synthesis for development of reports of ecosystem health in the Torres Strait Region* on these opportunities and challenges, and suggest future research directions in this arena.

Factors affecting the evolution of bleaching resistance in corals

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MTSRF Project 2.5i.3

We present a mathematical model of co-evolutionary interactions between partners in a coral-algae mutualistic symbiosis. Our goal is to better understand factors affecting the potential evolution of bleaching resistance in corals, in response to increased average sea temperatures. We explore the evolutionary consequences of four factors: (i) tradeoffs among fitness components; (ii) different proximate mechanisms of coral bleaching; (iii) the genetic determination of bleaching resistance; and (iv) the mode of sexual reproduction. We show that traits in mutualistic symbioses, such as thermal tolerance in corals, are potentially subject to novel kinds of evolutionary constraints, and that these constraints are mediated by ecological dynamics. We also show that some proximate mechanisms of bleaching yield faster evolutionary responses to temperature stress, and that the nature of interspecific control of bleaching resistance and the mode of sexual reproduction interact to strongly influence the rate of spread of resistance alleles. These qualitative theoretical results highlight important future directions for empirical research in order to quantify the potential for coral reefs to evolve resistance to thermal stress.

Visitation and recreation in the WTWHA: a comparison of urban and regional residents

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MTSRF Project 4.9.2 (b) (i)

The Wet Tropics World Heritage Area (WTWHA) is a popular destination for tourists as well as being an important recreational resource for residents of the region. Understanding the attitudes of local residents towards aspects of the management and use of natural resources such as the WTWHA and their access to areas of this nature is important for management organisations and government. Previous work in this area by Bentrupperbäumer and Reser (2006) indicated an overall favourable response of residents. One of the aims of this research was to compare the attitudes of residents of major urban areas with those living in smaller communities. Data was collected via an attitude and perception survey distributed to residents of the Wet Tropics bioregion from May to October 2007. A total of 853 responses were received. For the purposes of this research the attitudes of Cairns respondents are compared with those residing in the Daintree region, southern Wet Tropics region and the Atherton Tablelands.

Residents responding to the survey:

- Ranged in age from 14 -93 years and averaged 49 years;

- 54% had a trades or tertiary level of education;
- Lived an average of 24 years in tropical North Queensland; and
- 55% lived in suburban residential areas (including suburbs of Cairns, Mission Beach, Babinda and Innisfail) and 21% lived in rural residential settings.

One significant finding was that residents of Cairns are willing to travel beyond their immediate locality to sites on the Atherton Tablelands and the Daintree area for recreation with friends and family. Residents of smaller communities are more likely to use sites that involve less travel. The paper details further differences and similarities between the community types identified earlier and comments on management implications.

Restoration outcomes from government investment in rainforest revegetation

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MTSRF Project 4.9.5

Enthusiasm for revegetation of native forest, for a range of environmental outcomes, has mushroomed over the past two decades. This revegetation has often involved tree-planting, supported by government funds. The outcomes of replanting projects can vary widely. In successful rainforest restoration a closed canopy (a key indicator of rainforest structure and process) forms within five years or less. But some sites can become sparsely-treed areas of tall grass or weeds in which planted seedlings have largely struggled or failed to survive, in the face of pressures such as grazing, flood or fire. To what extent does financial investment in revegetation lead to tangible ecological outcomes? We have found that this can be a surprisingly difficult question to answer, because of a lack of systematic recordkeeping in past revegetation projects, combined with a lack of monitoring the outcomes. In this talk we consider and quantify the outcomes in the Wet Tropics of the major nationwide government-funded revegetation scheme: the Natural Heritage Trust's first phase ('NHT1', 1999 to 2002). We ask: what has been attempted, how can outcomes be tracked, what outcomes are apparent so far from recent monitoring, and what are the lessons from this? A database was compiled of all 87 NHT1 vegetation-focused projects in the Wet Tropics. These projects' final reports to the government included objectives and short-term outcomes, although there was no system of independent ground verification. In 2007 we surveyed a stratified random sample of around thirty of these projects (at around fifty sites) for broad vegetation outcomes (such as the area covered by vegetation of varying quality). We will discuss the results of this assessment, including whether factors such as project size, planting design or early 'success' can be linked to later outcomes.

Timing of acroporid coral mortality on two inshore reefs of the Great Barrier Reef: A pilot study

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MTSRF Project 1.1.4

There is a growing concern that inshore reefs of the Great Barrier Reef (GBR) have become severely degraded since European settlement (~1860 AD) with phase shifts from acroporid to algal dominated communities. However, little is known about the exact timing and cause of mortality and whether these losses can be attributed to human or environmental impacts. Dating *in situ* coral rubble (death assemblages) can allow for the temporal bracketing of coral mortality in inshore reef environments in the GBR. High precision ($2 \pm$ up to 1 year) uranium-series (U-series) dating using thermal ionisation mass spectrometry (TIMS) of coral rubble from three sites at Pelorus reef, off of Townsville, revealed three distinctly clustered time periods when most of the coral mortality occurred. Two of the sites were characterized by a dead acroporid coral substrate aged between 1920 and 1950 AD, interspersed by living massive and soft corals. The third site, with modern coral cover being dominated by *Pavona* and *Goniopora* spp., revealed a death assemblage consisting primarily of these two genera that died within the last two decades. To determine whether the demise of inshore reefs occurred at a similar time or sequentially over a larger spatial scale following the onset of European settlement, an extensive dating program will be applied to the inshore reefs off Townsville and Mackay. U-series dating of acroporid coral rubble from Keswick Island, Mackay (now dominated by large stands of brown macroalgae), revealed that the majority of coral mortality occurred between 1880 and 1990. These preliminary results appear to suggest a long-term decline of previously dominant acroporid corals on the inshore reefs in these specific sites. To determine the possible cause/s for mortality, an examination of trace elements in massive corals will be incorporated into this study to investigate the correlation between changes in coral reef community structure and both climate change and the coastal development of Queensland.

Designing a policy package solution for a cassowary population objective

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MTSRF Project 4.9.6(c)

Policy intervention to generate an environmental outcome is often discussed in terms of discrete policy instruments (regulation, market based or incentive instruments or suasive or voluntary instruments). A policy package incorporating synergistic components of some or all, may provide the most effective and efficient solution. But how do you know what to include in the policy mix and how much of which policy type to include, where, when and targeted to who? With the objective of creating a policy solution to move towards the

objective of a viable cassowary population, in this paper we work through a number of steps to begin to answer this policy package conundrum. An effective and efficient package of policy intervention is one which targets actions that directly relate to the objective and operate to best influence human behavior to generate these actions. Targeting actions requires biophysical information (in this case, what do cassowaries need to maintain and increase in numbers) as well as information on the likely behaviour responses to incentives from those that can undertake the required actions. To recommend an instrument type and mode of operation mix we take the biophysical and human behaviour information and demonstrate which instruments generate the greatest net benefit under which circumstances and according to a variety of actor priorities and characteristics. We complete this paper by highlighting the critical operational components of the recommended instrument mix, presenting parameters influential to instrument effectiveness to be tested in the future.

The importance of the Great Barrier Reef as an attraction in Tropical North Queensland

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MTSRF Project 4.8.6 and Project 4.9.2

Reef tourism is arguably the largest tourism sector in Tropical North Queensland, employing a large number of people and generating substantial local income. The profile and branding of the Great Barrier Reef has been so successful that, to some, Tropical North Queensland (a tourism destination) and the Great Barrier Reef (a tourist attraction within the destination) have become almost synonymous. Here we examine the travel behaviour of visitors to the reef, and compare it to nature-based tourists visiting the Wet Tropics World Heritage Area and to more general visitors to the region. The results include interesting differences in visitor profile and travel motivations. In addition, studies of visitors to the region reveal that whilst eighty percent of respondents had visited the rainforest during their visit to the region, seventy percent of respondents had visited the reef. The lower figure for visitors to the Great Barrier Reef is partly explained by the travel behaviour of domestic visitors, only 44.5% of whom visited the Great Barrier Reef. For the remaining 55.5% of domestic visitors, reasons for not visiting the reef included:

- 'Not enough time' (42.9%);
- 'I have been to the Great Barrier Reef before' (28.6%);
- 'Too expensive' (12.1%);
- 'I get seasick' (8.1%);
- 'Don't like diving/snorkelling' (6.9%);
- Other (26%);
- 'I am not a very confident swimmer' (5.7%);
- 'Not interested in the Great Barrier Reef' (2.6%) and;
- 'The reef is too damaged' (1.2%).

These results highlight the importance of continued monitoring of the drivers and trends of tourism on the reef, such as visitor profiles, travel behaviour and satisfaction ratings, particularly as the Reef faces increases environmental threats. We also argue for the need to place the Reef in context as an attraction within the Tropical North Queensland tourism

industry, as a key to understanding overall resilience of the largest income earner in the North.

Status and Trend for seagrass communities in the Great Barrier Reef World Heritage Area

Dr Rob Coles, QDPI&F

Rob Coles, Len McKenzie, Michael Rasheed, Jane Mellors, Helen Taylor, Kara Dew, Skye McKenna, Tonia Sankey, Alex Carter and Alana Grech

MTSRF Project 1.1.3

At the scale of the entire east coast of the Great Barrier Reef World Heritage Area (GBRWHA), seagrass is in a healthy state. At a regional scale, considerable pressures on seagrass meadows remain along the urban coast from river discharge, water quality and urban and industrial development. At small spatial scales (bays, estuaries, meadows), there is considerable variability in meadow biomass and percent cover but there is no evidence of sustained losses or gains where monitoring is occurring. Most changes noted are clearly linked to short-term environmental events. With increasing urban and catchment development further research is required to understand the synergistic effects between high nutrient availability and exposure to pollutants, and between water quality parameters and other disturbances or factors that influence health and production of seagrass and the associated fauna. We are fortunate however that at the moment a great proportion of seagrass meadows are remote from these effects and subject only to natural disturbances and fluctuations. There is a potential of loss from catastrophic events such as oil spills but these risks are generally low for most meadows. There are information gaps. We poorly understand trophic links and resilience, and our ability to populate scenario models with parameters that reflect the tropical environment is limited. Carbon and nutrient mapping of seagrass has not been undertaken in the GBRWHA. The seagrass program within the GBRWHA supported by the MTSRF has been successful in monitoring seagrass condition and assessing risk at a variety of locations and habitats. It is one of the most comprehensive seagrass programs outside the east coast of North America. We report from this program on the status and trends in the seagrass communities within six Natural Resource Management Regions and three community types, estuary, coasts and reefs.

Seabirds in hot water: climate variation and upper trophic level dynamics on the GBR

Dr Brad Congdon, JCU

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MTSRF Project 2.5i.2

Our research aims to identify functional linkages between climatic/oceanographic variation and seabird reproductive and life-history parameters at a range of spatial and temporal scales. To date we have shown that El-Niño associated climate variation impacts seabird

foraging success at two different temporal scales, via (i) between-season, El-Niño-specific decreases in food availability and (ii) via smallscale fluctuations in prey accessibility associated with day-to-day variation in sea-surface temperature (SST). Between-season changes in breeding participation of pelagic foraging species are highly, and independently, correlated with precursive changes in both thermocline depth and productivity linked to El-Niño intensity. Significant negative impacts of these precursors can be observed up to a year in advance of registered El-Niño events. Within-season SST relationships are also consistent among pelagic foraging species. SST effects are seen in all years and locations, independent of prevailing El-Niño conditions, but negative impacts are particularly intense during El-Niños where SST increases of 2-4°C are maintained for extended periods. Preliminary diet and high resolution foraging data combined, suggest that changes in the local availability of preferred feeding habitat and/or *Spratelloides spp.* are likely responsible. Preliminary PTT satellite tracking also identifies clear linkages between seabird reproductive success in the southern GBR and food availability around seamounts in the central Coral Sea. Adult shearwaters travel up to two thousand kilometres to access areas having specific oceanographic features known to be associated with consistent high productivity. At present the potential impact of El-Niño level variation on these at-distance foraging locations is unknown.

Coral reef resilience: quantifying herbivory the capacity for reef regeneration

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MTSRF Project 2.5i.3

Threats to coral reefs are often manifest through an increase in macroalgae. Across the globe, phaseshifts from coral to macroalgal dominance have been reported from the Caribbean, Indian and Pacific Oceans. The Great Barrier Reef (GBR) is in relatively good condition; however, inshore reefs may have over fifty percent macroalgal cover. The critical questions are: what stops the macroalgae from expanding across the shelf and, once established, could macroalgal dominance be reversed? Our main goal was to identify the species responsible for algal removal and develop a robust bioassay for macroalgal herbivory. Using a remote video bioassay approach we quantified herbivory in three bays along the leeward margin of Orpheus Island. Despite considerable within-bay variation there was no detectable statistical difference in the rates of herbivory among bays. However, of the 45 herbivore species recorded from the island only three species played a significant role in bioassay removal, with only one species predominating in each bay. Overall, the bioassay proved to be extremely sensitive to local variation in herbivory and revealed high levels of spatial heterogeneity in both rates of herbivory and the taxa responsible. Reefs of the GBR may be more vulnerable than previously thought, with the removal of macroalgae depending on just a few species which exhibit considerable spatial variability in their feeding behaviour.

Biodiversity and health of coral reefs of the GBR: spatial patterns, temporal change and drivers

Dr Glenn De'ath, AIMS

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MTSRF Project 1.1.5

Coral reefs world-wide are under severe anthropogenic pressure, and effective management of these assets is a subject of interest and debate. A number of diverse large-scale and long-term biotic and environmental data are now available, and we used them to assess spatial patterns and temporal trends of reefs of the Great Barrier Reef through statistical models. We also relate such change to environmental drivers, and identify thresholds of change and link them to indicators of reef health.

2008 flood plumes from the Burdekin and Fitzroy Rivers in the GBR lagoon

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MTSRF Project 3.7.2

Grab sampling was taken in flood plumes discharging from the Burdekin and the Fitzroy in January and February 2008. Both events were sampled at least twice, with a first event focussing on the initial low salinity river waters discharging into the near shore environment. Typically the earlier plume processes and spatial extent of the plume water were controlled by the movement and dispersion of sediment. The later events focussed on the sampling of reef and offshore waters targeting the less turbid plume waters with high levels of phytoplankton production. In all events, we sampled for suspended particulate matter, nutrients, chlorophyll, some pesticides, phytoplankton speciation, dissolved trace metals and CDOM. Spatial extent of plumes in relation to weather characteristics and flow will be demonstrated and compared to historic plume extents. This paper will present some preliminary findings in the differential transport (and trapping) of particulate matter versus dissolved material including the different behaviour of particulate nutrients versus dissolved inorganic nutrients.

Wet tropics rural landholders' Natural Resource Management practices, attitudes and values

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MTSRF Project 4.9.4

This presentation provides an overview of the results of the Wet Tropics Sustainable Agriculture survey, a survey of rural landholders undertaken to aid Natural Resource Management (NRM) program design and delivery in late 2007, early 2008. The survey used mail delivered, self-administered questionnaires to gather information about landholders' natural resource management practices, attitude to currently recommended practices, their goals for land management, perceptions about rural development issues, communication behaviour and socioeconomic circumstances. Most respondents reported few NRM problems on their land apart from weed management. As a rural development issue, the majority are concerned about the declining profitability of farming due to falling commodity prices and rising prices of inputs. Approximately 25% of respondents have a map of remnant vegetation on their property. A similar proportion has prepared a written management plan, with 25% expressing interest in developing a plan. Almost fifteen percent of respondents have an environmental management program in place. Few landholders with native vegetation have active management programs in place. The majority of landholders have a personal interest in native forests and like the look of forests on their property. Their greatest concerns about managing native forests were the costs and the amount of intervention of government agencies. Most livestock producers reported using rotational grazing strategies to maintain grass cover and some soil testing to determine fertiliser requirements. Fewer quarantine new stock or use feedlots when grass cover drops too low. Most crop producers reported adopting a number of recommended practices including minimum tillage, the retention of grass on headlands, application of lime, the use of legume crops and retaining stubble when harvesting. The use of these practices appears to be reasonably common in the community. Some discussion of the intended analysis and reporting of the survey results is provided.

What would school-community level resilience indicators look like? A preliminary discussion of the qualitative data

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MTSRF Project 4.9.7

Staff from schools in far north Queensland catchments, where sustainability education has been a feature of school curriculum and practice, participated in the first round of data collection in 2007 and early 2008. Semi-structured interviews were held with teachers and principals of schools who had won local and state level environmental awards or were implementing the Queensland Environmentally Sustainable Schools Initiative. Participants were invited to explain their school practices and to discuss their understandings of social resilience and sustainability. As researchers, we made the assumption that teaching and administration staff familiar with sustainability principles would be valuable informants to researching of social ecological resilience and water quality. In our presentation we will

present initial results and discuss our ideas about what school community level resilience indicators might look like from a qualitative and descriptive perspective. Our interview data indicate a certain range of identifiable 'enabling practices' are likely to be important in enhancing socio-ecological resilience at community level that may have eventual impacts on water quality in Great Barrier Reef catchments.

Risk, resilience and response atlas for the Great Barrier Reef

Dr Katharina Fabricius, AIMS

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MTSRF Project 1.1.5

Effective management and conservation of biodiversity requires detailed knowledge of the Great Barrier Reef (GBR) including the major risks and factors that determine resilience. In the last few years, the availability of large-scale data and modelling tools has increased substantially. Available data are based on large-scale and long-term surveys, real-time monitoring and satellite-based information, complemented by experimental studies, theoretical models and expert opinion. They include key components of biodiversity (reef, seafloor, seagrass, threatened species), processes that determine biodiversity (such as genetic resilience or physical environmental conditions), and the principal threats to them (climate change, water quality, fishing, tourism use, shipping through invasive species and incidents, and crown-of-thorns starfish) and their interactions. The Reef Atlas is a new effort by the Reef and Rainforest Research Centre Ltd to develop a portal to the GBR. The Reef Atlas project is in the process of compiling a data repository and of developing tools to explore and display such disparate data. We are developing interactive maps, visualisations and interpretative text. We are also in the process of developing the conceptual and statistical framework to integrate and interrogate existing data sets on biodiversity and risks, interpret the various risk factors and produce maps of environmental conditions and distributions of taxa on the GBR. Further, we will use process models and statistical models to assess risk and to prioritise sources of risk. By relating spatial distributions to environmental and socio-economic drivers and thresholds, we can estimate exposure and forecast changes in biotic communities under various risk scenarios (especially temperature and water quality regimes). In this talk, we will present the concepts that underpin the Atlas, show first products of the Reef Atlas, and will outline planned future developments.

Developing indicators of social resilience to changes in Townsville's water quality

Dr Margaret Gooch, JCU

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MTSRF Project Number 4.9.7

The Black Ross water quality improvement plan (WQIP) is being developed by Townsville and Thuringowa City Councils through the *Creek to Coral* program in collaboration with key stakeholders. The plan focuses on both point and non-point sources of water pollution. In the first phase of this study, 22 stakeholders with either a professional or personal interest in water quality were interviewed to ascertain their understandings of social resilience in relation to water quality. These were analysed using directed content analysis to systematically identify key words and phrases. To do this, interview transcriptions were read and re-read, tagging words and phrases that corresponded with specific properties of resilience management in linked socio-ecological systems derived from the literature. These properties are, (i) *resilience* – being able to maintain the same fundamental structure, function and purpose; (ii) *adaptability*; (iii) *transformability*; and (iv) *scale*. These four broad categories were further divided into ecological, institutional, social, economic, cultural, and personal, as these are dimensions of social and environmental impacts identified in literature on social impact assessment. From this analysis, a set of proto-indicators were derived that will be further developed and refined through workshops with key stakeholders. At the same time, stakeholders will be invited to identify barriers and benefits to adopting specific practices required to achieve the water quality targets identified in the WQIP. Workshop results will be used to develop a baseline survey of attitudes and practices that can be repeated over time. Through an approach known as community-based social marketing (CBSM), we aim to enhance the benefits and diminish the barriers to adopting preferred practices articulated in the WQIP. The survey will be repeated after the CBSM intervention has been implemented, to measure the extent to which attitudes and/or practices change.

Assessing the habitat quality of remnant and riparian vegetation

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MTSRF Project 4.9.3

In fragmented landscapes remnant and riparian vegetation may still provide valuable habitat for a subset of native faunal and floral species as well as connectivity between larger habitat blocks. However, such habitat is subject to edge effects and other disturbances that may diminish the quality of habitat, both for resident species and transient faunal use as corridors or 'stepping stones' through the cleared matrix. In August, 2007, a stakeholder workshop considered Wet Tropics areas, placing highest priority on assessment of habitat quality in the urbanizing and agricultural landscape of Mission Beach and surrounds. Remote sensing using post-Cyclone *Larry* aerial photographs rectified to a base mosaic was followed by an

Anaglyph technique that allows stereoscopic examination on the computer screen. This resulted in new post-cyclone vegetation polygons with associated canopy cover classes. Initial analysis in the coastal urbanising areas from Bingil Bay south to Hull Heads was followed by the potential upland-lowland connectivity area through Smith's Gap; and thirdly the Maria Creek catchment to the north and the Tully-Mission Beach Road developments to the south. Canopy cover classes were field-truthed and combined with remnant area or riparian width to form a habitat quality class. These quickly-assessed factors have previously been found to be an excellent surrogate of field-determined habitat quality in the Douglas Shire. Field investigation of vegetation quality classes in the Mission Beach area will commence in May 2008. Rapid transect assessments of vegetation structure and disturbance variables at field sites will use proformas from Project 4.9.5 and also examine microclimate parameters. Habitat quality for fauna will be assessed through replicated bird surveys during the 2008 dry season. The outcome will be a map of the region which outlines habitat quality throughout the cleared landscape and suggests priority areas for maintenance and restoration of connectivity through the landscape.

Climate Change Impacts on Coral Bleaching in the Great Barrier Reef Marine Park and the Socio-Economic Implications

Professor Iain Gordon, CSIRO

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MTSRF Project 2.5i.4

Climate change represents a major threat to the long term functioning and survival of the Great Barrier Reef (GBR). As ocean temperatures rise, the risk that corals will bleach increases and when the exposure is prolonged the corals may die. The problem is compounded when there are additional stressors on the corals including high pollutant concentrations in the surrounding waters. The implications of coral bleaching are many fold including the changes in reef condition, coral and fish assemblages and reef productivity which in turn affects the economic enterprises associated with the reef (i.e. fishing and visual appeal for tourism). A great deal of public money is being provided to improve the management of land based agricultural activities to reduce the supply of pollutants (particularly dissolved organic nitrogen [DIN]) flowing out of the rivers and onto the GBR lagoon, ultimately protecting the health of the reef. In this project we are developing a systems level model that links agricultural land management to the flow of DIN from rivers affecting the risks of coral bleaching in the face of climate change. Ultimately we wish to predict the economic and environmental trade-offs associated with investment in land management to protect the GBR.

Marine species and communities of conservation concern

Ms Alana Grech, JCU

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MTSRF Project 1.4.1 and Project 1.4.2

This program aims to enhance the natural and social science base of issues associated with the management of species and communities of conservation concern in the Great Barrier Reef (GBR) World Heritage Area and Torres Strait, including dugongs, marine turtles, coastal dolphins and dwarf minke whales. We discuss three aspects of the program related to climate change, risk assessment and community training. The influence of cyclones, sand temperatures and sand characteristics on sea turtle distribution were mapped for the northern GBR and Torres Strait and it was found that Bramble Cay and Raine Island have beaches are the susceptible to predicted sea level rise. Information from the times series of dugong aerial surveys was used to investigate the influence of rainfall, Southern Oscillation Index sea temperature on dugong fecundity. Increased rainfall was associated with reduced dugong fecundity with a two year time lag in the Northern Great Barrier Reef Region. Spatial models of dugong distribution and abundance were developed for Torres Strait and the northern GBR. A spatial risk assessment approach located specific sites that may require management attention because of the presence of anthropogenic hazards in high density dugong areas in the GBR. Dugong models and outcomes of the spatial risk assessment were provided to the Torres Strait Regional Authority (TSRA) Torres Strait dugong and turtle project officers and other relevant government agencies to assist in management of the species. The outcomes of the program including the results of dugong aerial surveys conducted in Torres Strait and the northern GBR were delivered to stakeholders through community workshops and presentations. Workshops included an exercise to assess management priorities for key stakeholders, including indigenous custodians and environmental managers. The exercise demonstrated fundamental differences in priorities between Indigenous people and managers. GPS and computer mapping training was conducted in early 2008 on nine different communities of Torres Strait to build the capacity of those communities to effectively manage their natural resources, including dugongs and turtles. Two field based turtle training trips were conducted with TSRA dugong and turtle project officers in 2007: twenty people were trained in turtle tagging and track counts.

Potential effects of climate change on dinoflagellate – macroalgal associations and its consequences for human health

Dr Kirsten Heimann, JCU

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MTSRF Project 2.6.1

Ciguatera, also known as reef-fish poisoning, used to be considered a tropical disease only. However, cases of ciguatera are increasingly being reported from subtropical regions. Ciguatera is associated with trophic transfer of dinoflagellate toxins by herbivorous fish and possibly invertebrates. The benthic dinoflagellate genus *Gambierdiscus*, currently containing eleven recognised species, is a resident of the Great Barrier Reef associating with

macroalgae and with detritus that accumulates on dead coral. Species of *Gambierdiscus* produce gambiertoxins, which are thought to be the precursors of ciguatoxins (trophically transformed gambiertoxins). Higher order predators, such as finfish who feed on these, bioaccumulate the transformed toxins. The extent of dinoflagellate – macroalgal associations is currently unknown for the GBR, but in other tropical regions of the world *Gambierdiscus* species have been identified on more than fifty different macroalgal genera with cell densities reaching more than 70,000 cells/ g macroalga. Climate change has been predicted to cause phase-shifts on coral reefs, where declining live coral cover encourages growth and range expansions of macroalgae. Increases in macroalgal cover will provide additional substrate for associated benthic dinoflagellates as well as increased food supply for herbivorous fish. *Gambierdiscus* species have a relatively broad tolerance for temperature, salinity, and light intensities. Because of this adaptability and increased substrate availability, range expansions are likely to result in correlated increases of ciguatera. To predict the impact of climate change on the incidence of ciguatera requires a solid understanding of current patterns of dinoflagellate – macroalgal associations in the GBR. This will be a major step towards preventative management strategies for commercial and recreational fisheries in the region.

How might evergreen, broad-leaved rainforests affect anthropogenic climate change in the next decades?

Dr David Hilbert, CSIRO

Dr David Hilbert
CSIRO Sustainable Ecosystems, Tropical Forest Research Centre, Atherton QLD

MTSRF Project 2.5ii.3

Several high-profile papers in the previous decade have addressed the question of whether broad-leaved evergreen, tropical rainforests will become increasingly strong, global sinks for atmospheric CO₂ due to “carbon fertilisation” and or increasing temperatures. Based on time-series analyses of a small number of large rainforest plots (typically fifty hectares in size), it has been suggested that elevated atmospheric CO₂ concentrations might stimulate rainforest growth and increase their sequestration of anthropogenic carbon emissions. However, recent publications, focusing on response to observed changes in climate at one or two large rainforest plots conclude that rainforests may not help to ameliorate climate change due to human emissions of CO₂. CSIRO’s series of long-term permanent plots in the rainforests of the Wet Tropics Bioregion provide a unique opportunity to contribute to this debate. The plots are small, 0.5 hectares compared to fifty hectares for most reports on this subject, but they span a very large climatic range (mean annual temperatures and rainfall) within a single bioregion. They have also been censused for an unusually long time period, as much as 35 years. In these data, tree growth rates increase with increasing mean temperature, suggesting that annual, net primary productivity also increase. However, warmer climates are clearly associated with higher tree mortality rates. Consequently, the equilibrium stock of biomass or carbon is less in the warmer lowlands than in the cooler highlands. These results have important implications for how undisturbed tropical rainforests contribute to the global carbon budget and the course of global climate change in this century.

Reef Check Australia community coral reef monitoring of the Great Barrier Reef

Ms Jos Hill, Reef Check Australia

Hill, J
Reef Check Australia, Townsville

MTSRF Project 1.1.2

Reef Check Australia is an environmental non-profit organisation that engages the general public in monitoring the health of Australia's coral reefs. Under the MTSRF program, community volunteers monitor 25 key dive sites on the Great Barrier Reef with the support of dive tourist operators. Surveys are conducted from February to June each year which is the low season for tourism operators. Key outputs include a measure of coral cover, algae blooms and abundance and size-class of crown-of-thorns starfish which are reported as observations and digital images. Outputs are presented in a Google Earth™ layer which enables managers and community members to keep track on the status and trends of Reef Check sites. Other program outputs include community awareness and education initiatives such as community service announcements, a national photo competition and interpretation material for dive tourism operators. Communication initiatives will be run as part of the International Year of the Reef campaign during 2008.

Cassowary conservation through adaptive, collaborative planning at Mission Beach

Dr Rosemary Hill, CSIRO

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MTSRF Project 4.9.6 (b)

Collaborative approaches to natural resource management are emerging internationally as an effective means of solving complex, contentious problems, with authentic dialogue, networks and institutional capacity as the key (Innes and Booher 2004). The emphasis is on the thoughtful process of deliberating together on challenging and usually controversial issues, thereby generating strong community ownership of solutions. However, collaborations also risk jeopardizing conservation outcomes through processes such as elite capture and interest heterogeneity undermining collective action, and jeopardizing internal institution building and resultant outcomes for sustainability (Tai 2007). Terrain NRM's Mission Beach Habitat Network Action Plan (MBHNAP) aims to solve the long-running problem of achieving cassowary conservation through embedding collaboration within an adaptive management framework. This embedding is being achieved through two important planning system innovations: a multi-phase Local Area Planning Framework that emphasises adaptation; and a nested regional planning system that clearly articulates the role of MBHNAP within the hierarchy of the wet tropics regional, State and national regulatory/voluntary plans. In addition, a number of adaptive collaborative instruments are being trialled through a co-research approach. A focus on the biodiversity values, Indigenous cultural values and aesthetic/lifestyle values has proven effective in building collaboration across the diversity of views about what is important in Mission Beach. Modelling a Business-As-Usual scenario attracted wide community interest in a target-setting workshop

hosted in December 2007. Targets developed at this workshop showed a surprising degree of community cohesion in relation to the cassowary conservation issue, suggesting that the adaptive collaborative innovations presented in this paper may prove successful in generating lasting cassowary conservation solutions.

Innes, J.E. and Booher, D.E. (2004) Reframing Public Participation: Strategies for the 21st Century. *Planning Theory and Practice* 5(4): 419-436.

Tai, H.-S. (2007). Development through Conservation: An Institutional Analysis of Indigenous Community-based Conservation in Taiwan. *World Development* 35(7): 1186-1203.

Do green zones benefit fish populations beyond their boundaries? An experimental evaluation

Professor Geoff Jones, JCU

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MTSRF Project 4.8.2

The benefits of no-take marine protected areas (MPAs) to fish populations within their boundaries have been widely documented. However, the extent to which MPAs supplement adjacent exploited populations has not been fully evaluated. On the Great Barrier Reef (GBR), many recreationally important fish species increase in abundance and biomass in no-take 'green' zones. Here we describe the first experiment designed to assess the magnitude of adult migration and larval export from green to blue zones on the GBR. Researchers from James Cook University worked along side volunteer recreational fishers from the Capricorn region to capture, tag and release adult reef fish within four green zones at the Keppel Island Group. More than six thousand fish were externally tagged using standard t-bar anchor tags prior to two spawning periods between November 2007 and February 2008. The numbered tags provide instructions for fishers to report recaptured fish to Infofish services. Recapture data will provide valuable information on movement patterns of reef fish and potential rates of adult 'spill-over' from green zone reefs to surrounding fished reefs. In addition, all coral trout (*Plectropomus* spp.), stripey snapper (*Lutjanus carponotatus*) and long-finned rockcod (*Epinephelus quoyanus*) were injected with a small dose of enriched stable isotope barium chloride (BaCl₂) solution and fin-clipped for DNA fingerprinting. The barium injection is a novel chemical marking technique, with the barium signature passed from reproductive females to the core of the otoliths (ear bones) of their larval offspring. Recruit (juvenile) fish will be collected from reefs throughout Keppel region between March and June 2008. Each individual will be screened for Barium marks and their DNA sampled for genetic parentage analysis. The combination of unique Ba markers and parentage studies will enable us to determine the natal origins of any juveniles successfully exported from green zones to the surrounding fished reefs.

An assessment of wetland connectivity in the Tully-Murray floodplain using a hydrodynamic model

Dr Fazlul Karim, CSIRO

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⁴ Griffith University, Brisbane

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MTSRF Project 3.7.4

The wetlands in floodplains provide a range of ecosystem goods and services in addition to their ability to improve water quality. The ecological condition of a wetland depends on many factors, but a key determinant is how the wetland is connected to other wetlands, streams, rivers and the ocean. Connectivity has major consequences for wetland of different types and the habitats and biodiversity each type can support. Wetland connectivity is driven by the hydrology of the floodplain, which determines both the ambient flow and associated connectivity and the inundation regime and connectivity under flood conditions. This paper describes an initial assessment of the present status of connectivity among the wetlands and streams in the Tully-Murray floodplain under flood conditions. Connectivity was quantified using a hydrodynamic model to calculate the timing, duration and spatial extent of the connections between a number of wetland types. The wetland types were selected from the Environmental Protection Agency Wetland Mapping and Classification and they were reproduced within the hydrodynamic model using a high resolution digital elevation model (DEM). The hydrodynamic model was then run for a number of flood extents, and its outputs of the spatial and temporal variations of water surface elevation were used to compute the timing and duration of connection between the selected wetlands under different flood conditions. The results of these simulations provide a means of identifying the degree of connectivity of different wetlands, ranging from those wetlands that are more permanently connected with streams to those that are connected only when there are over bank floods. The implications of the hydrodynamically derived connectivity are discussed in relation to its importance for wetland habitats, fish passage and biodiversity.

Loads estimation in the Great Barrier Reef: Reporting credible estimates of loads in the face of uncertainty

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MTSRF Project 3.7.7

Pollutant loads from Great Barrier Reef catchments have a central role in water quality improvement plans (WQIPs), as the basis for targets and assessing the effectiveness of on the ground action management actions. This project is focused on identifying robust and scientifically defensible statistical methods for the estimation of annual pollutant loads using monitoring data. A key element of this research will be the development of methods for quantifying uncertainty in loads calculations. Suitable case studies from the GBR will be

identified and used to demonstrate the performance of these methods. This presentation will provide a synthesis of existing knowledge and information relating to loads calculations and will put forward a framework for reporting credible estimates of loads that will be explored in subsequent years of the project.

Pesticide residues in the GBR: A threat to marine ecosystems?

Dr Stephen Lewis, JCU

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⁴ Department of Natural Resources and Water

MTSRF Project 3.7.2

Pesticide residues have been monitored in flood plumes associated with wet season discharge of rivers in northern and central Queensland as the river water disperses into the Great Barrier Reef (GBR) lagoon. Plumes from the rivers Tully, Murray, Haughton, Barratta, Burdekin, Proserpine, O'Connell and Pioneer in the wet seasons of 2005 to 2007 were studied. The most commonly found residues were herbicides such as diuron, atrazine, ametryn and hexazinone which are, for example, used in sugarcane cultivation. Some residues of simazine, most likely associated with catchment plantation forestry use, and tebuthiuron, most likely associated with weed control in beef grazing lands were also detected. Concentrations in the plumes could be related to concentrations of the same residues measured in the river producing the discharge plume which were being measured at the same time. Concentrations of the residues decreased from inshore to offshore as the river water mixed with ocean water but ecologically significant concentrations of a number of the herbicides were detected even at the furthest sites sampled approximately thirty kilometres from the coast and fifty kilometres from the river mouth. Concentrations of diuron and atrazine detected were above those known to produce measurable inhibition of photosynthesis in seagrasses and coral zooxanthellae but the duration of exposure is not clearly known and long-term risk to these organisms not yet able to be assessed accurately. However it is now clear that herbicide residue, primarily associated with sugarcane cultivation runoff, are regularly present in waters of the GBR and that these residues have the potential to cause long-term detrimental effects to GBR ecosystems.

Wet Tropics Management Authority: Making Sense of MTSRF Research

Mr Andrew Maclean, WTMA

Andrew Maclean

Wet Tropics Management Authority, Cairns

Land managers have long recognised the importance of incorporating scientific knowledge into management planning and implementation efforts. However, both managers and researchers have struggled to identify effective processes for doing this. Whilst scientists work to make their studies useful and available, it can be difficult for them to know what

information managers need, when they need it, what format is most useful, and what communication avenues are most effective. Likewise, land managers can struggle to identify issues or effectively articulate them to scientists. Policy makers and resource managers have limited time to search for research results and can be overwhelmed by the abundance of potentially relevant information. They also have a variety of individual and organisational capabilities that influence how they learn about science and how they incorporate science into management.

Collaborative partnerships between the Wet Tropics Management Authority, the Reef and Rainforest Research Centre Ltd and MTSRF researchers highlight the fact that environmental issues are highly complex and require considerations that extend beyond the realms of science. From the Wet Tropic Management Authority's perspective, the delivery and application of MTSRF research can be especially challenging because heritage management includes a broad range of ecological and social topics about which managers and policy makers are expected to be knowledgeable. The alignment and flow of knowledge between researchers and end users has always been a challenge, even though the partners are generally keen to contribute to solutions-based science and effective implementation of resource management policies. The MTSRF program represents an important step in the right direction but systems must be supported by appropriate behaviours among participants. We can speed up the adoption of MTSRF research by involving end users in the knowledge creation by developing meaningful partnerships and interactions; designing integrated research frameworks; sustaining dialogue and better articulation and sharing of knowledge to achieve effective delivery and implementation of outcomes. We are doing this now but must continue to improve.

Just a pretty bunch of trees? Rainforest tourism in the Wet Tropics World Heritage Area

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McNamara, KE and Prideaux, B
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MTSRF Project 4.9.2(a)

While there have been a number of studies on tourist patterns in the Wet Tropics rainforest, they have been undertaken on a-basis and lack a longitudinal framework that allows for the identification of trends and season variations. To rectify these deficiencies a multi site, monthly survey commenced in Nov 2006. The aim of this study is to develop a longitudinal survey framework that reports on a range of visitor characteristics including developing socio-demographic profiles, motivations, satisfaction, seasonality and visitor dispersal. Quantitative surveys were adopted as the primary methodology. In the reporting period (Jan to Dec 2007) a total of 1,408 visitors were surveyed at 6 key sites throughout the region. This paper seeks to address two key questions, 'How important is it for tourists to visit the Wet Tropics rainforest?' and 'Where in the Wet Tropics do tourists visit?' The answers to these questions are important for both management agencies as well as the commercial tourism sector.

Broad trends identified in the research include:

- Visiting the Wet Tropics rainforest was of high importance to visitors (mean = 4.31/5), as was visiting rainforest scenery (mean = 3.51/4).

- Over 80% of visitors believed that if the Wet Tropics rainforest was not world heritage listed, they would still have visited.
- Key hotspots for experiencing the rainforest included Mossman Gorge (60.5%), Daintree (55%) and Kuranda (47.7%).
- Domestic visitors were more likely to visit a number of rainforest locations, compared with international visitors.
- Overall, the satisfaction levels of visitors to the rainforest was high (mean=8.55/10).

We conclude that the data gathered has provided new insights into the profile, motivation and dispersal patterns of visitors, and provides data that will assist management agencies and the commercial sector in the conduct of their operations in the Wet Tropics.

Predicting the biodiversity trajectory of isolated natural forest fragments based on age, size and landscape position

Dr Dan Metcalfe, CSIRO

Metcalfe, DJ, Ford, A and Lawson, T
CSIRO Sustainable Ecosystems

MTSRF Project 1.4.3

Isolation of forest fragments is known to contribute to biodiversity loss and decline in ecosystem health due to changes, for example, in forest microclimate, disruption of ecosystem services such as pollination and seed dispersal, and changes in the relative abundance of seed predators. In order to better quantify the rate at which biodiversity and ecosystem health declines in coastal lowland communities we have begun a program of surveys to look at the current condition of fragments of varying size, distance from larger remnant patches and age since isolation. Work is largely focused in simple-complex mesophyll/notophyll vine forest (Regional Ecosystem 7.3.10a), with bird and plant surveys underway. Ageing of fragments has been achieved through use of old aerial photographs and maps, with fragmentation grouped into recent (less than ten years), middle-age fragments, mostly dating from the King Ranch era of clearances (thirty to fifty years) and long-isolated fragments, including prewar and early colonisation fragmentation. We have also been assessing the characteristics of species which are first lost from fragments, and those of species which recruit into or become more common in fragments, in order to better understand the impact of changes in species composition, and whether there is any replacement of roles as some species disappear and others appear.

Mapping the distribution of weeds and ferals in the Wet Tropics Bioregion

Dr Dan Metcalfe, CSIRO

Metcalfe, DJ, Lawson, T and Butler, J
CSIRO Sustainable Ecosystems

MTSRF Project 1.2.1

The Wet Topics Bioregion hosts more than five hundred naturalised exotic plant species and at least 28 species of feral vertebrates. Many of these species are likely to be harmless, and do not pose a significant threat. A smaller number are serious pests causing major environmental, economic or cultural damage. A third group is so-called 'sleeper' or 'sneaker' species, which apparently are doing little harm but monitoring may indicate that these are potentially serious pests of the future. We are concerned that a serious issue facing the monitoring of the status of and trends in invasive species distribution is the lack of a coherent overview of all pests. Consequently we are attempting to map the distribution of weeds and ferals across the Bioregion in order to (i) highlight clusters of pest species or potential pest species; (ii) relate the distribution of weeds and ferals to environmental and socio-economic variables; and (iii) investigate the gaps in understanding of distributions which may represent significant shortcomings in current monitoring arrangements. We are collating data from Federal and State agencies, from local councils and Natural Resource Management bodies, and from projects funded by the MTSRF, CSIRO and Weeds CRC. This work is at an early stage, but has already identified issues around poor reporting of species with low or no legislative status, species which have now become so common or widespread that they no longer warrant mention, and inconsistent monitoring approaches among stakeholders. Presentation to managers of results collated from various sources is raising awareness of distributional patterns across jurisdictional boundaries, and highlighting mis-matched control effort in some instances. Continued mapping should enhance our ability to support monitoring and control efforts.

Key drivers of wetland health – land use, water quality, connectivity and habitats

Professor Richard Pearson, JCU

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MTSRF Project 3.7.3

Project 3.7.3 aims to develop indicators of ecosystem health and to identify thresholds of concern for freshwater systems in the Great Barrier Reef catchment. These systems range from the fast clear perennial streams of the wet tropics to the large seasonal rivers and waterholes of the dry tropics. The project has previously focused on the streams of the wet tropics and is now moving into the lacustrine wetlands on the Tully-Murray floodplain. It aims to elucidate the key processes that affect ecosystem health in these wetlands, through conceptual modelling, targeted field work and through strong links with Project 3.7.4, which is investigating water movement and wetland linkages throughout the catchment. Predicted key drivers of ecosystem health include land use in the immediate vicinity of the wetlands and in the upstream catchment including impacts of weeds and riparian degradation, water quality

including water clarity, nutrient inputs and dissolved oxygen dynamics; and connectivity between wetlands during major floods, ambient flows, and intervening dry periods. All of these drivers influence the spatial and temporal distribution and characteristics of habitat for aquatic biota. Understanding these influences on habitats, biota and ecosystem function (e.g. food web structure) is the key to appropriate management and to identifying thresholds of concern and appropriate indicators of ecosystem health. This paper presents preliminary models of the main drivers and ecosystem dynamics, and shows how selected indicators (e.g. water quality, invertebrate community structure, fish assemblages, key components of food webs) might be used to assess wetland condition and monitor changes resulting from past and future changes in land use, land management, climate and other influences.

Climate Change Projections for the MTSRF region

Dr Suppiah Ramasamy, CSIRO

Ramasamy Suppiah, John McGregor, Marcus Thatcher, Kim Nguyen, Jim Ricketts, Debbie Abbs and Penny Whetton
CSIRO, Marine and Atmospheric Research, Aspendale VIC

MTSRF Project 2.5ii.1

Climate change projections for the tropical rainforest region based on fifteen global climate model results have been completed. Annual temperature is projected to increase by between +0.5 and +1.4°C by 2030 and between +1.0 and +4.2°C by 2070. Rainfall changes are more uncertain due to strong model-to-model variations. By 2030, projected rainfall changes are between -6% and +5% and for 2070 between -19% and +14%. Much less warming and narrower ranges in rainfall are projected in scenarios with stabilized CO₂ concentrations. Since the publication of the report (Suppiah *et al.* 2007), we have developed climate change projections using probabilistic methods and results are available for four seasons for the whole of Australia. In the future, we intend to produce probabilistic based projections for a number of variables for seasons specifically relevant to the MTSRF region. As a requirement for the wider MTSRF project, we have conducted control and climate change experiments using the CSIRO high resolution, Conformal Cubic Atmospheric Model (CCAM). The horizontal resolution of this model is fifteen kilometres and control and climate change experiments were done for the periods, 1971-2000 and 2055-2085. The CCAM simulations are nested in CSIRO Mk3.0 global climate model (A2 emission scenario). Results based on these experiments will be discussed and necessary data will be made available for end users. A summary of the Development of OzClim, a scenario generator tool, will be given and a demonstration of this tool will also be given. A preliminary analysis of tropical cyclones over tropical Australia has been done using CCAM outputs and these results will be presented.

Suppiah, R., Macadam, I. and Whetton, P. H. (2007) Climate Change Projections for the Tropical Rainforest Region of North Queensland. Unpublished report to the Marine and Tropical Research Facility. Reef and rainforest Research Centre Limited. Cairns (38pp.).

A SMART assessment of water quality partnership needs in Great Barrier Reef catchments

Dr Catherine Robinson, CSIRO

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MTSRF Project 4.9.6(a)

There has been considerable effort to set SMART (specific, measurable, achievable, realistic and timed) targets to halt the decline in the quality of water entering the Great Barrier Reef from diffuse sources. Less attention has been paid to assessing collaborative delivery options needed to meet these targets with industry and catchment communities. Conventional evaluations of collaboration often focus on consensus building processes rather than if and how such arrangements achieve outcomes. This paper adapts the SMART criteria to assess partnership needs to help deliver proposed water quality management outcomes. The criteria were used to guide agricultural industry and local government sector focus group discussions to assess partnership implications of Queensland's Tully-Murray Water Quality Improvement Plan (WQIP). This formative assessment enabled these sectors to assess if and how existing collaborative arrangements adequately considered the *specific* place and purpose of proposed water quality management activities; develop compatible *measures* of delivery and partnerships success between relevant collaborators; negotiate fair distribution of delivery cost and responsibilities between partners to ensure proposed water quality management practices are *achievable*; align water quality activities with partner agendas and capabilities to ensure activities are understood and *relevant* to partners; and consider how delivery through partnerships can be *timed* to maximise benefits of proposed actions. We suggest that the framework can be helpful for collaborators and researchers interested in systematically assessing whether partnerships can adaptively 'fit' collaborator needs to deliver collaborative water quality management plans.

Developing a framework for regional level indicators of social resilience

Professor Helen Ross, UQ

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MTSRF Project 4.9.7

This research involves a collaborative multi-stakeholder approach directed towards the development of a social resilience monitoring and reporting framework. The purpose of this framework is to contribute to our partners' planning and management, and State of the Region reporting. Our role within a larger project is to contribute indicators for social resilience, and a framework for their use, at a scale that roughly equates with that of a regional body's management. Our approach is participatory, and integrates the needs of several partners working within overlapping boundaries. The five person research team for this project comprises diverse disciplinary backgrounds. Initial team meetings identified two cross-disciplinary goals for the research, (a) the need to draw out the current knowledge from a diverse range of disciplinary literature relating to the broad topic of reporting social outcomes of development; and (b) to adopt a holistic approach in developing regional level

indicators of social resilience that draws from diverse disciplinary perspectives. This paper will present the draft framework, which is currently under discussion with our partners. It will also present an overview of the types of indicator that might, according to the literature, be most useful within this framework. Our framework will focus on two uses, monitoring for the 'state' of the social environment within which our partners work, and monitoring for program improvement. In this context a framework for regional level indicators of social resilience requires three key components, a clearly articulated:

- Purpose for developing the framework;
- Conceptual and operational approaches underpinning the framework; and
- Social resilience domains, monitoring criteria and indicators.

An increased understanding of the social aspects of development, gained through the monitoring and reporting of social resilience, will enhance the capacity of regional level governance to manage for social and ecological change.

Monitoring the effects of management zoning on inshore coral reefs of the Great Barrier Reef Marine Park

Professor Garry Russ, JCU

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MTSRF Project 4.8.2

James Cook University (JCU) began monitoring effects of Marine Park no-take zoning on inshore coral reefs in the Palm Islands in 1998, the Whitsunday Islands in 1999 and the Keppel Islands in 2002. The program documented up to a two- to four-fold higher density and biomass of coral trout (the major target of the recreational and commercial line fisheries on the GBR) in no-take ('green') zones protected for eleven to fifteen years than in 'blue' zones open to fishing. These were the largest differences in coral trout abundance between green and blue zones ever documented on the Great Barrier Reef. Combined with reliable data showing relatively low coral trout density in 1984 (pre-1987 zoning) in the Palm and Whitsunday Islands, the results suggested that zoning was the likely *cause* of the higher trout abundance in green zones inshore. Subsequent monitoring has demonstrated that the zoning effect on coral trout has persisted inshore for almost a decade. Other evidence suggests that zoning also influenced abundance of coral trout prey fish. In early 2004 James Cook University researchers systematically collected baseline (pre-Representative Areas Program or *RAP*) data on fish and coral abundance inshore. Areas designated to become new green zones were surveyed *before* RAP implementation, along with control areas remaining open to fishing. James Cook University documented significant increases (by 65-68%) in coral trout density in two of three inshore island groups (Whitsundays, Palms) just 1½-2 years after zoning. Similar surveys by the Australian Institute of Marine Science recorded significantly higher (by 31-64%) coral trout density on new green reefs relative to blue reefs in four of five offshore regions 1½-2 years post-RAP. Here we briefly report on the most recent (three years post-RAP) monitoring of inshore reefs. Results have generally documented that no-take zoning can produce "more fish and bigger fish". The next question is: does this extra breeding potential in green zones 'connect' to fished (blue) zones?

Reducing distribution and impacts of invasive fish species using environmental predictor variables

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MTSRF Project 2.6.2

Understanding the distribution and abundance of invasive fish species in landscapes enables prediction of those landscape features that may drive invasion. Specifically, the ability to spatially predict presence and abundance of invasive fish in landscapes based on (combinations of) environmental variables can be used to (i) highlight the most probable locations for inspection and remediation, and (ii) provide recommendations for landscape rehabilitation and management to prevent and reduce spread. Predictive understanding of invasive species' distribution and abundance in a landscape context can be greatly enhanced through the use of new information processing systems, such as Artificial Neural Networks (ANN). The key element of an ANN is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurones) working in unison to solve specific problems. An ANN is configured and trained for a specific application, such as pattern recognition or data classification, through a learning process. In previous CSIRO work, ANN has been trained to produce a non-linear relationship between biophysical indicators and vegetation types in the Wet Tropics. More recently, using existing data from CSIRO and the Queensland Department of Primary Industries and Fisheries, we have provided a proof-of-concept that an ANN can be trained, and, most importantly, can predict the presence of invasive fish based on environmental variables at individual sampling locations in three Wet Tropic streams. We believe that this success warrants further research investment to develop ANN at a catchment-wide scale, including spatial data on landscape features and invasive fish abundance. If successful, such an ANN would contribute significantly to the development of targeted management strategies to control, contain and prevent spread of invasive fish species at the landscape level.

Can we really predict how species will respond to contemporary climate warming? Finding rainforest birds with a thermometer and rain gauge

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MTSRF Project 2.5ii.4

A critical question in global change biology is whether models that successfully predict current species' distributions will provide meaningful predictions of species' distributions under future climate change? The obvious hurdle for evaluating model performance under climate change is that there are no data against which predictions of future ranges can be tested. One way to overcome this problem is to test models through "space-for-time" substitution. That is, distribution models can be trained in one region and used to predict distribution in another region. The extent to which predictions match reality is then an explicit test of the 'transferability' of the model. In the Australian Wet Tropics, model algorithms of

species-climate relationships have already been employed to predict impacts of contemporary climate change on the unique, endemic rainforest fauna. While the resultant impact predictions are severe, no attempt has yet been made to evaluate the transferability of the models on which such predictions have been founded. Here, we address this deficiency by testing predictive distribution models using a “space-for-time” approach and data on rainforest birds. Specifically, we use species-climate relationships established within the Wet Tropics region to predict the distribution of the same species in warmer, lower latitude rainforests on Cape York Peninsula. We then use independently collected observation data to test these predictions.

The ‘Other’ reef fish species: resilience based on life history

Dr Colin Simpfendorfer, JCU

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James Cook University

MTSRF Project 4.8.3

The Coral Reef Fin Fish Fishery on the Great Barrier Reef has three quota groups – *coral trout*, *red throat emperor* and *other* species. The ‘other’ species group includes a wide range of species, most of which are biologically poorly known. The life history of the more commonly captured species in this group are being examined based on samples collected during the Effects of Line Fishing experiment from 1995 to 2005. The life history of four members of the Family Lethrinidae (*Lethrinus atkinsoni*, *L. lentjan*, *L. nebulosus* and *L. olivaceus*) were examined in the current study. Life history was highly variable between species, and was independent of maximum size. Maximum ages varied from fourteen years for *L. olivaceus* and 36 years for *L. atkinsoni*. *Lethrinus olivaceus* grows rapidly to a large size, while *L. atkinsoni* grows slowly and to much smaller sizes. Growth of *L. nebulosus* was also rapid and they changed from female to male at four years of age. Although members of the family are considered to be protogynous hermaphrodites, the data suggested complex reproductive patterns including the existence of juvenile hermaphrodites in some species. The implications of the highly variable life history for the resilience of coral reef fish communities and their management will be discussed.

Downscaling climate change to a reef on the Great Barrier Reef: the Heron Island case study

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MTSRF Project 2.5i.1

A coarse-resolution, climate change version of a global ocean-atmosphere model will provide scenarios of future climate change in the oceans around Australia. Its high-resolution, eddy-resolving version will provide information about climate change on a horizontal scale of ten kilometres around Australia. Further downscaling with a suite of three increasingly higher-

resolution, nested models will allow simulation of climate change scenarios at the reef-scale (less than one hundred metres' horizontal resolution). The suite of models focused on Heron Island in the Capricorn Bunker group in the Southern Great Barrier Reef will be calibrated against an intensive physical oceanographic array of instrumentation. The field study was undertaken in the Capricorn Bunker region over 2005-2006 and coincided with a mild bleaching event. A sister project (MTSRF Project 2.5i.2) is analysing this data together with remotely sensed observations in order to characterise the current state of local oceanography. Ten austral summers for the period 2060-2070, will be modelled in order to discern any changes in circulation, temperature response, and mixed layer depth and ocean-shelf interactions. A review of impacts of climate change on the physical oceanography of the Great Barrier Reef is providing a basis upon which we can explore what processes may be affected by climate change when analysing the different scenarios. Key processes that may be affected are the circulation, temperature response, mixed layer depth and ocean-shelf interactions.

Recreational fishers' perceptions of the costs and benefits of the 2004 Great Barrier Reef Marine Park Zoning Plan

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Stephen G. Sutton

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MTSRF Project 4.8.5

In 2004, the Great Barrier Reef Marine Park Authority implemented a controversial Zoning Plan that increased no-fishing zones from five percent to 33% of the total Marine Park area. Anecdotal evidence suggested a high level of opposition towards the rezoning among recreational fishers before and after implementation of the Zoning Plan. Results from a recent survey of recreational fishers revealed that approximately 60% of fishers support the plan and believe it will enhance the sustainability of the Great Barrier Reef and associated fisheries. In general, the effects of the 2004 Zoning Plan on recreational fishing activity appear to be less severe than fishers had expected with most fishers (73%) reporting that the rezoning has had little negative impact on their fishing activity. However, fishers who were more avid, experienced, and committed to fishing (representing approximately twenty percent of the recreational fisher population) reported experiencing significantly more impacts on their catch rates, ability to access quality fishing locations, cost of fishing, and fishing satisfaction than the majority. A significant number of recreational fishers did not believe that the concerns of recreational fishers were adequately considered in the rezoning process, resulting in a low level of trust in the Great Barrier Reef Marine Park Authority among recreational fishers. Results suggest that opposition towards the 2004 Zoning Plan expressed publicly by some recreational fishers is due to dissatisfaction with the rezoning and consultation processes rather than dissatisfaction with the outcomes of the 2004 Zoning Plan. Support for marine protected areas and coral reef conservation among recreational fishers could be enhanced by developing more effective methods of engaging the recreational fishing community in the decision making process.

Update on the status of reefs of the Great Barrier Reef from the AIMS Long-term Monitoring Program

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MTSRF Project 1.1.2

The eighth Status Report on the Great Barrier Reef based on the Long-term Monitoring Program of the Australian Institute of Marine Science is scheduled for completion in March 2008. The report includes summaries of long-term monitoring data for the whole Great Barrier Reef, for latitudinal sectors and for individual survey reefs. Particular emphasis will be given to current status of *Acanthaster planci* outbreaks and impacts of coral diseases.

Desperately seeking Symbiodinium: Biogeography of a symbiont

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MTSRF Project 2.5i.2

The identity of endosymbiotic dinoflagellates (*Symbiodinium*) living in a wide variety of reef organisms, such as stony corals and soft corals, is of major importance because physiological differences between *Symbiodinium* types partly determine the response of their host to increased water temperature and bleaching. We have compiled the current state of knowledge of *Symbiodinium* diversity on the Great Barrier Reef (GBR), establishing a database that comprises approximately 1,500 samples, from fifty locations and spans multiple host taxa. Whilst five different *Symbiodinium* clades (A, B, C, D and G) are identified on the GBR, the majority of taxa contain clade C with a vast variety of subcladal C types. Despite the wealth of information contained in this database, it has also highlighted numerous areas of the GBR that are still largely understudied and really should be included in diversity estimates. In response, collections and collaborations have been established to include inshore sections of the GBR, as well as collections from the Far Northern Section of the GBR. ITS2-DGGE will be used to assess the diversity of these new locations and the information populated into the existing database. The outcomes from this large-scale project will be assessed in relation to a wide range of environmental factors obtained from satellite imagery and on site long-term monitoring efforts, and the combination of these data-sets is envisaged to yield a valuable tool to improve our ability to predict sensitivity risks on the GBR in response to future climatic change.

Ecological impacts of tropical cyclones on terrestrial ecosystems of the Wet Tropics region: insights from Cyclone Larry

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Turton, SM
James Cook University / CSIRO Tropical Landscapes Joint Venture

Related to all MTSRF Rainforest and Catchments Projects

Cyclone *Larry* (Category 4) was the most severe tropical cyclone to impact on the Wet Tropics bioregion since the devastating 1918 Innisfail cyclone. Based on an analysis of earlier cyclones impacting on this region over the period 1856-2006, it was determined that *Larry* was a one in fifty year event. This significant disturbance event provided researchers with a unique opportunity to examine ecological impacts and recovery of continuous and fragmented forests along a gradient from the coastal plain south of Cairns through to the Atherton Tablelands. Under the auspices of the Tropical Landscapes Joint Venture an integrated program of research was undertaken after the cyclone with many projects linked to the MTSRF portfolio of research. Most researchers had extensive pre-cyclone data for these landscapes, providing opportunities to quantify impacts at species, community and ecosystem levels and to put in place long-term studies of recovery. Outcomes of this program of research are to be published in a special issue of *Austral Ecology* in May 2008. This paper will give an overview of the major findings and insights of the “Cyclone *Larry*” research program and what we have learnt from this significant environmental catastrophe. Implications of these insights from Cyclone *Larry* for future management and conservation of our wet tropics landscapes will be discussed, particularly in relation to future climate and landuse change scenarios.

Hot and Productive? The impacts of climate change on above ground productivity in the Australian Wet Tropics

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MTSRF Project 2.5ii.4

Primary productivity is an important component in understanding patterns of biodiversity, terrestrial carbon fixation and the prediction of potential changes in forest ecosystems as a response to projected climate change. In order to maximise our adaptive management potential in the face of climate change, a mechanistic understanding of the links between productivity and biodiversity is important in the highly productive and diverse forests of the tropics. Despite its significance, direct measurements of productivity are lacking in most tropical ecosystems, including the Australian Wet Tropics, due to the cost and complexity of the measurements. This project addresses this gap in our knowledge by monitoring aboveground primary productivity across the major altitudinal and latitudinal gradients of the region. I am estimating productivity using leaf litter turnover rates and woody growth combined with local climatic surrogates. Results to-date suggest significant changes in productivity are predicted under expected climate change across both, altitude and latitude. The first is directly related to the amount of rainfall and cloud cover, causing mountaintop

forests to increase their productivity in the short term due to improved light interception and reduced water saturation. The latter is related to seasonality, with southern areas experiencing lower rainfall and a longer dry season, thereby reducing overall productivity in those areas. The results of this research will add significantly to our understanding of the links between ecosystem processes and biodiversity and allow more robust predictions about the impacts that climate change will have in the rainforests of the Wet Tropics World Heritage Area.

Stability begets diversity: patterns of rainforest vertebrate diversity in Australia's Wet Tropics in light of long term habitat and short term climatic stability patterns

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MTSRF Project 1.2.1 and Project 2.5ii.4

Of the many hypotheses proposed to account for large-scale patterns of species richness, it is widely believed that some aspect of contemporary climate (precipitation, temperature, net primary productivity, etc.) ultimately controls large-scale patterns of species richness. However, historical factors, such as fluctuations in habitat associated with late Quaternary climate fluctuations, have been shown to improve our understanding biogeography, evolutionary dynamics and patterns of biodiversity. Here we propose that stability in terms of long-term habitat and short-term climate can explain much of the patterns of diversity in the Australia Wet Tropics (AWT). Total and taxon-specific species richness estimates were created based on overlapping modelled distributions of vertebrate rainforest species. Habitat stability estimates were based upon rainforest stability since the last glacial maximum and climatic means and stability (temperature and precipitation) was estimated using Anuclim. Long-term habitat and short-term climatic -stability generally explained nearly the same amount of variation in species richness with contemporary climate means being the best predictor. The best regression models were often the models that included aspects of historical habitat stability and both contemporary climate means and stability. These models were able to explain up to 75% of the variation in species richness. This has important implications with respect to climate change. While the climate projections for the AWT suggest that temperature will increase and precipitation may or may not change, the seasonality of both is projected to dramatically increase. The stability of the habitat (e.g. long timelag associated with shifting vegetation) may be able to mitigate some of the immediate changes in climate.

Socio-economic constraints to and incentives for the adoption of land use and management options for water quality improvement

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MTSRF Project 3.7.5

Agricultural land use in coastal catchments of the Great Barrier Reef (GBR) region in Australia is shown to lead to (diffuse source) water pollution and subsequent resource degradation in the downstream marine environment. To ensure sustainable economic development of coastal regions, we need to balance marginal benefits from terrestrial (agricultural) water pollution and associated marginal costs from marine resource degradation. Water pollution from GBR catchments is, however, considered an externality and, consequently, market-based instruments can be used to internalize this externality such that market behaviour could lead to a social welfare maximizing outcome. We employ a spatial environmental-economic modelling approach that integrates a land use and value chain model with a hydrological model, to assess the cost-effectiveness of various market-based instruments in promoting industry adoption of management practices for water quality improvement.

Genetic approaches to assess the susceptibility and adaptive potential of corals to climate change

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MTSRF Project 2.5i.2 and Project 2.5i.3

Corals are suffering a growing frequency and intensity of coral bleaching with rising global temperature. The potential to adapt to increasing temperatures depends on the extent to which there is an underlying variable genetic component for thermal tolerance, which has never been estimated in corals. Here we (1) Assess the heritable genetic variation in thermal tolerance in one common coral species by partitioning the variance among coral clones (environmental differences) versus that among genetically distinct coral colonies (environmental and genetic differences), and (2) Determine whether past adaptation has occurred in distinct thermal environments on the GBR. Heritable genetic variation was estimated for several traits related to thermal tolerance and found to be fairly high. However, the predicted increase in thermal tolerance from one generation to the next in response to selection was small, suggesting little potential to cope with rapid climate change through genetic adaptation. Other populations are currently being examined to test whether adaptive potential varies across populations. Past adaptation was investigated through comparing

patterns of gene expression of field-sampled coral colonies from two distinct thermal environments followed by a ten-day acclimation in a common environment. A number of genes were differentially expressed in the two thermal environments, with this difference being maintained after acclimation. These data suggest that past adaptation to local environmental conditions has occurred. A considerable number of genes were differentially expressed following acclimation but showed no difference between sampling locations, suggesting a substantial potential to up and down-regulate genes through acclimatisation to ambient temperatures. Gene variants associated with the bleaching response and thermal tolerances are likely under selection and can potentially be used as markers of bleaching susceptibility and risk mapping. Several genes are being targeted for this purpose and preliminary results will be presented.

The contribution of floods to sediment and nutrient export to the Great Barrier Reef lagoon: an example from the Tully and Murray catchments

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MTSRF Project 3.7.4

Current estimates of the loads of sediment and nutrient to the GBR lagoon are based on river water quality runoff modelling and measurements of river discharge and sediment and nutrient concentrations. However, some of the load may be transported to the ocean in large flood events, where over bank flows are not well recorded by standard river gauges. In addition, the concentrations of sediment and nutrients during floods may not be the same as those recorded during channelised flow. This paper describes an analysis of sediment and nutrient concentrations that were measured in flood waters on the Tully and Murray floodplains in northern Queensland. These concentration data were combined with estimates of flood discharge to calculate the loads of sediment and nutrient delivered to the GBR lagoon during floods in 2006 and 2007. Although absolute concentrations of sediment and nutrient were relatively low, the large volume of water discharged during floods means that they make a very significant contribution to the marine load. For example, during the 2007 wet season the three flood events alone carried sediment and nutrient loads similar to the total annual average river borne loads. Since much of the flood discharge is not measured by the river gauges, this flood load will be largely additional to the currently estimated annual riverine load. The implications of this for marine load reduction plans are discussed.

Eddy and upwelling dynamics in the southern Great Barrier Reef

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MTSRF Project 2.5i.2

This study focuses on the physical oceanographic processes in the southern Great Barrier Reef (GBR) and, in particular, the East Australian Current (EAC) and mesoscale eddies that impact the ecosystem. Upwelling processes play an important role in ecosystem dynamics by bringing cooler, nutrient-rich waters onto the continental shelf. In the southern GBR, coral reefs located on the mid to outer continental shelf are susceptible to frequent eddy intrusions from the EAC, the associated upwelling modulated by the wind and tide. A highly variable circulation is apparent in the southern GBR. The presence of an eddy in the region was first noted in 1970 in a surface drifter study (Woodhead, 1970). Subsequent oceanographic deployments and satellite sea surface temperature studies (Middleton *et al.* 1994, Kleypas and Burrage *et al.* 1994, Burrage *et al.* 1996) have shown these to trigger upwelling along the continental shelf. In this study, we seek to advance understanding of the mechanisms driving circulation in the southern GBR by utilising concurrent in situ and satellite image observations. An intensive array of oceanographic instruments was deployed in the Capricorn Bunker group of reefs over the summer of 2005-2006. The array was designed to observe current patterns, and to detect temperature and salinity variability. Current meter moorings were deployed on the shelf slope and on the shelf. Satellite data were obtained from the MODIS sensor aboard NASA's satellites and sea surface temperature and chlorophyll imagery generated to provide a spatial context in which to interpret the in situ data. The main processes influencing the circulation in the southern GBR are shown to be the EAC recirculation (mesoscale eddy) dynamics, wind and the tide. The analysis of the data captures a coral bleaching event in January 2006. A three-dimensional regional model was applied to clarify the large scale circulation and the shelf-ocean interactions.

Understanding the impact and spread of fleshy-fruited rainforest invasives

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MTSRF Project 2.6.2

Invasive rainforest plants are a serious threat to the environmental values of the Wet Tropics Region and have the potential to result in severe financial costs. Because of the complexity of topography, plant communities and vegetation structure in the Wet Tropics, monitoring and managing rainforest invasions an expensive and exhausting task. Thus understanding the impact of invasive species represents an important consideration prior to instigating management while developing an ability to predict the scale and pattern of spread represents an efficient means of improving management effectiveness. To examine impacts we

documented co-occurrences between four common exotics and rare native species in the endangered rainforest vegetation type, *Complex Notophyll Vine Forest* (Type 5b). In plots in which ‘strong’ invaders occurred, rare native species were less likely to occur, there were fewer native species overall, and, fewer native functional groups. Rare species from abundant functional groups were most affected. To predict invasive spread we are using a detailed, empirically-based, mechanistic model of vertebrate seed dispersal processes in Wet Tropics rainforests to develop a spatially-explicit, predictive model of the invasive spread of key weeds such as the fleshy-fruited Melastome, *Miconia calvescens*. We tested the model by post-predicting the spread of *M. calvescens* over a thirty year period at a major infestation at El Arish. Our goal was to assess the ability of the model to predict spread and to use discrepancies between the predicted and actual distribution of plants to identify limitations in our modelling as well as possible barriers and conduits to dispersal. The model under-predicts the frequency of short-distance dispersal while over-predicting maximum dispersal distances. Comparison of predicted and actual distributions highlights the benefit of incorporating spatially explicit aspects of both dispersal activity and recruitment probabilities into the modelling framework.

Current, pre-clearing and 2025 scenarios of vegetation cover and cassowary habitat in Mission Beach and surrounds

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MTSRF Project 4.9.6 (b)

Before settlement, the vegetation of Mission Beach, Northern Queensland, was dominated by tropical forest and woodland with minor occurrences of scrub, grassland and wetlands. Cassowary ranged throughout the coastal, hinterland and tableland areas of the Wet Tropics, favouring the low lying coastal areas of Mission Beach. By 2004, however, more than thirty percent of the original vegetation had been cleared from the most arable and accessible parts of the coast and hinterland of Mission Beach. Open forest and woodland vegetation were preferentially removed and only about fifty percent remain today. Large areas of closed forest were also cleared but more than seventy percent remains intact; much of which is now protected. Increasing concerns about the fate of cassowary and biodiversity in general are being addressed through adaptive, collaborative planning. Under a ‘business-as-usual’ scenario, intensive land use to accommodate human population growth was projected to result in clearing of the majority of unprotected coastal forest vegetation by 2025 which has major implications for cassowary conservation. This information was used to support community consultation and collaboration in the Mission Beach Habitat Network Action Plan, an initiative of Terrain NRM.

Potential gaps in the complementary representation of regional ecosystems within protected areas of the Wet Tropics Natural Resource Management (NRM) region

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MTSRF Project 4.9.6 (b)

Australia's National Reserve System (NRS) is a network of protected areas conserving examples of our natural heritage for future generations. The scientific underpinning of the NRS is a framework for achieving a 'comprehensive, adequate and representative' (CAR) system of protected areas¹. By addressing the requirements of component ecosystems, this framework aims to ensure the greatest probability of long term survival of native species, communities and ecosystems. In the context of this framework we consider whether there is a need for further work to meet the strategic direction of the NRS in the Wet Tropics. We are tackling this problem by separately addressing each element of the CAR reserve system and a prioritization framework for their integration. Here we present the results of our analysis of comprehensiveness applied to the Queensland regional ecosystem framework². Comprehensiveness is formulated within the principle of complementarity³. The goal of the NRS is to represent at least fifteen percent of the original extent of each bioregional ecosystem type within protected areas, with higher targets for rare or threatened ecosystems. Protected areas include privately owned and managed nature reserves that are legally recognised through covenant on title and managed resource protection areas such as State Forests and Timber Reserves. We applied a model of complementarity which uses traditional 'fixed' targets, including requirements for threatened ecosystems, and found that 36% of the Wet Tropics NRM plan region was needed to satisfy comprehensiveness. We can also derive comparable targets utilising species-area relationships which recognise that some ecosystems will have higher rates of species turnover than others. This approach boosts the rigor of our analysis and again highlights the need for more work on the NRS. Our approach to comprehensiveness addresses the goals of the NRS and improves the biodiversity surrogacy value of vegetation mapping data. This improvement addresses one of the perceived limitations of systematic conservation planning, that "setting targets for representing conservation features is not possible"⁴.

1 Natural Resource Management Ministerial Council (2005) *Directions for the National Reserve System – A Partnership Approach*. Australian Government: Department of the Environment and Heritage, Canberra, ACT.

2 Neldner, VJ, Wilson, BA, Thompson, EJ and Dillewaard HA (2005) *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland, Version 3.1*, Queensland Herbarium, Environmental Protection Agency, Brisbane 128pp.

3 Margules CR and Pressey RL (2000) Systematic conservation planning. *Nature*, 405: 243-53.

4 Smith, RJ, Goodman, PS and Matthews, WS (2006) Systematic conservation planning: a review of perceived limitations and an illustration of the benefits, using a case study from Maputaland, South Africa. *Oryx*, 40: 400-410.

5 Ferrier, S, Manion, G, Elith, J and Richardson, K (2007) Using generalised dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. *Diversity and Distributions*, 13: 252-264.

Assessing the vulnerability of biodiversity to global climate change: a case study using Australian tropical rainforests

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MTSRF Project 2.5ii.4

Description of a general conceptual model to assess the relative vulnerability of biodiversity to global climate change. Assessing relative vulnerability and the factors determining or alleviating vulnerability is a key step towards the efficient allocation of management resources. I will illustrate the model with empirical data from extensive ongoing research on rainforest biodiversity in the Australian Wet Tropics bioregion carried out in the Centre for Tropical Biodiversity and Climate Change. Vulnerability is a function of both the degree to which an organism, habitat or process is exposed to change and its relative sensitivity to the change. The realized exposure to a climatic change will be dependent on the degree of change that occurs across the range of the organism and the degree to which local microhabitat or topographic buffering might reduce the exposure. The sensitivity of an organism will be dependent on a number of factors intrinsic to the specific organism especially its life history, physiological tolerances and preferences, the area required to maintain a viable population and its general ecology. However, all organisms will also have some intrinsic capacity to adapt to changing conditions via ecological plasticity and/or evolutionary adaptation. The realised sensitivity will thus be the result of the intrinsic sensitivity mediated by its natural adaptive capacity. The combination of the realized exposure and realized sensitivity will determine the potential impacts on the species/habitat/process. Finally, any impacts in biological systems will inevitably have flow-on effects and produce further changes in biotic interactions, changes in assemblage composition and ecosystem processes. These feedback effects will produce further changes to the ecology and both biotic and abiotic interactions, thereby altering the intrinsic sensitivity of the species or habitat. These feedback mechanisms and complex interactions make impact prediction extremely complicated and require an adaptive management approach with short to medium term predictions that are constantly re-evaluated.

Identifying links between thermal anomalies and coral disease prevalence

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MTSRF Project 2.5i.3

Coral disease outbreaks represent an emerging risk on Indo-Pacific reefs that is likely to escalate with ocean warming. We are using a combined field and modeling approach to assess whether elevated seawater temperatures are linked to patterns in the prevalence or abundance of coral disease on the Great Barrier Reef. Seasonal surveys are demonstrating

that overall disease prevalence increases dramatically in summer compared to winter surveys, with prevalence of the most common diseases increasing by up to three-fold in summer. Building on a recent model that links the abundance of coral disease with elevated temperature anomalies and percent cover of coral hosts, we are further refining temperature metrics to include both the duration and magnitude of temperature anomalies and to differentiate between the effects of warm versus cool seasonal anomalies on disease risk. Using a nine-year data set of disease records for white syndrome on 48 reefs spanning more than one thousand kilometres along the Great Barrier Reef from the AIMS LTMP, we are exploring patterns in disease abundance with percent coral cover and with deviations in both mean summer and mean winter sea surface temperatures. The addition of winter temperature anomalies to the model is improving its explanatory power, potentially reflecting impacts of cold temperatures on pathogen loads. The AIMS LTMP data set is proving invaluable for identifying the role that seasonal thermal anomalies play in enhancing or decreasing the vulnerability of corals to disease, and highlights both the need to maintain an annual survey program and the importance of survey timing. With the incorporation of further factors, such as current speed and host susceptibility, our aim is to provide reef managers with an expert system for predicting disease risk on coral reefs. In combination, these results highlight the likelihood of increased disease risk in association with climate change.

Ecological function and economic value of Sponges in Torres Strait

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MTSRF Project 1.3.2

Sponges are a dominant organism on coral reefs throughout Torres Strait and as such can be an important component in many reef habitats in terms of biomass and diversity. They may interact with the wider community in several important ways. Sponges can provide food or shelter for other organisms. They can also filter and extract much of the available phytoplankton to the possible detriment to other suspension feeding organisms. Sponges can compete for and dominate the substrate and thereby exclude other organisms from settling and recruiting into the community. In addition to their ecological value in community dynamics, some sponges also have commercial value. A Torres Strait-wide survey in 2004 and a more targeted survey undertaken in 2006 indicated that a commercial bath sponge species, *Coscinoderma mathewsi* is most abundant in the Yorke Island-group. The island community hopes to soon establish Australia's first sponge farm. Broodstock will initially be produced by fragmentation of larger wild donor sponges, but ultimately be grown within the farm. This presentation will summarise the initial results of a research program conducted to understand the ecological role of these sponges which underpins the establishment of this new industry for Australia. The project, which was established with consultation with regulatory authorities and other stakeholders, is developing an understanding of the biology, ecology and population dynamics of wild populations and their physical environment to allow an estimation of potential environmental issues and their control. It also proposes monitoring and research activities that could be undertaken in association with the development of sponge farming, to further elucidate environmental factors associated with *in-situ* aquaculture.

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