The value of Australia's tropical river ecosystem services

Prepared by Anna Straton[a] and Kerstin Zander[b]

August 2009

Tropical Rivers and Coastal Knowledge

a CSIRO Sustainable Ecosystems
b Charles Darwin University

Australian Government
Department of the Environment, Water, Heritage and the Arts
Land & Water Australia
National Water Commission

CSIRO

Charles Darwin University

Disclaimer

TRaCK has published the information contained in this publication to assist public knowledge and discussion and to help improve the sustainable management of Australia's tropical rivers and coasts. Where technical information has been prepared by or contributed by authors external to TRaCK, readers should contact the author(s), and conduct their own enquiries, before making use of that information. No person should act on the contents of this publication whether as to matters of fact or opinion or other content, without first obtaining specific independent professional advice which confirms the information contained within this publication.

While all reasonable efforts have been made to ensure that the information in this publication is correct, matters covered by the publication are subject to change. Charles Darwin University does not assume and hereby disclaims any express or implied liability whatsoever to any party for any loss or damage caused by errors or omissions, whether these errors or omissions result from negligence, accident or any other cause.

Copyright

This publication is copyright. Apart from any fair dealing for the purpose of private study, research, criticism or review as permitted under the Copyright Act, no part may be reproduced, by any process, without written permission from the publisher, Enquiries should be made to the publisher, Charles Darwin University, c/- TRaCK, Casuarina Campus, Building Red 1 Level 3, Darwin NT 0909.

TRaCK brings together leading tropical river researchers and managers from Charles Darwin University, Griffith University, the University of Western Australia, CSIRO, James Cook University, the Australian National University, Geoscience Australia, the Environmental Research Institute of the Supervising Scientist, the Australian Institute of Marine Science, the North Australia Indigenous Land and Sea Management Alliance, and the Governments of Queensland, the Northern Territory and Western Australia.

TRaCK receives major funding for its research through the Australian Government's Commonwealth Environment Research Facilities initiative; the Australian Government's Raising National Water Standards Program; Land and Water Australia; the Fisheries Research and Development Corporation and the Queensland Government's Smart State Innovation Fund.

Straton, A. and Zander, K. (2009).The value of Australia's tropical ecosystem services. Charles Darwin University, Darwin.

For further information about this publication:
Anna Straton, TRaCK
Email: anna.straton@csiro.au

Or to find out more about TRaCK

Visit:	http://www.track.gov.au/	ISBN:	978-1-921576-16-4
Email:	track@cdu.edu.au	Published by:	Charles Darwin University
Phone:	08 8946 7444	Printed by:	Charles Darwin University

Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

The authors would like to thank the members of the project team: Drs Sue Jackson and Nick Abel, CSIRO Sustainable Ecosystems; Professor Stephen Garnett and Dr Adam Drucker, School for Environmental Research, Charles Darwin University; and Dr Mark Kennard, Australian Rivers Institute, Griffith University.

The project team acknowledge the assistance of co-researchers Rowena Parkes, April Mirindo, Sharna Palmer and Marceil Lawrence and the Kowanyama Aboriginal Land and Natural Resource Management Office in organising and accompanying the authors on field trips to interview Aboriginal people in each river catchment. The facilitation and interpretation skills of these researchers were critical in ensuring that Aboriginal people's preferences were included in this project. We also thank Viv Sinnamon, Gail Smiler, Karen Dayman and Kate Golson for advice on field trip protocols.

The project team thank Professor John Rolfe from the Environmental Economics Research Hub and Central Queensland University, Rockhampton and Rosemary Hill and Sorada Tapsuwan of CSIRO Sustainable Ecosystems for providing thorough and timely reviews of this report; and the Executive and staff of TRaCK for support and guidance throughout this research.

The project team thank the government, non-government and community stakeholders in each catchment for their time and input; and the hundreds of people Australia-wide who took the time to read and fill in the questionnaire.

This project was funded by the Myer Foundation and Land and Water Australia.

EXECUTIVE SUMMARY

The tropical rivers and groundwater systems of northern Australia contain approximately 70% of Australia's freshwater resources (Hamilton and Gehrke 2005). These tropical river systems provide ecosystem services that underpin the survival and well-being of people; multiple industries, such as pastoralism and horticulture; activities, such as cultural resource management and recreational fishing; and the continued health and functioning of the ecosystems of the region.

An ongoing drought in southern Australia and increasing awareness of the value of water worldwide is drawing attention to the potential for development in northern Australia. Any development in the tropical rivers region will have impacts on the ecosystems and ecosystem services of tropical river systems. These impacts will also likely affect the uses and benefits underpinned by these ecosystem services.

This project provides assessments of the potential impacts of future development scenarios on the ecosystem services of Australia's tropical rivers. In doing so, this work builds on existing knowledge of the values and assets of Australia's tropical rivers by identifying the ecosystem services of Australia's tropical river systems, their contribution to human well-being, and the drivers that impact on them. The study assess the impacts of potential development scenarios through: (1) estimating the economic value of four particular ecosystem services; and (2) analysing key changes in the past for insight into the future. It does this through three case studies: the Fitzroy River in Western Australia (WA), the Daly River in the Northern Territory (NT) and the Mitchell River in Queensland (Qld).

Economic valuation

The economic valuation was undertaken using the choice modelling method, selected for its ability to enable the measurement of people's willingness to pay for the non-use values associated with tropical river ecosystem services, and to elicit preferences for a number of environmental attributes at the one time. A questionnaire about the future of each case study river system was presented to people living in each river catchment, the capital city of the state/territory each catchment is in, and capital cities in southern Australia. Respondents were asked about their preferences for: (1) provision of floodplain habitat in good environmental condition; (2) provision of river conditions for quality recreational fishing; (3) provision of species and habitat important to Aboriginal customary activity at waterholes; and (4) production from irrigated agriculture.

Different levels for each of the four ecosystem services were identified: low, medium and high. The lowest levels are: (1) the smallest area of floodplain in good environmental condition, (2) the worst quality of the river for recreational fishing, (3) waterholes important to Aboriginal people are in poor condition, and (4) the lowest level of income from irrigated agriculture. The medium and highest levels represent improvements on each of these.

The results of the economic valuation include estimates of willingness to pay (implicit prices), aggregate willingness to pay, and compensating surplus from a series of different models. Respondents from each targeted population express a value for improvements in all four ecosystem services whether they have visited or intend to visit the region or not. In estimating value, we calculated a few different types of models that make different assumptions about how people make choices, so we present a range of estimates.

Fitzroy River

The range of values that different groups of people have for medium and large improvements in the ecosystem services of the Fitzroy River are as follows (once-off payments per household):

	Residents of the Fitzroy River catchment	Indigenous residents of the Fitzroy River catchment	Residents of Perth and Melbourne
Medium level area of floodplain in good environmental condition	\$117.59 - \$121.03	\$110.79 - \$122.11	\$30.16 - \$47.43
Highest level area of floodplain in good environmental condition	\$139.50 - \$146.08	\$96.24 - \$118.97	\$132.74 - \$151.70
Medium level quality of the river for recreational fishing	\$223.09 - \$252.84	\$185.79 - \$200.50	\$70.62 - \$78.14
Highest level quality of the river for recreational fishing	\$222.95 - \$243.85	\$223.65 - \$260.60	\$143.33 - \$150.27
Medium level condition of waterholes important to Aboriginal people	\$228.36 - \$250.59	\$264.36 - \$290.55	\$141.77 - \$151.68
Highest level condition of waterholes important to Aboriginal people	\$314.58 - \$363.08	\$347.51 - \$426.38	\$281.32 - \$282.64
Medium level income from irrigated agriculture			\$110.09 - \$122.04
Highest level income from irrigated agriculture			\$82.10 - \$87.60

There are no estimates for the two levels of income from irrigated agriculture because the relevant coefficients were statistically insignificant. This means that they did not influence people when they were making their choices and we cannot calculate willingness to pay or any other estimates of value for these levels of the ecosystem service.

Daly River

The range of values that different groups of people have for medium and large improvements in the ecosystem services of the Daly River are as follows (once-off payments per household):

	Residents of the Daly River catchment	Indigenous residents of the Daly River catchment	Residents of Darwin and Sydney
Medium level area of floodplain in good environmental condition	$52.58 - $69.26	$115.86 - $129.80	$61.11 - $63.07
Highest level area of floodplain in good environmental condition	$94.45 - $128.81	$101.43 - $156.06	$155.23 - $176.83
Medium level quality of the river for recreational fishing	$191.15 - $221.21	$152.36 - $163.72	$92.90 - $111.18
Highest level quality of the river for recreational fishing	$243.81 - $244.92	$342.78 - $344.75	$154.62 - $156.42
Medium level condition of waterholes important to Aboriginal people	$178.63 - $197.70	$329.16 - $340.28	$117.98 - $157.44
Highest level condition of waterholes important to Aboriginal people	$266.89 - $282.75	$429.42 - $447.22	$204.80 - $226.55
Medium level income from irrigated agriculture			$71.57 - $118.20
Highest level income from irrigated agriculture			$28.13 - $47.22

The reason why there are no estimates for the two levels of income from irrigated agriculture is the same as explained for the Fitzroy River.

Mitchell River

The range of values that people from Brisbane and Canberra have for medium and large improvements in the ecosystem services of the Mitchell River are as follows (once-off payments per household):

	Residents of Brisbane and Canberra
Medium level area of floodplain in good environmental condition	$67.78 - $74.04
Highest level area of floodplain in good environmental condition	$171.13 - $203.74
Medium level quality of the river for recreational fishing	$107.31 - $107.38
Highest level quality of the river for recreational fishing	$153.53 - $174.50
Medium level condition of waterholes important to Aboriginal people	$131.82 - $155.63
Highest level condition of waterholes important to Aboriginal people	$277.91 - $278.95
Medium level income from irrigated agriculture	$146.52 - $223.58
Highest level income from irrigated agriculture	$130.60 - $136.31

There are no estimates for residents of the Mitchell catchment because the coefficient for the management cost variable was statistically insignificant. This means that it did not influence people when they were making their choices and, because this coefficient is used in the calculation of willingness to pay, we could not calculate any estimates of willingness to pay for that sample.

There are no estimates for Indigenous residents of the Mitchell catchment because the models did not converge. This means that the range of opinions people have about their preferred future for the Mitchell River is too wide for the models to work.

For the models that yield statistically significant results, there are some similarities across river systems for the different types of models:

- Respondents for all three rivers value the highest level condition of waterholes important to Aboriginal people the most.

- Respondents for all three rivers living in a city are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels, and more for the medium level of income from irrigated agriculture than the highest level. This indicates that people generally want to see the maintenance of tropical river systems in excellent condition for environmental, recreational and cultural values and uses, and they value medium rather than large scale expansion of irrigated agriculture.

Given that the incomes of Aboriginal people living on remote communities are lower than for Australians generally (Steering Committee for the Review of Government Service Provision 2005), the relatively high willingness to pay among Indigenous residents is interesting. This result highlights that there is likely a difference between willingness to pay and ability to pay or the actual making of a payment if requested.

There are two main ways that these results can be used to support decision-making. The first is by multiplying the implicit prices by a proportion of the total number of households in a population to calculate the aggregate benefit of an improvement. The second is by forming a ‘scenario’ from a bundle of ecosystem service improvements and calculating the benefit received from a shift from the status quo scenario to this new scenario. This is known as compensating surplus. Both of these calculations must be undertaken with great care and with attention to the assumptions that are being made and the estimates of willingness to pay that are chosen for use in these further calculations.

We provide estimates of aggregate value and compensating surplus for each of the river systems and discuss the policy implications of these estimates. For example, the estimates of aggregate value indicate the value of the benefit of projects to improve each of the ecosystem services. Based on a cost-benefit analysis, if the cost of a project is less than the benefit, then it should be undertaken.

The results of the valuation exercise provide information about the impacts of development scenarios on these ecosystem services in dollar terms for ease of comparison with other costs and benefits in the making of management and policy decisions. This information about non-market impacts was previously unavailable and will help to ensure that a more complete set of costs and benefits are incorporated into decision-making. We acknowledge, however, that some aspects of these ecosystem services cannot be captured in dollar terms, i.e., they are priceless. This means that the economic values that we calculate are likely underestimates of the true or full value of these ecosystem services.

Resilience analysis: analysing key changes in the past for insight into the future

The second approach to assessing the impacts of potential development on tropical river ecosystem services uses resilience theory to guide the exploration of complex interactions between the social and ecological variables and processes of the tropical rivers region. The resilience analysis involves the compilation of information about:

- the processes underpinning the provision of the four focal ecosystem services,
- the processes that threaten the provision of the four focal ecosystem services,
- the cross-scale interactions that influence the provision of ecosystem services
- the thresholds of ecosystem functioning beyond which the provision of these ecosystem services may be significantly and possibly irreversibly compromised, and
- the slowly changing variables that control the structure of tropical river systems that is responsible for the continued provision of these valued ecosystem services.

The provision of the four focal ecosystem services is underpinned by stream flows, the flow regime, water quality, floodplain vegetation, riparian vegetation, and the diversity and abundance of certain species. These variables are threatened by water extraction, river impoundments, sediment build up due in part to erosion from poor riparian management, feral animals, land clearing and inappropriate fire regimes, chemical use, weed infestation, and habitat modification. These land and water uses and practices are themselves influenced by values and attitudes, policies and other institutions, market conditions, technology, demographic change and other economic incentives.

All of these processes operate at different spatial and temporal scales, and interactions between them lead to outcomes for the tropical rivers region that can sometimes be unintended. We provide a few examples of cross-scale interactions that influence the provision of ecosystem services.

Our survey of the history of the tropical rivers region enables the observation of several cycles of change, called ‘adaptive cycles’ in resilience theory, and insight into what might happen next given current trajectories. One example of the next phase of development in the tropical rivers region could be borne of a significant development of water resources. As existing research for the tropical rivers region seems to indicate, and as experience in the Murray-Darling basin of southern Australia dictates, any significant modification of stream flows and the flow regime may see the social-ecological system of the tropical rivers region move through the current phase of conservation and into a collapse similar to that seen in the Murray-Darling system. Alternatively, the system could shift to a new state organised around significantly different land-uses that do not require large input of water.

Resilience theory also brings attention to the important role that thresholds play in managing the capacity of complex adaptive social-ecological systems to continue to provide the ecosystem services that are valued and critical for human well-being. The important questions here are: (1) how much can the provision of an ecosystem service be reduced before there is significant and potentially irreversible impact on community welfare/human well-being; and (2) how much can an ecosystem be impacted by various threats before its capacity to provide ecosystem services is significantly and potentially irreversibly affected? Based on the estimates of willingness to pay for each of the ecosystem services reported above, we suggest that shifting over these thresholds will also significantly impact the value associated with each ecosystem service in terms of an associated economic impact on community welfare.

While there is currently little information to answer questions about a range of important thresholds, we summarise that which is available and point out that more is being undertaken through the Tropical Rivers and Coastal Knowledge Research Hub (http://www.track.gov.au/) and for the Northern Australia Land and Water Taskforce (http://www.nalwt.gov.au/).

Another key insight of resilience theory is that the dynamics of the faster and more localised variables (from which use, utility and value are derived) are often determined by those of the more slowly changing variables (referred to as "controlling variables") (Carpenter *et al.* 2001). We put forward some ideas about the slowly changing variables that control the structure of the tropical rivers region and that are relevant to maintaining the provision of ecosystem services. These slowly changing variables for tropical rivers are: changes in values and attitudes (including the increasing influence of Indigenous people in the debate), changes in policies and other institutions, dominant grazing practices, and how different stream flows are from the natural flow regime. More research is needed to better understand the thresholds and slowly changing variables important for the continued provision and value of tropical river ecosystem services.

1. BACKGROUND, AIMS AND APPROACH OF THIS RESEARCH

The tropical rivers and groundwater systems of northern Australia contain approximately 70% of Australia's freshwater resources (Hamilton and Gehrke 2005). This fact, plus an ongoing drought in southern Australia and increasing awareness of the value of water worldwide, means that there is increasing interest in the potential for development opportunities in northern Australia.

The Tropical Rivers and Coastal Knowledge Research Hub (TRaCK) is providing science and knowledge to underpin the sustainable use and management of Australia's tropical rivers in this time of increasing development interest. This project is one of two TRaCK projects that are identifying and assessing the values and assets of tropical river systems. Here 'values' refers to "what is desirable, to deeply ingrained standards that determine future directions and justify past actions" (Braithwaite and Scott 1991, p.661). Knowledge of the natural and other assets that underpin the wealth of a region is needed to ensure that the source of wealth is not compromised over time, and knowledge of the values and value associated with these assets is essential for decision-making about the allocation of resources to multiple and sometimes competing uses. In the vernacular, 'value' refers to the general importance or desirability of something (Bingham *et al.* 1995). For much of this study, we refer to economic value as a measure of the extent of worth in dollar terms.

There are several studies that have documented the assets of Australia's tropical rivers region (for example, Storey *et al.* 2001; Woinarski *et al.* 2007; Lukacs and Finlayson 2008; van Dam *et al.* 2008), and work has also been done on documenting the values and value associated with Australia's tropical rivers (for example, Toussaint *et al.* 2001; Jackson and O'Leary 2006; Stoeckl *et al.* 2006). This project contributes the next step of this research agenda by focussing in on the 'ecosystem services' that flow from the assets of Australia's tropical rivers: identifying them, identifying their drivers, and assessing their economic value. In doing so, it complements and builds on an assessment of the economic value of wetland services in the Northern Territory by de Groot, Finlayson *et al.* (2008) and a preliminary assessment of the relationships between ecosystem services, drivers of change and human well-being by Finlayson, Bellio *et al.* (2005).

Ecosystem services

'Ecosystem services' is the term used to describe the goods and services provided by ecosystems that benefit, sustain and support the well-being of people. Some examples include production of food and medicine; regulation of climate; and provision of productive soil, clean water, and landscapes that provide recreational and amenity benefits. Ecosystem services are the 'flows' of goods and services from ecosystems as the 'natural capital' or assets.

Ecosystem services often go unrecognised in markets, policies and natural resource management practices. This is because most ecosystem services are difficult to see and measure, so their contribution to human well-being is rarely considered. We can start to correct this by documenting the existence and role of ecosystem services, and assessing the value of their contribution to human well-being.

Australia's tropical river systems and their ecosystem services underpin and provide for:

(a) the survival and well-being of approximately a quarter of a million people who live there, including millions of visitors each year and more than 77 different Indigenous language groups (Stoeckl *et al.* 2006);

(b) the industries of the region, including pastoralism, mining, Aboriginal enterprise (including natural and cultural resource management, art and music), tourism, commercial and recreational fishing, agriculture/horticulture, defence and government services (Begg 2001; Australian Tropical Rivers Group 2004; Stoeckl *et al.* 2006; de Groot *et al.* 2008); and

(c) the continued health and functioning of the ecosystems of the tropical rivers region, and the recognition of Australia's tropical savanna bioregion "as being of outstanding national or international significance for biodiversity" (Woinarski *et al.* 2007, p.15).

Any development in the tropical rivers region will have impacts on the ecosystems and ecosystem services of tropical river systems. These impacts will also likely affect the uses and benefits underpinned by these ecosystem services. These impacts can be better understood by (1) understanding the drivers of change in the tropical rivers region and how a new development might flow through the social-ecological system to impact on ecosystem services, and (2) measuring and comparing the relative 'value' of the impacts on ecosystem services.

This project uses the Millennium Ecosystem Assessment framework (Millennium Ecosystem Assessment 2005) to identify the ecosystem services of Australia's tropical river systems, their contribution to human well-being, and the drivers that impact on them. It assesses the impacts of potential development scenarios through (1) estimating the economic value of four particular ecosystem services; and (2) analysing key changes in the past for insight into the future.

This research is undertaken through focus on three case study river systems: the Fitzroy River in Western Australia (WA), the Daly River in the Northern Territory (NT) and the Mitchell River in Queensland (Qld). These rivers were chosen to match three of the focal catchments of the Tropical Rivers and Coastal Knowledge research hub. Key stakeholders for each river system have been consulted throughout. The methods used include desktop literature review, economic valuation, and resilience analysis.

The report is structured as follows. Section 2 describes Australia's tropical river ecosystem services and their contribution to human well-being. Section 3 describes and reports the estimation of economic value for four particular ecosystem services. Section 4 describes the drivers that impact on tropical river ecosystem services and reports the analysis of past changes. Section 5 contains conclusions about the potential impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers.

2. AUSTRALIA'S TROPICAL RIVER ECOSYSTEM SERVICES

Australia's tropical rivers region stretches across approximately 1.3 million km^2 of the northern part of the continent (Figure 1). The landforms of this region include undulating plains at low elevation; wetlands including river and stream channels, floodplains and billabongs; and the spectacular ranges and escarpments that provide the basis for much tourism interest and hold "the richest rock art galleries in the world" (Woinarski *et al.* 2007, p.11).

Figure 1: Australia's tropical rivers region as included in research by the Tropical Rivers and Coastal Knowledge research hub (the rivers along the eastern coast of north Queensland are studied by the Marine and Tropical Sciences Research Facility)

Australia's tropical river systems are a key feature of the landscape. They are comprised of waterways (Photo 1), wetlands (Photo 2), aquifers, riparian vegetation, groundwater dependent ecosystems, and aquatic communities and species, some of which are endemic to the region and/or rare, threatened and endangered. These assets and their extent have been identified in several studies of the natural values of the region (Northern Gulf Resource Management Group 2001; Daly Region Community Reference Group 2004; Rangelands NRM Coordinating Group 2004; Blanch *et al.* 2005; Lukacs and Finlayson 2008; van Dam *et al.* 2008). Appendix A contains a more detailed description of the natural assets of the region.

Photo 1: The Fitzroy River at the end of the dry season from the bridge at Fitzroy Crossing

Photo 2: The Mitchell River near Kowanyama

The ecosystem services provided by these natural assets underpin much economic and other activity in the region (Begg 2001; Australian Tropical Rivers Group 2004; Stoeckl *et al.* 2006; de Groot *et al.* 2008):

- The tropical river systems of northern Australia provide drinking water for people, cattle and wildlife, and water to support native vegetation, aquatic species, horticulture, agriculture, aquaculture, fishing and mining;
- Riparian vegetation provides shade, aesthetic benefit, habitat, medicinal resources, fuel, building material and subsistence nutrition, and stabilises river banks;
- Tropical river systems provide habitat for species that play a role in tropical river food webs, have conservation value and/or are harvested in recreational and subsistence fishing, hunting and gathering;
- The river channels, waterholes and wetlands have conservation value and provide places for people to relax, swim, bathe, socialise and learn;
- The processes of the river systems help to regulate the local climate, provide water and runoff (especially to sites distant from the river channels via flood pulses), help to retain and form soil, regulate water quality (through regulating nutrients and wastes) and support off-shore fisheries;
- The tropical river systems as a whole provide for scientific and educational benefit;
- The landscapes (for example, gorges, waterholes and waterfalls) and experiences (for example, fishing and boating) associated with tropical river systems have aesthetic and recreational benefit and attract tourists; and
- The country in and around tropical rivers, and the tropical rivers and features themselves, are the source of important and unique cultural stories, responsibilities, identities and relationships for local Aboriginal people, and important to the identities, lifestyle and well-being of all people living in the region.

As an indication of the extent of economic activity in the region:

- The region is home to approximately a quarter of a million people (less than 2% of Australia's total population), including more than 77 different Indigenous language groups (Stoeckl *et al.* 2006);
- Indigenous people are significant landowners in the region – the Indigenous estate makes up 20% of the Australian land mass, a proportion of which is in northern Australia (Altman *et al.* 2007) – and a major and growing proportion of the population (Woinarski *et al.* 2007);
- Most Indigenous people in northern Australia live outside the main towns, residing instead on remote Aboriginal communities (Altman 2006), and rely directly on water resources for nutrition, medicine and other resources (Toussaint *et al.* 2001);

- The gross value of production for pastoralism across the northern pastoral region of Australia in 2005-06 was approximately $948 million (83% of the total $1.14 billion total value of agricultural production in the region) and $110 million for vegetables and fruit (Australian Bureau of Agricultural and Resource Economics 2008);

- Mining in the Kimberley region alone was worth $1,544 million in 2007-08 (Western Australia Department of Mines and Petroleum 2008);

- Tourism was worth $657 million in the Top End of the Northern Territory in 2003-04 (Northern Territory Tourist Commission 2004);

- Most visitors to the Shire of Carpentaria in northern Queensland go for the fishing and inject $14million per year into the local economy (Greiner *et al.* 2004); and

- Expenditure in the NT directly attributable to recreational fishing came to $34 million and 1.9 million hours of fishing effort in 1995 (Coleman 2003).

The Millennium Ecosystem Assessment (2005) provides guidelines for categorising ecosystem services as 'provisioning', 'regulating', 'cultural' or 'supporting'. The ecosystem services of Australia's tropical rivers and their contribution to human well-being in the form of the goods, activities and benefits they provide are summarised in Table 1.

These ecosystem services reflect those identified in studies of other river and wetland systems around the world (Turner *et al.* 2000; Brauman *et al.* 2007) and through the *Wetlands and Water Synthesis* of the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005).

Table 1: Ecosystem services of Australia's tropical river systems and examples of the activities and benefits they provide (adapted from Millennium Ecosystem Assessment 2005, p.2; de Groot *et al.* 2008, p.8)

Ecosystem services	**Examples of goods, activities and benefits provided**
Provisioning	
Food	Production of fish, other aquatic and terrestrial species, fruit, and grains for recreational and subsistence hunting and gathering
Fresh water[a]	Storage and retention of water for domestic, ecological, aquaculture, mining, fishing, and agricultural use
Fibre and fuel	Production of logs, fuelwood, and fodder for building, cooking, and warmth
Ornamental resources	Production of ornaments
Biochemical	Production of biochemicals and medicines
Genetic materials	Production of genetic material
Regulating	
Climate regulation	Source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	Groundwater recharge/discharge; hydrological regime is key driver of ecosystem processes and food-web structure
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control, storm protection
Biological control	Control of pests and diseases
Cultural	
Spiritual and inspirational	Source of inspiration for well-being and art; spiritual benefit; specific and unique Indigenous spiritual and cultural values
Recreational	Opportunities for recreational activities and tourism
Heritage and sense of place	Cultural heritage and identity
Aesthetic	Many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	Opportunities for formal and informal education and training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Habitat provision	Provision of habitat for wildlife feeding, shelter, and reproduction
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

2.1 Assessing the impacts of potential development scenarios on ecosystem services

We now turn to assessing the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers. Any development in the tropical rivers region will have impacts on the structure and/or functioning of ecosystems, which will lead to changes in the provision of ecosystem services, either in quantity or quality. We are assessing the impacts of these marginal changes on community welfare.

The first method assesses impacts by estimating the economic value of four particular ecosystem services and the impact of changes in these ecosystem services on community welfare. While there will likely be impacts on a wider range of ecosystem services, we have had to choose a small number as indicators. The four focal ecosystem services are: (1) provision of floodplain habitat; (2) provision of river conditions for recreational fishing; (3) provision of species and habitat important to Aboriginal customary activity at waterholes; and (4) production from irrigated agriculture. These were chosen as broadly representative of four key values or uses of Australia's tropical rivers, being ecological significance, recreational fishing, Aboriginal values and customary use, and agricultural production.

Provision of floodplain habitat

The provision of floodplain habitat for vegetation and wildlife underpins significant ecological values of Australia's tropical rivers. These floodplains are important in Australia for local waterbirds and aquatic species and have international significance for migratory waterbirds and in supporting biodiversity (van Dam *et al.* 2008). There are several wetlands of International Importance in the region and 70 wetlands of National Importance (van Dam *et al.* 2008). There are flow-on services from this habitat: the wildlife and vegetation are a source of nutrition for local Indigenous people; floodplains provide fertile pastures for cattle; and many aquatic species that breed and feed there are important to recreational and commercial fishing and tourism. The floodplains and estuaries can also provide aesthetic benefit.

Provision of river conditions for recreational fishing

Recreational fishing is a significant value of Australia's tropical rivers. For example, there are over 22,000 fishing households in the Northern Territory and over 40,000 non-Indigenous residents of the Northern Territory fish there annually (Coleman 2003). The provision of species, habitat and the river conditions needed to underpin this activity is thus a key ecosystem service. While not all aspects of a recreational fishing experience are related solely to ecological factors and processes – for example, the motivations for recreational fishing include being with friends and family or alone, and relaxing and unwinding – the quality of the waterways and fringing vegetation, and the abundance of fish are key components.

Provision of species and habitat important to Aboriginal customary activity at waterholes

Aboriginal people are significant landowners in the tropical rivers region and are a major and growing proportion of the population (Woinarski *et al.* 2007). The entirety of a river system is central to people's daily and spiritual lives. Waterholes are of particular importance in cosmological beliefs, stories and as sources of food and medicine and places for customary activities (Toussaint *et al.* 2001), and especially so towards the end of the dry season when surface water becomes scarce. Similarly to recreational fishing, not all aspects of Aboriginal people's benefit from waterholes are related solely to ecological factors and processes – for example, having access and privacy to carry out cultural responsibilities are also key components – however, the provision of species and habitat are important.

Production from irrigated agriculture

While irrigated agriculture is not currently one of the largest industries in the tropical rivers region in terms of gross value of production, much exploration of development potential in the region centres on the availability of water for horticulture and irrigated agriculture. Therefore, in the context of decision-making for the future of the region, production from irrigated agriculture is a key ecosystem service and we are interested in people's preferences for seeing irrigated agriculture continue as a land use and possibly expand.

3. ECONOMIC VALUATION OF AUSTRALIA'S TROPICAL RIVER ECOSYSTEM SERVICES

3.1 Rationale

Any development in the tropical rivers region will have economic, social and ecological impacts. Because these impacts are all of a different nature and are measured in different ways, it can be difficult to weigh alternative developments against each other. One way to enable easy comparison is to estimate all impacts in dollar terms. However, while economic costs and benefits can be readily estimated through existing market prices, social and ecological impacts often do not have a market (are 'non-market'), making it harder to measure them in dollar terms.

One way to quantify non-market impacts for the purpose of decision-making is through economic valuation, which provides an estimate of the gain or loss in community welfare from each impact in dollar terms. A framework that helps to illustrate this is 'total economic value' (Pearce and Turner 1990, ; Figure 2), which categorises the different values of an ecosystem that can be impacted by a development. Direct use values include the harvest of marketed outputs such as timber or grain, and unpriced benefits such as forms of recreation that involve direct interaction with the environment. Indirect use values include the provision of many ecosystem services that support and regulate the environment for human well-being but that humans do not directly interact with. Non-use values include any value received that is not related to using the ecosystem, for example, having the option to use it in the future, being able to bequeath it to future generations, or gaining benefit from its existence.

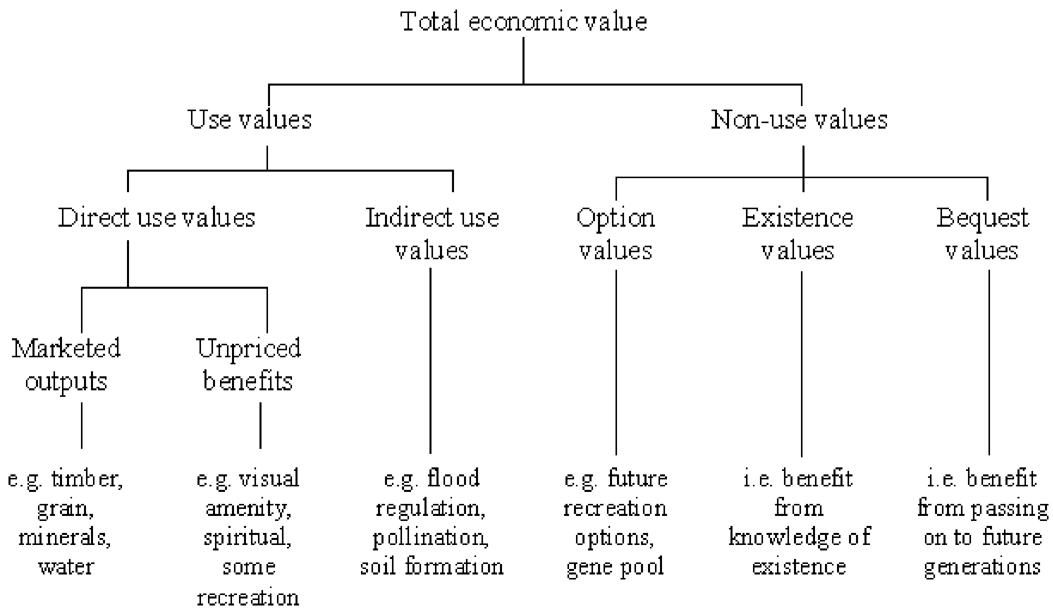


Figure 2: Total economic value (adapted from Hodge 1995)

Impacts on most direct use values are often observed either directly or indirectly through market transactions, while impacts on unpriced benefits, non-use and some indirect use values are not, and so must be estimated through a technique of economic valuation.

The first part of this study provides estimates of the economic value associated with the four focal tropical river ecosystem services described above for three tropical river catchments using an economic valuation method called choice modelling. The three case study catchments – the Fitzroy (WA), Daly (NT) and Mitchell (Qld) – are shown in Figure 3.

Figure 3: Australia's tropical rivers region and the three focal catchments: the Fitzroy in Western Australia, the Daly in the Northern Territory, and the Mitchell in Queensland

The first ecosystem service – provision of floodplain habitat – fits into the indirect use category, but also has elements of existence value for those who live far from the river system. The second – provision of river conditions for recreational fishing – and third – provision of species and habitat important to Aboriginal customary activity at waterholes – have components of indirect use value, but also have some unpriced recreational, amenity and spiritual benefits and again, elements of existence value for those who live far from the river system. The fourth – production from irrigated agriculture – has a direct use component that could be estimated through a production function of the contribution of water as an input into irrigated agriculture, however, in the context of this study, people are asked for their preference for seeing irrigated agriculture continue and potentially expand, which is about the indirect and non-use values of irrigated agriculture as a land use rather than as a source of income for each respondent. This conceptualisation will be important when the values estimated here are to be used in a cost-benefit analysis. The issues arising will be addressed in the discussion section.

The purpose of this valuation exercise is to provide information about the impacts of development scenarios on these ecosystem services in dollar terms for ease of comparison with other costs and benefits in the making of management and policy decisions. This will provide information about non-market impacts that was previously unavailable and will help to ensure that a more complete set of costs and benefits are incorporated into decision-making. Appendix B provides a brief summary of economic values estimated for comparable ecosystem services.

3.2 Method

There are several different types of economic valuation methodology: (1) methods that use market prices, for example, the replacement cost and preventative expenditure approaches; (2) methods that ask people to reveal preferences using related markets, for example, the hedonic pricing and travel cost approaches; and (3) methods that ask people to state their preferences in hypothetical markets, for example, the contingent valuation and choice modelling approaches. Different methods are suited to estimating different types of value, for example, market price techniques are better suited to estimating direct use values and some indirect use values and stated preference techniques are better suited to estimating most non-use values.

The choice modelling method was chosen for this study for several reasons. First, it is well suited to estimating non-use values, which is important for this study as most of the populations sampled live far from each river catchment. Second, choice modelling enables the valuation of several ecosystem services at a time. Third, choice modelling is a viable alternative where there is limited data available for market price methods, which is the case for much of the tropical rivers region. Fourth, in comparison with the contingent valuation method (another stated preference technique), choice modelling has been argued by some as being less susceptible to some forms of bias (Morrison *et al.* 1996; Hanley *et al.* 2001).

Key stakeholders for each river system were consulted about the use of choice modelling for the project. Three stakeholders expressed concern, not with the choice modelling method in particular, but with the practice of economic valuation generally. The concerns and our responses are described in Appendix C. The choice modelling questionnaires were reviewed and modified in response to these concerns and the agreement of these stakeholders was sought before proceeding with the survey.

Choice modelling involves presenting a set of options to people and asking them to choose which one they prefer. It has been used in studies of marketing (Louviere and Woodworth 1983) and transport (Louviere and Hensher 1982), and more recently applied as a method for valuing non-market ecological impacts. It has been used in Australia to estimate the economic value of remnant vegetation in central Queensland (Blamey *et al.* 2000), environmental attributes of rivers (Morrison and Bennett 2004; Bennett *et al.* 2008), wetland quality (Whitten and Bennett 2001; Morrison 2002), diversification choices in agriculture (Windle and Rolfe 2005), habitat and agriculture (Hatton MacDonald and Morrison 2005), options for reserve water (Rolfe and Windle 2005), and the protection of Aboriginal cultural heritage sites (Rolfe and Windle 2003).

For this study, a choice modelling questionnaire was developed for each of the three river systems. Each questionnaire presented a number of hypothetical options describing how the river system could look in the future given a different investment in management. Each option thus involves a different management cost and provides different levels of the four ecosystem services (a description of the ecosystem services and their levels can be found in Appendix D). The options were organised into 'choice sets' (see Figure 4 for an example), and respondents were presented with several of these and asked to choose their preferred option each time.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

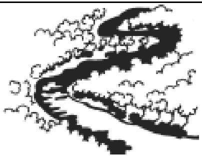
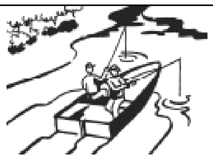
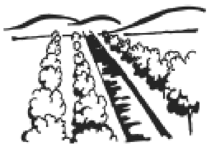
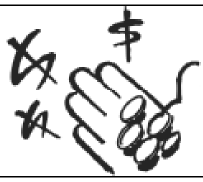
What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	5,025 km^2 (the current level)	3,518 km^2 (30% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	3-star	4-star	1-star
Condition of waterholes important to Aboriginal people 	Ok	Good	Poor
Income from irrigated agriculture 	$100 m/yr	$36 m/yr	$100 m/yr
How much would I pay? 	$50	$10	NIL
I prefer (mark one box only) ☒	☐	☐	☐

Figure 4: Example choice set from the Daly River choice modelling questionnaire

In every choice set, Option 3 is always the same and has no associated cost. This option represents a hypothetical ‘future base’ scenario, which describes how each river system could look in the future if there is maximum development (within existing legislative constraints) and minimal management. The other two options represent scenarios where more is spent on management and the conditions for some ecosystem services are improved. By choosing between options, respondents provide information on their preferences for different combinations of the ecosystem services and how much of each ecosystem service they would be willing to give up, on average, to secure more of another. The inclusion of a management cost enables this trade-off to be measured in monetary terms, which represents the amount respondents are willing to pay for an extra unit of each ecosystem service.

3.2.1 Questionnaire design and piloting

The choice of ecosystem services to be included in the questionnaires took place over several steps. First, key stakeholders for each case study river were identified and consulted about values and issues during several field trips and follow up reports, phone calls and emails. Second, values and issues common to all three case study river systems were compiled into a short list and expressed as corresponding ecosystem services. Third, the project team evaluated which ecosystem services would be most useful to value given the development and management decisions facing managers; which were relevant across all case studies; and which could be relevant to Indigenous and non-Indigenous people, respondents living in each catchment and those living far from each catchment.

While it was difficult to satisfy all of these criteria and the requirements of the method, the four ecosystem services described above were chosen to include in the study. The description of each ecosystem service and how each could be affected by management are included in the example information sheet in Appendix D. The choice of levels for each ecosystem service for each river system was undertaken through consultation with staff in several government departments and tropical river researchers. These levels were chosen to be reasonable and realistic given current and potential future development scenarios and government legislation and water plans (Table 2). We decided to use qualitative indicators for the quality of the river for recreational fishing and condition of waterholes important to Aboriginal people because each involved a composite of characteristics (as described in the information sheet in Appendix D). The levels of the management cost were chosen to cover a range of realistic options given the range of socio-economic demographics for the samples and were based on the levels used in previous Australian choice modelling studies by Hatton MacDonald and Morrison (2005) and Rolfe and Windle (2003; 2005).

Table 2: Levels of each ecosystem service for each river system

Ecosystem service	**Levels for the Fitzroy survey**	**Levels for the Daly survey**	**Levels for the Mitchell survey**
Area of floodplain in good environmental condition	4,350 km^2, 4,930 km^2, 5,800 km^2	2,513 km^2, 3,518 km^2, 5,035 km^2	6,000 km^2, 8,400 km^2, 12,000 km^2
Quality of the river for recreational fishing	1-star, 3-star, 4-star	1-star, 3-star, 4-star	1-star, 3-star, 4-star
Condition of waterholes important to Aboriginal people	Poor, good, ok	Poor, good, ok	Poor, good, ok
Income from irrigated agriculture per year	$2m, 5m, 10m	$36m, 68m, 100m	$2m, 13m, 70m
Once-off levy	$0, 10, 50, 100	$0, 10, 50, 100	$0, 10, 50, 100

A questionnaire was prepared for each river system. Each questionnaire consisted of three parts: questions about environmental attitudes, the choice sets of the choice experiment, and questions on household data/socio-demographic characteristics. The choices for all three river systems were framed as being about hypothetical options for the future of the river region. Respondents read a version of the following text (example from the Daly River questionnaire):

- There are a number of different ways in which economic and community development can occur in the Daly River region, each of which has its own advantages and disadvantages. Each option will have different impacts on people, their values and aspirations, and on natural resources, such as native plants and animals.
- Some people have suggested that irrigated agriculture in the area could increase to support more food production in Australia. This would mean that more water from the river system would need to be allocated to farming.
- Others suggest that the natural values of the river system are significant and should be used to support tourism and other forms of economic activity that don't require much water.

The management cost of each option was framed as a once-off payment by Australian households that could be used for a number of management measures, for example, continued funding of government and non-government agencies to manage weeds on riverbanks; giving assistance to landowners to set aside land for animal habitat on their property; or awarding grants to people starting tourism or other businesses that don't use much water.

The time frame over which the hypothetical options might take place was not specified in the questionnaires, however, the following statement was made early in the questionnaire to set the frame as current:

Across Australia there is increasing awareness of the value of water. The recent drought conditions in some parts of Australia have also raised questions about the use of water for food production and the potential that the tropical rivers of northern Australia may have for this purpose and for other forms of development.

It is assumed that respondents framed the scenarios and trade-offs in this context. Respondents were also asked to acknowledge the following prior to making their choices:

When deciding on the options you prefer and the associated cost, keep in mind your available income and all other things you have to spend money on. Please answer each and every question. Even though they may look the same, each question is different. Some options may seem strange but there are many different ways that impacts can play out in the real world.

Information sheets were prepared for each river catchment describing the catchment, the ecosystem services and levels, and were included with each questionnaire. The draft questionnaire was piloted with ten members of the Melbourne public and revised based on feedback received from respondents and an external reviewer, and from discussions with water managers in each catchment. As an example, the Daly River questionnaire and information sheet are included as Appendix D.

3.2.2 Experimental design

The experimental design for a choice modelling exercise requires that all of the attributes (the four ecosystem services and the management cost) and their levels are put together in as many different combinations as possible. It is impossible to present the full set of resulting attribute-level combinations in choice sets, so a representative sample must be chosen. This representative sample can be chosen based on a design that maximises efficiency criteria and minimises error criteria (Campbell 2007). This process was undertaken using the statistical software package, Ngene (Institute of Transport and Logistics Studies 2007). We created 48 profiles which resulted in 24 choice sets for each river system. We compared several designs, choosing the one for this study based on a d-error of 0.00066, and a B-error of 31.47% (see Campbell *et al.* 2007; Ferrini and Scarpa 2007, for more detail on efficient designs).

As 24 choice sets are too many to ask respondents to consider, they were allocated to three different versions of each questionnaire. As the cost of the survey was already going to be substantial, we used a Bayesian information structure for the design to define the minimum sample size as 45 completed questionnaires per version (i.e. about 135 in total). The information about the necessary priors was taken from a literature search on similar choice modelling studies (for example, Rolfe *et al.* 2000; Birol *et al.* 2006; Rolfe and Prayaga 2007).

3.2.3 Data collection and sampling

The survey was undertaken through a mail-out and face-to-face interviews. Samples of households to receive the mail-out questionnaires were drawn from populations in each river catchment, the capital city of the state/territory of each catchment, and three capital cities in southern Australia (Table 3). This spread of samples was chosen to reflect the diversity of the Australian population. The experimental design process described above yielded the required sample size for each sub-population as 135.

The catchment sub-population was further broken into Indigenous and non-Indigenous populations based on the proportion of people in each catchment identifying as Indigenous. Indigenous respondents received the questionnaire through face-to-face interviews so as to ensure inclusion of their preferences in the value estimates. The face-to-face interviews were mainly carried out by Aboriginal co-researchers, allowing them to convey all necessary information for the choice experiment in a narrative way. Loomis, Ellingson *et al*. (2006) concluded that language rather than ethnicity could influence the willingness to pay/willingness to accept results in valuation surveys and by employing Aboriginal co-researchers we aimed to alleviate this problem.

A modified version of the Dillman (2007) technique was employed for the mail-out survey, involving an introductory letter followed by the questionnaire, a personalised cover letter, dollar coin incentive and addressed reply envelope with a real stamp. Introductory letters were sent to 3377 household addresses randomly selected from the Australian White Pages®. Addresses on envelopes that were returned to us (approximately 14% of the total number of addresses) were removed from the database, and questionnaires sent to the 2914 remaining addresses. Examples of the introductory and cover letters are included in Appendix E.

Table 3: Survey populations and target samples

Sub-population	Fitzroy Location	Fitzroy Sample size	Daly Location	Daly Sample size	Mitchell Location	Mitchell Sample size
Catchment (Indigenous face-to-face respondents)	Fitzroy catchment	84[a]	Daly catchment	34[b]	Mitchell catchment	38[c]
Catchment (whole community)	Fitzroy catchment	51	Daly catchment	101	Mitchell catchment	97
Total catchment	Fitzroy catchment	135	Daly catchment	135	Mitchell catchment	135
Capital city	Perth	135	Darwin	135	Brisbane	135
City in southern Australia	Melbourne	135	Sydney	135	Canberra	135

[a] Based on 62% of the Derby-West Kimberley and Halls Creek Local Government Area populations identifying as Indigenous (Australian Bureau of Statistics 2006; Australian Bureau of Statistics 2006)
[b] Based on 25.5% identifying as Indigenous (Griffith 2004)
[c] Based on 28% identifying as Indigenous (Queensland Department of Natural Resources and Water 2006)

3.2.4 Modelling

There are several different statistical methods that can be used to explain the choices people make. Each method models how the levels of the four ecosystem services, the amount of the management cost, and the socio-demographic and attitudinal characteristics of respondents impact on the probability that a particular scenario will be chosen, and is based on a slightly different model of choice behaviour. Two types of models are estimated for this study: a multinomial logit and a mixed logit model. The modelling was undertaken using LIMDEP 8.0 Nlogit 3 (Greene 2003).

The multinomial logit model is usually the first model that choice modelling practitioners estimate due to the fact that it is the most basic model of choice and can provide a base for comparison of subsequent modelling results. This model states that the likelihood of an individual choosing an option is dependent on the utility associated with the levels of each of the attributes (ecosystem services) and the amount of the cost.

The utility, U, of option i consists of an observable component, $\beta' x_{ni}$, and an unobservable or random component, ε.

$$U_{ni} = \beta' x_{ni} + \varepsilon_{ni} \qquad [1]$$

where x is a vector of the attributes and β is a vector of taste weights or utility parameters associated with each attribute.

The multinomial logit model assumes that the likelihood that an individual will choose an option increases as the utility they associate with that option increases. It also assumes that each taste coefficient, β, is fixed and the same for every individual; the unobservable component of utility has a particular distribution, being 'independently and identically distributed' (IID), which means that the unobserved factors that influence a person's choice are new every time they make the choice; and that there is 'independence from irrelevant alternatives' (IIA), meaning that changing the options in a choice set will not influence the parameter estimates.

Some of these assumptions of the multinomial logit model are too restrictive for some datasets and may not be appropriate to actual choice behaviour. If this is the case, there are several other models available to describe the choice process, including nested logit, probit and mixed logit. The mixed logit model has been chosen for comparison with the multinomial logit because it allows each taste coefficient, β, to vary across respondents; and assumes that there is correlation in the unobserved factors that affect a person's choice over time, so does not require the assumption of IIA. Given the heterogeneity of the samples for this study, the mixed logit model is more appropriate to our data. The mixed logit models presented here allow for panel data and random parameters to be normally distributed. The management cost attribute was specified as fixed in all three models so as to facilitate the estimation of distributions of willingness to pay (Hensher *et al.* 2005).

3.3 Results

The response rate for the whole survey was 34.8%. Table 4 summarises the numbers of questionnaires mailed out and face-to-face interviews requested, the numbers of questionnaires completed, and the response rates for each sub-sample. There were two refusals to respond to the face-to-face questionnaire in the Fitzroy River catchment.

Table 4: Numbers of questionnaires mailed out and face-to-face interviews requested (No. RQ), completed questionnaires (No. CQ), and response rates (RR)

	Fitzroy			Daly			Mitchell			All		
Sub-sample	**No. RQ**	**No. CQ**	**RR (%)**	**No. RQ**	**No. CQ**	**RR (%)**	**No. RQ**	**No. CQ**	**RR (%)**	**No. RQ**	**No. CQ**	**RR (%)**
Catchment (face-to-face Indigenous respondents)	93	91	97.8	37	37	100	42	42	100	172	170	98.8
Catchment (mail-out respondents)	179	47	26.3	146	39	26.7	346	109	31.5	671	195	29.1
Catchment total	272	138	50.7	183	76	41.5	388	151	38.9	843	365	43.3
Capital city	359	118	32.9	493	168	34.1	368	99	26.9	1220	385	31.6
City in southern Australia	372	123	33.1	300	97	32.3	351	103	29.3	1023	323	31.6
Cities – total	731	241	33.0	793	265	33.4	719	202	28.1	2243	708	31.6
Mail-out total[a]	910	288	31.6	939	304	32.4	1065	311	29.2	2914	903	31.0
TOTAL	1003	379	37.8	976	341	34.9	1107	353	31.9	3086	1073	34.8

[a] Mail-out total = Catchment (mail-out respondents) + Capital city + City in southern Australia

3.3.1 Socio-demographic and attitudinal statistics

Fitzroy River questionnaire

Respondents to the Fitzroy River questionnaire have the following characteristics:

- 49.1% were male and 50.7% female;
- Mean age of 51;
- 85.3% have children;
- 29.1% have primary school as the highest level of education they have obtained and 20.5% have completed a tertiary degree;
- 14.9% have an annual household income before tax of $100,000 or more;

- Percent who rank the following as the most important issue in the management of Australia's tropical rivers:
  - Preserving Australia's tropical rivers for biodiversity and natural habitat – 44.9%,
  - Providing food for Australia – 26.1%,
  - Preserving Australia's rivers for those who live there and visitors – 18.8%,
  - Developing northern Australia – 6.5%, and
  - Providing food for the world – 3.7%;
- 42.4% tend to favour preservation of the environment, 4.5% tend to favour development, and 51.5% tend to favour preservation of the environment and development equally;
- 53.6% are very interested in the future of the river system (37.1% are a little bit interested and 5.6% are not at all interested; and
- 83% ticked 'yes' to a question about whether they understood the information in the questionnaire, 2% ticked 'no' and 15% ticked 'maybe'.

Table 5 summarises the socio-demographic and attitudinal characteristics of the sub-samples of the Fitzroy River questionnaire.

Table 5: Characteristics of Fitzroy questionnaire sub-samples

Variable	**Catchm-ent**	**Perth**	**Melbou-rne**	**Cities (Perth + Melb.)**	**Indigen-ous face-to-face**	**All samples**
Socio-demographic characteristics						
Male[a]	38.8%	54.4%	54.5%	54.5%	33.3%	49.1%
Female[a]	61.2%	44.8%	45.5%	45.1%	66.7%	50.7%
Mean age	48	54	50	52	46	51
Have children	92.2%	80.8%	82.6%	81.7%	95.6%	85.3%
Highest level of education obtained:						
Primary school[a]		0.8%	2.5%	1.6%		29.1%
High school Yr 10[a]		12.0%	19.8%	15.9%		10.4%
High school Yr 12[a]		13.6%	14.9%	14.2%		9.3%
Diploma or trade certificate[a]		27.2%	28.9%	28.0%		18.4%
Tertiary degree[a]		36.8%	25.6%	31.3%		20.5%
Annual household income before tax of $100,000 or more	6.2%	17.6%	21.5%	19.5%	1.1%	14.9%
Family or self involved in farming		20.0%	9.9%	15.0%		
Member of/ donate to environmental organisation		18.4%	18.2%	18.3%		
Live in or have visited the tropical rivers region	99.2%	54.4%	45.5%	50.0%	100.0%	66.9%
May visit in the future	NA	58.4%	66.9%	62.6%		
Had heard of the river prior to receiving questionnaire		78.4%	75.2%	76.8%		
Attitudes						
Proportion of respondents choose this as the most important issue for management of Australia's tropical rivers:						
Preserving Australia's tropical rivers for biodiversity and natural habitat	40.9%	47.5%	46.3%	46.9%	40.4%	44.9%
Preserving Australia's tropical rivers for the people who live there and visitors	35.4%	12.3%	9.0%	10.5%	42.7%	18.8%
Providing food for Australia	12.6%	31.1%	34.3%	32.8%	9.0%	26.1%
Developing northern Australia	10.2%	3.3%	6.0%	4.7%	6.7%	6.5%
Providing food for the world	0.8%	5.7%	4.5%	5.1%	1.1%	3.7%
Tendency to favour:						
Preservation of the environment[a]	42.6%	36.8%	47.9%	42.3%	45.6%	42.4%
Development[a]	7.0%	3.2%	3.3%	3.3%	4.4%	4.5%
Preservation of the environment and development equally[a]	49.6%	57.6%	47.1%	52.4%	50.0%	51.5%
Level of interest in the future of the river system:						
Very interested[a]		40.0%	42.1%	41.1%	72.2%	53.6%
A little bit interested[a]		48.0%	50.4%	49.2%	17.8%	37.1%
Not at all interested[a]		4.8%	4.1%	4.5%	10.0%	5.6%

[a] Where totals do not add to 100% this is because not all respondents answered the question.

Daly River questionnaire

Respondents to the Daly River questionnaire have the following characteristics:

- 51.3% were male and 48.1% female;
- Mean age of 51;
- 82% have children;
- 30.1% have an annual household income before tax of $100,000 or more;
- Percent who rank the following as the most important issue in the management of Australia's tropical rivers:
    - Preserving Australia's tropical rivers for biodiversity and natural habitat – 46.3%,
    - Providing food for Australia – 25.1%,
    - Preserving Australia's rivers for those who live there and visitors – 20.9%,
    - Developing northern Australia – 4.8%, and
    - Providing food for the world – 3.0%;
- 43.9% tend to favour preservation of the environment, 3.9% tend to favour development, and 50.1% tend to favour preservation of the environment and development equally;
- 51.0% are very interested in the future of the river system (40.9% are a little bit interested and 5.4% are not at all interested; and
- 82% ticked 'yes' to a question about whether they understood the information in the questionnaire, 2% ticked 'no' and 16% ticked 'maybe'.

Table 6 summarises the socio-demographic and attitudinal characteristics of the sub-samples of the Daly River questionnaire.

Table 6: Characteristics of Daly questionnaire sub-samples

Variable	Catchm-ent	Darwin	Sydney	Cities (Darwin + Sydney)	Indigen-ous face-to-face	All samples
Socio-demographic characteristics						
Male[a]	39.4%	54%	55.4%	54.5%	29.7%	51.3%
Female[a]	59.2%	45.4%	44.6%	45.1%	70.3%	48.1%
Mean age	44	54	52	53	39	51
Have children		82.8%	84.2%	83.3%		82%
Highest level of education obtained:						
Primary school[a]	52.1%	0.6%	4.0%	1.9%		
High school Yr 10[a]	9.9%	18.4%	11.9%	15.9%		
High school Yr 12[a]	2.8%	14.7%	8.9%	12.5%		
Diploma or trade certificate[a]	16.9%	24.5%	27.7%	25.8%		
Tertiary degree[a]	9.9%	39.3%	43.6%	40.9%		
Annual household income before tax of $100,000 or more	14.1%	35.0%	33.7%	34.5%	0.0%	30.1%
Family or self involved in farming		9.8%	7.9%			
Member of/ donate to environmental organisation		17.2%	18.8%	17.8%		
Live in or have visited the tropical rivers region	60.6%	32.5%	64.4%	73.9%	100%	71.0%
May visit in the future	NA	32.5%	64.4%	44.7%	NA	
Had heard of the river prior to receiving questionnaire		93.3%	49.5%	76.5%		
Have family or friends who own land/work in catchment		28.8%		18.2%		
Attitudes						
Proportion of respondents choose this as the most important issue for management of Australia's tropical rivers:						
Preserving Australia's tropical rivers for biodiversity and natural habitat	38.2%	48.8%	46.0%	47.5%	25.6%	46.3%
Preserving Australia's tropical rivers for the people who live there and visitors	31.6%	18.9%	15.0%	17.4%	41.9%	20.9%
Providing food for Australia	14.5%	27.4%	27.0%	27.5%	7.0%	25.1%
Developing northern Australia	7.9%	4.3%	3.0%	3.8%	11.6%	4.8%
Providing food for the world	7.9%	0.6%	9.0%	3.8%	9.3%	3.0%
Tendency to favour:						
Preservation of the environment[a]	40.8%	42.9%	47.5%	44.7%	32.4%	43.9%
Development[a]	4.2%	3.7%	4.0%	3.8%	2.7%	3.9%
Preservation of the environment and development equally[a]	53.5%	50.3%	47.5%	49.2%	59.5%	50.1%
Level of interest in the future of the river system:						
Very interested[a]	67.6%	52.8%	36.6%	46.6%	67.6%	51.0%
A little bit interested[a]	23.9%	39.9%	54.5%	45.5%	24.3%	40.9%
Not at all interested[a]	7.0%	3.7%	6.9%	4.9%	8.1%	5.4%

[a] Where totals do not add to 100% this is because not all respondents answered the question.

Mitchell River questionnaire

Respondents to the Mitchell River questionnaire have the following characteristics:

- 57.9% were male and 41.5% female;
- Mean age of 51;
- 84% have children;
- 15.2% have primary school as the highest level of education they have obtained and 35.2% have completed a tertiary degree;
- 28.7% have an annual household income before tax of $100,000 or more;
- Percent who rank the following as the most important issue in the management of Australia's tropical rivers:
    - Preserving Australia's tropical rivers for biodiversity and natural habitat – 38.5%,
    - Providing food for Australia – 29.8%,
    - Preserving Australia's rivers for those who live there and visitors – 20.8%,
    - Developing northern Australia – 6.7%, and
    - Providing food for the world – 4.2%;
- 39.8% tend to favour preservation of the environment, 6.6% tend to favour development, and 50.7% tend to favour preservation of the environment and development equally;
- 44.7% are very interested in the future of the river system (43.6% are a little bit interested and 6.3% are not at all interested; and
- 83% ticked 'yes' to a question about whether they understood the information in the questionnaire, 1% ticked 'no' and 16% ticked 'maybe'.

Table 7 summarises the socio-demographic and attitudinal characteristics of the sub-samples of the Mitchell River questionnaire.

Table 7: Characteristics of Mitchell questionnaire sub-samples

Variable	**Catchm-ent**	**Canber-ra**	**Brisban-e**	**Cities (Can. + Bris.)**	**Indigen-ous face-to-face**	**All samples**
Socio-demographic characteristics						
Male[a]	55.3%	68.2%	50.5%	59.6%	67.4%	57.9%
Female[a]	44.7%	31.8%	47.5%	39.4%	32.6%	41.5%
Mean age	49	54	51	53	42	51
Have children		76.6%	80.2%	78.4%		84%
Highest level of education obtained:						
Primary school[a]	30.5%	3.7%	5.9%	4.8%		15.2%
High school Yr 10[a]	14.9%	20.6%	19.8%	20.2%		18.1%
High school Yr 12[a]	7.1%	9.3%	6.9%	8.2%		7.7%
Diploma or trade certificate[a]	17.7%	21.5%	15.8%	18.8%		18.3%
Tertiary degree[a]	24.1%	43.0%	42.6%	42.8%		35.2%
Annual household income before tax of $100,000 or more	20.6%	32.7%	35.6%	34.1%		28.7%
Family or self involved in farming		31.8%	24.8%	28.4%		
Member of/donate to environmental organisation		22.4%	24.8%	23.6%		
Live in or have visited the tropical rivers region	73.0%	60.7%	66.3%	63.5%	81.4%	67.3%
May visit in the future	NA	52.3%	59.4%	55.8%		
Had heard of the river prior to receiving questionnaire		67.3%	56.4%	62.0%		
Have family or friends who own land/work in catchment		18.7%	27.7%	23.1%	88.4%	31.2%
Attitudes						
Proportion of respondents choose this as the most important issue for management of Australia's tropical rivers:						
Preserving Australia's tropical rivers for biodiversity and natural habitat	37.0%	39.6%	4.4%	39.5%	44.2%	38.5%
Preserving Australia's tropical rivers for the people who live there and visitors	24.0%	18.0%	22.8%	18.6%	46.5%	20.8%
Providing food for Australia	28.8%	29.7%	28.7%	30.5%	0.0%	29.8%
Developing northern Australia	7.5%	8.1%	41.2%	6.2%	7.0%	6.7%
Providing food for the world	2.7%	4.5%	2.9%	5.2%	2.3%	4.2%
Tendency to favour:						
Preservation of the environment[a]		43.0%	4.0%	40.9%	37.2%	39.8%
Development[a]		8.4%	18.8%	6.3%	11.6%	6.6%
Preservation of the environment and development equally[a]		43.0%	38.6%	49.0%	51.2%	50.7%
Level of interest in the future of the river system:						
Very interested[a]		43.9%	38.6%	41.3%	83.7%	44.7%
A little bit interested[a]		46.7%	42.6%	44.7%	16.3%	43.6%
Not at all interested[a]		6.5%	11.9%	9.1%	0.0%	6.3%

[a] Where totals do not add to 100% this is because not all respondents answered the question.

The high percentage of respondents from cities in southern Australia (Perth, Melbourne, Sydney, Brisbane and Canberra) who tick 'yes' to living in or having visited the tropical rivers region is interesting. This indicates that a large proportion of respondents have had some direct experience with the tropical rivers region of Australia, although not necessarily the three catchments in particular. This may indicate a bias in at least some of the respondents.

3.3.2 Choice models

Multinomial and mixed logit models were estimated for all respondents to each questionnaire and for the following sub-samples for each questionnaire: (1) respondents living in the catchment; (2) Indigenous respondents to the face-to-face questionnaire; and (3) respondents living in cities. This was to enable comparison across samples for which there may be differences in preferences. The face-to-face Indigenous sample is a sub-sample of the catchment sub-sample, and the catchment and cities sub-samples are combined for the all samples models. We acknowledge that there were some respondents to the mail-out questionnaires who identify as Aboriginal or Torres Strait Islander. The preferences of all Indigenous respondents will be explored in future work with this dataset. The explanatory variables are described in Table 8.

Even though some ecosystem services were expressed in quantitative terms in the questionnaires, all attributes are modelled as qualitative dummy variables with the lowest level as the base level with in the model. Because of perfect linearity, only the medium and highest levels of the attributes were therefore estimated. This enabled the comparison of results across river systems. Simple multinomial and mixed logit models without the inclusion of socio-demographic variables are reported for all sub-samples for each river to enable comparison across all sub-samples and all rivers. We also report mixed logit models for the all samples sample for each river with interactions of socio-demographic and attitudinal variables with attributes. This allows for the testing of which characteristics of respondents may be influencing choice. There are no population weights at this stage for the all samples models. Modelling with weights and attribute attendance will be undertaken in future work with this dataset.

Table 8: Explanatory variables

Variable name	Description
FP_MED	Dummy variable for the medium level area of floodplain in good environmental condition
FP_LARGE	Dummy variable for the highest level area of floodplain in good environmental condition
FISH3	Dummy variable for the medium level quality of the river for recreational fishing
FISH4	Dummy variable for the highest level quality of the river for recreational fishing
WH_OK	Dummy variable for the medium level condition of waterholes important to Aboriginal people
WH_GOOD	Dummy variable for the highest level condition of waterholes important to Aboriginal people
INC_MED	Dummy variable for the medium level of income from irrigated agriculture
INC_LOT	Dummy variable for the highest level of income from irrigated agriculture
COST	Once-off payment per household
I	Income in categories (the higher the category the higher the income)
E	Level of education in categories (the higher the category the more educated)
A	Age as continuous variable
M	Gender in categories 1 for male and 0 for female
IN	Interest for rivers in categories 1 for very interested and 0 for little bit/not at all

Multinomial logit models

Fitzroy River

The results of the multinomial logit (MNL) models for the Fitzroy River are reported in Table 9. For the all samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign, with improvements from the lowest to the medium or highest level of each ecosystem service positively influencing the probability of choosing a particular option and increases in the cost attribute negatively influencing the probability of choosing a particular option.

For the Fitzroy catchment and face-to-face Indigenous samples models, all estimated coefficients except for the medium and highest levels of income from irrigated agriculture are statistically significant at the 1% level and have the expected sign. Estimated coefficients for the medium and highest levels of income from irrigated agriculture are both insignificant. This suggests that income from irrigated agriculture did not influence respondents from the face-to-face Indigenous and Fitzroy catchment sub-samples in making their choices.

For the city samples model, all estimated coefficient are statistically significant at the 1% level except for the medium level area of floodplain in good environmental condition, which is statistically significant at the 10% level. All estimated coefficients have the expected sign.

For models of choice, an R^2-adjusted (RsqAdj) between 0.2 and 0.4 indicates that the model has a good overall goodness-of-fit (Louviere *et al.* 2000). The RsqAdj for all of the Fitzroy MNL models sit within this range.

Table 9: Fitzroy River multinomial logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Fitzroy catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
FP_MED	0.252*** (0.081)	0.508*** (0.143)	0.559*** (0.176)	0.164* (0.093)
FP_LARGE	0.658*** (0.089)	0.613*** (0.155)	0.545*** (0.194)	0.723243*** (0.101)
FISH3	0.505*** (0.095)	0.936*** (0.174)	0.918*** (0.219)	0.385*** (0.107)
FISH4	0.826*** (0.068)	0.936*** (0.118)	1.024*** (0.145)	0.781*** (0.078)
WH_OK	0.867*** (0.111)	0.958*** (0.205)	1.211*** (0.262)	0.773*** (0.124)
WH_GOOD	1.525*** (0.065)	1.320*** (0.108)	1.592*** (0.136)	1.533*** (0.076)
INC_MED	0.470*** (0.108)	0.034 (0.190)	-0.163 (0.243)	0.665*** (0.123)
INC_LOT	0.344*** (0.061)	0.008 (0.099)	-0.062 (0.123)	0.477*** (0.071)
COST	-0.005*** (0.001)	-0.004*** (0.001)	-0.005*** (0.002)	-0.006*** (0.001)
No. of observations	2856	989	696	2159
Log likelihood function	-2411.9	-808.606	-526.76	-1853.4
RsqAdj	0.230	0.252	0.307	0.217
*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level				

Daly River

The results of the MNL models for the Daly River are reported in Table 10. For the all samples model, all estimated coefficients are significant at the 1% level and have the expected sign.

For the Daly catchment sample model, all estimated coefficients are significant at the 1% or 10% level except for the medium and highest levels of income from irrigated agriculture, suggesting that these variables did not influence respondents from catchment in making their choices. We note that this model is based on a sample size less than that required by the experimental design.

The basic model for the face-to-face Indigenous sample yielded insignificant coefficients for several variables, including the management cost. This may be due to the fact that this model is based on a sample size less than that required by the experimental design. Estimated coefficients became significant once we removed the two most insignificant variables (the medium and highest levels of income from irrigated agriculture) and the resulting model is reported in Table 10. All estimated coefficients are statistically significant at the 1% or 5% level and have the expected sign.

For the city samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign. The RsqAdj for all models reveals good overall goodness-of-fit.

Table 10: Daly River multinomial logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Daly catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
FP_MED	0.436*** (0.089)	0.394* (0.206)	0.576** (0.293)	0.427*** (0.099)
FP_LARGE	1.103*** (0.099)	0.732*** (0.224)	0.777*** (0.280)	1.198*** (0.111)
FISH3	0.726*** (0.107)	1.086*** (0.250)	0.815** (0.371)	0.629*** (0.119)
FISH4	1.119*** (0.071)	1.385*** (0.162)	1.715*** (0.257)	1.059*** (0.080)
WH_OK	0.850*** (0.126)	1.015*** (0.300)	1.638*** (0.521)	0.799*** (0.140)
WH_GOOD	1.404*** (0.067)	1.517*** (0.154)	2.137*** (0.243)	1.387*** (0.074)
INC_MED	0.417*** (0.119)	0.213 (0.270)		0.485*** (0.133)
INC_LOT	0.167*** (0.062)	0.081 (0.143)		0.191*** (0.069)
COST	-0.007*** (0.001)	-0.006*** (0.002)	-0.005** (0.003)	-0.007*** (0.001)
No. of observations	2558	539	284	2019
Log likelihood function	-2056.7	-402.995	-178.551	-1641.66
RsqAdj	0.267	0.314	0.42059	0.258
*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level				

Mitchell River

The results of the MNL models for the Mitchell River are reported in Table 11. For the all samples model, all estimated coefficients are statistically significant at the 1% or 5% level and have the expected sign.

For the Mitchell catchment sample model, estimated coefficients for the medium level condition of waterholes important to Aboriginal people, medium level income from irrigated agriculture and the management cost are statistically insignificant (all others are significant at the 1% level and have the expected sign). This suggests that these variables did not influence respondents in making their choices.

The face-to-face Indigenous sample model failed to converge with all variables. This may be due to the fact that it is based on a sample size less than that required by the experimental design and/or that there was wide variation in responses.

For the cities samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign. The RsqAdj for the all samples, Mitchell catchment and city samples models are low but acceptable for a model of choice.

Table 11: Mitchell River multinomial logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Mitchell catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
FP_MED	0.558*** (0.081)	0.706*** (0.123)	Failed to converge	0.307*** (0.091)
FP_LARGE	0.788*** (0.087)	0.567*** (0.126)		0.844*** (0.101)
FISH3	0.761*** (0.099)	1.157*** (0.154)		0.444*** (0.107)
FISH4	0.653*** (0.071)	0.720*** (0.109)		0.723*** (0.078)
WH_OK	0.466*** (0.117)	0.231 (0.195)		0.546*** (0.120)
WH_GOOD	0.971*** (0.069)	0.948*** (0.115)		1.151*** (0.072)
INC_MED	0.204** (0.090)	0.022 (0.119)		0.607*** (0.121)
INC_LOT	0.463*** (0.065)	0.391*** (0.106)		0.541*** (0.070)
COST	-0.002*** (0.001)	-0.000 (0.001)		-0.004*** (0.001)
No. of observations	2417	1053		2101
Log likelihood function	-2217.69	-938.172		-1902.07
RsqAdj	0.163	0.186		0.174

*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level

Mixed logit models

Fitzroy River

The results of the mixed logit (MXL) models for the Fitzroy River are reported in Table 12. For the all samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign.

For the Fitzroy catchment and face-to-face Indigenous sample models, all estimated coefficients except for the medium and highest levels of income from irrigated agriculture are statistically significant at the 1% or 5% level and have the expected sign. Estimated coefficients for the medium and highest levels of income from irrigated agriculture are both insignificant in both models. This suggests that income from irrigated agriculture did not influence respondents from the face-to-face Indigenous and Fitzroy catchment sub-sample in making their choices.

For the cities samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign.

The derived standard deviation of each variable (the Ns variables in Tables 12 to 14) indicates whether there is heterogeneity in the parameter estimates across respondents around the mean parameter estimate (Hensher *et al.* 2005). If the Ns variable is significant, there is heterogeneity between respondents and "different individuals possess individual-specific parameter estimates that may be different from the sample population mean parameter estimate" (Hensher *et al.* 2005, p.633). If it is insignificant, the parameter does not vary between respondents and "all information in the distribution is captured within the mean" (Hensher *et al.* 2005, p.633). Most derived standard deviations in the Fitzroy models are significant, except for the medium level condition of waterholes important to Aboriginal people and the medium level income from irrigated agriculture for the Fitzroy catchment sample model, and the medium levels of area of floodplain in good environmental condition, quality of the river for recreational fishing, and income from irrigated agriculture and the highest level income from irrigated agriculture for the city samples model. This indicates that the MXL specification is more appropriate to these data than the MNL.

The RsqAdj for all models reveals a good overall goodness-of-fit. The increase in RsqAdj and increase in the log likelihood function for all models reveals an improvement on the MNL models for the Fitzroy.

Table 12: Fitzroy River mixed logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Fitzroy catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
Random parameters in utility functions				
FP_MED	0.493*** (0.088)	0.685*** (0.214)	0.751*** (0.266)	0.271*** (0.096)
FP_LARGE	0.938*** (0.098)	0.813*** (0.214)	0.653** (0.278)	0.866*** (0.106)
FISH3	0.625*** (0.108)	1.473*** (0.315)	1.260*** (0.399)	0.446*** (0.115)
FISH4	1.023*** (0.073)	1.420*** (0.227)	1.768*** (0.320)	0.858*** (0.080)
WH_OK	1.157*** (0.132)	1.460*** (0.323)	1.971*** (0.456)	0.866*** (0.132)
WH_GOOD	1.705*** (0.073)	2.115*** (0.234)	2.892*** (0.393)	1.614*** (0.078)
INC_MED	0.409*** (0.121)	0.137 (0.286)	0.115 (0.406)	0.629*** (0.130)
INC_LOT	0.266*** (0.066)	0.206 (0.170)	0.017 (0.224)	0.469*** (0.073)
Nonrandom parameters in utility functions				
COST	-0.006*** (0.001)	-0.006*** (0.002)	-0.007** (0.003)	-0.006*** (0.001)
Derived standard deviations of parameter distributions				
NsFP_MED	0.001*** (0.001)	0.681** (0.287)	0.704* (0.391)	0.001 (0.001)
NsFP_LARGE	0.001*** (0.000)	0.769*** (0.252)	0.634** (0.444)	0.003*** (0.001)
NsFISH3	0.001* (0.000)	1.535*** (0.336)	1.848** (0.751)	0.001 (0.001)
NsFISH4	0.002*** (0.000)	1.396*** (0.230)	1.430*** (0.297)	0.001** (0.001)
NsWH_OK	0.002*** (0.000)	0.436 (0.405)	1.348** (0.552)	0.002** (0.001)
NsWH_GOOD	0.002*** (0.000)	1.435*** (0.255)	1.877*** (0.329)	0.003*** (0.001)
NsINC_MED	0.001* (0.001)	0.698 (1.349)	1.796*** (0.441)	0.001 (0.001)
NsINC_LOT	0.001** (0.001)	1.081*** (0.211)	1.130*** (0.285)	0.000 (0.001)
No. of observations	2856	989	696	2159
Log likelihood function	-2308.88	-746.66	-474.63	-1795.25
RsqAdj	0.262	0.307	0.372	0.240
Chi squared	1657.505	679.737	580.003	1153.301
Halton draws	200	200	200	200

*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level

Daly River

The results of the MXL models for the Daly River are reported in Table 13. For the all samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign.

For the Daly catchment sample model, all estimated coefficients are statistically significant at the 1% or 10% level except for the medium and highest levels of income from irrigated agriculture and all have the expected sign. The statistical insignificance of the medium and highest levels of income from irrigated agriculture suggests that these variables did not influence respondents from the catchment in making their choices. We note that this model is based on a sample size less than that required by the experimental design.

Similarly to the MNL model for the face-to-face Indigenous sample, the MXL model yielded insignificant coefficients for several variables, including COST. This may be due to the fact that this model is based on a sample size less than that required by the experimental design. Estimated coefficients became significant once we removed the two most insignificant variables (the medium and highest levels of income from irrigated agriculture) and the resulting model is reported in Table 13. All estimated coefficients are statistically significant at the 1% or 5% level and have the expected sign.

For the cities samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign.

Most derived standard deviations in the Daly models are significant, except for the medium level are of floodplain in good environmental condition for the Daly catchment and face-to-face Indigenous samples models. This indicates that the MXL specification is more appropriate to these data than the MNL.

The RsqAdj for all models reveals a good overall goodness-of-fit. The increase in RsqAdj and decrease in the log likelihood function for all models reveals an improvement on the MNL models for the Daly.

Table 13: Daly River mixed logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Daly catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
Random parameters in utility functions				
FP_MED	0.775*** (0.164)	0.602* (0.327)	1.336** (0.566)	0.841*** (0.212)
FP_LARGE	1.811*** (0.194)	1.082*** (0.369)	1.044** (0.465)	2.136*** (0.247)
FISH3	1.357*** (0.238)	2.534*** (0.604)	1.568** (0.701)	1.530*** (0.310)
FISH4	1.924*** (0.185)	2.806*** (0.532)	3.527*** (0.965)	2.128*** (0.236)
WH_OK	2.077*** (0.307)	2.265*** (0.630)	3.501*** (1.283)	2.167*** (0.404)
WH_GOOD	2.696*** (0.211)	3.239*** (0.507)	4.601*** (1.150)	3.118*** (0.263)
INC_MED	1.335*** (0.230)	0.391 (0.421)		1.627*** (0.273)
INC_LOT	0.548*** (0.134)	0.297 (0.259)		0.650*** (0.167)
Nonrandom parameters in utility functions				
COST	-0.013*** (0.002)	-0.012*** (0.004)	-0.010** (0.005)	-0.014*** (0.002)
Derived standard deviations of parameter distributions				
NsFP_MED	1.119*** (0.199)	0.231 (0.323)	0.502 (0.510)	1.365*** (0.260)
NsFP_LARGE	1.524*** (0.187)	1.358*** (0.341)	1.327* (0.705)	1.874*** (0.223)
NsFISH3	1.981*** (0.330)	2.815*** (0.716)	2.176*** (0.792)	1.909*** (0.325)
NsFISH4	2.014*** (0.197)	2.105*** (0.395)	2.409*** (0.765)	2.708*** (0.282)
NsWH_OK	2.182*** (0.316)	2.108*** (0.797)	3.777** (1.546)	2.580*** (0.431)
NsWH_GOOD	2.432*** (0.226)	2.062*** (0.385)	3.921*** (1.351)	2.632*** (0.258)
NsINC_MED	1.169*** (0.251)	1.184* (0.616)		1.051*** (0.293)
NsINC_LOT	1.297*** (0.179)	1.000*** (0.302)		1.506*** (0.240)
No. of observations	2558	577	284	1981
Log likelihood function	-1742.32	-354.25	-157.59	-1354.62
RsqAdj	0.378	0.392	0.483	0.387
Chi squared	2135.863	475.801	308.839	1726.955
Halton draws	200	200	200	200

*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level

Mitchell River

The results of the MXL models for the Mitchell River are reported in Table 14. For the all samples model, all estimated coefficients are statistically significant at the 1% or 5% level and have the expected sign.

For the Mitchell catchment sample model, all estimated coefficients except for the management cost are statistically significant at the 1% or 5% level and all have the expected sign, except for the management cost. The statistical insignificance of the management cost suggests that it did not influence respondents from the catchment in making their choices.

The face-to-face Indigenous sample model failed to converge with all variables. This may be due to the fact that it is based on a sample size less than that required by the experimental design.

For the cities samples model, all estimated coefficients are statistically significant at the 1% level and have the expected sign.

Most derived standard deviations in the Mitchell models are significant, except for the medium level area of floodplain in good environmental condition for the Mitchell catchment sample model, and the medium level quality of the river for recreational fishing for the city samples model. This indicates that the MXL specification is more appropriate to these data than the MNL.

The RsqAdj for all models reveals a good overall goodness-of-fit. The increase in RsqAdj and decrease in the log likelihood function for all models reveals an improvement on the MNL models for the Mitchell.

Table 14: Mitchell River mixed logit models

Variable	Coefficient for all samples (standard error)	Coefficient for Mitchell catchment sample (standard error)	Coefficient for face-to-face Indigenous sample (standard error)	Coefficient for city samples (standard error)
Random parameters in utility functions				
FP_MED	1.029*** (0.130)	1.138*** (0.237)		0.580*** (0.159)
FP_LARGE	0.971*** (0.172)	0.593*** (0.230)		1.464*** (0.223)
FISH3	1.621*** (0.230)	1.710*** (0.322)		0.919*** (0.209)
FISH4	1.045*** (0.145)	0.908*** (0.231)	Failed to converge	1.314*** (0.168)
WH_OK	1.719*** (0.293)	0.876** (0.403)		1.332*** (0.239)
WH_GOOD	1.750*** (0.196)	1.640*** (0.339)		2.387*** (0.217)
INC_MED	0.939*** (0.219)	0.691** (0.305)		1.913*** (0.288)
INC_LOT	1.115*** (0.165)	0.896*** (0.239)		1.166*** (0.174)
Nonrandom parameters in utility functions				
COST	-0.003** (0.002)	0.003 (0.002)	Failed to converge	-0.009*** (0.002)
Derived standard deviations of parameter distributions				
NsFP_MED	0.318 (0.345)	1.097*** (0.383)		1.012*** (0.279)
NsFP_LARGE	1.756*** (0.200)	0.988*** (0.266)		2.080*** (0.209)
NsFISH3	2.086*** (0.241)	2.127*** (0.403)		0.339 (0.654)
NsFISH4	1.481*** (0.150)	1.674*** (0.263)	Failed to converge	1.645*** (0.205)
NsWH_OK	2.139*** (0.295)	1.915*** (0.589)		1.681*** (0.480)
NsWH_GOOD	2.320*** (0.212)	2.204*** (0.391)		2.265*** (0.222)
NsINC_MED	1.605*** (0.218)	1.919*** (0.330)		1.450*** (0.362)
NsINC_LOT	1.874*** (0.174)	1.642*** (0.251)		1.958*** (0.187)
No. of observations	2417	1053		2101
Log likelihood function	-1884.18	-822.99		-1569.18
RsqAdj	0.288	0.283		0.317
Chi squared	1542.343	667.700		1478.011
Halton draws	200	200	200	200

*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level

Inclusion of socio-demographic and attitudinal variables

Inclusion of socio-demographic and attitudinal variables allows for testing of which characteristics of respondents may be influencing choice. We report three MXL models with interactions, one for each river system, based on the data from all samples. The socio-demographic and attitudinal variables that are interacted with the attributes are: (1) respondent income in categories (the higher the category the higher the income); (2) respondent level of education in categories (the higher the category the higher the level of education completed); (3) respondent age as continuous variable; (4) respondent gender in categories (1 for male and 0 for female); and (5) respondent interest in the future of the river system (1 for very interested and 0 for little bit/not at all). These variables have been interacted with all of the attributes and only significant interactions have been included in the final models presented here in Table 15.

All estimated coefficients for the attribute variables are statistically significant at the 1% level in all of the models, except for the highest level area of floodplain in good environmental condition in the Daly model. All estimated coefficients for the attribute variables have the expected sign. All models have a good goodness-of-fit and, compared to their equivalent basic MXL models, all have improved RsqAdj and log likelihood function.

For the Fitzroy model, respondents who have achieved a higher level of education are less likely to choose options with the highest level quality of the river for recreational fishing and the medium level area of floodplain in good environmental condition. Male respondents are less likely to choose options with the highest level condition of waterholes important to Aboriginal people. Respondents with higher incomes are more likely to choose options with the highest level quality of the river for recreational fishing, and the medium and highest levels of condition of waterholes important to Aboriginal people. Respondents with children are more likely to choose options with the highest level condition of waterholes important to Aboriginal people and the higher levels of cost.

For the Daly model, respondents who have achieved a higher level of education are more likely to choose options with the medium level quality of the river for recreational fishing. Male respondents are more likely to choose options with the highest level quality of the river for recreational fishing and are less likely to choose options with the medium level area of floodplain in good environmental condition. Respondents with higher incomes are more likely to choose options with the highest levels of income from irrigated agriculture. Respondents with children are less likely to choose options with the highest level area of floodplain in good environmental condition. Respondents who are very interested in the future of the river system are more likely to choose options with the highest quality of the river for recreational fishing, and area of floodplain in good environmental condition. The older a respondent is, the more likely they are to choose options with the highest level area of floodplain in good environmental condition.

For the Mitchell model, male respondents are less likely to choose options with the highest level quality of river for recreational fishing. Respondents with higher incomes are more likely to choose options with the highest level quality of river for recreational fishing, the medium level income from irrigated agriculture, the highest level area of floodplain in good environmental condition, and the medium level condition of waterholes important to Aboriginal people. Respondents with higher incomes are less likely to choose options with the medium level area of floodplain in good environmental condition, and higher levels of cost. Respondents with children are more likely to choose options with the highest level quality of the river for recreational fishing. Respondents who are very interested in the future of the river are more likely to choose options with higher levels of cost.

These results raise questions about the influence of socio-economic and attitudinal characteristics on people's choices that will be explore in future work with these datasets.

Table 15: Mixed logit models for all samples for all rivers with interactions

Fitzroy River all samples		Daly River all samples		Mitchell River all samples	
Variable	**Coefficient (standard error)**	**Variable**	**Coefficient (standard error)**	**Variable**	**Coefficient (standard error)**
FP_MED	0.530*** (0.136)	FP_MED	0.973*** (0.224)	FP_MED	0.790*** (0.159)
FP_LARGE	0.944*** (0.146)	FP_LARGE	0.464 (0.335)	FP_LARGE	1.315*** (0.205)
FISH3	0.696*** (0.147)	FISH3	1.376*** (0.237)	FISH3	1.295*** (0.198)
FISH4	1.439*** (0.142)	FISH4	1.099*** (0.297)	FISH4	1.259*** (0.199)
WH_OK	1.582*** (0.207)	WH_OK	1.899*** (0.275)	WH_OK	1.184*** (0.221)
WH_GOOD	3.109*** (0.207)	WH_GOOD	2.832*** (0.216)	WH_GOOD	1.964*** (0.196)
INC_MED	1.089*** (0.179)	INC_MED	1.113*** (0.215)	INC_MED	1.350*** (0.220)
INC_LOT	0.808*** (0.113)	INC_LOT	0.624*** (0.130)	INC_LOT	1.417*** (0.179)
COST	-0.008*** (0.001)	COST	-0.012*** (0.002)	COST	-0.011*** (0.002)
E*FISH4	-0.020** (0.010)	E*FISH3	0.033*** (0.012)	M*FISH4	-0.412** (0.196)
E*FPMED	-0.022** (0.009)	M*FISH4	0.892** (0.326)	I*FISH4	0.010*** (0.003)
M*WHGOOD	-0.786*** (0.236)	M*FPMED	-0.571* (0.288)	I*INCMED	0.012*** (0.004)
I*FISH4	0.009* (0.005)	I*INCLOT	0.009** (0.003)	I*FPMED	-0.008** (0.004)
I*WHOK	0.014** (0.005)	CH*FPLARG	-0.051*** (0.014)	I*FPLARGE	0.012*** (0.004)
I*WHGOOD	0.010** (0.005)	IN*FISH4	0.981*** (0.335)	I*WHOK	0.013* (0.008)
CH*WHGOOD	0.041*** (0.013)	IN*FPLARG	0.674** (0.278)	I*COST	-1.91E-04*** (3.35E-05)
CH*COST	0.000** (9.99E-05)	A*FPLARGE	0.018*** (0.006)	CH*FISH4	0.406** (1.97E-01)
				IN*COST	0.012*** (0.002)
NsFP_MED	1.215*** (0.157)	NsFP_MED	1.450*** (0.191)	NsFP_MED	1.250*** (1.250)
NsFP_LARGE	1.338*** (0.137)	NsFP_LARGE	1.635*** (0.205)	NsFP_LARGE	2.095*** (0.208)
NsFISH3	0.379 (0.264)	NsFISH3	2.044*** (0.320)	NsFISH3	1.530*** (0.264)
NsFISH4	1.508*** (0.163)	NsFISH4	2.237*** (0.217)	NsFISH4	1.547*** (0.161)
NsWH_OK	1.252*** (0.265)	NsWH_OK	2.096*** (0.276)	NsWH_OK	1.095*** (0.419)
NsWH_GOOD	1.822*** (0.144)	NsWH_GOOD	2.440*** (0.206)	NsWH_GOOD	2.283*** (0.233)
NsINC_MED	1.256***	NsINC_MED	0.815*	NsINC_MED	1.480***

	(0.208)		(0.422)		(0.317)
NsINC_LOT	1.189*** (0.130)	NsINC_LOT	1.147*** (0.173)	NsINC_LOT	2.045*** (0.210)
No. of observations	2856	No. of observations	2558	No. of observations	2417
Log likelihood function	-2088.288	Log likelihood function	-1711.503	Log likelihood function	-1846.709
RsqAdj	0.332	RsqAdj	0.388	RsqAdj	0.301
Chi squared	2098.698	Chi squared	2197.495	Chi squared	1617.274
Halton draws	120	Halton draws	120	Halton draws	120
*** significantly different from 0 at the 1% level, ** 5% level, or * 10% level					

3.3.3 Estimation of implicit prices

The amount respondents are willing to pay for an extra unit of each ecosystem service can be calculated from the models. This amount is called the implicit price and, in this study, is a once-off value per household. Implicit prices, *IP*, are calculated by dividing each ecosystem service coefficient by the cost coefficient, for example:

$$IP = -\frac{\beta_{FP\_MED}}{\beta_{COST}}$$

Implicit prices are calculated with an assumption that everything else stays the same. Thus they provide information on the relative importance of the ecosystem services to respondents.

The lowest level for all ecosystem services was modelled as the status quo, so the implicit prices reported in Tables 16, 18 and 20 represent the amount people are willing to pay to see a change from the lowest to the medium or highest level of each ecosystem service. We report implicit prices for the MNL and MXL models for all rivers and all samples where estimated coefficients are statistically significant, and implicit prices for the MXL models with interactions (MXL plus) for the all samples sample for each river. Implicit prices are not calculated with coefficients that are statistically insignificant. We present 95% confidence intervals for the all samples MNL and MXL models calculated using the procedure recommended by Krinsky and Robb (1986). The rankings of ecosystem services are reported in Tables 17, 19 and 21. Appendix F presents implicit prices in tables according to the model type and sub-sample to enable further comparison.

For the models that yield statistically significant results, there are some similarities across river systems for the different types of models:

- Respondents for all three rivers value the highest level condition of waterholes important to Aboriginal people the most. This is the case for all types of models.
- Respondents for all three rivers living in a city are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than

the medium levels, and more for the medium level of income from irrigated agriculture than the highest level. This is the case for both the MNL and MXL models.

- The statistical insignificance of the income from irrigated agriculture variables reveals that they did not influence the choices of people living in the Fitzroy and Daly catchments. This means that, when making their choices, people living in the Fitzroy and Daly catchments only considered the other variables. This does not necessarily mean that the level of income from irrigated agriculture was not important to people.

There are some similarities across respondent samples for river systems:

- All respondents for all three rivers value the highest level condition of waterholes important to Aboriginal people the most. This is the case for all types of models.

- Respondents living the Fitzroy and Daly catchments have similarities in their preferences with the medium and highest levels of both quality of the river for recreational fishing and condition of waterholes important to Aboriginal people being ranked in their top four ecosystem services and the medium and highest levels of area of floodplain in good environmental condition being the bottom two. This is the case for both the MNL and MXL models.

- Respondents for all rivers living in a city have similarities in their preferences with the highest levels of condition of waterholes important to Aboriginal people and area of floodplain in good environmental condition ranked in their top four ecosystem services, and the medium levels of area of floodplain in good environmental condition and quality of the river for recreational fishing, and the highest level of income from irrigated agriculture in the bottom four. This is the case for both the MNL and MXL models.

There are some differences between respondent samples across river systems:

- Respondents to the Fitzroy and Daly questionnaires living in a city value the medium level of income from irrigated agriculture in the bottom four and the highest level of quality of the river for recreational fishing in the top four, while respondents to the Mitchell questionnaire living in a city place the medium level of income from irrigated agriculture in the top four and the highest level of quality of the river for recreational fishing in the bottom four.

Implicit prices and ranking of Fitzroy River ecosystem services

Based on all models of choice for the ecosystem services of the Fitzroy River (Tables 16 and 17):

- All respondents value the highest level condition of waterholes important to Aboriginal people the most.
- Respondents living in the catchment are willing to pay more for improvements in the quality of the river for recreational fishing and the condition of waterholes important to Aboriginal people than respondents living in cities.
- Respondents living in the catchment are willing to pay more for the medium level of floodplain in good environmental condition than respondents living in cities.
- Where the income from irrigated agriculture variables are significant, respondents value the medium level of income from irrigated agriculture more than the highest level.
- Respondents living in the cities are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels, and more for the medium level of income from irrigated agriculture than the highest level.
- Respondents living in the catchment are willing to pay more for the highest levels of area of floodplain in good environmental condition and condition of waterholes important to Aboriginal people than the medium levels, and more for the medium level quality of the river for recreational fishing than the highest level.
- Face-to-face Indigenous respondents are willing to pay more for the highest levels of quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels, and more for the medium level area of floodplain in good environmental condition than the highest level.

Table 16: Implicit prices for Fitzroy River ecosystem services (once-off payment per household) and 95% confidence intervals for some models

	Medium area floodplain in good condition	Large area floodplain in good condition	Medium quality river for rec. fishing	High quality river for rec. fishing	Medium condition waterholes	Good condition waterholes	Medium income from irrigated agric.	High income from irrigated agric.
All samples								
MNL	$49.15 ($17.08-$90.60)	$128.54 ($93.86-$179.66)	$98.65 ($58.60-$149.89)	$161.41 ($127.25-$221.99)	$169.30 ($120.76-$245.04)	$297.80 ($231.06-$413.83)	$91.76 ($45.66-$166.41)	$67.19 ($37.12-$109.49)
MXL	$86.47 ($29.05-$112.49)	$164.64 ($82.91-$165.76)	$109.63 ($69.20-$168.88)	$179.52 ($123.08-$225.23)	$203.00 ($146.54-$306.50)	$299.08 ($223.61-$433.38)	$71.82 ($79.96-$235.98)	$46.65 ($55.61-$157.14)
MXL plus	$66.88	$119.08	$87.77	$181.44	$199.49	$392.07	$137.30	$101.94
Fitzroy catchment sample								
MNL	$121.03	$146.08	$223.09	$222.95	$228.36	$314.58	*	*
MXL	$117.59	$139.50	$252.84	$243.85	$250.59	$363.08	*	*
Face-to-face Indigenous sample								
MNL	$122.11	$118.97	$200.50	$223.65	$264.36	$347.51	*	*
MXL	$110.79	$96.24	$185.79	$260.60	$290.55	$426.38	*	*
Cities sample								
MNL	$30.16	$132.74	$70.62	$143.33	$141.77	$281.32	$122.04	$87.60
MXL	$47.43	$151.70	$78.14	$150.27	$151.68	$282.64	$110.09	$82.10

* Variable is statistically insignificant from zero

Table 17: Ranking of Fitzroy River ecosystem services

	All samples			Catchment sample		Face-to-face Indigenous sample		Cities samples	
Rank	**MNL**	**MXL**	**MXL plus**	**MNL**	**MXL**	**MNL**	**MXL**	**MNL**	**MXL**
1	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD
2	WH_OK	WH_OK	WH_OK	WH_OK	FISH3	WH_OK	WH_OK	FISH4	FP_LARGE
3	FISH4	FISH4	FISH4	FISH3	WH_OK	FISH4	FISH4	WH_OK	WH_OK
4	FP_LARGE	FP_LARGE	INC_MED	FISH4	FISH4	FISH3	FISH3	FP_LARGE	FISH4
5	FISH3	FISH3	FP_LARGE	FP_LARGE	FP_LARGE	FP_MED	FP_MED	INC_MED	INC_MED
6	INC_MED	FP_MED	INC_LOT	FP_MED	FP_MED	FP_LARGE	FP_LARGE	INC_LOT	INC_LOT
7	INC_LOT	INC_MED	FISH3					FISH3	FISH3
8	FP_MED	INC_LOT	FP_MED					FP_MED	FP_MED

Implicit prices and ranking of Daly River ecosystem services

Based on all models of choice for the ecosystem services of the Daly River (Tables 18 and 19), and noting that the face-to-face Indigenous sample model results are not strictly comparable due to the omission of the INC variables:

- All respondents value the highest level condition of waterholes important to Aboriginal people the most.
- Where the income from irrigated agriculture variables are significant, respondents value the medium level of income from irrigated agriculture more than the highest level.
- Respondents living in the cities are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels, and more for the medium level of income from irrigated agriculture than the highest level.
- Respondents living in the catchment are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels.

Implicit prices and ranking of Mitchell River ecosystem services

Some of the implicit prices for the all samples basic MNL and MXL models for the Mitchell are 2-8 times higher than the same variables in the equivalent models for the Fitzroy and Daly Rivers, while for the MXL plus model, these differences are no longer evident. These differences are also not evident for the cities samples models. The lack of good models for the catchment and face-to-face Indigenous samples makes it difficult to explore whether these differences are due to the catchment and face-to-face Indigenous data, however we assume that this is the case, and that the MXL plus model for the all samples sample is more appropriate than the basic MNL and MXL models because it incorporates interaction variables that account for some differences in the characteristics of respondents. We report all implicit prices in Table 20 below but only use implicit prices from the all samples MXL plus model in further calculations. This is also due to the very wide range given by the 95% confidence intervals for the basic MNL and MXL models.

Comparisons between city, catchment and face-to-face Indigenous respondents are difficult due to the lack of good models for catchment and Indigenous samples, however, based on all models of choice for the ecosystem services of the Mitchell River (Tables 20 and 21):

- Respondents living in the cities and for the all samples models value the highest level condition of waterholes important to Aboriginal people the most.
- Respondents living in the cities are willing to pay more for the highest levels of area of floodplain in good environmental condition, quality of the river for recreational fishing and condition of waterholes important to Aboriginal people than the medium levels,

and more for the medium level of income from irrigated agriculture than the highest level.

Table 18: Implicit prices for Daly River ecosystem services (once-off payment per household) and 95% confidence intervals for some models

	Medium area floodplain in good condition	Large area floodplain in good condition	Medium quality river for rec. fishing	High quality river for rec. fishing	Medium condition waterholes	Good condition waterholes	Medium income from irrigated agric.	High income from irrigated agric.
All samples								
MNL	$66.56 ($37.31-$102.37)	$168.60 ($133.79-$219.33)	$110.98 ($74.67-$155.31)	$170.99 ($140.99-$217.55)	$129.95 ($90.75-$181.16)	$214.51 ($174.33-$280.16)	$63.65 ($27.01-$113.73)	$25.47 ($6.00-$48.27)
MXL	$61.99 ($33.74-$94.86)	$144.84 ($111.74-$186.05)	$108.50 ($72.68-$153.75)	$153.85 ($122.92-$200.91)	$166.09 ($114.00-$235.83)	$215.56 ($168.36-$284.28)	$106.75 ($64.23-$164.17)	$43.84 ($20.96-$75.92)
MXL plus	$79.86	$38.04	$112.90	$90.21	$155.82	$232.42	$91.32	$51.20
Daly catchment sample								
MNL	$69.26	$128.81	$191.15	$243.81	$178.63	$266.89	*	*
MXL	$52.58	$94.45	$221.21	$244.92	$197.70	$282.75	*	*
Face-to-face Indigenous sample								
MNL	$115.86	$156.06	$163.72	$344.75	$329.16	$429.42	**	**
MXL	$129.80	$101.43	$152.36	$342.78	$340.28	$447.22	**	**
Cities sample								
MNL	$63.07	$176.83	$92.90	$156.42	$117.98	$204.80	$71.57	$28.13
MXL	$61.11	$155.23	$111.18	$154.62	$157.44	$226.55	$118.20	$47.22

* Variable is statistically insignificant from zero ** Variable not included in final model

Table 19: Ranking of Daly River ecosystem services

	All samples			Catchment sample		Face-to-face Indigenous sample		Cities samples	
Rank	**MNL**	**MXL**	**MXL plus**	**MNL**	**MXL**	**MNL**	**MXL**	**MNL**	**MXL**
1	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD	WH_GOOD
2	FISH4	WH_OK	WH_OK	FISH4	FISH4	FISH4	FISH4	FP_LARGE	WH_OK
3	FP_LARGE	FISH4	FISH3	FISH3	FISH3	WH_OK	WH_OK	FISH4	FP_LARGE
4	WH_OK	FP_LARGE	INC_MED	WH_OK	WH_OK	FISH3	FISH3	WH_OK	FISH4
5	FISH3	FISH3	FISH4	FP_LARGE	FP_LARGE	FP_LARGE	FP_MED	FISH3	INC_MED
6	FP_MED	INC_MED	FP_MED	FP_MED	FP_MED	FP_MED	FP_LARGE	INC_MED	FISH3
7	INC_MED	FP_MED	INC_LOT					FP_MED	FP_MED
8	INC_LOT	INC_LOT	FP_LARGE					INC_LOT	INC_LOT

Table 20: Implicit prices for Mitchell River ecosystem services (once-off payment per household) and 95% confidence intervals for some models

	Medium area floodplain in good condition	Large area floodplain in good condition	Medium quality river for rec. fishing	High quality river for rec. fishing	Medium condition waterholes	Good condition waterholes	Medium income from irrigated agric.	High income from irrigated agric.
All samples								
MNL	$246.73 ($119.39-$721.31)	$348.48 ($205.34-$952.29)	$336.82 ($186.31-$928.35)	$288.72 ($176.24-$781.91)	$206.08 ($95.53-$619.68)	$429.79 ($252.81-$1257.65)	$90.07 ($10.41-$356.83)	$204.92 ($99.53-$682.06)
MXL	$322.06 ($147.70-$1710.14)	$304.12 ($151.59-$1451.16)	$507.59 ($232.37-$2646.95)	$327.19 ($169.71-$1501.12)	$538.09 ($248.70-$2610.06)	$547.89 ($267.82-$2684.34)	$293.92 ($88.25-$1828.13)	$349.03 ($136.50-$1957.71)
MXL plus	$69.41	$115.57	$113.81	$110.66	$104.07	$172.65	$118.70	$124.53
Mitchell catchment sample								
MNL	COST statistically insignificant from zero							
MXL	COST statistically insignificant from zero							
Face-to-face Indigenous sample								
MNL	Failed to converge							
MXL	Failed to converge							
Cities sample								
MNL	$74.04	$203.74	$107.31	$174.50	$131.82	$277.91	$146.52	$130.60
MXL	$67.78	$171.13	$107.38	$153.53	$155.63	$278.95	$223.58	$136.31

Table 21: Ranking of Mitchell River ecosystem services

	All samples			Catchment sample		Face-to-face Indigenous sample		Cities samples	
Rank	**MNL**	**MXL**	**MXL plus**	**MNL**	**MXL**	**MNL**	**MXL**	**MNL**	**MXL**
1	WH_GOOD	WH_GOOD	WH_GOOD					WH_GOOD	WH_GOOD
2	FP_LARGE	WH_OK	INC_LOT					FP_LARGE	INC_MED
3	FISH3	FISH3	INC_MED					FISH4	FP_LARGE
4	FISH4	INC_LOT	FP_LARGE					INC_MED	WH_OK
5	FP_MED	FISH4	FISH3					WH_OK	FISH4
6	WH_OK	FP_MED	FISH4					INC_LOT	INC_LOT
7	INC_LOT	FP_LARGE	WH_OK					FISH3	FISH3
8	INC_MED	INC_MED	FP_MED					FP_MED	FP_MED

3.4 Discussion

The high percentage of respondents from cities in southern Australia (Perth, Melbourne, Sydney, Brisbane and Canberra) who tick 'yes' to living in or having visited the tropical rivers region indicates that the sample of people who responded to the questionnaires may be biased towards those who have had some direct experience with the tropical rivers region of Australia, although not necessarily the three catchments in particular. Comparison of the willingness to pay of those who have visited the region with those who have not and don't intend to will be explored in further work with this dataset.

As a stated preference method, choice modelling assumes that all people have the same marginal value for money, in other words, that the benefit of an additional dollar is the same to each individual. It also cannot distinguish between willingness to pay and ability to pay or the actual making of a payment. The incomes of Aboriginal people living on remote communities are lower than for Australians generally (Steering Committee for the Review of Government Service Provision 2005), yet their willingness to pay is often higher than that of other respondents. This may indicate that there is a larger difference between willingness to pay and ability to pay for these and other low-income respondents.

This, and other challenges of eliciting individual valuation responses from Indigenous people, are discussed by Venn and Quiggin (2007). Our impressions of the responses of Aboriginal people to the questionnaire delivered face-to-face are that people perceived the choices in the intended way and were capable of evaluating the trade-offs that each choice set presented. The choice modelling format does not enable compliance bias in the same way that other valuation questionnaires might because there is no clear 'correct' answer to each choice question. The potential impact of the face-to-face delivery method on the implicit prices will be explored in further work with this dataset.

Care is required in extrapolating these implicit prices to other river systems in the tropical rivers region. The similarity in implicit prices for some attributes across the different city populations might suggest that respondents are valuing a generic river in northern Australia. If respondents were faced with a similar questionnaire for other river systems, they might be willing to pay so much for a set of river systems, or willing to pay less for additional river systems as the marginal benefits of protection for each additional river decreases. If this is the case, care should be taken in transferring these results to other rivers.

3.4.1 Application to management and policy questions: aggregation of implicit prices

For this economic valuation exercise, it is not necessary to specify the specific nature of the development for which impacts are being assessed; rather, we estimate the impact of the potential resulting change in ecosystem services on community welfare in dollar terms. This enables the use of the valuation results in standard cost-benefit analyses where estimates of the relative value of new tropical river resource allocations and/or management strategies are needed.

One way to do this is by aggregating the implicit prices across a proportion of the total number of households for each sub-population to give an estimate of the total amount that households in a city or region would be willing to pay for improvements in each of the ecosystem services.

The aggregate willingness to pay of each sub-population is calculated by multiplying the average implicit prices per household obtained for the sub-samples by the number of households in a sub-population, and multiplying this result by a proportion of each sub-population equivalent to the response rate for each sub-population (Table 4). We assume that the response rates are indicative of the proportion of each population who have the same preferences as respondents in the study. We assume 2.6 people per household for non-Indigenous sub-populations (Australian Bureau of Statistics 2004) and 4.9 people per household for Indigenous sub-populations (Australian Bureau of Statistics 2006). The populations and number of households are reported in Table 22. We assume the same average implicit prices for a river apply to each city. The aggregate willingness to pay for river ecosystem services by each sub-population is presented in Tables 23 to 25.

Table 22: Sub-populations (Australian Bureau of Statistics 2006; Australian Bureau of Statistics 2007)

Fitzroy questionnaire			**Daly questionnaire**			**Mitchell questionnaire**		
Sub-population	Population	No. of households	Sub-population	Population	No. of households	Sub-population	Population	No. of households
Fitzroy	10,888	4,188	Daly	13,648	5,249	Mitchell	20,906	8,041
Fitzroy Indigenous	7,611	1,553	Daly Indigenous	5,978	1,220	Mitchell Indigenous	3,537	722
Perth	1,501,773	577,605	Darwin	1,168,44	44,940	Brisbane	1,856,966	714,218
Melbourne	3,805,755	1,463,752	Sydney	4,266,183	1,640,840	Canberra	339,474	130,567

Table 23: Willingness to pay for Fitzroy River ecosystem services (once-off payment) – sub-population aggregation (million)

	Medium area floodplain in good condition	**Large area floodplain in good condition**	**Medium quality river for rec. fishing**	**High quality river for rec. fishing**	**Medium condition waterholes**	**Good condition waterholes**	**Medium income from irrigated agric.**	**High income from irrigated agric.**
Fitzroy catchment, Perth and Melbourne								
MNL	$33.33	$87.17	$66.90	$109.46	$114.82	$201.96	$62.23	$45.57
MXL	$58.64	$111.66	$74.35	$121.75	$137.67	$202.83	$48.71	$31.64
MXL plus	$45.36	$80.76	$59.52	$123.05	$135.29	$265.89	$93.11	$69.13
Fitzroy catchment								
MNL	$0.26	$0.31	$0.47	$0.47	$0.48	$0.67	*	*
MXL	$0.25	$0.30	$0.54	$0.52	$0.53	$0.77	*	*
Indigenous people in the Fitzroy catchment								
MNL	$0.19	$0.18	$0.30	$0.34	$0.40	$0.53	*	*
MXL	$0.17	$0.15	$0.28	$0.40	$0.44	$0.65	*	*
Perth								
MNL	$5.73	$25.22	$13.42	$27.24	$26.94	$53.46	$23.19	$16.65
MXL	$9.01	$28.83	$14.85	$28.56	$28.82	$53.71	$20.92	$15.60
Melbourne								
MNL	$14.61	$64.31	$34.22	$69.44	$68.69	$136.30	$59.13	$42.44
MXL	$22.98	$73.50	$37.86	$72.81	$73.49	$136.94	$53.34	$39.78

* Variable is statistically insignificant from zero

Table 24: Willingness to pay for Daly River ecosystem services (once-off payment) – sub-population aggregation (million)

	Medium area floodplain in good condition	**Large area floodplain in good condition**	**Medium quality river for rec. fishing**	**High quality river for rec. fishing**	**Medium condition waterholes**	**Good condition waterholes**	**Medium income from irrigated agric.**	**High income from irrigated agric.**
Daly catchment, Darwin and Sydney								
MNL	$36.52	$92.51	$60.90	$93.82	$71.31	$117.70	$34.93	$13.98
MXL	$34.01	$79.48	$59.54	$84.42	$91.14	$118.28	$58.58	$24.06
MXL plus	$43.82	$20.87	$61.95	$49.50	$85.50	$127.53	$50.11	$28.09
Daly catchment								
MNL	$0.15	$0.28	$0.42	$0.53	$0.39	$0.58	*	*
MXL	$0.11	$0.21	$0.48	$0.53	$0.43	$0.62	*	*
Indigenous people in the Daly catchment								
MNL	$0.14	$0.19	$0.20	$0.42	$0.40	$0.52	**	**
MXL	$0.16	$0.12	$0.19	$0.42	$0.42	$0.55	**	**
Darwin								
MNL	$0.97	$2.71	$1.42	$2.40	$1.81	$3.14	$1.10	$0.43
MXL	$0.94	$2.38	$1.70	$2.37	$2.41	$3.47	$1.81	$0.72
Sydney								
MNL	$33.43	$93.72	$49.24	$82.90	$62.53	$108.54	$37.93	$14.91
MXL	$32.39	$82.27	$58.92	$81.95	$83.44	$120.07	$62.64	$25.03

* Variable is statistically insignificant from zero

Table 25: Willingness to pay for Mitchell River ecosystem services (once-off payment) – sub-population aggregation (million)

	Medium area floodplain in good condition	Large area floodplain in good condition	Medium quality river for rec. fishing	High quality river for rec. fishing	Medium condition waterholes	Good condition waterholes	Medium income from irrigated agric.	High income from irrigated agric.
Mitchell catchment, Brisbane and Canberra								
MXL plus	$16.26	$27.07	$26.66	$25.92	$24.38	$40.44	$27.80	$29.17
Mitchell catchment								
MNL	COST statistically insignificant from zero							
MXL	COST statistically insignificant from zero							
Indigenous people in the Mitchell catchment								
MNL	Failed to converge							
MXL	Failed to converge							
Brisbane								
MNL	$14.22	$39.14	$20.62	$33.53	$25.33	$53.39	$28.15	$25.09
MXL	$13.02	$32.88	$20.63	$29.50	$29.90	$53.59	$42.96	$26.19
Canberra								
MNL	$2.83	$7.79	$4.11	$6.68	$5.04	$10.63	$5.61	$5.00
MXL	$2.59	$6.55	$4.11	$5.87	$5.95	$10.67	$8.55	$5.21

* Variable is statistically insignificant from zero

If there were to be a project to improve the quality of waterholes important to Aboriginal people to the highest quality, for example, the value of these improvements to people living in the Fitzroy catchment and in Perth is estimated at around $54 million. Based on a cost-benefit analysis, if the cost of the project is less than $54 million, then it should be undertaken.

We note that these aggregate estimates are dependent on the specific framing and definitions of the questionnaire, and will change with different assumptions about the number of people per household, and about the proportion of each population who have the same preferences as respondents in the study. For example, while the questionnaire mailed to households in Melbourne was completed and returned by 33.1% of receivers, this only comes to 0.03% (123) of Melbourne's approximately 484,502 households. Hence the assumption that 33.1% of all Melbourne households share the same preferences may not be appropriate and these results must be treated with great caution.

3.4.2 Application to management and policy questions: evaluating potential development scenarios

Another way to calculate estimates that can be used in cost-benefit analyses is through the calculation of 'compensating surplus'. Compensating surplus approximates how much people would be willing to pay to move from one scenario to another, or how much they would need to be paid in compensation to make them indifferent between the two. Compensating surplus can be calculated using the following equation (Boxall *et al.* 1996, p.251):

$$CS = \frac{-1}{\beta_{COST}}(V_0 - V_1)$$

The coefficient of COST, β_{COST}, is the marginal utility of income; V_0 is the utility of the initial situation, and V_1 is the utility of the new situation. Similarly to implicit price calculations, we assume that everything else stays the same.

The initial scenario in this study is defined by the following attribute-level combination: (a) lowest level area of floodplain in good environmental condition; (b) lowest level quality of the river for recreational fishing; (c) lowest level condition of waterholes important to Aboriginal people; and (d) lowest level income from irrigated agriculture.

We have chosen two examples of alternative scenarios with different impacts on the four ecosystem services:

Scenario 1: (a) medium level area of floodplain in good environmental condition; (b) medium level quality of the river for recreational fishing; (c) medium level condition of waterholes important to Aboriginal people; and (d) medium level income from irrigated agriculture.

Scenario 2: (a) highest level area of floodplain in good environmental condition; (b) highest level quality of the river for recreational fishing; (c) highest level condition of waterholes important to Aboriginal people; and (d) highest level income from irrigated agriculture.

Estimates of compensating surplus for the two scenarios enable an assessment of the impact of each scenario on community welfare. Tables 26 to 28 present compensating surplus estimates for both scenarios for all rivers and all samples and for all models. Estimates are italicised where they do not contain implicit prices for all attributes.

For the Fitzroy River,

- Perth and Melbourne households are willing to pay a once-off payment of $364.59 - $387.34 for a scenario where all ecosystem services improve from their lowest to their medium levels and nearly twice as much ($644.99 - $666.71) for a scenario where all ecosystem services improve from their lowest to their highest levels.;

- Indigenous households in the Fitzroy catchment are willing to pay a once-off payment of $586.97 - $587.13 for a scenario where all ecosystem services improve from their lowest to their medium levels and $690.13 - $783.22 for a scenario where all ecosystem services improve from their lowest to their highest levels;

- All households in the Fitzroy catchment are willing to pay a once-off payment of $572.48 - $621.02 for a scenario where all ecosystem services improve from their lowest to their medium levels and $683.61 - $746.43 for a scenario where all ecosystem services improve from their lowest to their highest levels.

Table 26: Estimates of compensating surplus for two scenarios for the Fitzroy River (once-off payment per household)

Scenario	Fitzroy catchment, Perth and Melbourne	Fitzroy catchment	Indigenous people living in the Fitzroy catchment	Perth and Melbourne
MNL				
1	$408.86	*$572.48*	*$586.97*	$364.59
2	$654.94	*$683.61*	*$690.13*	$644.99
MXL				
1	$470.92	$621.02	$587.13	$387.34
2	$689.89	$746.43	$783.22	$666.71
MXL plus				
1	$491.44			
2	$794.53			

For the Daly River,

- Darwin and Sydney households are willing to pay a once-off payment of $345.52 - $447.93 for a scenario where all ecosystem services improve from their lowest to their medium levels and $566.18 - $583.62 for a scenario where all ecosystem services improve from their lowest to their highest levels;

- Indigenous households in the Daly catchment are willing to pay a once-off payment of $608.74 - $622.44 for a scenario where all ecosystem services improve from their lowest to their medium levels and $891.43 - $930.23 for a scenario where all ecosystem services improve from their lowest to their highest levels;

- All households in the Daly catchment are willing to pay a once-off payment of $439.04 - $471.49 for a scenario where all ecosystem services improve from their lowest to their medium levels and $622.12 - $639.51 for a scenario where all ecosystem services improve from their lowest to their highest levels.

Table 27: Estimates of compensating surplus for two scenarios for the Daly River (once-off payment per household)

Scenario	Daly catchment, Darwin and Sydney	Daly catchment	Indigenous people living in the Daly catchment	Darwin and Sydney
MNL				
1	$371.14	*$439.04*	*$608.74*	$345.52
2	$579.57	*$639.51*	*$930.23*	$566.18
MXL				
1	$443.33	*$471.49*	*$622.44*	$447.93
2	$558.09	*$622.12*	*$891.43*	$583.62
MXL plus				
1	$439.90			
2	$411.87			

For the Mitchell River,

- Brisbane and Canberra households are willing to pay a once-off payment of $459.69 - $554.37 for a scenario where all ecosystem services improve from their lowest to their medium levels and $739.92 - $786.75 for a scenario where all ecosystem services improve from their lowest to their highest levels;

Table 28: Estimates of compensating surplus for two scenarios for the Mitchell River (once-off payment per household)

Scenario	**Mitchell catchment, Brisbane and Canberra**	**Mitchell catchment**	**Indigenous people living in the Mitchell catchment**	**Brisbane and Canberra**
MNL				
1				$459.69
2				$786.75
MXL				
1				$554.37
2				$739.92
MXL plus				
1	$405.99			
2	$523.41			

These estimates of compensating surplus can also be aggregated across whole populations.

Care must be taken in using the implicit prices in cost-benefit analysis particularly when it comes to the benefits and costs of irrigated agriculture. As noted in section 3.1, the production ecosystem service indicated by income from irrigated agriculture is conceptualised as the value of seeing irrigated agriculture continue as a land use in the region and potentially expand. This captures the indirect and non-use aspects of irrigated agriculture as a land use, rather than the direct use values associated with gaining an income from undertaking irrigated agriculture. There may be an issue here if respondents believed that some of the direct benefits (income) might flow to them, in which case the inclusion of the implicit prices estimated here and the gross value of production from irrigated agriculture may be a double counting of the benefits. It is fair to assume, however, that the implicit prices estimated for income from irrigated agriculture in this exercise are only estimates of the indirect/non-use values of this land use and so can be added to the gross value of production without concern for double counting.

We now turn to assessing the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers using another approach based on resilience theory and an analysis of how changes in the past have impacted on tropical river ecosystem services. This approach is based on an understanding of drivers of change in the tropical rivers region and seeks to understand further the interactions that influence the capacity of Australia's tropical river systems to provide these valued ecosystem services.

4. UNDERSTANDING INTERACTIONS THAT INFLUENCE AUSTRALIA'S TROPICAL RIVER ECOSYSTEM SERVICES

4.1 Rationale

The tropical river systems of Australia are complex adaptive social-ecological systems. This has several implications for the management of these systems. When a system is complex, the dynamics of the whole system cannot be understood by looking at separate components of the system. Due to the many interconnections between parts of the system, a change in one component can lead to changes in others that were not predictable and these responses are often non-linear. Changes can be irreversible because there are so many components that can change at one time and, somewhat frustratingly for managers, very seldom is there a stable or 'resting point' for the whole system that can be used to guide all management decisions into the future.

For this reason, the economic valuation of impacts presented above provides a simplified story of how a potential development trajectory might impact on the ecosystem services of Australia's tropical rivers, and the results are only relevant to a specific set of circumstances defined by the framing of the exercise. The story is a simplified one because the economic theory of value and the methods of economic valuation make many simplifying assumptions about human choice behaviour and about interactions between the components of tropical river systems. However, the results from an economic valuation are useful precisely because they provide some information where often none is available.

Complete and integrated analysis of how a new development might impact on the provision of ecosystem services is, of course, one of the great challenges for scientists and policy-makers. Assessing how and when a particular activity might lead to a significant and detrimental downturn in the provision of a valued ecosystem service is perhaps the holy grail of much environmental and other policy-related research, although, as non-linear systems, they are always likely to surprise us no matter how much we learn. In this situation, learning how to recognise it when they are approaching a critical threshold is perhaps the most that we can do.

The analysis presented here does not presume to make much headway in answering such questions without the input of findings from other TRaCK research that is currently underway, however, this second approach to assessing the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers goes some way to providing greater understanding of how complex interactions between social and ecological systems impact on ecosystem services and affect human well-being. To do this, we use the Millennium Ecosystem Assessment conceptual framework and resilience theory and analysis to explore past changes in the tropical rivers region. While resilience analysis does not enable prediction, a better understanding of the behaviour of the tropical rivers region in the past may give insight into some of the behaviours that might occur in the future.

4.2 Method

4.2.1 Understanding drivers of change in Australia's tropical rivers region

The Millennium Ecosystem Assessment (2005) provides a useful framework for understanding the factors that influence ecosystem services and human well-being, these being the direct and indirect drivers of change in a social-ecological system (Figure 5).

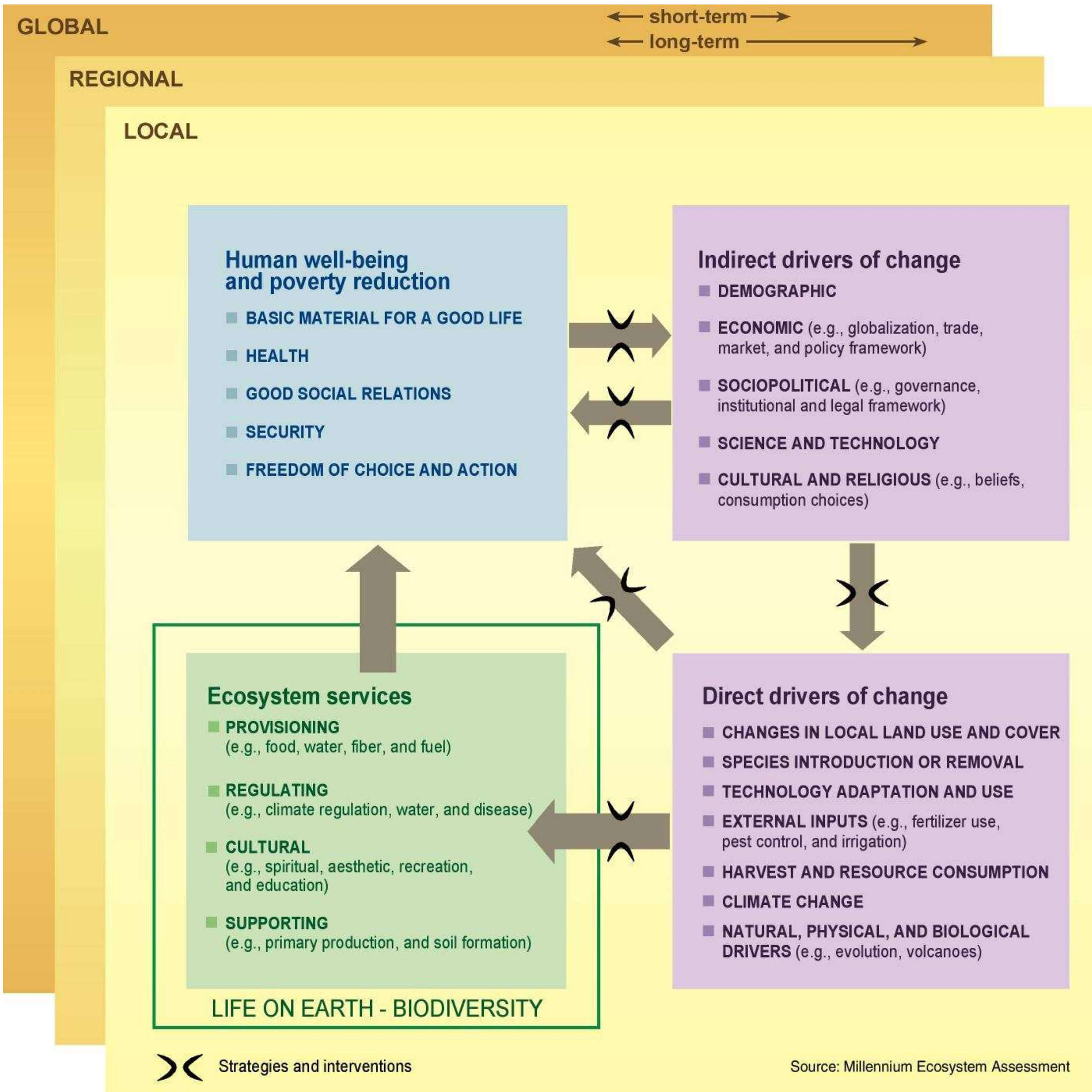


Figure 5: Millennium Ecosystem Assessment framework (Millennium Ecosystem Assessment 2005)

The tropical river systems of Australia comprise biophysical components and processes – ecosystems and their natural or modified relationships and cycles (e.g. the hydrological regime, food webs, material budgets) – and human components and processes – families, communities, companies, industries, organisations, social interactions, and economic interactions. The tropical rivers region of Australia can thus be referred to as a social-ecological system.

As described by the Millennium Ecosystem Assessment framework (Figure 5), people impact on ecosystems through direct and indirect drivers of change, such as demographic change and changes in local land use and cover, and ecosystem services impact on people through providing the basic material for a good life, for example. The social and ecological systems are inextricably interconnected in that the dynamics of the whole tropical rivers region are driven by interactions between these components and processes.

To better understand how a development might impact on tropical river ecosystem services it is useful to understand the direct and indirect drivers of change in the tropical rivers region. Finlayson, Bellio *et al.* (2005) document some knowledge about direct and indirect drivers of change for Australia's tropical wetlands. They suggest the use of the Millennium Ecosystem Assessment framework to guide decisions about the wise use of these wetlands in the future. While we do not follow the exact categories suggested by the Millennium Ecosystem Assessment framework, we apply the concepts generally and build on the work of Finlayson, Bellio *et al.* (2005) by providing further information about several variables, processes and relationships. This then forms the basis for a resilience analysis of thresholds, cross-scale interactions and how new developments might impact on the capacity of tropical river systems to provide tropical river ecosystem services.

4.2.2 Resilience theory and analysis

Resilience theory describes the ability of a social-ecological system to experience disturbances without significant qualitative change in its basic functional organisation (see, for example, Holling 1973; Arrow *et al.* 1995; Gunderson *et al.* 1995; Batabyal 1998; Berkes and Folke 1998; Levin 1998). Resilience theory suggests that there is a certain state of a social-ecological system within which it is capable of performing its essential functions, including providing certain ecosystem services. Assessing the resilience of a system to certain disturbances or disturbing processes, such as climate change, requires asking how and when a disturbance might cause the system to shift out of its current state and across thresholds into a state less desirable in its functioning. Resilience analysis thus focuses on where these thresholds might be for desired functions; for example, how much can the stream flow of a tropical river be altered from its natural regime before the quality of the river for recreational fishing crosses a threshold from which it cannot easily return.

Resilience theory is also based on an understanding of social-ecological systems as having slow- and fast-moving processes and operating over a range of spatial scales. All of the components and processes of the tropical rivers region exist and operate at different spatial and temporal scales, for example, some relate to small sections of a river, some are relevant to the whole region, some happen within a very short period of time, while others take place over a longer term.

Key properties of social-ecological systems emerge from the interactions between the slow- and fast-moving processes, and from interactions between processes with large spatial reach and those that are relatively localised (Holling *et al.* 2001). The dynamics of the faster variables (from which use, utility and value are derived) are often determined by those of the more slowly changing variables (referred to as "controlling variables") (Carpenter *et al.* 2001). Resilience theory proposes that it is the levels of and variations in these slow variables that maintain a system in a particular state. This shifts attention from trying to control fluctuations in the fast variables to understanding and managing the slow variables that influence the structure of the system (Scheffer *et al.* 2001).

Another key concept in resilience theory is the adaptive cycle (Holling 1994; Holling and Gunderson 2002). The adaptive cycle was originally developed as a model of change in productive ecosystems. It has since been extended to help explain change in social and social-ecological systems. The cycle has four phases: (1) the phase of growth or exploitation (r); (2) the phase of conservation (K); (3) the phase of collapse or release (Ω); and (4) the phase of reorganisation (α) (Figure 6). The growth phase (r) takes place after a period of reorganisation that follows an event of collapse or release.

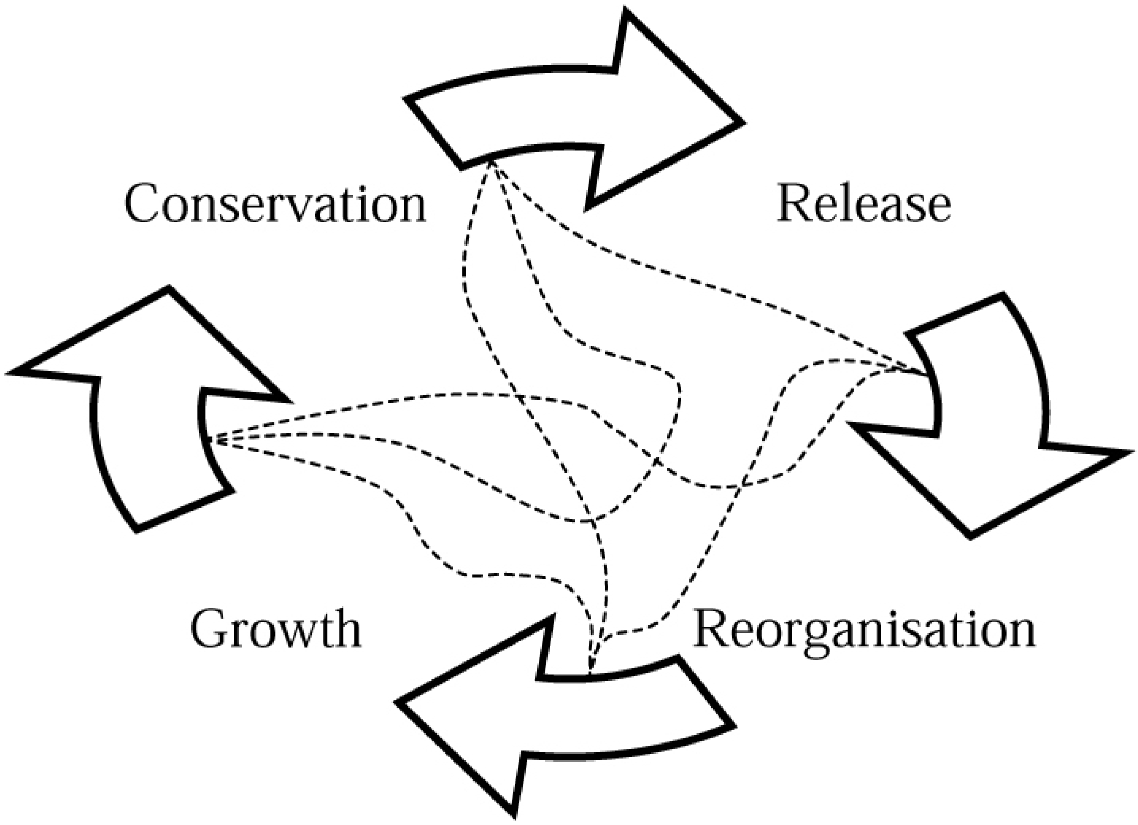


Figure 6: The adaptive cycle (McAllister *et al.* 2006)

An example is the establishment and growth of a settler society in Australia following the British invasion (and the consequent collapse of Indigenous social-ecological systems), succeeded by a period during which institutions are established and become increasingly complex, and resources are used more intensively (conservation phase, K). The system is thought to lose resilience as options are reduced and increasing complexities of infrastructure, institutions and social expectations lead to rigidity, until a disturbance of some kind – economic, political, military or environmental, for example – precipitates a collapse phase (Ω) and the resources are released, followed by reorganisation (α) where resources are recombined to take advantage of new opportunities (Holling 2001).

According to resilience theory, a social-ecological system at a particular scale interacts with social-ecological systems at finer and broader scales. For example, farms influence and are influenced by interactions with regional, state and national social-ecological systems. Adaptive cycles are believed to occur at each scale, and are not necessarily synchronous – they may be in different phases of the adaptive cycle at the one time. A set of such multi-scale cycles is called a 'panarchy' (Holling 2001).

In Australia, resilience theory has been applied to the analysis of social-ecological systems including the Goulburn-Broken region in southeast Australia (Walker *et al.* 2009), the Western Australian agricultural region (Allison and Hobbs 2004) and pastoralism in Australia's drylands (McAllister *et al.* 2006).

The method employed for this study involves a literature review of ecological, social, economic and historical research in books, reports and journal articles, and a resilience analysis following parts of the method set out by the Resilience Alliance (2007). Information is compiled on key variables and processes relevant to Australia's tropical rivers region and thresholds for the provision of the four focal ecosystem services of the valuation exercise. This information is organised to provide an historical perspective and so includes key past events and changes that have shaped the whole tropical rivers region, and have impacted on the capacity of tropical river systems to provide ecosystem services.

Using resilience theory, this information is analysed for insight into (1) slowly changing variables, (2) examples of cross-scale interactions that have had particular impacts on the tropical rivers region and tropical river ecosystem services, and (3) distinct phases for the state of the tropical rivers region based on the adaptive cycle. We then discuss the implications of these findings for our assessment of the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers.

4.3 Results

4.3.1 What are the ecosystem services that people care about?

The variables of concern in this study are the four focal ecosystem services for which economic values were estimated in section 3: (1) provision of floodplain habitat; (2) provision of river conditions for recreational fishing; (3) provision of species and habitat important to Aboriginal customary activity at waterholes; and (4) production from irrigated agriculture. There are many other features and aspects that are important to people (see, for example, Jackson and O'Leary 2006; Stoeckl *et al.* 2006), however, due to the limitations of time and space, we will restrict our discussion to these four.

4.3.2 Which factors directly influence the provision of ecosystem services?

The state of each of these ecosystem services is determined in the first instance by the following variables:

- The provision of floodplain habitat, river conditions for recreational fishing, and species and habitat important to Aboriginal customary activity at waterholes are all influenced by the flow regime and water quality.

- The provision of healthy floodplain habitat is also influenced by the diversity and cover of floodplain vegetation and the incidence of weeds.

- The provision of river conditions for recreational fishing and species and habitat important to Aboriginal customary activity at waterholes are also influenced by the diversity and cover of riparian vegetation and the abundance and diversity of species.

- Production from irrigated agriculture is influenced by the availability and quality of water and soil.

These ecosystem services are also influenced by other non-biophysical variables and processes, for example, the quality of a recreational fishing experience is also influenced by people's access to fishing sites, and how crowded and unpolluted these sites are. Aboriginal customary activity at waterholes is also influenced by people's access to these places and their privacy when there. Production from irrigated agriculture is also influenced by a range of social and economic variables, such as institutional arrangements, technology, and market conditions.

4.3.3 What variables and/or processes threaten the factors that directly influence the provision of ecosystem services?

There are multiple other variables and/or processes that impact on and threaten these factors that directly influence the provision of ecosystem services. These variables and/or processes include:

- weeds, such as mimosa, salvinia, water hyacinth, paragrass, and parkinsonia;

- water extraction and river impoundments;

- water pollution from mineral extraction and processing and agricultural chemicals;

- feral animals, such as water buffaloes, pigs and cane toads;

- pastoral activities, such as the clearing of native vegetation, grazing and introduced pastoral species; and

- tourism and recreational activities (Finlayson *et al.* 2005; Woinarski *et al.* 2007; van Dam *et al.* 2008).

Climate change will also have an impact. Research has found that the likely impacts of climate change for the tropical rivers region are an increase in the average temperature by between 1 and 4ºC by 2070, and a change in rainfall of between -10 and +2% (Commonwealth Scientific and Industrial Research Organisation 2007). Knowledge about the potential impacts of this change on specific species and processes of the tropical rivers region is summarised in van

Dam, Bartolo *et al.* (2008). Table 29 summarises the local biophysical processes relevant to each of the four ecosystem services, and some of the threats to each.

Table 29: Ecosystem services, relevant ecosystem processes and some threats

Tropical river ecosystem service	Related slow variables	Threats
Provision of healthy floodplain habitat	Maintenance of stream flows	Surface and groundwater extraction, river impoundments, sediment build up
	Maintenance of water quality (sediment and nutrient levels)	Pollution and erosion (chemical use, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals)
	Maintenance of floodplain vegetation	Weeds, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals
Provision of river conditions for recreational fishing	Maintenance of stream flows	Surface and groundwater extraction, river impoundments, sediment build up
	Maintenance of water quality (sediment and nutrient levels)	Pollution and erosion (chemical use, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals)
	Maintenance of riparian vegetation	Erosion (poor riparian management, cattle, feral animals)
	Maintenance of species abundance and diversity	Habitat modification
Provision of species and habitat important to Aboriginal customary activity at waterholes	Maintenance of stream flows	Surface and groundwater extraction, river impoundments, sediment build up
	Maintenance of water quality (sediment and nutrients levels)	Pollution and erosion (chemical use, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals)
	Maintenance of riparian vegetation	Erosion (poor riparian management, cattle, feral animals)
	Maintenance of species abundance and diversity	Habitat modification
Production from irrigated agriculture	Maintenance of water supply	Surface and groundwater extraction, river impoundments, climate change
	Maintenance of water quality (sediment and nutrients levels)	Pollution and erosion (chemical use, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals)

Each of these threats has their roots in variables and processes operating at larger regional, national or global scales. Broadly, all are influenced by the values and attitudes of the Australian community, expressed through its elected representatives and institutions. Values are "presumed to encapsulate the aspirations of individuals and societies: They pertain to what is desirable, to deeply ingrained standards that determine future directions and justify past actions" (Braithwaite and Scott 1991, p.661). Values and attitudes have determined the trajectory of development in the tropical rivers region, and the ways in which decisions are made and development is undertaken. For example, the development of the Ord Irrigation Scheme in the mid-1900s reflects the development imperative of the time. The values and attitudes that have been expressed for the tropical rivers region of Australia have changed through time, and the impact of different aspirations coming to dominance in the national psyche can be seen in the types and processes of development that have taken place in northern Australia (Jackson *et al.* 2008).

One of the main ways by which values and attitudes influence the provision of ecosystem services is through policies and other institutions, being sets of rules and norms that guide and govern the behaviour of individuals and organisations, such as government departments and community groups (North 1990; Ostrom 1990). Some examples of legislation and policy directives that impact directly on the four focal ecosystem services are the National Water Initiative, the Water Acts of each state/territory, the *Environmental Protection and Biodiversity Conservation Act 1999* (C'th), the National Strategy for Ecologically Sustainable Development and the Intergovernmental Agreement on the Environment. It is worth noting that changes in rules that guide and govern behaviours on the ground can also sometimes feed back to influence the set of values.

The determinants of and threats to the four focal ecosystem services are all influenced most directly by actual land and water uses and practices on the ground: water extraction, land clearing, grazing practices, fencing of riparian zones, chemical use, burning regimes, and weed dispersal, for example. Land and water uses and practices are primarily determined by what is possible given the natural resources of a region, driven by the ecology, landscape and water cycle, and by the net economic returns available, and are also driven and guided by values and attitudes, policies and other institutions, and other social and economic processes (such as demographic change, available technology, and market conditions, for example). Water extraction is also influenced by demographic change and rates of water use for domestic, industrial and agricultural use. Whether or not specific practices are required or sanctioned by legislation, their practice by land-owners or managers will be determined by a number of factors, including the availability of technology, economic incentives and how well enforced legislation is.

Figure 7 summarises the relationships between variables and processes that influence the provision of tropical river ecosystem services generally.

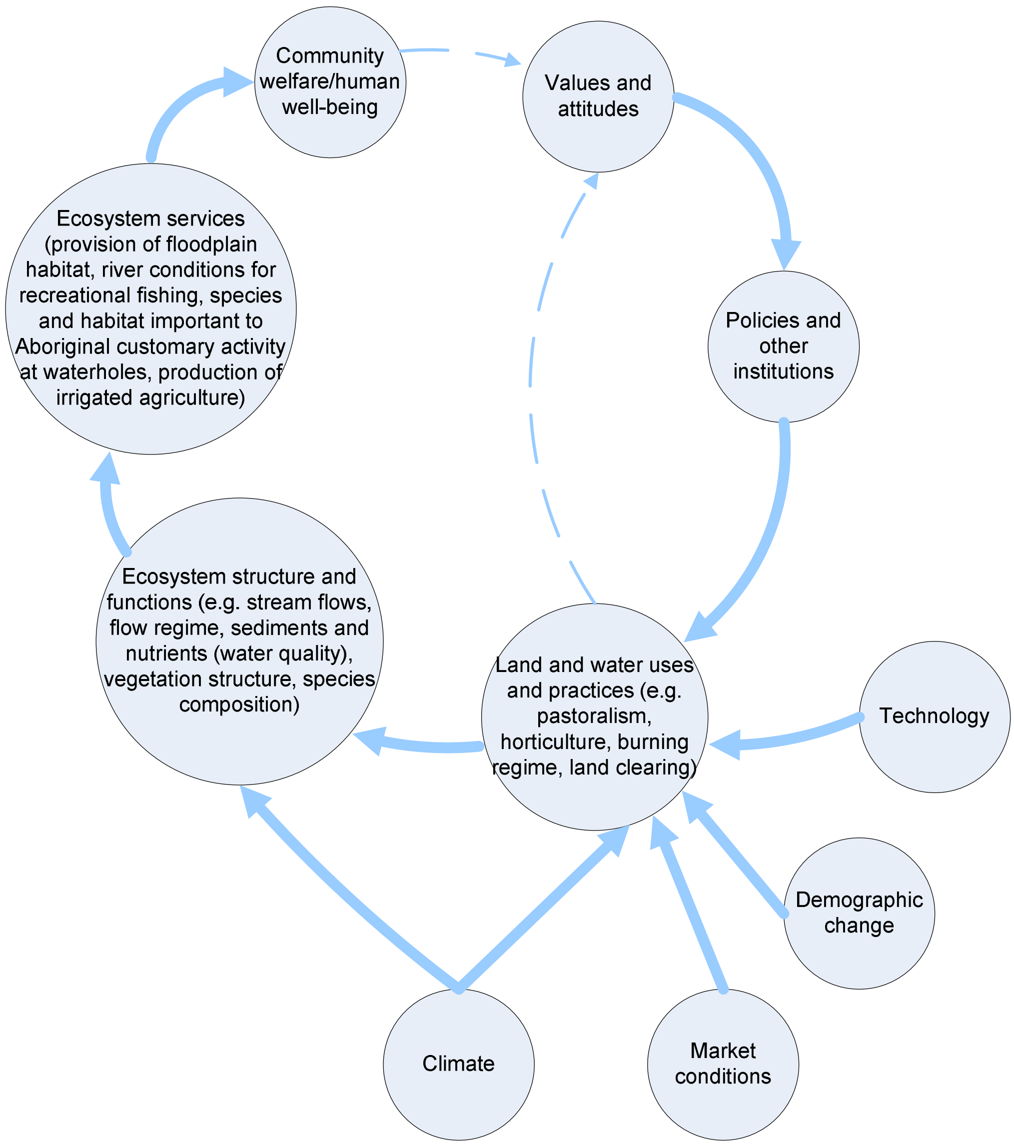


Figure 7: Conceptual model of processes influencing the provision of tropical river ecosystem services

4.3.4 How have these processes changed over time?

There have been changes in all of these variables and processes over time. Appendix G contains summaries of trends in values and attitudes, policies and other institutions, demographics, market conditions and technology, and land and water uses and practices with examples drawn from the three case study river systems. The material in these brief histories is drawn on for the rest of the analysis.

4.3.5 What cross-scale interactions influence the provision of ecosystem services?

The histories presented in Appendix G illustrate that there are multiple processes in Australia's tropical rivers region operating at multiple scales, and therefore multiple cross-scale interactions that influence the provision of ecosystem services. The following provides some examples of combinations of changes across sub-systems and spatiotemporal scales, often leading to unintended or unexpected impacts on the provision of ecosystem services.

There are several descriptions in the literature of the negative impacts of combinations of land management practices and extreme rainfall events. For example, burning in the late dry or early wet season, followed by high intensity wet season rainfall can increase erosion and the flow of sediments into aquatic habitats (Daly Region Community Reference Group 2004). Excess sediment can reduce the clarity of water impacting on aquatic plant growth and can, in turn, lead to de-oxygenation (Rangelands NRM Coordinating Group 2004), thereby impacting on aquatic habitats important for species abundance and diversity that underpin the provision of species and habitat important for recreational fishing and to Aboriginal customary activity at waterholes. There will be threshold points at which the combined impacts of burning and rainfall events will significantly influence water quality, and at which decreases in water quality will significantly affect recreational fishing and Aboriginal customary activity and the value of recreational fishing and Aboriginal customary activity.

Another example is the building of infrastructure. Aboriginal people in the Fitzroy Valley report that the all-weather Broome-Derby road acts like a dam across the Fitzroy River floodplain, which can increase pasture productivity (Ivan Watson in Marshall 1988). Pastoralists increased stocking rates in response to this and the pastures were over-grazed. When the large flood event of 1986 took place, the damming action of the road meant that the water receded with much greater force than usual and, given the degraded state of the floodplain pastures, gouged out the river frontage and tributaries, and uprooted trees and fences (Ivan Watson in Marshall 1988). Both the overgrazing and the force of the water in this case impacted negatively on the provision of floodplain habitat and there will be threshold points at which the combined impacts of over-grazing and rainfall events will significantly influence floodplain health, and at which decreases in floodplain health will significantly affect the environmental values associated with healthy floodplains.

The interaction of the introduction of new technology with new legislation has impacted on social dynamics in parts of the tropical rivers region. For example, the increasing use of technology in the pastoral industry, such as helicopters and fencing, from the late 1960s onwards tended to decrease demand for Aboriginal labour and, along with the impacts of the *Federal Pastoral Industry Award 1968*, lead to many Aboriginal people moving into townships, thereby increasing pressure on available resources, including water, laying the groundwork for some of the social pressures to come (Toussaint *et al.* 2001), and also bringing a decline in customary natural resource management (Sullivan 2006).

The compilation of information on variables and processes presented in Appendix G also provides insight into some combinations that have the potential to significantly change the tropical rivers region and the provision of ecosystem services in the future. For example, the combination of daily water use attitudes and practices in Darwin, a lack of appropriate incentives to manage demand, and a low rainfall year could lead to a flow regime that causes irreversible damage to groundwater dependent ecosystems and the provision of ecosystem services. There will be threshold points at which the combined impacts of water extraction, demand management and rainfall events will significantly influence the flow regime, and at which changes in the flow regime will significantly affect all other uses and values of tropical rivers.

Scenarios developed by the Daly Region Community Reference Group (2004) considered the potential loss of perennial stream flow occurring through a combination of excessive surface and groundwater extraction, the building of dams or other surface water storage devices, and altered rainfall due to shorter summer monsoons, for example. The loss of stream flow would impact on the provision of all four focal ecosystem services. The Reference Group also considered the potential for changed stream morphology occurring through a combination of late dry season fires and early wet season rains, poor land clearing and management practices, and increased sediment flows into rivers; and habitat degradation through a combination of land clearing, inappropriate fire regimes, weeds and feral animals, excessive surface and groundwater extraction, erosion, increased sedimentation and nutrient loads, and change in the structure of riparian and in-stream vegetation. This would impact on the provision of provision of floodplain habitat, river conditions for good quality recreational fishing, and species and habitat important to Aboriginal customary activity at waterholes.

Adaptive cycles for the tropical rivers region

Cross-scale interactions can also be seen in the analysis of adaptive cycles of the tropical rivers social-ecological system. Key events in the history of the tropical rivers region are distilled from the histories provided in Appendix G and are summarised in Table 30. There are three relatively distinct adaptive cycles identifiable for the tropical rivers region (Figure 8). The first sees the exploration and colonisation of northern Australia by European settlers in the early 1800s and the establishment of settlements and industry (mining, pastoralism and early attempts at agriculture). This is an example of the r phase of exploitation and growth.

Table 30: Key events in the history of the tropical rivers region

Year	Events
Pre-colonisation	Indigenous customary tenure and activity
1788	European colonisation
Early-1800s	Exploration of northern Australia – description of vast, empty spaces to be populated, huge potential for agriculture recognised English common law governs water allocation and use
Mid-1800s	Establishment of sheep and cattle farms and some small mining ventures First failures of pastoral ventures Introduction of some feral species Introduction of drugs and alcohol to Aboriginal communities
Late-1800s	Severe droughts across Australia English common law gives way to regulatory control through administrative grants Pearling industry established Periodic gold rushes Development of some townships
Early-1900's	Establishment of market gardens and some small cropping ventures Proposal for a Jewish settlement in the East Kimberley
1910	*Aborigines Act* – separation of Aboriginal children from parents
Mid-1900s	Several large dams built Proposals to divert tropical rivers inland Policy to assimilate Aboriginal people into European society Proposal for Jewish settlement rejected Further irrigated cropping experiments
1963	Ord River Irrigation Scheme dam and water delivery system built
1968	*Federal Pastoral Industry Award* – movement of many Aboriginal people into townships
1969	Establishment of Camballin irrigation area in Fitzroy River catchment
1970s onwards	Critique of Ord River Scheme (subsidisation of agriculture in northern Australia, environmental and human health consequences, lack of planning and analysis) Peak and decline of livestock numbers
1976	*Aboriginal Land Rights Act* Increasingly complicated water allocation arrangements
1980s	Resource assessments of rangelands find land and riverbanks degraded from grazing Camballin project abandoned due to flood damage, crop pests and diseases, and insufficient economies of scale
1992	National Strategy for Ecologically Sustainable Development
1993	*Native Title Act*

1999	*Environmental Protection and Biodiversity Conservation Act*
Late-1990s	Increasing recognition of natural, recreational and Indigenous values for water worldwide Feasibility study of irrigated agriculture in Fitzroy River catchment
Early-2000s	Increasing attempts to incorporate natural, recreational and Indigenous values for water and consult community in decision-making
2004	Intergovernmental Agreement on a National Water Initiative signed ushering in national program of water reform Proposal to take water from the Fitzroy River in WA to Perth becomes a State election issue
2006	Studies of social, economic and ecological values of Australia's tropical rivers and risks associated with range of pressures and threats published, major research hub – Tropical Rivers and Coastal Knowledge – launched
2007	Northern Australian Land and Water Taskforce established
2008	Northern Australia Sustainable Yields project commences to assess sustainable extraction

The second cycle begins in the mid-1800s with an r to K phase of growth in terms of the early development of the tropical rivers region, including crop trials, and the establishment of market gardens, missions and townships. Investment in capital and infrastructure increases, cattle stocking rates increase, social networks grow as more people move to the region, and political and economic fortunes are built on the promises of developments such as the new Ord Irrigation Scheme. Water allocation arrangements become increasingly complicated and rigid. The combined negative impacts of some grazing practices highlight the increasing degradation of the landscape and risks to ecosystem services.

Criticism of the Ord Irrigation Scheme from the 1970s onwards and public outcry in response to a large irrigation proposal in the Fitzroy region served to dampen development optimism and herald an Ω phase of the collapse or release mainly of old ideas, although there were also several collapses of agricultural enterprises during this time and some degradation of land due to over-grazing. It could also be argued that there has been some degree of collapse in Aboriginal social systems due to a range of policies causing wide-scale movement from traditional lands. The following α phase sees reorganisation around a diversified set of values in the late 1990s and early 2000s, and exploration of alternative development futures through events such as the appropriate economies roundtables in the Kimberley and north Queensland. This can be seen as reflecting a growing environmental awareness worldwide during this time.

The third cycle begins with the r phase growth of the new institutional arrangements of the NWI, the Tropical Rivers and Coastal Knowledge Research Hub and commitments to community engagement, which are all building connections as improved scientific knowledge, new legislation and regulations, and tighter social networks. These trends are currently taking root through the Northern Australia Land and Water Taskforce and the Northern Australia Water Futures Assessment as we move from the r to the K phase. The next Ω phase of collapse or release will likely be triggered by a development decision, election, other governmental restructuring or global catastrophe, for example.

This set of adaptive cycles describes the cycles of exploitation, conservation, release and reorganisation mainly around ideas, values, attitudes and aspirations. There is some evidence of changes in physical components and conditions for people, for example, collapses in agricultural endeavours due to pests, or collapse in the social systems of local Aboriginal people. One example of the next phase of this cycle that might be seen in physical components and actual behaviours could be borne of a significant development of water resources in the region. As existing research for the tropical rivers region seems to indicate, and as experience in the Murray-Darling basin of southern Australia dictates, any significant modification of stream flows and the flow regime may see the social-ecological system of the tropical rivers region move through the current conservation phase (K) and into a collapse similar to that seen in the Murray-Darling system. Alternatively, the system could shift to a new state organised around significantly different land-uses that do not require large inputs of water.

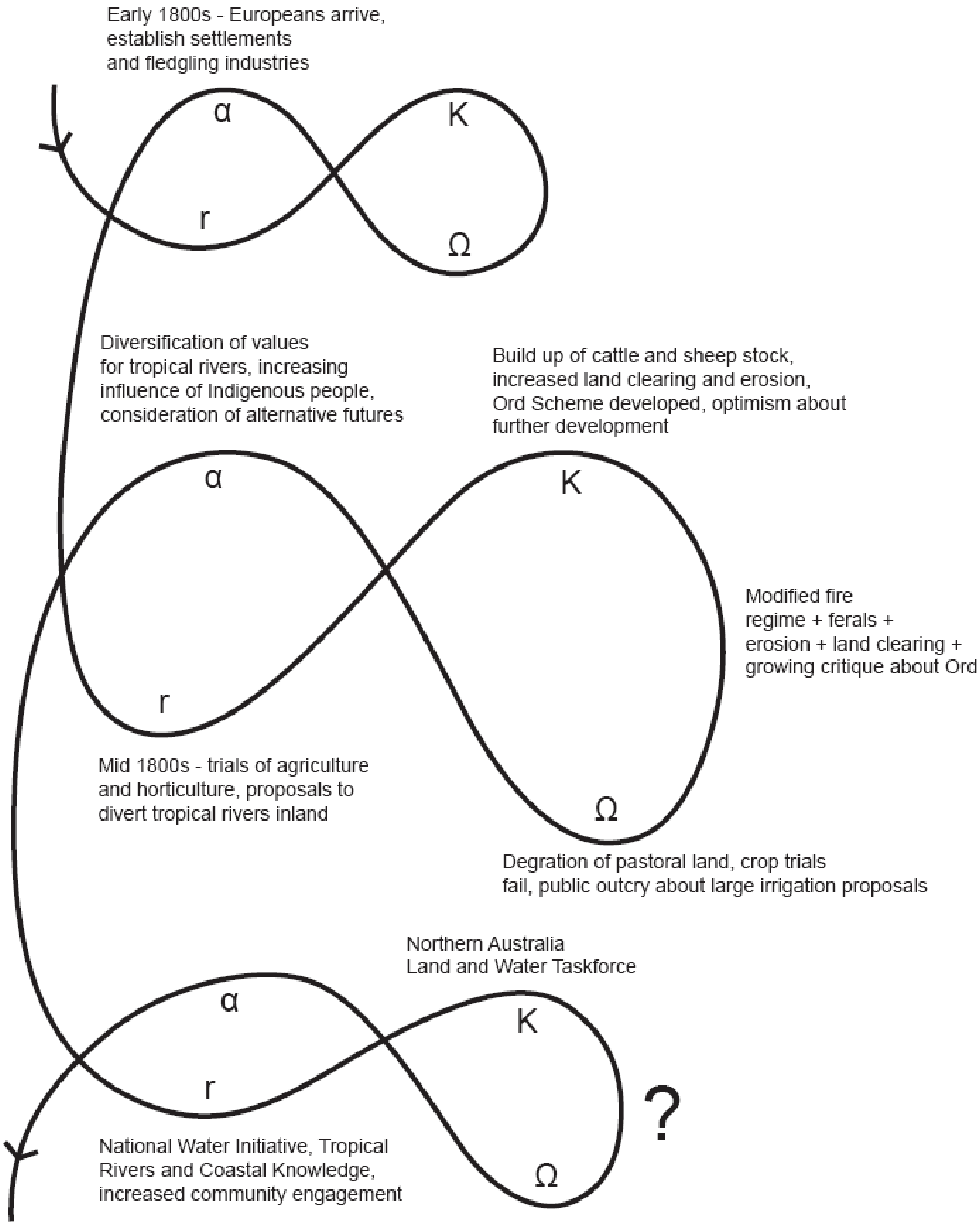


Figure 8: Three phases of the adaptive cycle for the tropical rivers region (r: growth or exploitation; K: conservation; Ω: collapse or release; and α: reorganisation)

4.3.6 How is the provision of ecosystem services affected by threatening processes?

There is currently relatively little knowledge about how these threatening processes, separately and in combination, impact on the provision of the four focal ecosystem services. This is the subject of further research by the Tropical Rivers and Coastal Knowledge Research Hub. From the resilience perspective, of particular interest is where thresholds of ecosystem functioning exist, beyond which the provision of ecosystem services may be significantly and irreversibly impaired. Based on the estimates of willingness to pay for each of the ecosystem services reported in section 3, we suggest that shifting over these thresholds will also significantly impact the value associated with each ecosystem service in terms of an associated economic impact on community welfare.

The following sections summarise information about how some of the threats discussed above impact on the ecosystem processes underpinning the provision of the four focal ecosystem services, and information about biophysical thresholds beyond which impacts on these ecosystem processes may significantly compromise the provision of ecosystem services. While climate change will likely impact on all of these processes, we focus here on local scale impacts and interactions. We also do not provide any information on thresholds in other processes such as population levels, rates of water use, prices, visitor numbers, or technology, for example. The exploration of social and economic thresholds is the subject of future research.

Stream flows and water supply

For Australia's tropical rivers, seasonal hydrology is a key driver of ecosystem processes and food-web structure (Douglas *et al.* 2005). While there is much to be learned about these relationships, especially of groundwater and surface water interactions, some understanding does exist. van Dam, Bartolo *et al.* (2008) summarise the state of knowledge about the potential impacts of changes in stream flow on in-stream ecosystems, groundwater dependent ecosystems, vegetation structure, native fauna, wildlife refugia, the structure of aquatic communities, the pool of biota for recolonisation, and water quality.

The most certain knowledge about the impacts of flow modification on tropical river systems and the provision of ecosystem services comes from the experience of the Ord River and the Camballin Irrigation Scheme on the lower reaches of the Fitzroy River. The Ord River and Kununurra Diversion Dams have significantly modified the flow regime of the Ord River, leading to the submersion of previously terrestrial habitats and creating new aquatic ecosystems where none previously existed (Storey *et al.* 2001). The dams and increase in irrigated agriculture have lead to rising groundwater levels and increased salinity in an agricultural zone of the Ord River Irrigation Area (Salama *et al.* 2002). These dams have also influenced the hydrological regime through enabling significant evaporation (van Dam *et al.* 2008). Barriers such as the barrage at Camballin have limited the ability of various aquatic species to migrate and have increased predation of these species because they congregate around the barrier (Morgan *et al.* 2005). Other ecological impacts on river flows, sediments, nutrients, energy and biota are summarised by van Dam, Bartolo *et al.* (2008) and Storey, Davies *et al.* (2001).

As for information on specific thresholds, research for the Daly River by Erskine *et al.* (2003) and Erskine *et al.* (2004) makes a recommendation for a 20% cap on extraction based on the levels of flow at which certain aquatic species and habitats are likely to be significantly compromised. Besides giving specific flow recommendations for certain river crossings in the catchment, they also draw attention to the importance of the first flush events of each wet season in delivering nutrients to waterways, waterholes and floodplains, and of flood peaks in cueing biotic processes; maintaining channels; connecting floodplains, streams and waterholes; and shifting sand bars (Erskine *et al.* 2003; Erskine *et al.* 2004).

Threats to stream flows and water supply come from groundwater extraction, surface water extraction, water impoundment, and land clearance/loss of native vegetation cover (van Dam *et al.* 2008). The relevant resilience questions here are about how much water can be extracted and native vegetation can be cleared before there are significant negative and perhaps irreversible impacts on the condition of floodplain habitat, the quality of the river for recreational fishing, and the condition of waterholes important to Aboriginal people (income from irrigated agriculture will most likely increase if the water is extracted for this purpose). Subsequent resilience questions are about what processes drive the threats to stream flows and water supply (discussed above); and which slowly changing variables control the structure of the system relevant to maintained stream flows and can be managed to maintain the system in its desired state (discussed below).

The trade-off between water extracted for uses such as irrigated agriculture, and water required to remain in the system for the provision of the other focal ecosystem services can be explored using the results of the economic valuation exercise, which revealed that most people value the environmental, recreational and cultural values more than the production value, however, we must also consider the value of the income from irrigated agriculture, the employment opportunities created and the flow on benefit from increased spending in the region, noting the issue of double counting raised in section 3.4.2 above.

Water quality (sediment and nutrient levels)

There is some knowledge about the impacts of land uses and practices, such as agriculture, grazing, land clearing and mining, on water quality. Significantly higher concentrations of suspended sediment, iron and manganese were found in storm runoff in catchments where there had been fires late in the dry season (Townsend and Douglas 2000). Clearing of native vegetation and land degradation reduce infiltration and increase runoff (Harris 2001), which can lead to erosion and sedimentation (Rangelands NRM Coordinating Group 2004; Landcare Council of the Northern Territory 2005). Excess sediment can reduce the clarity of water, which impacts on aquatic plant growth. This, in turn, can lead to de-oxygenation (Rangelands NRM Coordinating Group 2004), and excess nutrients can lead to eutrophication and algal blooms (Harris 2001). Exotic animals, such as cattle, donkeys, pigs and buffalo, can cause turbidity due to their trampling of wetlands and riverbanks. This can reduce light for aquatic primary production (Rangelands NRM Coordinating Group 2004). Herbicides, pesticides and fertilisers from agriculture and horticulture, metals from mining, sewage and stormwater from townships, and sediment and nutrients from land clearing, over grazing and wildfires can all impact negatively on water quality (Landcare Council of the Northern Territory 2005).

Current knowledge about specific thresholds comes from a quantitative ecological risk assessment of the impacts of water extraction and land clearing on surface water quality in the Daly River catchment by Bayliss *et al.* (2008). This work used Bayesian Belief Networks to model potential impacts based on conceptual models of the interactions between assets and threats. Bayliss *et al.* (2008) categorised impacts on in-stream health as being 'Excellent', 'Ok' or 'Poor', and found that when no water is extracted, 65% of the assessment of in-stream health is classified as 'Ok' and 'Excellent', with the majority being 'Excellent' (48%). This is compared with 20% wet season water extraction, when only 17% of the assessment of in-stream health is classified as 'Ok' and 'Excellent', with the majority being 'Poor' (83%).

Threats to water quality come from pollution and erosion (chemical use, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals) (van Dam *et al.* 2008). The relevant resilience questions here are about how much the quality of water can be affected before there are significant negative impacts on the condition of floodplain habitat, the quality of the river for recreational fishing, the condition of waterholes important to Aboriginal people and the income from irrigated agriculture. We are also interested in what drives the processes that threaten these ecosystem services (discussed above); and which slowly changing variables control the structure of the system relevant to water quality and can be managed to maintain the system in its desired state (discussed below). The thresholds will likely be different for each ecosystem service, for example, the provision of floodplain habitat in good environmental condition is likely more sensitive to water quality than production from irrigated agriculture.

Floodplain vegetation and habitat

Research has shown that riparian vegetation and wetlands are more vulnerable than surrounding environments to infestation by weeds (Douglas *et al.* 1998). For example, olive hymenachne can completely replace native vegetation and limit habitat and food for native fauna (Weeds Cooperative Research Centre 2003) and floodplain burning at least once in every five years is required to maintain diversity of wetland plant species by managing monocultures and weeds (Bayliss *et al.* 2006). Other threats comes from exotic animals, such as cattle, donkeys, pigs and buffalo, which can cause erosion, vegetation damage and sedimentation due to their trampling of wetlands and riverbanks (Northern Territory Government 2003; Landcare Council of the Northern Territory 2005).

In terms of specific thresholds, current knowledge comes from a quantitative ecological risk assessment by Bayliss *et al.* (2008) of the impacts of water extraction and wetland weeds on floodplain health (including plant biodiversity) in the Daly River catchment. Bayliss *et al.* (2008) found that the main influence on floodplain health is the extent of floodplain weeds, and that limiting cover of the weed mimosa to 10% of the floodplain substantially increased the probability that the floodplain would be in 'Good' condition.

Threats to floodplain vegetation and habitat come from weeds, inappropriate fire regimes, land clearing, poor riparian management, cattle, feral animals (van Dam *et al.* 2008). The relevant resilience questions here are about how much these threats can continue unmanaged before there are significant negative impacts on the condition of floodplains as habitat and breeding ground; what processes drive these threats (discussed above); and which slowly changing variables control the structure of the system relevant to floodplain condition and can be managed to maintain the system in its desired state (discussed below).

Species abundance and diversity

Aquatic biodiversity is affected by changes in water flows and quality (Rangelands NRM Coordinating Group 2004), exotic pests such as cane toads (Doody *et al.* 2006), and other exotic fish species through predation, competition and disease (Arthington 1991; McDonald and Dawson 2004).

A world-wide review of studies of habitat fragmentation has found that 30% habitat retention is a critical threshold below which species are rapidly lost from landscapes (Andren 1994). Current knowledge on specific thresholds for Australia's tropical rivers region comes from a quantitative ecological risk assessment of the impacts of water extraction and land clearing on barramundi stock in the Daly River by Bayliss *et al.* (2008). This study found that the abundance of the catchable population appears highly sensitive to water extraction. Barramundi populations decrease as the percentage of wet season water extraction increases, for example, 20% simulated wet season water extraction will reduce barramundi populations by 32% and reduce the value of the recreational fishery by approximately 77% ($129,000 to $29,000). Fifty percent water extraction will reduce populations by 58%. Bayliss *et al.* (2008) also modelled the impacts of water extraction and wetland weeds on magpie goose nesting success in the Daly River floodplain finding that the density of magpie goose nests declines in direct proportion to water extraction. Another study of fisheries thresholds to river flow found a strong relationship between river flow and catch from the Northern Prawn Fishery, and other coastal barramundi and mud crab fisheries (Robins *et al.* 2005).

Threats to species abundance and diversity come from habitat modification (van Dam *et al.* 2008). The relevant resilience questions here are about how much habitats can continue to be modified before there are significant negative impacts on the quality of the river for recreational fishing and condition of waterholes important to Aboriginal people; what processes drive habitat modification (discussed above); and which slowly changing variables control the structure of the system relevant to important habitat and can be managed to maintain the system in its desired state (discussed below).

Riparian vegetation

Few riparian vegetation species in the tropical rivers region are fire tolerant (Landcare Council of the Northern Territory 2005). Damage to riparian vegetation can result in increased growth of algae and macrophytes in-stream and allow increased amounts of soil and nutrients into waterways (Douglas *et al.* 2003; Daly Region Community Reference Group 2004). A study of the impact of reduced river flows on the crop of the alga, *Spirogyra*, found that flow rates lower than the natural flow regime resulted in smaller crops, which is problematic as the alga is a food source for turtles (Townsend and Padovan 2009).

Reports by Aboriginal people of the impact of the Seventeen Mile Dam and the barrage at Camballin in the Fitzroy River catchment include observations that the river frontage had been "scoured" due to the impact of the levee banks on water flows during floods: when the water recedes from the levee banks, it uproots trees and washes out fences (Ivan Watson in Marshall 1988).

Threats to riparian vegetation and habitat come from erosion (poor riparian management, cattle, feral animals) and weeds (van Dam *et al.* 2008). The relevant resilience questions here are about how much erosion and weed dispersal and growth can continue to be take place before there are significant negative impacts on the quality of the river for recreational fishing and condition of waterholes important to Aboriginal people; what processes drive erosion and weeds (discussed above); and which slowly changing variables control the structure of the system relevant to species abundance and diversity and can be managed to maintain the system in its desired state (discussed below).

Current thresholds research

Further research about some thresholds of ecosystem functioning for the provision of ecosystem services is currently being undertaken as part of the Tropical Rivers and Coastal Knowledge Research Hub (http://www.track.gov.au/) and the Northern Australia Land and Water Taskforce (http://www.nalwt.gov.au/).

In the absence of these findings, however, the next resilience questions to ask are about the processes that may lead to a threshold being crossed (often involving cross-scale interactions), and the slowly changing variables that control those processes and can be managed to maintain the system in its desired state.

4.3.7 What are the slowly changing variables that control the provision of ecosystem services?

The discussion of thresholds above and the histories presented in Appendix G help to reveal some of the slowly changing variables for the whole tropical rivers region social-ecological system that appear to significantly influence the provision of ecosystem services. In particular, we are interested in the slowly changing variables that control the structure of the system that is relevant to maintaining stream flows, water quality, floodplain habitat, riparian vegetation and species abundance and diversity. We are also interested in those variables that can be managed to maintain the system in its desired state for the ongoing provision of these valued ecosystem services and the activities, benefits and values of Australia's tropical rivers that they underpin.

Changes in values and attitudes generally take place over long time periods, have had significant impacts on the tropical rivers region in the past, and will do in the future. For example, if the tendency towards large engineering developments grew in dominance as compared to arguments about economic efficiency or ecologically sustainable development, it is likely that major infrastructure works would take place to either ensure water supplies in southern Australia or increase agricultural output in the tropical rivers region. Any such regulation of a tropical river would likely have significant impacts on hydrology, ecological processes and the provision of ecosystem services, as discussed by Storey *et al.* (2001) regarding the potential impacts of an impoundment on the Fitzroy River in the Kimberley region of Western Australia.

As it is, the changes in values and attitudes have precipitated associated changes in the policies and other institutions guiding and governing water use, both in terms of their goals and the ways in which they are to be achieved. The shift in values and attitudes towards sustainable development, the recognition of diverse values, and the importance of community consultation have shifted the types, process and pace at which development and development decisions take place. Of particular note is the increasing influence of Indigenous people in discussions about development in northern Australia, for example, the establishment and funding of the

Indigenous Water Policy Group and the Indigenous Community Water Facilitator Network, and the recent appointment of an Indigenous person as the Chair of the new Northern Australia Land and Water Taskforce. Even so, values and attitudes could shift in response to a series of elections, for example, or a global event precipitating large influxes of people into Australia or steeply growing demand for our natural resources, which may see very different development decisions being made.

Changes in policies and other institutions guiding and governing water use, including the enforcement of institutional arrangements, have also taken place over long time periods and in synchrony with changes in values and attitudes to an extent. The application of English common law from the early 1800s covered the time from colonisation, through early exploration and optimistic agricultural experimentation, to the droughts at the end of the century. New water allocation arrangements took over and presided over the next century, which saw the lock-in of a range of significant changes to land and water in the tropical rivers region through the building of large dams, further agricultural development, and the expansion of pastoralism and its impacts. The *Environmental Protection and Biodiversity Conservation Act 1999* (C'th) and the NWI of the late 1900s herald another shift. Capacity to enforce legislation and regulations is another aspect of institutional arrangements that changes relatively slowly and has a significant impact on land and water uses and practices on the ground.

In terms of direct impact on the land and water resources of the tropical rivers region, the set of dominant grazing practices is considered a slowly changing variable that impacts on the dynamics of faster and more localised variables. Decisions about stocking rates, fire management, water access points, the introduction of improved pasture and land clearing all impact on tropical river ecosystem services through impacts on water quality, weed cover, riparian and floodplain vegetation and species abundance and diversity. Significant changes in grazing practices take place over long periods of time as legislation changes, new research is undertaken, and/or new technology becomes available. Any changes over shorter terms are made in response to changes in input costs, prices and/or demand, though these decisions are unlikely to be about significant change in practices.

The final slowly changing variable that is likely to have a significant impact on the provision of ecosystem services in the tropical rivers region how different flows are from the natural flow regime. As stated earlier, seasonal hydrology is a key driver of ecosystem processes and food-web structure (Douglas *et al.* 2005) and the adequate quantity, quality, timing and temporal variability of water flows is critical to freshwater ecosystems (Baron *et al.* 2002; Bunn and Arthington 2002). As flow regimes become more and more modified due to water extraction or through impacts on water quality, impacts on other variables, such as the abundance of species and riparian vegetation, will influence the uses and values of Australia's tropical rivers.

4.4 Discussion: implications of the resilience approach

4.4.1 Assessing the impacts of potential development scenarios on tropical river ecosystem services

There are several implications of these findings for assessing the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers. First, there are multiple, complex interactions that are involved with the introduction of a new development and how it may impact on the provision of ecosystem services. What we do know from past experience in the tropical rivers region is that the operating environment for new ventures (climate, distance from markets, lack of fertile soils, wildlife, fire dynamics) is extremely challenging and has contributed to the failure of many of these ventures in the past. Research to date suggests that the structure and functions of tropical river ecosystems can be significantly modified by developments, and that this can impact significantly and irreversibly on the provision of valued ecosystem services (Storey and Trayler 2006).

Second, this resilience analysis has given some insight into the different processes at work, and how interactions between these different processes can sometimes lead to unintended consequences. The assessment of impacts of potential development scenarios on tropical river ecosystem services needs to explore these cross-scale interactions to probe the system for the unintended impacts of any future development.

Third, another implication for assessing the impacts of potential development scenarios on the ecosystem services of Australia's tropical rivers is the importance of thresholds. There are two main questions here: (1) how much can the provision of an ecosystem service be reduced before there is significant and potentially irreversible impact on community welfare/human well-being; and (2) how much can an ecosystem be impacted by various threats before its capacity to provide ecosystem services is significantly and potentially irreversibly affected? We have provided information about some biophysical thresholds where available because they are most relevant to the ecosystem services explored in this study. However, there are many remaining questions for biophysical researchers and we have not touched on the social and economic thresholds that will also be important in the continued provision of ecosystem services and the resilience of the tropical rivers region as a whole. This is a subject for future research.

Fourth, more research is also required to further identify the slowly changing variables that control the structure of the system that is relevant to maintaining the provision of ecosystem services. We have provided a preliminary exploration. It is anticipated that this list will be refined as the results of further biophysical and social research is undertaken for the Tropical Rivers and Coastal Knowledge Research Hub.

4.4.2 Maintaining the capacity of tropical river systems to provide ecosystem services

The implications of the resilience approach for management are primarily about maintaining the capacity of tropical river systems to provide ecosystem services. It suggests that managers are guided by their answers to the following questions:

1. What are the values that people care about?

2. What are the processes that underpin these values, producing them, enabling them or influencing them?

3. What threatens these processes? These will usually be sets of processes interacting at different spatio-temporal scales.

4. What are the slowly changing variables that control the structure and functions of the system that maintaining the values that people care about?

5. What are the thresholds beyond which the provision of the values that people care about will be significantly and possibly irreversibly compromised?

6. Which slowly changing variables can be managed for the continued provision of the values people care about?

More research is required to answer these questions with greater certainty.

5. CONCLUSIONS

Any development in Australia's tropical rivers region will have impacts on tropical river ecosystems, the provision of tropical river ecosystem services, and the industries, activities and benefits that these ecosystem services underpin. This study has provided assessments of the potential impacts of development based on two different approaches: the estimation of impacts on community welfare measured in dollar terms through economic valuation, and the analysis of some complex cross-scale interactions in the tropical rivers region and thresholds for the provision of ecosystem services. These approaches come from different theories. They provide insights that are complementary in that they help to tell a more complete story about the value of tropical river ecosystem services and how development might impact on ecosystem services than could be told by either on its own.

The economic valuation reveals that Australians place a higher value on large improvements in river health to underpin environmental, recreational and cultural uses/benefits than moderate improvements, whereas they place a higher value on the moderate expansion of irrigated agriculture than large-scale expansion. In addition, Australians value large improvements in the condition of waterholes important to Aboriginal people the most out of all possible improvements in all of the four ecosystem services. This reveals that people have a strong preference for seeing waterholes that are important to Aboriginal people in the best possible condition. Both of these main findings are the same for all three river systems and all three target respondent groups.

We acknowledge that some aspects of these ecosystem services cannot be captured in dollar terms, i.e., they are priceless. Also there are many valuable aspects of these ecosystem services that are not covered by the method of valuation used in this project, for example, the expenditure on equipment for recreational fishing, the time spent undertaking customary activity, and the gross value of production and contribution to employment by irrigated agriculture. This means that the economic values that we calculate are likely underestimates of the true or full value of these ecosystem services.

Further calculations with the estimates of economic value provide estimates of the benefits of programs or policies to improve ecosystem services or the costs of actions that degrade ecosystem services. As such, these numbers can be used in cost-benefit analyses to underpin further decision-making, giving communities, industries and decision-makers information was not previously available and enabling the incorporation of a more complete set of costs and benefits into decision-making about future development.

The resilience analysis and existing information on biophysical thresholds tells us that if there is sufficient modification to stream flows, the flow regime, water quality, floodplain vegetation, riparian vegetation, and the diversity and abundance of certain species, the provision of tropical river ecosystem services like healthy floodplain, river conditions for good recreational fishing, species and habitat important to Aboriginal customary activity at waterholes, and production from irrigated agriculture will likely be impacted. We need more knowledge of where these thresholds might be. As tropical river systems are complex, non-linear systems, it may be that the most effective management tool will be one that brings improvements in our ability to recognise it when important slow variables are approaching a critical threshold.

If we apply the results of the economic valuation to the findings of the resilience analysis, we get a more complete picture of the impact of any changes in the provision of ecosystem services on community welfare as measured in dollar terms, and we have information to enable the weighing up of more of the costs and benefits of potential developments. Shifting back from the economic valuation to the resilience analysis then, we are reminded that some of these costs and benefits might also cross a threshold where they rapidly increase or decrease based on a significant and potentially irreversible change in the capacity of the tropical river ecosystem to provide the desired ecosystem services. Both sets of qualitative and quantitative information can together provide a more complete story and assessment of potential impacts. A multi-criteria evaluation tool may provide an alternative to cost-benefit analysis in enabling the exploration of qualitative and quantitative trade-offs.

These analyses have also revealed that there will sometimes be trade-offs between ecosystem services. In some aspects, the provision of ecosystem services related to production activities such as irrigated agriculture will impact on the provision of other ecosystem services by competing for water resources and contributing to other negative impacts. These impacts are currently managed through caps on extraction and a range of water and land management legislation. The economic valuation reveals that Australians are willing to pay more for higher levels of environmental, recreational and cultural outcomes than they are for higher levels of irrigated agriculture production, thus it appears that they are willing to trade the latter for the former. However, these are only estimates of the non-use components of total value, and each ecosystem service also has use and indirect use components that need to be valued and taken into consideration before concluding either way. This is an important area for further research.

One key area that has not been touched on in any detail in either analysis is by whom the costs, benefits and impacts of potential developments are borne. The impacts of some past events and current circumstances on local Aboriginal people are mentioned in the histories provided in Appendix G. Stakeholder analyses for the region have been undertaken previously (see, for example, de Groot *et al.* 2008), however, this is another area that will require significant research in the near future. Similarly, we have also not touched on questions about where the social and economic thresholds important to the maintenance of ecosystem services might exist. While all thresholds may not be important to the four focal ecosystem services discussed in this study, they will be important to other parts of the story about sustainable development of the tropical rivers region of Australia.

Other issues that are raised by this study include questions about what kinds of decision tools, management strategies and institutions might be required to address distributional inequities and trade-offs and possible incompatibilities between values. Tools that support transparent and structured decision-making might be useful here. One such tool is the deliberative multi-criteria evaluation (Proctor and Drechsler 2006), which has been applied to scenario evaluation for the Howard River catchment in the Northern Territory (Straton *et al.* 2008). We touch on some implications for resource management agencies in earlier discussions. Institutional requirements include greater institutional capacity to recognise and manage around thresholds and slow moving variables, and coordination across management agencies in recognition of system interdependencies.

In summary, the areas for further research arising from this work include:

1. further exploration of the datasets for insight into differences in willingness to pay between people with different socio-economic backgrounds and the impact of the different delivery techniques on willingness to pay;

2. the estimation of economic values for the use, indirect use and non-use components of ecosystem services to enable complete cost-benefit analyses of alternative development proposals;

3. identification of the location of critical thresholds for the provision of ecosystem services and/or indicators that critical thresholds are being approached;

4. identification of the location of critical thresholds for the value of ecosystem services and/or indicators that critical thresholds are being approached;

5. identification of slow moving variables and management strategies;

6. identification of the qualitative and quantitative impacts of developments to enable multi-criteria analysis of alternative proposals; and

7. further exploration of complementarities between different approaches to the assessment of impacts;

8. assessment of the distribution of costs and benefits among stakeholders; and

9. identification of how to improve coordination between management agencies and build institutional capacity to recognise and manage around thresholds and slow moving variables.

This assessment of the value of Australia's tropical river ecosystem services and the impacts of potential development on these ecosystem services shows that the non-market aspects of these features have value that can be measured in economic terms and incorporated into decision-making based on comparisons of the relative costs and benefits of alternative proposals. Without these estimates of value (even though they are themselves underestimates), their non-inclusion in a cost-benefit analysis for want of a number would imply that they are worth nothing, which is obviously not the case. As such, these findings provide information that was not previously available and can substantially improve the quality of decisions about the future of Australia's tropical rivers.

REFERENCES

Aboriginal Land Commissioner (1991) Upper Daly Land Claim Volumes 1, 2 and 3. Canberra, Australian Government Publishing Service.

Abrahams, H., M. Mulvaney, D. Glasco and A. Bugg (1995) Areas of conservation significance on Cape York Peninsula. Canberra, Australian Heritage Commission.

ACIL Tasman Pty Ltd and Worley Parsons (2005) West Kimberley Resource Development Study Main Report. Perty, Western Australia Government Department of Industry and Resources.

ACIL Tasman Pty Ltd and WorleyParsons (2005) West Kimberley Resource Development Study Main Report. Perth, Government of Western Australia - Department of Industry and Resources**:** 238.

Allison, H. E. and R. J. Hobbs (2004) "Resilience, adaptive capacity, and the "lock-in trap" of the Western Australian agricultural region." Ecology and Society **9**(1): 3.

Altman, J. (2006) In search of an outstation policy for Indigenous Australians under the new administrative arrangements. Canberra, Centre for Aboriginal Economic Policy Research, Australian National University.

Altman, J., G. J. Buchanan and L. Larsen (2007) The environmental significance of the Indigenous estate: natural resource management as economic development in remote Australia. Canberra, Centre for Aboriginal Economic Policy Research.

Andersen, A. N. (2000) The Ants of Northern Australia: a Guide to the Monsoonal Fauna. Melbourne, CSIRO Publishing.

Andersen, A. N., L. M. Lowe and D. C. F. Rentz (2000) "The grasshopper (Orthoptera: Acridoidea, Eumastacoidea and Tettigonioidea) fauna of Kakadu National Park in the Australian seasonal tropics: biogeography, habitat associations and functional groups." Australian Journal of Zoology **48**: 431-442.

Andren, H. (1994) "Effects of habitat fragmentation on birds and mammals in landscapes with different proporions of suitable habitat: a review." Oikos **71**: 355-366.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C. S. Holling, B. Jansson, S. Levin, K. Maler, C. Perrings and D. Pimentel (1995) "Economic growth, carrying capacity, and the environment." Journal of Ecological Economics **15**: 91-95.

Arthington, A. (1991) "Ecological and genetic impacts of introduced and translocated freshwater fishes in Australia." Canadian Journal of Fisheries and Aquatic Sciences **48**: 33-43.

Arthington, A. H., S. E. Bunn, N. L. Poff and R. J. Naiman (2006) "The challenge of providing environmental flow rules to sustin river ecosystems." Ecological Applications **16**(4): 1311-1318.

Arthur, J. (1997) An unobtrusive goanna. Tracking knowledge in north Australian landscapes. D. Rose and A. Clarke. Darwin, North Australia Research Unit, Australian National University.

Australian Bureau of Agricultural and Resource Economics (2008) Performance of agriculture and resource industries in northern pastoral Australia. Canberra, Australian Bureau of Agricultural and Resource Economics.

Australian Bureau of Statistics (2004) 3236.0 - Household and family projections, Australia, 2001 to 2026. Canberra, Australian Bureau of Statistics.

Australian Bureau of Statistics (2006) 3238.0.55.001 - Experimental estimates of Aboriginal and Torres Strait Islander Australians, Jun 2006. Canberra, Australian Bureau of Statistics.

Australian Bureau of Statistics (2006) 4713.0 - Population characteristics, Aboriginal and Torres Strait Islander Australians, 2006. Canberra, Australian Bureau of Statistics.

Australian Bureau of Statistics. (2006) "National Regional Profile: Derby-West Kimberley (S) (Local Government Area) LGA52800." Retrieved 15 May 2007.
Australian Bureau of Statistics. (2006) "National Regional Profile: Halls Creek (S) (Local Government Area) LGA53920." Retrieved 15 May 2007.
Australian Bureau of Statistics (2007) 3235.0 - Population by age and sex, regions of Australia, 2007. Canberra, Australian Bureau of Statistics.
Australian Tropical Rivers Group (2004) Securing the North: Australia's Tropical Rivers. A Statement by the Australian Tropical Rivers Group. Sydney, WWF Australia.
Baron, J. S., N. L. Poff, P. L. Angermeier, C. N. Dahm, P. H. Gleick, N. G. Hairston Jr., R. B. Jackson, C. A. Johnston, B. D. Richter and A. D. Steinman (2002) "Meeting ecological and societal needs for freshwater." Ecological Applications **12**(5): 1247-1260.
Batabyal, A. A. (1998) "On some aspects of ecological resilience and the conservation of species." Journal of Environmental Management **52**: 373-378.
Bayliss, P. (1985) Report on the 1985 aerial survey of feral animals in the Top End of the NT. Darwin, Conservation Commission of the Northern Territory.
Bayliss, P., R. Bartolo and R. van Dam (2008) Chapter 4 - Quantitative ecological risk assessments for the Daly River. In Bartolo, R., Bayliss, P. and van Dam, R. (eds.) Ecological risk assessment for Australia's northern tropical rivers. Sub-project 2 of Australia's tropical rivers - an integrated data assessment and analysis (DET18). Darwin, Environmental Research Institute of the Supervising Scientist, National Centre for Tropical Wetland Research.
Bayliss, P., R. van Dam, J. Boyden and D. Walden (2006) Ecological risk assessment of Magela floodplain to differentiate mining and non-mining impacts. In Evans, K.G., Rovis-Hermann, J., Webb, A. and Jones, D.R. (eds.) ***eriss*** research summary 2004-05. Darwin, Supervising Scientist.
Begg, G. W. (2001) The values and benefits of wetlands. National Centre for Tropical Wetland Research Note 1.
Bennett, J., R. Dumsday, G. Howell, C. Lloyd, N. Sturgess and L. Van Raalte (2008) "The economic value of improved environmental health in Victorian rivers." Australasian Journal of Environmental Management **15**: 138-148.
Bergmann, W. (2006) Wunyumbu: keynote address. Kimberley Appropriate Economies Roundtable Forum Proceedings. R. Hill, K. Golson, P. Loweet al. Cairns, Australian Conservation Foundation.
Berkes, F. and C. Folke (1998) Linking Social and Ecological Systems for Resilience and Sustainability. Cambridge, Cambridge University Press.
Bingham, G., R. Bishop, M. Brody, D. Bromley, E. Clark, W. Cooper, R. Costanza, T. Hale, G. Hayden, S. Kellert, R. Norgaard, B. Norton, J. Payne, C. Russell and G. W. Suter (1995) "Issues in ecosystem valuation: improving information for decision making." Journal of Ecological Economics **14**: 73-90.
Birol, E., K. Karousakis and P. Koundouri (2006) "Using a choice experiment to account for preference heterogeneity in wetland attributes: the case of Cheimaditida wetland in Greece." Ecological Economics **60**: 145-156.
Blamey, R. K., J. Gordon and R. Chapman (1999) "Choice modelling: assessing the environmental values of water supply options." The Australian Journal of Agricultural and Resource Economics **43**(3): 337-57.
Blamey, R. K., J. Rolfe, J. Bennett and M. D. Morrison (2000) "Valuing remnant vegetation in Central Queensland using choice modelling." The Australian Journal of Agricultural and Resource Economics **44**(3): 439-456.
Blanch, S., N. Rea and G. Scott (2005) Aquatic Conservation Values of the Daly River Catchment, Northern Territory, Australia. Darwin, WWF-Australia, Charles Darwin University and the Environment Centre NT.

Bowman, D. J. M. S. and L. McDonough (1991) "Feral pig (Sus Scrofa) rooting in a monsoon forest-wetland transition, Northern Australia." Wildlife Research **18**: 761-765.
Boxall, P. C., V. L. Adamowicz, J. Swait, M. Williams and J. Louviere (1996) "A comparison of stated preference methods for environmental valuation." Journal of Ecological Economics **18**: 243-253.
Braithwaite, V. A. and W. A. Scott (1991) Values. Measures of personality and social psychological attitudes. J. P. Robinson, P. R. Shaver and L. S. Wrightsman. New York, Academic Press**:** 661-749.
Brauman, K. A., G. C. Daily, T. K. Duarte and H. A. Mooney (2007) "The nature and value of ecosystem services: an overview highlighting hydrologic services." Annual Review of Environment and Resources **32**: 67-98.
Brouwer, R. (2009) Multi-attribute choice modelling of Australia's rivers and wetlands: a meta-analysis of ten years of research. Socio-Economics and the Environment in Discussion CSIRO Working Paper Series. C. L. Spash. Canberra, CSIRO.
Bunn, S. E. and A. H. Arthington (2002) "Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity." Environmental Management **30**: 492-507.
Burnett, S. (1997) "Colonising cane toads cause population declines in native predators: reliable anecdotal information and management implications." Pacific Conservation Biology **3**: 65-72.
Burnside, D. G. (1979) The pastoral industry of the north-west, Kimberley and goldfields. Agriculture in Western Australia : 150 years of Development and Achievement. G. H. Burvill. Perth, University of WA**:** 249-262.
Burrows, D. W. (2004) A review of aquatic management issues and needs for the Northern Gulf NRM Planning Region. Townsville, James Cook University.
Campbell, D. (2007) "Willingness to pay for rural landscape improvements: combining mixed logit and random effects models." Journal of Agricultural Economics **58**(3): 467-483.
Campbell, D., R. Scarpa and W. G. Hutchinson (2007) "Benefit estimates for landscape improvements: sequential Bayesian design and respondents' rationality in a choice experiment study." Land Economics **83**(4): 401-417.
Carpenter, S., B. Walker, J. M. Anderies and N. Abel (2001) "From metaphor to measurement: resilience of what to what?" Ecosystems **4**: 765-781.
Carson, D., A. Taylor and S. Campbell (2009) Demographic trends and likely futures for Australia's tropical rivers. Darwin, Charles Darwin University, Tropical Rivers and Coastal Knowledge.
Charters, A. D. (1975) Ecology of trematodes and the Ord River Dam. Man-made lakes and human health. N. F. Stanley and M. P. Alpers. London, Academic Press**:** 137-148.
Chase, A. and B. Meehan (1983) Upper Daly land claim. Darwin, Northern Land Council.
Christian, C. S. and G. A. Steward (1953) General report on survey of the Katherine-Darwin region, 1946. Land Research Series. Melbourne, CSIRO.
Coleman, A. P. M. (2003) The National Recreational Fishing Survey: the Northern Territory. Darwin, Northern Territory Government Department of Business, Industry and Resource Development.
Commonwealth of Australia (1959) Prospects of agriculture in the Northern Territory. Canberra, Department of Territories.
Commonwealth Scientific and Industrial Research Organisation (2007) Climate change in Australia. Canberra, CSIRO and the Australian Bureau of Meteorology.
Cook, G. and L. Dias (2006) "It was no accident: deliberate plant introductions by Australian government agencies during the 20th century." Australian Journal of Botany **54**: 601-625.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton and M. van den Belt (1997) "The value of the world's ecosystem services and natural capital." Nature **387**: 253-260.

Council of Australian Governments. (2004) "Intergovernmental Agreement on a National Water Initiative." Retrieved 29 May 2006, from www.coag.gov.au/meetings/250604/iga_national_water_initiative.pdf.

Daly Region Community Reference Group (2004) Executive Summary and Draft Report of the Daly Region Community Reference Group. Darwin, Daly Region Community Reference Group, Northern Territory Government.

Davidson, B. R. (1965) The Northern Myth: a Study of the Physical and Economic Limits to Agricultural and Pastoral Development in Tropical Australia. Adelaide, Melbourne University Press.

de Groot, R., M. Finlayson, B. Verschuuren, O. Ypma and M. Zylstra (2008) Integrated assessment of wetland services and values as a tool to analyse policy trade-offs and management options: a case study in the Daly and Mary River catchments, northern Australia. Darwin, Environment Research Institute of the Supervising Scientist and Australian Centre for Tropical Freshwater Research.

Dillman, D. A. (2007) Mail and internet surveys: the tailored design method. 2007 update with new internet, visual and mixed-mode guide. San Francisco, John Wiley & Sons, Inc.

Doody, J. S., B. Green, R. Sims, D. Rhind, P. West and D. Steer (2006) "Indirect impacts of invasive cane toads *Bufo marinus* on nest predation in pig-nosed turtles *Carettochelys insculpta*." Wildlife Research **33**: 349-354.

Douglas, M., C. M. Finlayson and M. J. Storrs (1998) Weed management in tropical wetlands of the Northern Territory Australia. In Wetlands in a dry land: understanding for management. Canberra, Biodiversity Group, Environment Australia.

Douglas, M. M., S. E. Bunn and P. M. Davies (2005) "River and wetland food webs in Australia's wet-dry tropics: general principles and implications for management." Marine and Freshwater Research **56**: 329-342.

Douglas, M. M., S. A. Townsend and P. S. Lake (2003) Streams. Fire in tropical savannas. A. N. Andersen, G. D. Cook and R. J. Williams. New York, Springer-Verlag**:** 59-78.

Dyer, R. and M. Stafford Smith (2003) "Ecological and economic assessment of prescribed burning impacts in semi-arid pastoral lands of northern Australia." International Journal of Wildland Fire **12**: 403-413.

Economic Associates Pty Ltd (2006) Mitchell draft water resource plan: economic and social assessment report. Brisbane, Queensland Government Department of Natural Resources and Water.

Erskine, W. D., G. W. Begg, P. Jolly, A. Georges, A. O'Grady, D. Eamus, N. Rea, P. Dostine, S. Townsend and A. Padovan (2003) Recommended environmental water requirements for the Daly River, Northern Territory, based on ecological, hydrological and biological principles. Darwin, Supervising Scientist.

Erskine, W. D., P. Jolly and I. Smith (2004) Environmental Water Requirements of the Daly River: Revision of Recommendations of Erskine *et al.* (2003). Darwin, Northern Territory Government Department of Infrastructure, Planning and Environment.

Faulks, J. J. (1998) Daly River Catchment: An Assessment of the Physical and Ecological Condition of the Daly River and its Major Tributaries. Top End Waterways Project. Katherine, Northern Territory Government Department of Lands, Planning and Environment.

Ferrini, S. and R. Scarpa (2007) "Designs with a priori information for nonmarket valuation with choice experiments: a Monte Carlo study." Journal of Environmental Economics and Management **53**: 342-363.

Finlayson, C. M., M. G. Bellio and J. B. Lowry (2005) "A conceptual basis for the wise use of wetlands in northern Australia - linking information needs, integrated analyses, drivers of change and human well-being." Marine and Freshwater Research **56**: 269-277.

Froend, R., N. Pettit and A. Payne (1998) Riparian vegetation of the Fitzroy River: water requirements. Limnology of the Fitzroy River, Western Australia: a technical report, Edith Cowan University, Claremont.

Gehrke, P. C. and J. H. Harris (2000) "Large-scale patterns in species richness and composition of temperate riverine fish communities, south-eastern Australia." Marine and Freshwater Research **51**: 165-182.

Graham-Taylor, S. (1979) A history of the Ord River Scheme: a study in incrementalism. Perth, Murdoch University.

Greene, W. H. (2003) LIMDEP Version 8.0 NLogit Version 3.0. Plainview, Economic Software, Inc.

Greiner, R. and A. K. Johnson (2000) "The Northern Myth revisited: a resource economics research approach to renewed interest in the agricultural development of the Kimberley region." Australian Agribusiness Perspective **8**(Paper 38).

Greiner, R., S. Larson, A. Herr and P. Pinger (2005) Independent travellers in the north Kimberley: benefits, impacts and management challenges. Townsville, CSIRO and Tropical Savannas Cooperative Research Centre.

Greiner, R., C. Mayocchi, S. Larson, N. Stoeckl and R. Schweigert (2004) Benefits and costs from tourism in remote communities. Case study for the Carpenttaria Shire in north-west Queensland. Townsville and Savanna CRC, Darwin, CSIRO Sustainable Ecosystems.

Griffith, D. A. (2004) Demographic profile of the Daly River region. Darwin, Daly Region Community Reference Group.

Gunderson, L. H., C. S. Holling and S. S. Light (1995) Barriers and Bridges to the Renewal of Ecosystems and Institutions. New York, Columbia University Press.

Hamilton, S. and P. Gehrke (2005) "Australia's tropical river systems: current scientific understanding and critical knowledge gaps for sustainable management." Marine and Freshwater Research **56**: 243-252.

Hanley, N., S. Mourato and R. E. Wright (2001) "Choice modelling approaches: a superior alternative for environmental valuation?" Journal of Economic Surveys **15**(3): 435-462.

Harris, G. P. (2001) "Biogeochemistry of nitrogen and phosphorus in Australian catchments, rivers and estuaries: effects of land use and flow regulation and comparisions with global patterns." Marine and Freshwater Research **52**: 139-149.

Hatton MacDonald, D. and M. D. Morrison (2005) The Value of Habitat and Agriculture. Adelaide, CSIRO Land & Water.

Head, L. (1999) "The northern myth revisited? Aborigines, environment and agriculture in the Ord River Irrigation Scheme, Stages One and Two." Australian Geographer **30**(2): 141-158.

Hensher, D. A., J. M. Rose and W. H. Greene (2005) Applied Choice Analysis: a Primer. New York, Cambridge University Press.

Hensher, D. A., N. Shore and K. Train (2005) "Household's willingness to pay for water service attributes." Environmental and Resource Economics **32**: 509-531.

Holling, C. S. (1973) "Resilience and stability of ecological systems." Annual Review of Ecology and Systematics **4**: 1-24.

Holling, C. S. (1994) "Simplifying the complex: the paradigms of ecological function and structure." Futures **26**(6): 598-609.

Holling, C. S. (2001) "Understanding the complexity of economic, ecological and social systems." Ecosystems **4**: 390-405.

Holling, C. S. and L. H. Gunderson (2002) Resilience and adaptive cycles. Panarchy: understanding transformations in human and natural systems. L. H. Gunderson and C. S. Holling. Washington D.C., Island Press: 25-62.

Holling, C. S., L. H. Gunderson and D. Ludwig (2001) In quest of a theory of adaptive change. Panarchy: Understanding Transformations in Human and Natural Systems. L. H. Gunderson and C. S. Holling. Washington D.C., Island Press: 3-24.

Idriess, I. (1949) The Great Boomerang. Sydney, Angus and Roberston.

Institute of Transport and Logistics Studies (2007) Ngene - a software capability to design and generate choice experiments. Sydney, The University of Sydney.

Jack, R. L. (1921) Northmost Australia. London, Simpkin, Marshall, Hamilton, Kent & Co.

Jackson, S. (2004) Preliminary Report on Aboriginal perspectives on land-use and water management in the Daly River region, Northern Territory. Darwin, CSIRO Sustainable Ecosystems and the Northern Land Council.

Jackson, S. (2006) "Compartmentalising culture: the articulation and consideration of Indigenous values in water resource management." Australian Geographer **37**(1): 19-31.

Jackson, S. and P. O'Leary (2006) Indigenous interests in tropical rivers: research and management issues. Darwin, North Australian Indigenous Land and Sea Management Alliance.

Jackson, S., N. Stoeckl, A. T. Straton and O. Stanley (2008) "The changing value of Australian tropical rivers." Geographical Research **46**(3): 275-290.

Jackson, S., M. Storrs and J. Morrison (2005) "Recognition of Aboriginal rights, interests and values in river research and management: perspectives from northern Australia." Ecological Management and Restoration **6**(2): 105-110.

Kragt, M., J. Bennett, C. Lloyd and R. Dumsday (2007) Comparing choice models of river health improvement for the Goulburn River. 51st Conference of the Australian Agricultural and Resource Economics Society. Queenstown, New Zealand.

Krinsky, I. and A. Robb (1986) "On approximating the statistical properties of elasticities." Review of Economics and Statistics **72**: 189-190.

Landcare Council of the Northern Territory (2005) Integrated Natural Resource Management Plan for the Northern Territory. Darwin, Northern Territory Government Department of Infrastructure, Planning and Environment and the Landcare Council of the Northern Territory.

Langton, M. (2002) Freshwater Background Briefing Papers: Indigenous rights to waters. Broome, Lingiari Foundation.

Larson, S. and K. Alexandridis (2009) Socio-economic profiling of tropical rivers. Townsville, CSIRO and Tropical Rivers and Coastal Knowledge.

Lawford, A. D. (2006) Bohemia Downs Station. Kimberley Appropriate Economies Roundtable Forum Proceedings. R. Hill, K. Golson, P. Loweet al. Cairns, Australian Conservation Foundation.

Levin, S. (1998) "Ecosystems and the biospere as complex adaptive systems." Ecosystems **1**: 431-436.

Liddle, D. T., B. W. Brook, J. Matthews, S. M. Taylor and P. Caley (2006) "Threat and response: a decade of deline in a regionally endangered rainforest palm affected by fire and introduced animals." Biological Conservation **132**(3): 362-375.

Lindsay, R. P. and D. P. Commander (2006) Hydrogeological assessment of the Fitzroy alluvium. Perth, Western Australian Government Department of Water.

Lonsdale, W. M. (1994) "Inviting trouble: introduced pasture species in northern Australia." Australian Journal of Ecology **19**: 345-354.

Loomis, J., L. Ellingson, A. Gonzalez-Caban and A. Seidl (2006) "The role of ethnicity and language in contingent valuation analysis: a fire prevention policy application." The American Journal of Economic and Sociology **65**: 559-596.

Louviere, J. and D. A. Hensher (1982) "On the design and analysis of simulated choice or allocation experiments in travel choice modelling." Transportation Research Record **890**: 11-17.

Louviere, J., D. A. Hensher and J. Swait (2000) Stated Choice Methods: Analysis and Application. Cambridge, Cambridge University Press.

Louviere, J. and G. Woodworth (1983) "Design and analysis of simulated consumer choice or allocation experiments: an approach based on aggregate data." Journal of Marketing Research **20**: 350-367.

Lukacs, G. P. and C. M. Finlayson (2008) A compendium of ecological information on Australia's northern tropical rivers. Sub-project 1 of Australia's tropical rivers - an integrated data assessment and analysis (DET18). Townsville, National Centre for Tropical Wetland Research.

Mackinnon, D., M. Foster, S. Fletcher and P. Martin (2009) Commodity outlook and financial performance of key agricultural industries in the Kimberley. Canberra, Australian Bureau of Agricultural and Resource Economics.

Mackinnon, D., P. Martin and T. Gleeson (2008) Performance of agriculture and resource industries in northern pastoral Australia. Canberra, Australian Bureau of Agricultural and Resource Economics.

Marshall, P. (1988) Raparapa Kularr Martuwarra: Stories from the Fitzroy River Drovers. Broome, Magabala Books.

McAllister, R. J., N. Abel, C. J. Stokes and I. J. Gordon (2006) "Australian pastoralists in time and space: the evolution of a complex adaptive system." Ecology and Society **11**(2): 41.

McDonald, G. T. and S. J. Dawson (2004) Northern Gulf region, Natural Resource Management Plan. Georgetown, Tropical Savannas Management CRC and NGRMG Ltd.

McGrath, A. (1985) Aborigines and colonialism in the Upper Daly Basin region. Casuarina, Northern Land Council.

McGrath, A. (1987) Born in the cattle. Sydney, Allen and Unwin.

McInnes, R. (2004) Cost-benefit analysis of Mary River salinity mitigation. Canberra, Australian Greenhouse Office.

McKay, J. (2005) "Water institutional reforms in Australia." Water Policy **7**: 35-52.

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. Washington D.C., Island Press.

Millennium Ecosystem Assessment (2005) Ecosystems and human wellbeing: wetlands and water synthesis. Washington D.C., World Resources Institute.

Millington, A. J. (1975) Agricultural implications of the Ord River Dam. Man-made lakes and human health. N. F. Stanley and M. P. Alpers. London, Academic Press**:** 113-136.

Millington, A. J. (1979) Agriculture in the northern half. Agriculture in Western Australia : 150 years of development and achievement 1820-1979. G. H. Burvill. Perth University of WA**:** 263-277.

Milne, F. and N. Watson (1985) The Northern Territory's water plan position paper. Water Planning in Australia: from Myths to Reality. W. Sewell, J. Handmer and D. Smith. Canberra, Centre for Resource and Environmental Studies, Australian National University**:** 69-78.

Moller, G., D. Johnson and N. Van Manen (2002) An ecological and physical assessment of the condition of streams in the Mitchell, Lynd, Palmer, Walsh and Alice River catchments. Brisbane, Department of Natural Resources and Mines.

Monaghan, J. (2004) Part B: Living on saltwater country: review of literature about Aboriginal rights, use, management and interests in northern Australia marine environments - Cape York Peninsula. Living on saltwater country: review of literature about Aboriginal rights, use, management and interests in northern Australia marine environments. National Oceans Office. Hobart, Balkanu Cape York Development Corporation, National Oceans Office.

Morgan, D., D. Thorburn, J. Fenton, H. Wallace-Smith and S. Goodson (2005) Influence of the Camballin Barrage on fish communities in the Fitzroy River, Western Australia. Perth, Murdoch University, Kimberley Land Council, Western Australia Government Department of Environment, Land and Water Australia.

Morrison, M. (2002) "Understanding local community preferences for wetland quality." Ecological Management and Restoration **3**(2): 127-134.

Morrison, M. and J. Bennett (2004) "Valuing New South Wales rivers for use in benefit transfer." The Australian Journal of Agricultural and Resource Economics **48**(4): 591-611.

Morrison, M., J. Bennett, R. Blamey and J. Louviere (2002) "Choice modelling and tests of benefit transfer." American Journal of Agricultural Economics **84**: 161-170.

Morrison, M. D., R. K. Blamey, J. Bennett and J. Louviere (1996) A comparison of stated preference techniques for estimating environmental values. Canberra, School of Economics and Management, The University of New South Wales.

National Water Commission (2005) National Competition Policy Assessment of Water Reform Progress. Canberra, National Water Commission.

National Water Commission. (2008) "National Water Initiative." Retrieved May 14, 2009, from http://www.nwc.gov.au/www/html/117-national-water-initiative.asp.

North, D. C. (1990) Institutions, Institutional Change and Economic Performance. Cambridge, Cambridge University Press.

Northern Gulf Resource Management Group (2001) Northern Gulf Regional Strategy. Georgetown, Northern Gulf Resource Management Group.

Northern Land Council and Aboriginal Areas Protection Authority (2004) An introduction to the Aboriginal people of the Daly River region: their history, land and sites. Darwin, Daly River Expert Reference Group.

Northern Territory Department of Natural Resources Environment the Arts and Sport (2008) Groundwater in the Darwin rural area: a powerpoint presentation. Darwin, Water Resources Branch, Land and Water Division, Northern Territory Government Department of Natural Resources, Environment, the Arts and Sport.

Northern Territory Government (2003) Draft Conservation Plan for the Daly Basin Bioregion. Darwin, Northern Territory Government Department of Infrastructure, Planning and Environment.

Northern Territory Tourist Commission (2004) Territory Tourism Selected Statistics. Darwin, Northern Territory Tourist Commission.

O'Gara, F. (1998) Striking the balance: sustainable farming and grazing systems for the semi-arid tropics of the Northern Territory. Darwin, Northern Territory Government Department of Primary Industry and Fisheries.

Ostrom, E. (1990) Governing the Commons: the Evolution of Institutions for Collective Action. Cambridge, Cambridge University Press.

Pearce, D. W. and R. K. Turner (1990) Economics of Natural Resources and the Environment. Hemel Hempstead, Harvester Wheatsheaf.

Pearce, H. (1983) Aboriginal sites in the Pine Creek District: a report to the Aboriginal Sacred Sites Authority, Northern Territory. Darwin, Aboriginal Sacred Sites Authority/Aboriginal Areas Protection Authority.

Petty, S. R., L. P. Hunt, R. A. Cowley, K. D. McCosker and A. Fisher (2007) "Recent advances in grazing management in northern Australia - the Pigeon Hole experience." Recent Advances in Animal Nutrition in Australia **16**: 235-239.

Powell, J. M. (1997) Enterprise and dependency: water management in Australia. Ecology and empire: environmental history of settler societies. T. Griffiths and L. Robin. Melbourne, Melbourne University Press.

Powell, J. M. (2000) Snakes and cannons: water management and the geographical imagination in Australia. Environmental History and Policy: Still Settling Australia. S. Dovers. Melbourne, Oxford University Press**:** 47-71.

Power and Water Corporation (2006) The Darwin Water Story. Darwin, Power and Water Corporation.

Proctor, W. and M. Drechsler (2006) "Deliberative multicriteria evaluation." Environment and Planning C: Government and Policy **24**: 169-190.

Pusey, B. J. and M. J. Kennard (1996) "Species richness and geographical variation in assemblage structure of the freshwater fish fauna of the wet tropics region of northern Queensland." Marine and Freshwater Research **47**: 563-573.

Queensland Department of Natural Resources and Water (2006) Mitchell draft water resource plan: overview report and draft plan. Brisbane, Queensland Government Department of Natural Resources and Water.

Rangelands NRM Coordinating Group (2004) Draft Kimberley Natural Resource Management Plan. Kununurra, Rangelands NRM Coordinating Group, Interim Kimberley Natural Resource Management Group, Natural Heritage Trust.

Resilience Alliance (2007) Assessing and managing resilience in social-ecological systems: a workbook for scientists. Version 1.1 Draft for testing and evaluation, Resilience Alliance.

Richter, B. D., R. Mathews, D. L. Harrison and R. Wigington (2003) "Ecologically sustainable water management: managing river flows for ecological integrity." Ecological Applications **13**(1): 206-224.

Robins, J., D. Mayer, J. Staunton-Smith, I. Halliday, B. Sawynok and M. Sellin (2006) "Variable growth rates of the tropical estuarine fish barramundi *Lates calcarifer* (Bloch) under different freshwater flow conditions." Journal of Fish Biology **69**: 379-391.

Robins, J. B., I. A. Halliday, J. Staunton-Smith, D. G. Mayer and M. J. Sellin (2005) "Freshwater-flow requirements of estuarine fisheries in tropical Australia: a review of the state of knowledge and application of a suggested approach." Marine and Freshwater Research **56**: 343-360.

Rolfe, J., J. Bennett and J. Louviere (2000) "Choice modelling and its potential application to tropical rainforest preservation." Ecological Economics **35**: 289-302.

Rolfe, J. and P. Prayaga (2007) "Estimating values for recreational fishing at freshwater dams in Queensland." The Australian Journal of Agricultural and Resource Economics **51**: 157-174.

Rolfe, J. and J. Windle (2003) "Valuing the protection of Aboriginal cultural heritage sites." The Economic Record **79**: S85-S95.

Rolfe, J. and J. Windle (2005) "Valuing options for reserve water in the Fitzroy Basin." The Australian Journal of Agricultural and Resource Economics **49**: 91-114.

Roseth, N. (2006) Community views on water shortages and conservation. Adelaide, Cooperative Research Centre for Water Quality and Treatment.

Salama, R., E. Bekele, D. Pollock, L. Bates, J. Byrne, W. Hicks, G. Watson and G. Bartle (2002) Hydrological response units of the Ord Stage 1 Irrigaiton Area and the dynamic filling of the aquifers of the Ivanhoe and Packsaddle Plains. Perth, CSIRO.

Scheffer, M., S. Carpenter, J. A. Foley and B. Walker (2001) "Catastrophic shifts in ecosystems." Nature **413**: 591-596.
Shaw, B. (1983) Banggaiyerri: the story of Jack Sullivan. Canberra, Australian Institute of Aboriginal Studies.
Speck, N. H., R. L. Wright, G. K. Rutherford, K. Fitzgerald, F. Thomas, J. M. Arnold, J. J. Basinski, E. A. Fitzpatrick, M. Lazarides and R. A. Perry (1964) General Report on Lands of the West Kimberley Area, W.A. Melbourne, CSIRO.
Stanley, N. F. (1975) The Ord River Dam of tropical Australia. Man-made lakes and human health. N. F. Stanley and M. P. Alpers. London, Academic Press**:** 103-112.
Stanley, O. (1985) The Mission and Peppimenarti: an economic study of two Daly River Aboriginal communities. North Australia Research Unit. Darwin, The Australian National University.
Steering Committee for the Review of Government Service Provision (2005) Overcoming Indigenous disadvantage: key indicators 2005. Canberra, Productivity Commission.
Stoeckl, N., O. Stanley, V. Brown, S. Jackson and A. T. Straton (2006) An assessment of social and economic values of Australia's tropical rivers. Canberra, Land and Water Australia, CSIRO, James Cook University.
Storey, A. and K. Trayler (2006) Allocating for the future of the lower Ord River: balancing ecological, social, cultural, and consumptive water requirements. Water: histories, cultures, ecologies. M. Leybourne and A. Gaynor. Crawley, University of Western Australia Press.
Storey, A. W., P. M. Davies and R. H. Froend (2001) Fitzroy River System: Environmental Values. Draft Report. Perth, University of Western Australia and Edith Cowan University**:** 134.
Strang, V. (1997) Uncommon ground: cultural landscapes and environmental values. Oxford, Berg.
Straton, A. T., S. Heckbert, A. Smajgl and J. Ward (2006) Institutions for water trading and policy-making in the tropical savannas: a case study of the Katherine-Daly River region. Darwin, Tropical Savannas Cooperative Research Centre and CSIRO Social and Economic Integration.
Straton, A. T., S. Jackson, O. Marinoni, W. Proctor and E. Woodward (2008) Evaluating scenarios for the Howard catchment: summary report for workshop participants and stakeholders. Darwin, CSIRO Sustainable Ecosystems.
Sullivan, P. (2006) Sustainable employment in the hybrid economies of dispersed Kimberley Aboriginal settlements. Kimberley Appropriate Economies Roundtable Forum Proceedings. R. Hill, K. Golson, P. Loweet al. Broome, Australian Conservation Foundation, Kimberley Land Council and environs Kimberley**:** 127-129.
Symanski, R. (1996) "Environmental mismanagement in Australia's far north." The Geographical Review **86**: 573-587.
Tan, P.-L. (2008) Collaborative water planning: legal and policy analysis. Brisbane, Tropical Rivers and Coastal Knowledge Research Hub, Australian Government Department of the Environment, Water, Heritage and the Arts, Land & Water Australia and the National Water Commission, CSIRO and Griffith University.
Tan, P.-L., S. Jackson, P. Oliver, J. Mackenzie, W. Proctor and M. Ayre (2008) Collaborative water planning: context and practice literature review. Brisbane, Tropical Rivers and Coastal Knowledge Research Hub, Australian Government Department of the Environment, Water, Heritage and the Arts, Land & Water Australia and the National Water Commission, CSIRO and Griffith University.
Toussaint, S. (2008) "Kimberley friction: complex attachments to water-places in northern Australia." Oceania **78**(1): 46-61.

Toussaint, S., P. Sullivan and S. Yu (2005) "Water ways in Aboriginal Australia: an interconnected analysis." Anthropological Forum **15**(1): 61-74.

Toussaint, S., P. Sullivan, S. Yu and M. Mularty Jnr. (2001) Fitzroy Valley Indigenous Cultural Values Study: a preliminary assessment. Perth, Water and Rivers Commission.

Townsend, S. A. and M. M. Douglas (2000) "The effect of three fire regimes on stream water quality, water yield and export coefficients in a tropical savanna (northern Australia)." Journal of Hydrology **229**: 118-137.

Townsend, S. A. and A. V. Padovan (2009) "A model to predict the response of the benthic macroalga *Spirogyra* to reduced base flow in tropical Australia." River Research and Applications.

Tredwell, R. and M. Nelson (2006) Effective approaches for environmental and wastewater management and training: the Birdwood Downs case studies in the Kimberley region of Western Australia. Murdoch ETC Conference. Perth.

Turner, R. K., J. C. J. M. van den Bergh, T. Soderqvist, A. Barendregt, J. van der Straaten, E. Maltby and E. C. van Ierland (2000) "Ecological-economic analysis of wetlands: scientific integration for management and policy." Ecological Economics **35**(1): 7-23.

van Dam, R., R. Bartolo and P. Bayliss (2008) Ecological risk assessment for Australia's northern tropical rivers. Sub-project 2 of Australia's tropical rivers - an integrated data assessment and analysis (DET18). Darwin, Environmental Research Institute of the Supervising Scientist, National Centre for Tropical Wetland Research.

Venn, T. J. and J. Quiggin (2007) "Accommodating indigenous cultural heritage values in resource assessment: Cape York Peninsula and the Murray-Darling Basin, Australia." **61**: 334-344.

Walker, B. H., N. Abel, J. M. Anderies and P. Ryan (2009) "Resilience, adaptability, and transformability in the Goulburn-Broken catchment, Australia." Ecology and Society **14**(1): 12.

Weeds Cooperative Research Centre (2003) Weed management guide: *Hymenachne* or *olive hymenachne*. Adelaide, Weeds Cooperative Research Centre.

Western Australia Department of Mines and Petroleum (2008) Regional and local government area resources data 2007-08. Perth, Western Australia Government Department of Mines and Petroleum.

Western Australia Department of the Premier and Cabinet (2006) Options for bringing water to Perth from the Kimberley. Perth, Department of the Premier and Cabinet, Government of Western Australia.

Wheeler, J. R., B. L. Rye, B. L. Koch and A. J. G. Wilson (1992) Flora of the Kimberley Region. Perth, Western Australian Herbarium.

Whitehead, P. (2003) Economic development and conservation in northern Australia: threats and opportunities. Culturally and environmentally appropriate economies for Cape York Peninsula. R. Hill and S. M. Turton (Eds.). Cairns, Rainforest CRC and Australian Conservation Foundation.

Whitten, S. M. and J. Bennett (2005) Non-use values of wetland resources. Managing wetlands for private and social good: theory, policy and cases from Australia. S. M. Whitten and J. Bennett. Cheltenham, Edward Elgar**:** 161-191.

Whitten, S. M. and J. W. Bennett (2001) Non-market values of wetlands: a choice modelling study of wetlands in the Upper South East of South Australia and the Murrumbidgee River floodplain in New South Wales. Canberra, School of Economics and Management, University College, The University of New South Wales, Land & Water Resources Research and Development Corporation and Environment Australia.

Williams, R. J., A. D. Griffiths and G. E. Allan (2002) Fire regimes and biodiversity in the savannas of northern Australia. Flammable Australia: the fire regimes and biodiversity

of a continent. R. A. Bradstock, J. E. Williams and M. A. Gill. Cambridge, Cambridge University Press**:** 281-304.
Wilson, S. (1999) The Wagiman online dictionary.
Windle, J. and J. Rolfe (2004) Assessing values for estuary protection with choice modelling using different payment mechanisms. Rockhampton, Central Queensland University.
Windle, J. and J. Rolfe (2005) "Diversification choices in agriculture: a choice modelling case study of sugarcane growers." The Australian Journal of Agricultural and Resource Economics **49**: 63-74.
Woinarski, J. C. Z., C. Hempel, I. Cowie, K. Brennan, R. Kerrigan, G. Leach and J. Russell-Smith (2006) "Distributional patterns of plant species endemic to the Northern Territory, Australia." Australian Journal of Botany **54**: 627-640.
Woinarski, J. C. Z., B. Mackey, H. Nix and B. Traill (2007) The nature of northern Australia: natural values, ecological processes and future prospects. Darwin, Tropical Savannas CRC, The Wilderness Society, The Myer Foundation and Charles Darwin University.
Young, N. (1979) Ord River Irrigation Area review 1978. Canberra, Australian Government Publishing Service.
Yuco Pty Ltd (2003) The impact of tourism on the Gibb River Road: a community perspective. Broome, Cooperative Research Centre for Tropical Savanna Management and the Land and Sea Unit, Kimberley Land Council.

APPENDIX A: DESCRIPTION OF THE NATURAL ASSETS OF AUSTRALIA'S TROPICAL RIVERS REGION

The tropical rivers region of Australia stretches across the northern part of the country, covering approximately 1.3 million km^2. The region includes land along the coast from just south of Broome in Western Australia through the Northern Territory and to just south of Innisfail in Queensland, and inland to south of Fitzroy Crossing, Daly Waters, Mt Isa and Hughenden. There are 55 river basins in the region that drain into the Timor Sea, Gulf of Carpentaria and the Great Barrier Reef and Coral Sea.

While the tropical rivers region of Australia covers some 15% of the mainland, it is sparsely populated, containing less than 2% of Australia's total population and with only three centres that have more than 15,000 people (Stoeckl *et al.* 2006). A majority of river basins have less than 1 person/ km^2 and just under half have less than 500 inhabitants (Stoeckl *et al.* 2006). The sparseness of the population might give the impression that northern Australia is not a preferred place to live, however this belies the importance of the region to the approximately 88,000 Indigenous people of more than 130 language groups who live there (Woinarski *et al.* 2007). Indigenous people are significant landowners in the region and a major and growing proportion of the population (Woinarski *et al.* 2007).

The main forms of tenure in the region are pastoral leasehold and freehold (70%), Aboriginal title (20%), conservation reserves (6%) and military purpose (1%) (Woinarski *et al.* 2007). The predominant industries in the region are pastoralism, mining, Aboriginal enterprise (including natural and cultural resource management, art and music), tourism, commercial and recreational fishing, agriculture/horticulture, defence and government services.

Most of the tropical rivers region is located in Australia's tropical savanna bioregion. Tropical savannas are characterised by "a tall dense grass layer with or without trees" (Woinarski *et al.* 2007, p.13) and can range from being treeless grasslands to denser woodlands. The tropical rivers region of Australia also contains Acacia woodlands and shrublands, heathlands, rainforest, mangroves and coastal vegetation, and freshwater and wetlands (Woinarski *et al.* 2007).

The landforms of the region include undulating plains at low elevation; wetlands including river and stream channels, floodplains and billabongs; and the spectacular ranges and escarpments that provide the basis for much tourism interest and hold "the richest rock art galleries in the world" (Woinarski *et al.* 2007, p.11). The soils are mostly thin and infertile, mainly due to the nutrient leaching and erosion caused by the intense tropical rain (Woinarski *et al.* 2007). Much of the tropical rivers region has a monsoonal climate with a dry season of 7-8 months of the year and wet season of storms and torrential rain. Rainfall in the region ranges from 800-3,200mm per year on average and up to 90% of this usually falls during the wet season (Faulks 1998). Temperatures in the tropical rivers region are high year-round and there are often cyclones during the wet season.

Australia's tropical savanna bioregion is "recognised as being of outstanding national or international significance for biodiversity" (Woinarski *et al.* 2007, p.15). Of the plants, parts of the tropical savannas contain up to 3,000 species (Wheeler *et al.* 1992; Abrahams *et al.* 1995;

Woinarski *et al.* 2006). Of the invertebrates, there are about 1,500 species of ants (Andersen 2000) and 65% of all Australian species of moths and butterflies (Andersen *et al.* 2000; Woinarski *et al.* 2007). Of the vertebrates, there are approximately 460 species of birds, 110 species of mammals, and 40% of Australia's reptile species (Woinarski *et al.* 2007). The tropical catchments of Australia have greater freshwater biodiversity than that of temperate Australia (Pusey and Kennard 1996; Gehrke and Harris 2000; Hamilton and Gehrke 2005). Approximately 225 species of freshwater fish, being over 75% of all species in Australia, are found in the tropical rivers region (Woinarski *et al.* 2007). Many species of animal and plant life in the tropical savannas are endemic to the bioregion.

The tropical river systems of the region include extensive floodplains, permanent and semi-permanent billabongs and waterholes, and extensive ephemeral wetlands (Woinarski *et al.* 2007). Many of the iconic species of northern Australia are associated with these water features, for example, saltwater crocodiles and Magpie Geese and other waterbirds (Woinarski *et al.* 2007). There are several sites recognised as being of national or international significance (for example, the Kakadu wetlands and the Southern Gulf Aggregation (Woinarski *et al.* 2007)).

While the tropical rivers and groundwater systems of the region contain approximately 70% of Australia's freshwater resources (Hamilton and Gehrke 2005), most of the tropical rivers of the region are episodic and shrink to a series of non-flowing pools in the dry season. This high variability of rainfall between the wet and dry seasons means that there is very little perennial surface water in the region throughout much of the dry season. Surface water is perennial where streams are fed by groundwater from aquifers such as for the Daly, Gregory and Jardine Rivers (Woinarski *et al.* 2007).

In sum, the tropical rivers region of Australia is one of the last remaining large natural areas in the world:

> Unlike much of southern and eastern Australia, nature remains in abundance in the North. Great flocks of birds still move over the land searching for nectar, seeds and fruit. Rivers still flow naturally. Floods come and go. In fertile billabongs, thousands of Magpie Geese, brolgas, egrets and other water birds still congregate. (Woinarski *et al.* 2007, p.1)

APPENDIX B: ECONOMIC VALUES ESTIMATED FOR COMPARABLE ECOSYSTEM SERVICES

There have been several choice modelling valuations of rivers and wetlands in Australia (for example, Blamey *et al.* 1999; Whitten and Bennett 2001; Morrison and Bennett 2004; Hatton MacDonald and Morrison 2005; Rolfe and Windle 2005). Brouwer (2009) provides a meta-analysis of ten years of research. Table 31 reports once-off willingness to pay estimates for ecosystem goods and services comparable to some included in this study. We note, however, the significant difference in the units used for our study at those reported below.

While there haven't been any other choice modelling valuations of Australia's tropical rivers, two valuation studies exist for river/wetland features of the tropical rivers region. de Groot, Finlayson *et al.* (2008) estimate the economic benefits provided by ten ecosystem services of Australia's tropical rivers using direct and extrapolated market values. Net economic benefits of ecosystem services are $50.7 million for the Mary River catchment (approximately $450/ha) and $82.4 million for the Daly River catchment (approximately $230/ha) (de Groot *et al.* 2008). The authors suggest that these are conservative estimates. They are not easily comparable with the implicit prices estimated here due to the different methods and units used.

Table 31: Willingness to pay estimates for comparable ecosystem services (adapted from Brouwer 2009, once-off payments, $2006)

Ecosystem service	Units	Mean willingness to pay	95% Confidence interval	No. of studies
Healthy waterways	Per % of river estuary in good health[a]	$0.30	-$3.10 - $3.70	2
Healthy wetlands	Per 1000km^2 of wetland receiving more water[b]; per 1000ha healthy wetland[c]	$3.40	-$7.30 - $14.1	4
Healthy native vegetation	Per % of river covered with healthy native vegetation[d]; per % of river length with healthy native vegetation[e]	$3.10	$2.30 - $4.00	12
Waterbirds	Per number of waterbirds breeding per year[b]; per waterbird[d]; per 1% increase in native birds[c]; per native waterbird and animal species[e]	$6.70	$1.20 - $12.20	13
Native fish species	Per fish species[d]	$4.40	$3.20 - $5.70	12
Quality – fishable	Per fishable/swimmable water quality[d]	$51.60	$40.50 - $62.70	7

[a] Windle and Rolfe (2004)
[b] Morrison, Bennett *et al.* (2002)
[c] Whitten and Bennett (2005)
[d] Morrison and Bennett (2004)
[e] Kragt, Bennett *et al.* (2007)

The only other economic valuation of Australia’s tropical rivers comes from a cost-benefit analysis of salinity mitigation options for the Mary River, which found that the net benefit of preventing the salinisation of the Mary River was in the order of $8 million (2003) under one mitigation option. This benefit included avoiding a loss of income to the agricultural, fishery and tourist industries, and gaining from reclaimed wetlands that are currently salinised (McInnes 2004).

APPENDIX C: STAKEHOLDER CONCERNS ABOUT ECONOMIC VALUATION AND OUR RESPONSE

Key stakeholders for each river system were consulted about the choice of choice modelling for the project. Three stakeholders expressed concern, not with the choice modelling method itself, but with the practice of economic valuation.

The concerns raised were: (1) the complexity of ecosystems and the social and economic systems that interact with them in making up each catchment means that valuation of individual features may not be realistic or valid; (2) some features may be non-negotiable to stakeholders and not able to be ‘traded’ against each other, as such they have absolute rather than relative value; (3) do the values of people living far from each river system carry the same weight as those living locally?; (4) how do we account for the different understandings people may have of tropical rivers?; (5) these values are incommensurable and cannot be meaningfully assessed through translation into dollar terms; and (6) Aboriginal people may find the questionnaire format challenging.

The first concern is addressed in this study through the second approach to assessing impacts. The second, third, fourth and fifth concerns are acknowledged as challenges presented by the theory and practice of economic valuation. In response to the second concern, the ecosystem services were defined in ways that avoided their description only in terms of things that would likely be considered as non-negotiable, such as ‘spiritual’ or ‘cultural’ benefit. This does not completely solve the problem because we cannot completely control how respondents perceive the attributes, but goes some way to alleviating it.

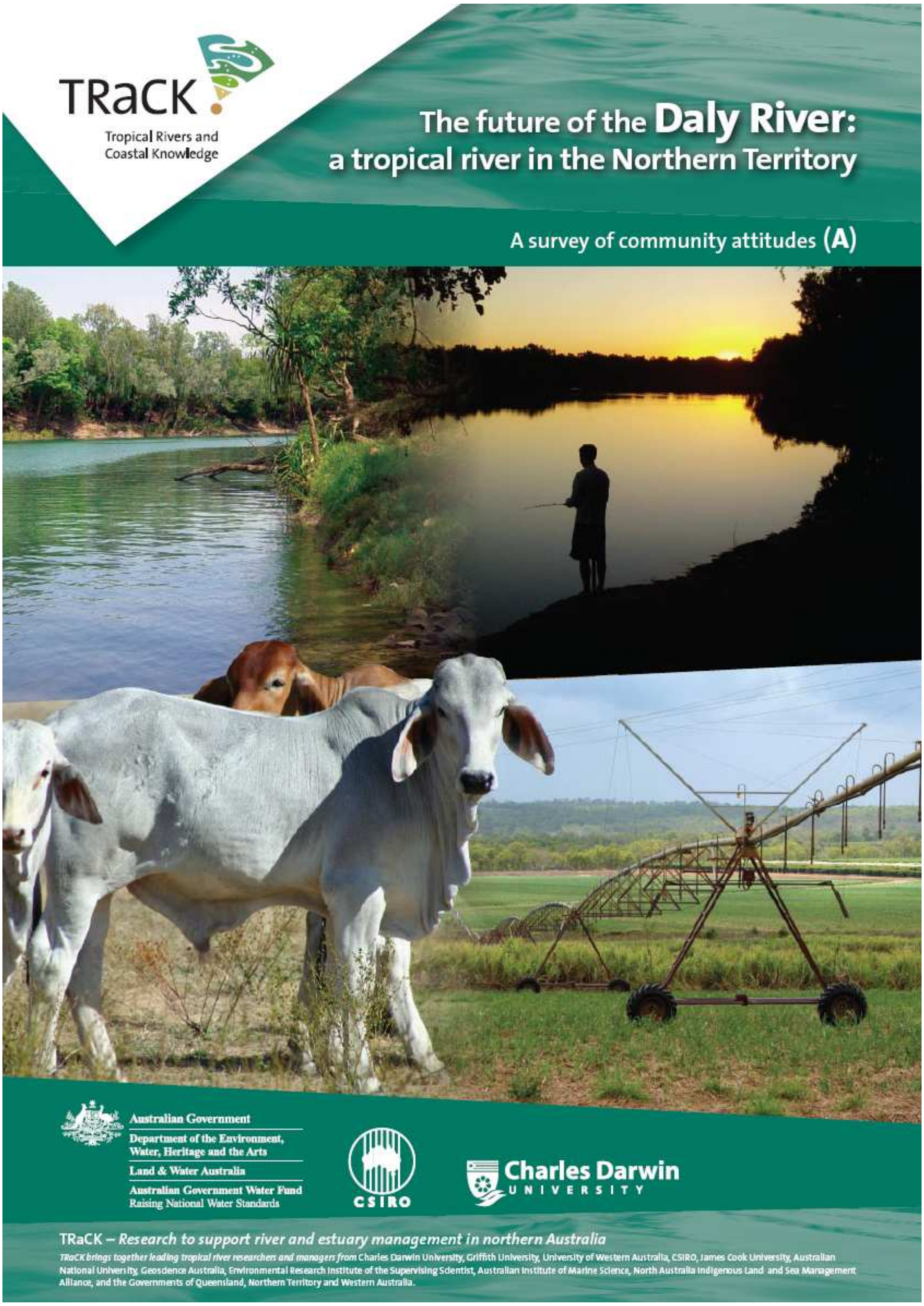
In response to the third concern, valuation results are presented in disaggregated form so that differences between the willingness to pay of people living in the catchment and those living in cities can be observed. Further work with this dataset will explore different weightings of responses in the all samples models.

As a method that measures the subjective preferences of individuals, it is difficult for stated preference methods to avoid the fourth concern raised. The information provided to frame the choice questions is used to create as common an understanding of the situation as is possible given the requirements of the method.

We accept the incommensurability of the values we seek to measure in dollar terms, and the second approach to assessing impacts provides another way of evaluating scenarios. However, we follow Costanza *et al.* (1997) in arguing that any evaluation implies a set of values and that it can be helpful to make these valuations explicit. The sixth concern is addressed through translation of the questionnaire by a linguist and the face-to-face method for delivery with Indigenous people.

In addition to these concerns, staff from a government department responsible for managing water resources expressed concern that the valuation questionnaire presented options for the management of a river system and that this was not appropriate at this stage of the government’s own planning processes. We clarified the necessity of using management options in the framing of the questionnaire, but rewrote certain sections to highlight and emphasise the hypothetical nature of these management options and removed all reference to specific government departments.

APPENDIX D: DALY RIVER QUESTIONNAIRE AND INFORMATION SHEET



A

What this survey is for

This survey is being undertaken as part of research by the Tropical Rivers and Coastal Knowledge Research Program to build understanding of people's preferences for the future of Australia's tropical rivers.

What we ask you to do

Any adult member of your household can complete this questionnaire. It should take about 30 minutes to complete.

You don't need to know about river management to do this survey. There are no right or wrong answers – we are interested in your views.

In most cases, you only need to tick the box representing the answer that is closest to your opinion.

Sometimes you need to place a number in the box – in these cases, write the number in the appropriate box provided.

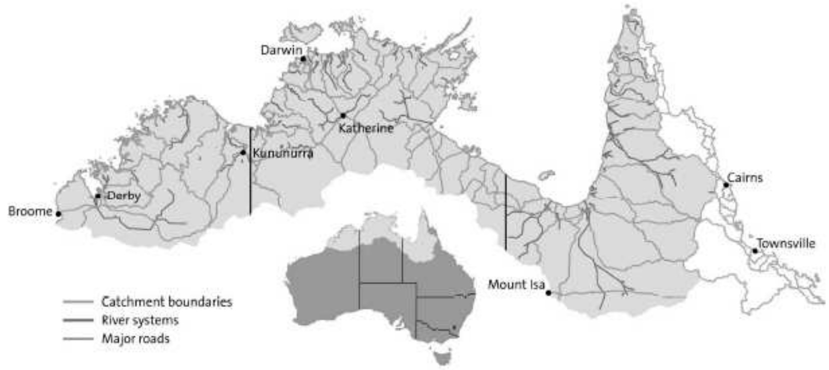
All your answers will be treated as completely confidential.

How to return this survey

Please return your completed questionnaire to us using the reply-paid envelope provided.

To start, we would like to ask you for your thoughts about tropical rivers and the environment in general.

The map below shows the part of Australia's tropical rivers region that is being studied by a new research program called Tropical Rivers and Coastal Knowledge (TRaCK).



Source: Tropical Rivers and Coastal Knowledge

QUESTION 1. Do you live in or have you visited the region shaded light grey in this map?

☐ Yes

☐ No

QUESTION 2. If you don't live there, do you think you will visit this region in the future?

☐ Yes

☐ No

☐ Unsure

What's a priority issue for Australia's tropical rivers?

Across Australia there is increasing awareness of the value of water. The recent drought conditions in some parts of Australia have also raised questions about the use of water for food production and the potential that the tropical rivers of northern Australia may have for this purpose and for other forms of development.

This raises a number of environmental and development issues. To start with, how do you compare and rate the following in terms of importance?

QUESTION 3. Please rank the following issues in order of importance to you. Please put a number in each of the boxes from 1 (most important) to 5 (least important).

- ☐ Providing food for Australia
- ☐ Providing food for the world
- ☐ Developing northern Australia
- ☐ Preserving Australia's tropical rivers for the people who live there and visitors
- ☐ Preserving Australia's tropical river environments for biodiversity and natural habitat

These kinds of issues arise whenever there are questions about how to balance the different possible uses of our natural resources.

QUESTION 4. Over the years, when you have heard about proposed projects where there is a conflict between development and the environment, have you tended to (please mark one box only):

- ☐ favour preservation of the environment more frequently?
- ☐ favour development more frequently?
- ☐ favour development and environmental preservation equally?

Even if people favour development, they often express concern about environmental problems, like declining water quality, erosion or animal extinction, but people can also differ as to which consequences or outcomes they are concerned about.

QUESTION 5. Here is a list of things that can be impacted by environmental problems. For each of these issues, please tick the box that best describes how concerned you are.

	Not at all concerned	A little bit concerned	Extremely concerned
Me and my future	☐	☐	☐
My children	☐	☐	☐
People in my region or community	☐	☐	☐
All people	☐	☐	☐
Future generations	☐	☐	☐
Nature, animals, plants and birds	☐	☐	☐

We would now like to ask you what you think about some hypothetical options for the future of the Daly River region in the Northern Territory. For this, we need to give you some background information. Please read the folded flyer enclosed with this questionnaire.

QUESTION 6. Had you heard of the Daly River before being contacted for this survey?

☐ Yes

☐ No

QUESTION 7. Do you have family or friends who own land or work in the Daly River region?

☐ Yes

☐ No

The future of the Daly River region

- There are a number of different ways in which economic and community development can occur in the Daly River region, each of which has its own advantages and disadvantages. Each option will have different impacts on people, their values and aspirations, and on natural resources, such as native plants and animals.
- Some people have suggested that irrigated agriculture in the area could increase to support more food production in Australia. This would mean that more water from the river system would need to be allocated to farming.
- Others suggest that the natural values of the river system are significant and should be used to support tourism and other forms of economic activity that don't require much water.

QUESTION 8. How interested are you in the management and future of the Daly River region? Please tick one box only.

☐ Very interested

☐ A little bit interested

☐ Not at all interested

Hypothetical options for the future

Each of the possible options for the future will cost money to manage and can be achieved in many different ways. The money could be used for a number of things, for example:

- continued funding of government and non-government agencies to manage weeds on riverbanks;
- giving assistance to landowners to set aside land for animal habitat on their property; or
- awarding grants to people starting tourism or other businesses that don't use much water.

These management provisions would involve some financial contributions from the community. These might be made through methods such as:

- increased taxes;
- higher rate payments to local councils (these would also flow through to higher rents); or
- higher prices for goods and services as farmers and businesses meet higher environmental standards.

This is a hypothetical situation and so none of these measures are actually on the table, but we would like you to consider these potential costs as if they were a **once-off amount** charged to your household. This will help us establish what people want for the future of the Daly River region.

What future is acceptable to you?

On the next few pages there are 8 choices to be made on the future of the Daly River region; one choice per page. Each one involves choosing between 3 options. In every case, Option 3 is always the same and it has no associated cost. This represents how the region could look if there is maximum development (within existing legislative constraints) and minimal management. The other 2 options represent changes to this situation.

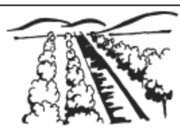
Each option is described by its impact on:

- the area of floodplain in good environmental condition
- the quality of the river for recreational fishing
- the condition of waterholes important to Aboriginal people
- the income from irrigated agriculture
- the cost to you as a once-off payment

When deciding on the options you prefer and the associated cost, keep in mind your available income and all other things you have to spend money on. Please answer each and every question. Even though they may look the same, each question is different. Some options may seem strange but there are many different ways that impacts can play out in the real world.

QUESTION 9.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?		**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition		2,513 km^2 (50% less than the current level)	5,025 km^2 (the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing		3-star	3-star	1-star
Condition of waterholes important to Aboriginal people		Ok	Ok	Poor
Income from irrigated agriculture		\$68 m/yr	\$68 m/yr	\$100 m/yr
How much would I pay?		\$10	\$50	NIL
I prefer (mark one box only) ☒		☐	☐	☐

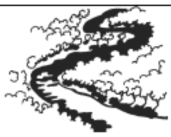
QUESTION 10.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?		Option 1	Option 2	Option 3
Area of floodplain in good environmental condition		3,518 km^2 (30% less than the current level)	3,518 km^2 (30% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing		4-star	1-star	1-star
Condition of waterholes important to Aboriginal people		Poor	Good	Poor
Income from irrigated agriculture		\$68 m/yr	\$68 m/yr	\$100 m/yr
How much would I pay?		\$100	\$10	NIL
I prefer (mark one box only) ☒		☐	☐	☐

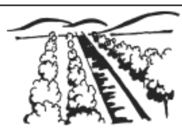
QUESTION 11.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	2,513 km^2 (50% less than the current level)	5,025 km^2 (the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	3-star	3-star	1-star
Condition of waterholes important to Aboriginal people 	Ok	Ok	Poor
Income from irrigated agriculture 	$36m/yr	$68 m/yr	$100 m/yr
How much would I pay? 	$100	$50	NIL
I prefer (mark one box only) ☒	☐	☐	☐

QUESTION 12.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	5,025 km^2 (the current level)	3,518 km^2 (30% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	3-star	4-star	1-star
Condition of waterholes important to Aboriginal people 	Ok	Good	Poor
Income from irrigated agriculture 	$100 m/yr	$36 m/yr	$100 m/yr
How much would I pay? 	$50	$10	NIL
I prefer (mark one box only) ☒	☐	☐	☐

<u>You're halfway through now!</u>

QUESTION 13.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	2,513 km^2 (50% less than the current level)	2,513 km^2 (50% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	1-star	4-star	1-star
Condition of waterholes important to Aboriginal people 	Good	Poor	Poor
Income from irrigated agriculture 	\$36 m/yr	\$100 m/yr	\$100 m/yr
How much would I pay? 	\$10	\$100	NIL
I prefer (mark one box only) ☒	☐	☐	☐

QUESTION 14.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	2,513 km^2 (50% less than the current level)	2,513 km^2 (50% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	4-star	1-star	1-star
Condition of waterholes important to Aboriginal people 	Poor	Good	Poor
Income from irrigated agriculture 	\$36 m/yr	\$100 m/yr	\$100 m/yr
How much would I pay? 	\$100	\$10	NIL
I prefer (mark one box only) ☒	☐	☐	☐

Only two more to go!

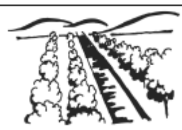
QUESTION 15.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	Option 1	Option 2	Option 3
Area of floodplain in good environmental condition 	3,518 km^2 (30% less than the current level)	2,513 km^2 (50% less than the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	1-star	3-star	1-star
Condition of waterholes important to Aboriginal people 	Poor	Good	Poor
Income from irrigated agriculture 	$100 m/yr	$36 m/yr	$100 m/yr
How much would I pay? 	$50	$100	NIL
I prefer (mark one box only) ☒	☐	☐	☐

QUESTION 16.

If options 1, 2 and 3 are the ONLY options available for the Daly River region, which one would you prefer? Choose only one option from the three below.

What could the Daly River look like?	**Option 1**	**Option 2**	**Option 3**
Area of floodplain in good environmental condition 	2,513 km^2 (50% less than the current level)	5,025 km^2 (the current level)	2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing 	3-star	3-star	1-star
Condition of waterholes important to Aboriginal people 	Ok	Ok	Poor
Income from irrigated agriculture 	$68 m/yr	$68 m/yr	$100 m/yr
How much would I pay? 	$10	$100	NIL
I prefer (mark one box only) ☒	☐	☐	☐

We would now like to ask you about your experiences in answering questions 9 to 16.

QUESTION 17. When answering questions 9 to 16 did you always choose Option 3?

- ☐ Yes
- ☐ No

If you answered yes, which statement most closely describes your reason for doing so?

- ☐ I support river management but cannot afford any of the levies mentioned
- ☐ Option 3 was my preferred option in each situation
- ☐ Some other reason. Please specify

  ____
  ____
  ____
  ____

QUESTION 18. Which attributes were important to you in making your decision for questions 9 to 16? Please tick the relevant boxes.

- ☐ Area of floodplain in good environmental condition
- ☐ Quality of the river for recreational fishing
- ☐ Condition of waterholes important to Aboriginal people
- ☐ Income from irrigated agriculture
- ☐ How much I would pay

Thinking about the information presented earlier about the Daly River region, please indicate your view for each statement.

QUESTION 19. Tick the box closest to your view for each statement.

	Yes	No	Maybe
I understood the information in the questionnaire.	☐	☐	☐
I needed more information than was provided.	☐	☐	☐
Information was biased towards environmental outcomes.	☐	☐	☐
I found the questionnaire confusing.	☐	☐	☐
Information was biased towards development outcomes.	☐	☐	☐

In this final section we would like to ask a few questions about you.

QUESTION 20. What is the postcode where you live? _________

QUESTION 21. What is your age? ________years

QUESTION 22. What is your gender?

☐ Male

☐ Female

QUESTION 23. Do you have children?

☐ Yes

☐ No

QUESTION 24. Do you identify as an Aboriginal or Torres Strait Islander person?

☐ Yes

☐ No

QUESTION 25. Are you or a member of your family involved in the farming industry?

☐ Yes

☐ No

QUESTION 26. Are you a member of or do you donate money to an environmental organisation?

☐ Yes

☐ No

QUESTION 27. What is the highest level of education you have obtained or are obtaining?

☐ Primary school

☐ High school Year 10

☐ High school Year 12

☐ Diploma or trade certificate

☐ Tertiary degree

☐ Other (please specify) _______________

QUESTION 28. To the best of your knowledge, please indicate the total annual income before taxes that you and your spouse (if applicable) earned last year:

☐ Under $6,000

☐ $6,000 – 14,999

☐ $15,000 – 24,999

☐ $25,000 – 49,999

☐ $50,000 – 69,999

☐ $70,000 – 99,999

☐ More than $100,000

☐ Don't know

If you would like to make any other comments about this issue, or about this questionnaire, please make them in the following space.

Thank you for completing this questionnaire. We hope that you enjoyed taking part in this survey.

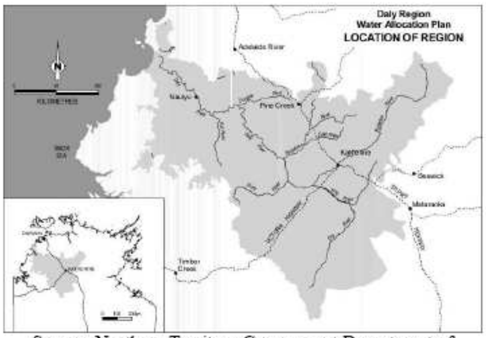
If you are interested in the outcomes or have any further comments, please contact Anna Straton at CSIRO.

Phone: (03) 9252 6403 or 0448 490 005
Fax: (08) 9252 6249
Email: anna.straton@csiro.au
Address: PO Box 56 Highett VIC 3190

This project receives funding from the Myer Foundation and Land & Water Australia.

THE DALY RIVER REGION

The Daly River region covers about 53,000 km^2 in the north-west of the Northern Territory (see map below). This is slightly smaller than the size of Tasmania.



Source: Northern Territory Government Department of Natural Resources, Environment and the Arts

About 14,000 people live in the region, mainly in the town of Katherine.

Aboriginal people make up about a quarter of the population. Eleven different Aboriginal language groups have traditional lands in the region.

The major economic activities that take place are irrigated and dryland agriculture including forestry; cattle grazing; mining; commercial fishing and tourism.

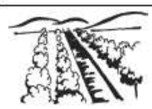
The region is very popular for recreational fishing. Parts of the floodplain are nationally recognised as important conservation areas and the bird life and natural features contribute to tourism in the region.

In answering the questions about the future of the Daly River region, we are interested in what outcome you want for the following features:

- the area of floodplain in good environmental condition,
- the quality of the river for recreational fishing,
- the condition of waterholes important for Aboriginal people, and
- the income from irrigated agriculture.

The following tables describe what these features could look like under different scenarios. Each of them has three different possible levels.

What could the Daly River region look like if there is maximum development (within existing legislative constraints) and minimal management?

Area of floodplain in good environmental condition		2,513 km^2 (50% less than the current level)
Quality of the river for recreational fishing		1-star
Condition of waterholes important to Aboriginal people		Poor
Income from irrigated agriculture		\$100 million/year

What could the region look like in the future if there is some management?

Area of floodplain in good environmental condition	This area could be greater at: 1. 5,025 km^2 (the current level) or 2. 3,518 km^2 (30% less)
Quality of the river for recreational fishing	The quality could be better at: 1. 3-star, or 2. 4-star.
Condition of waterholes important to Aboriginal people	The condition of waterholes could be better at: 1. 'ok', or 2. 'good'.
Income from irrigated agriculture	Income from irrigated agriculture could: 1. stay around current levels, \$36 million/year, or 2. be approximately \$68 million/year.

The following provides more information about each.

Area of floodplain in good environmental condition

- Floodplains store water, trap and filter pollutants, provide habitat for plants, fish, birds and animals, add nutrients to water, provide places for recreation and serve as attractive landscapes.
- A floodplain is in good environmental condition when it is getting enough water at the right times, has native vegetation with high cover and diversity, and does not have any weeds.
- Research for the Daly River estimates that if there is land clearing, weeds, chemical use or water extraction, then 10-50% of the floodplain would likely experience different water flows and other impacts. The amount of floodplain in good environmental condition would then decrease unless there is some management to mitigate these impacts.

Quality of the river for recreational fishing

- The Daly River is highly valued for recreational fishing.
- Having a good quality recreational fishing experience is about lots of things, including being out in nature with friends and family, 'getting away from it all', and catching healthy-looking fish.
- Research for the Daly River has shown that unmanaged development would likely lead to a 1-star fishing river:
  - A 1-star fishing river has much reduced flows and polluted water offering few fishing opportunities amid heavily modified scenery.
- If impacts are managed the river will be either:
  - A 4-star fishing river with mostly unmodified flows and unpolluted water offering abundant fishing opportunities amid mostly natural scenery. This is the current situation.
  - A 3-star fishing river with somewhat reduced flows and slightly polluted water offering some fishing opportunities amid modified scenery.

Condition of waterholes important to Aboriginal people

- The Daly River is home to about 3,500 Aboriginal people who have unique historical relationships with its land and water.
- There are waterholes that Aboriginal people in the region continue to visit to undertake activities including hunting, teaching and carrying out religious responsibilities to their country.
- Research for the Daly River has shown that unmanaged development will likely result in a 'poor' condition for these waterholes where:
  - there are few plants, fish and animals available, water flows are much reduced, there is a lot of sediment build up, there are lots of weeds, Aboriginal people have very limited access and there is very little privacy.
- If impacts are managed, the waterholes will likely remain in 'good' or 'ok' condition:
  - A waterhole is in 'good' condition when there is a wide range of plants, fish and animals for hunting and gathering, water and sediment are unmodified, there are no weeds, Aboriginal people have access and there is privacy.
  - It is in 'ok' condition when there are some plants, fish and animals available, water flows are somewhat reduced, there is some sediment build up, there are some weeds, Aboriginal people have some access and there is some disturbance in carrying out responsibilities and teaching.

Income from irrigated agriculture

- Irrigated agriculture is a key industry in the Daly River region that has been identified as having the potential for further development.
- The industry provides jobs for people and generates income and other flow on benefits for the region. It's also part of the 'lifestyle' and identity for some people living in the Daly.
- Irrigated agriculture uses more water than most other industries in the region and would require expenditure to ensure potential impacts are managed.

APPENDIX E: DALY RIVER INTRODUCTORY LETTER AND QUESTIONNAIRE COVER LETTER

Sustainable Ecosystems
Tropical Ecosystems Research Centre,
PMB 44, Winnellie NT 0822, Australia

Telephone: (03) 9252 6403 • Facsimile: (03) 9252 6249 • ABN 41 687 119 230

CSIRO

J. Smith
1 Smith St
Smithville 1000

1 October 2008

Dear J. Smith and family,

In a few days you will receive a questionnaire in the mail for a research project being undertaken by CSIRO and Charles Darwin University for the Tropical Rivers and Coastal Knowledge Research Program*.

The questionnaire aims to seek your opinion about the future of Australia's tropical rivers, and one in particular, the Daly River in the Northern Territory.

This important study will provide new information on the value Australians place on tropical rivers, now and into the future, and will aid decision-making about the future of Australia's tropical rivers.

Thank you for your time and consideration. It's only through the generous contribution of people like you that our research can be successful.

Sincerely,

Anna Straton
Research Scientist
anna.straton@csiro.au
(03) 9252 6403

P.S. We will be enclosing a small token of appreciation with the questionnaire as a way of saying thanks.

* For more information on the Tropical Rivers and Coastal Knowledge Research Program, please go to http://www.track.gov.au or contact Anna Straton to request an information brochure be sent to you.

Australian Science, Australia's Future www.csiro.au

Sustainable Ecosystems
Tropical Ecosystems Research Centre,
PMB 44, Winnellie NT 0822, Australia

Telephone: (03) 9252 6403 • Facsimile: (03) 9252 6249 • ABN 41 687 119 230

CSIRO

J. Smith
1 Smith St
Smithville 1000

27 October 2008

Dear J. Smith and family,

Hopefully by now you will have read a letter informing you that you will be receiving a questionnaire in the mail for a research project. You were selected to receive this questionnaire as part of a random sample of residents from your local phone directory. I am now writing to ask for your help in a study of people's opinions about the future of Australia's tropical rivers, and one in particular, the Daly River in the Northern Territory.

This study is funded by the Myer Foundation and Land & Water Australia and is being undertaken for the Tropical Rivers and Coastal Knowledge Research Program*. It will provide new information on the value Australians place on tropical rivers and will aid decision-making about the future of Australia's tropical rivers.

Your answers are completely confidential and will be released only as summaries in which no individual's answers can be identified. When you return your completed questionnaire your name will be deleted from the mailing list and never connected to your answers in any way.

This questionnaire is voluntary and even if you think that you may not have any experience in these matters everyone's opinions are useful and important to us. We have enclosed a small token of appreciation as a way of saying thanks for your help.

If you have any questions or comments about this study, we would be happy to talk with you. Please call Anna Straton on (03) 9252 6403 or 0448 490005, or you can write to us at PO Box 56 Highett VIC 3190, or send an email to anna.straton@csiro.au.

Thank you very much for helping us with this important study.

Sincerely,

Anna Straton
Research Scientist
anna.straton@csiro.au
(03) 9252 6403

* For more information on the Tropical Rivers and Coastal Knowledge Research Program, please go to http://www.track.gov.au or contact Anna Straton to request an information brochure be sent to you.

Australian Science, Australia's Future www.csiro.au

APPENDIX F: PRESENTATION OF IMPLICIT PRICES IN TABLES ACCORDING TO MODEL TYPE AND SUB-SAMPLE

Table 32: Implicit prices for ecosystem services from MNL models for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
All samples	$49.15	$128.54	$98.65	$161.41	$169.30	$297.80	$91.76	$67.19
Catchment sample	$121.03	$146.08	$223.09	$222.95	$228.36	$314.58	*	*
Face-to-face Indigenous sample	$122.11	$118.97	$200.50	$223.65	$264.36	$347.51	*	*
Cities sample	$30.16	$132.74	$70.62	$143.33	$141.77	$281.32	$122.04	$87.60
Daly River								
All samples	$66.56	$168.60	$110.98	$170.99	$129.95	$214.51	$63.65	$25.47
Catchment sample	$69.26	$128.81	$191.15	$243.81	$178.63	$266.89	*	*
Face-to-face Indigenous sample	$115.86	$156.06	$163.72	$344.75	$329.16	$429.42	**	**
Cities sample	$63.07	$176.83	$92.90	$156.42	$117.98	$204.80	$71.57	$28.13
Mitchell River								
All samples	$246.73	$348.48	$336.82	$288.72	$206.08	$429.79	$90.07	$204.92
Catchment sample	COST statistically insignificant from zero							
Face-to-face Indigenous sample	Failed to converge							
Cities sample	$74.04	$203.74	$107.31	$174.50	$131.82	$277.91	$146.52	$130.60

* Variable is statistically insignificant from zero
** Variable not included in final model

Table 33: Implicit prices for ecosystem services from MXL models for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
All samples	$86.47	$164.64	$109.63	$179.52	$203.00	$299.08	$71.82	$46.65
Catchment sample	$117.59	$139.50	$252.84	$243.85	$250.59	$363.08	*	*
Face-to-face Indigenous sample	$110.79	$96.24	$185.79	$260.60	$290.55	$426.38	*	*
Cities sample	$47.43	$151.70	$78.14	$150.27	$151.68	$282.64	$110.09	$82.10
Daly River								
All samples	$61.99	$144.84	$108.50	$153.85	$166.09	$215.56	$106.75	$43.84
Catchment sample	$52.58	$94.45	$221.21	$244.92	$197.70	$282.75	*	*
Face-to-face Indigenous sample	$129.80	$101.43	$152.36	$342.78	$340.28	$447.22	**	**
Cities sample	$61.11	$155.23	$111.18	$154.62	$157.44	$226.55	$118.20	$47.22
Mitchell River								
All samples	$322.06	$304.12	$507.59	$327.19	$538.09	$547.89	$293.92	$349.03
Catchment sample	COST statistically insignificant from zero							
Face-to-face Indigenous sample	Failed to converge							
Cities sample	$67.78	$171.13	$107.38	$153.53	$155.63	$278.95	$223.58	$136.31

* Variable is statistically insignificant from zero
** Variable not included in final model

Table 34: Implicit prices for ecosystem services from MXL models with interactions for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
All samples	$66.88	$119.08	$87.77	$181.44	$199.49	$392.07	$137.30	$101.94
Daly River								
All samples	$79.86	$38.04	$112.90	$90.21	$155.82	$232.42	$91.32	$51.20
Mitchell River								
All samples	$69.41	$115.57	$113.81	$110.66	$104.07	$172.65	$118.70	$124.53

Table 35: Implicit prices for ecosystem services by catchment respondents for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
MNL	$121.03	$146.08	$223.09	$222.95	$228.36	$314.58	*	*
MXL	$117.59	$139.50	$252.84	$243.85	$250.59	$363.08	*	*
Daly River								
MNL	$69.26	$128.81	$191.15	$243.81	$178.63	$266.89	*	*
MXL	$52.58	$94.45	$221.21	$244.92	$197.70	$282.75	*	*
Mitchell River								
MNL	COST statistically insignificant from zero							
MXL	COST statistically insignificant from zero							
* Variable is statistically insignificant from zero								

Table 36: Implicit prices for ecosystem services by face-to-face Indigenous respondents for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
MNL	$122.11	$118.97	$200.50	$223.65	$264.36	$347.51	*	*
MXL	$110.79	$96.24	$185.79	$260.60	$290.55	$426.38	*	*
Daly River								
MNL	$115.86	$156.06	$163.72	$344.75	$329.16	$429.42	**	**
MXL	$129.80	$101.43	$152.36	$342.78	$340.28	$447.22	**	**
Mitchell River								
MNL	Failed to converge							
MXL	Failed to converge							

* Variable is statistically insignificant from zero
** Variable not included in final model

Table 37: Implicit prices for ecosystem services by city respondents for all rivers

	FP_MED	FP_LARGE	FISH3	FISH4	WH_OK	WH_GOOD	INC_MED	INC_LOT
Fitzroy River								
MNL	$30.16	$132.74	$70.62	$143.33	$141.77	$281.32	$122.04	$87.60
MXL	$47.43	$151.70	$78.14	$150.27	$151.68	$282.64	$110.09	$82.10
Daly River								
MNL	$63.07	$176.83	$92.90	$156.42	$117.98	$204.80	$71.57	$28.13
MXL	$61.11	$155.23	$111.18	$154.62	$157.44	$226.55	$118.20	$47.22
Mitchell River								
MNL	$74.04	$203.74	$107.31	$174.50	$131.82	$277.91	$146.52	$130.60
MXL	$67.78	$171.13	$107.38	$153.53	$155.63	$278.95	$223.58	$136.31

APPENDIX G: DRIVERS OF CHANGE IN AUSTRALIA'S TROPICAL RIVERS REGION

Values and attitudes

The values and attitudes that have been expressed for the tropical rivers region of Australia have changed through time, influencing the types, processes and impacts of development in northern Australia (Jackson *et al.* 2008). Indigenous people have lived in the region for many thousands of years (Toussaint *et al.* 2005). Their connection with and values for tropical rivers reflect customary tenure, cosmological beliefs and knowledge of river systems from both Indigenous stories and direct experience (Strang 1997; Toussaint *et al.* 2001; Jackson 2004; Jackson *et al.* 2005). These values guide Indigenous use of tropical rivers as a source of nutrition, medicine and resources for ceremonies; and a place for the social and subsistence activities of fishing, hunting, gathering, bathing and teaching (Toussaint *et al.* 2001). Tropical rivers are also central to stories of identity for some Aboriginal groups (Bergmann 2006). These values and connections continue to the present day, influencing patterns of use and impact, although the rights and access of Indigenous people have been altered by colonisation and government policy. The tendency for the western scientific paradigm to dominate Indigenous systems of knowledge (Tan *et al.* 2008) and the marginalisation of Indigenous people means that the continued influence of Indigenous values and systems of knowledge on the ways in which tropical rivers are viewed and managed is also marginalised (Jackson *et al.* 2005).

In the early days of colonisation, northern Australia was seen as a place of "vast empty spaces" to be populated and civilised (Powell 2000, p.56), and as having considerable potential for agricultural development, both pastoralism and irrigated horticulture (Grey 1814, in Head 1999). Descriptions of the region suggested that water was "wasted" without adequate modification (Arthur 1997). This reflected a cultural/societal tendency to not acknowledge Aboriginal existence and ownership (Head 1999), and of optimism about the possibility of engineering solutions, such as dams and river diversion schemes (Idriess 1949; Graham-Taylor 1979). The development imperative was also stimulated by fears about having large, unpopulated and undefended tracts of land adjacent to Asia (Commonwealth of Australia 1959).

The first major development in northern Australia, the Ord River Irrigation Scheme, included a dam and water delivery system. It was built in 1963 and was symptomatic of the big dam building mentality of the 1950s and 60s that first emerged in the public consciousness in the late 1800s in response to a series of major droughts (Tan 2008; Tan *et al.* 2008). Enthusiasm about engineering solutions for the development of northern rivers was tempered from the 1960s with the publication of the first assessment of the Ord Irrigation Scheme by Davidson (1965), which critiqued the subsidisation of inefficient and inappropriate land uses. Other writers raised concerns about the environmental and human health consequences of the scheme (Charters 1975; Millington 1975; Stanley 1975), and still others critiqued the relative lack of planning for the development of water resources in the north (Milne and Watson 1985). Various reviews in the late 1970s found that the Ord project had not fulfilled expectations and that operations were marginal, mainly due to the high cost structure and a poor understanding of Ord agronomy (Young 1979). Local Aboriginal people reported fish losses, problems from overgrazing in the upper reaches of the catchment and concern about the health impacts of fertilisers and insecticides (Shaw 1983). Head (1999) and Toussaint (2008) explore how values and attitudes of the time relating to the role of water in the Australian story impacted on the resource decisions that were made, work practices and social activities.

Values for water in Australia have diversified since these earlier times (Jackson *et al.* 2008), partly in response to an ongoing drought in southern Australia and partly due to new voices being raised in the debate. The role of healthy waterways in underpinning human well-being has received growing attention worldwide through the work of the Millennium Ecosystem Assessment (2005), among others. A significant contribution to the practical ramifications of this is the work on environmental flow requirements (Richter *et al.* 2003; Arthington *et al.* 2006). Indigenous values and requirements for water are slowly being heard, if not yet fully taken into account, by policy-makers (Jackson 2006). The development of Ord Stage 2 required negotiation with Traditional Owners in the region. This reflects the growing influence of Indigenous people and changes in values and attitudes about Indigenous rights. This can also be seen in the establishment and funding of the Indigenous Water Policy Group and the Indigenous Community Water Facilitator Network, and the recent appointment of an Indigenous person as the Chair of the new Northern Australia Land and Water Taskforce. A recent study of the social and economic values of Australia's tropical rivers identified market values associated with the use of water in productive activity, and non-market values associated with aesthetics, identity, lifestyle, recreation and conservation (Stoeckl *et al.* 2006; Jackson *et al.* 2008). The need to recognise and plan for a wider range of values and uses has been recognised in the national program of water reform – the National Water Initiative (Council of Australian Governments 2004).

Alongside this change, however, exists continued investment in the further development of the Ord Irrigation Scheme and the occasional call for large-scale river diversion projects like that for taking water from the Kimberley to Perth (Western Australia Department of the Premier and Cabinet 2006), or the reinvigoration of the Bradfield Scheme in Queensland. Despite these manifestations of the engineering ethic, recent funding of research into Australia's tropical rivers and coasts and a new Taskforce of the Commonwealth Government is reflective of the new, expanded set of values and the desire to balance economic, social and environmental outcomes.

Even with this shift in approach, the values and attitudes of the past have contributed to the "lock-in" of some on-going issues for the tropical rivers region and its capacity to provide ecosystem services. These challenges include species decline, landscape change, altered fire regimes, foreign animals, disease and invasive plants, and they are rooted to a large extent in land management decisions of the past (Finlayson *et al.* 2005; Woinarski *et al.* 2007). Similarly, some current water use practices that are reflective of attitudes about scarcity and rights of use may contribute to water management challenges in the future. A national survey revealed that a higher proportion of Darwin respondents feel it is their right to use as much water as they want than respondents in southern cities (Roseth 2006). Water use by households in Darwin reflect this, being twice as much per person than in other capital cities in Australia (Power and Water Corporation 2006). The need for demand management has been acknowledged as a crucial component of managing water in the greater Darwin region (Power and Water Corporation 2006; Straton *et al.* 2008).

Policies and other institutions

Policies and other institutions are sets of rules and norms that guide and govern behaviour (North 1990; Ostrom 1990), and their associated organisational units, such as government departments, for example. Values and attitudes influence land and water uses and practices on the ground mainly through translation into legislation or other institutional arrangements. There are thousands of rules that guide and govern behaviours that impact on Australia's tropical rivers and their ecosystem services, both formalised in legislation and regulations and encoded as norms or rules-of-thumb. Some are reviewed in Tan (2008), Tan, Jackson *et al.* (2008) and Straton, Heckbert *et al.* (2006). While it is beyond the scope of this study to survey how each rule and combinations of rules lead to certain activities and outcomes, we provide a few examples of policies and other institutions that drive conditions and dynamics in the tropical rivers region and influence the provision of ecosystem services.

Values, attitudes and rules governing water Australia in the past have shaped the present legal framework (Powell 1997; Langton 2002; McKay 2005; Tan 2008; Tan *et al.* 2008). Before colonisation, Indigenous custodial obligations governed water use. Following settlement, English common law was applied until a regime of regulatory control through administrative grants was introduced in the late 1800s, partly in response to the first recorded major drought in 1864-66 (Tan *et al.* 2008). Water allocation arrangements became increasingly complicated until the 1970s and 80s, when concerns about environmental impacts and the inconsistency of administrative decision-making precipitated further changes (Tan *et al.* 2008). Most recently, "[e]conomic, environmental, political, ideological and pragmatic forces built up momentum that led to nationwide reform in the mid 1990s to early 2000" (Tan 2008, p.21). This national reform framework, the National Water Initiative (NWI), has precipitated the amendment or introduction of new water legislation and practice across most states and territories that will impact on tropical river ecosystem services.

Each of these phases of regulatory regime has influenced whether and how water is allocated to different uses, each of which has different value and impacts on tropical river systems. Indeed, one of the main objectives of the NWI is to establish efficient water markets to ensure that water flows to the highest value use. Other objectives of the NWI are to "prepare water plans with provision for the environment; deal with over-allocated or stressed water systems; introduce registers of water rights and standards for water accounting; improve pricing for water storage and delivery; and meet and manage urban water demands" (National Water Commission 2008). These objectives represent a shift in values and attitudes about the desired *outcomes* of water governance. The fact that the NWI also enshrines a commitment to water planning processes that involve stakeholders (Tan *et al.* 2008) reflects that values and attitudes about the desired *process* of water governance have also changed.

Other key pieces of legislation that guide and govern land use practices that impact on tropical river ecosystem services include those that relate to pastoral practices, including land clearing and fencing of riparian zones; weeds and feral animal management; and environmental protection and biodiversity conservation. The *Environmental Protection and Biodiversity Conservation Act 1999* (C'th) provides for the protection of nationally and internationally important plants, animals and places, and Queensland, Western Australia and the Northern Territory each have a range of environmental protection/assessment, heritage conservation, pastoral land, soil conservation, parks and wildlife conservation, water, and weeds management legislation and regulations. Most relevant pieces of legislation have as part of their objectives the prevention of ecosystem degradation and impacts on other users, and the maintenance of environmental and productive health. This is broadly in accordance with the ‘National Strategy for Ecologically Sustainable Development’ (ESD) and the ‘Intergovernmental Agreement on the Environment’. Despite this intent, a lack of certainty about the best policy to achieve sustainable development, a lack of monitoring systems appropriate to the extreme climatic conditions, and the challenges of enforcing legislation and regulations in the mostly remote and sometimes inaccessible tropical rivers region means that actual outcomes on the ground often don’t match the intention of the legislation.

Some particular rules regarding water use in the tropical rivers region provide a useful example of how legislation influences water use practices and the capacity of tropical river systems to provide ecosystem services. Under the *Water Act 1992* (NT), water extraction for stock and domestic purposes does not require a licence, nor does extraction of less than 15 litres per second by those outside of a Water Control District or inside the Darwin Rural Water Control District. As commented by a member of the Northern Territory Horticultural Association, “You can irrigate a lot with 14.5 litres per second” (pers. comm.). The lack of licensing and monitoring required for some types and levels of water extraction and use directly influences water use practices. For example, there has been a sharp increase in the number of bores drilled in the Darwin rural region (Northern Territory Department of Natural Resources Environment the Arts and Sport 2008), which appears to be having an impact on the groundwater dependent ecosystems and spring-based recreational activity in the Darwin rural region (Liddle *et al.* 2006).

Policies regarding Aboriginal people have also had an indelible impact on conditions and dynamics in northern Australia. The Aborigines Act of 1910 saw the separation of Aboriginal children from parents (Northern Land Council and Aboriginal Areas Protection Authority 2004). The Government’s policy on half-caste children meant that many were separated from their parents between 1920 and 1960 and that many Aboriginal families continually moved to avoid contact with welfare officers (Pearce 1983). The policies meant to assimilate Aboriginal people into European society were implemented from 1951 to 1963, and in the 1960s, the introduction of award wages for Aboriginal people through the *Federal Pastoral Industry Award 1968* saw many lose their jobs on the pastoral stations that held leases over their traditional lands and move to townships such as Pine Creek and Katherine in the NT (Northern Land Council and Aboriginal Areas Protection Authority 2004) and Hall’s Creek and Fitzroy Crossing in the Kimberley (Toussaint *et al.* 2001). The ability of Indigenous people to access and manage land using their own knowledge systems is both partly enabled and constrained by the *Aboriginal Land Rights Act 1976* and the *Native Title Act 1993*. These and other policies have had significantly negative impacts on the capacity of Indigenous people to engage with water and other decision-making processes (Langton 2002), which in turn influences the use and management of water. Jackson, Storrs *et al.* (2005) argue for the recognition of Aboriginal rights, interests and values in river research and management.

Demographics

Some aspects of the demographics of early stages in the history of the tropical rivers region were described in the section on values and attitudes and others will be described in the section on land and water uses and practices. Currently, the region is home to approximately 310,000 people (less than 2% of Australia's total population). There are only three centres that have more than 15,000 people (Stoeckl *et al.* 2006). Indigenous people are significant landowners in the region and a major and growing proportion of the population (Woinarski *et al.* 2007). The lifetime outcomes of Indigenous Australians, as revealed by headline indicators of health, income, education and home ownership, for example, are far worse than for Australians generally, and particularly so for Aboriginal people living on remote communities, many of which are in the tropical rivers region (Steering Committee for the Review of Government Service Provision 2005). Given the levels of socio-economic disadvantage experienced by Aboriginal people across Australia, the growing Indigenous population and an increasingly articulated desire by Indigenous groups for rights and access to water resources that can aid in creating wealth are significant drivers of social and economic conditions in the tropical rivers region now, and will be in the future. The implications for tropical river ecosystem services will depend on the outcomes of policies to improve conditions for Indigenous people and conflicts over ownership and access to tropical river resources such as that seen recently for the declared Wild Rivers of Queensland.

Some demographic trends and population projections have been identified for the tropical rivers region (Carson *et al.* 2009; Larson and Alexandridis 2009). Currently just over a third of the population in the region identifies as Indigenous and a majority of the child populations are Indigenous. The Indigenous population grew by 11% from 1996-2001 (compared to 4% for the non-Indigenous population) and 4% from 2001-2006 (compared to 2% for the non-Indigenous population). Most population growth is in the older age groups (45 and older), while the population of 20-34 year olds is decreasing. The population is projected to increase from 310,000 to 450,000 over the next 20 years. The region's population effectively doubles in peak tourist season with 75% of visitors coming between May and October. This places some additional pressure on infrastructure, resources and popular tourism and camping spots (Yuco Pty Ltd 2003; Greiner *et al.* 2004; Greiner *et al.* 2005), however, there was almost no growth in the domestic and international tourism markets between 2000 and 2007 and relatively little growth is projected (Carson *et al.* 2009).

Market conditions and technology

The scope of this review is limited to a few examples of how changing economics, market conditions and technology have impacted on the mix of land uses and other dynamics in the region over time. A recurring theme in the history of agricultural industries across northern Australia is a pattern of experimentation and failure that will be described in the section on land and water uses and practices. The relative values of production and productivity for these industries have also changed through time with changing rainfall, input costs, prices, technology, efficiency and market conditions, and this has impacted on the mix of land uses and other dynamics in the region over time. For example, peanut was the most important crop in the Daly region between 1920 and 1940, mainly due to high prices. When prices fell and crops were poor, new crop trials were begun, for example, cotton (Stanley 1985). Similarly low prices in the early to mid 1980s for many crops grown in the Daly region saw agriculturalists sell their land to pastoralists, thus changing the mix of land uses in the region (F. O'Gara, pers. comm.).

Now, however, growing demand for fruits and vegetables over the passed decade has seen the value of fruit and nut production grow by 4.2% per year in constant 2008-09 dollar terms, and 3.2% for vegetables (Mackinnon *et al.* 2009). Some growers in the Daly region reported taking up new drip irrigation techniques and technology to measure and report soil moisture, which had brought improvements in their efficiency of water use (Straton *et al.* 2006). More recently, a large peanut company has reinvested in the Daly region, and the trend towards forestry-based Managed Investment Schemes has seen further land use change. However, the global financial crisis has since seen the bankruptcy of some companies set up for this purpose, making the future of this land use less certain, and the continued shortage of labour presents yearly challenges to horticulturalists at harvest time (Straton *et al.* 2006).

Another example showing links to the global economy is that of pastoralism, the value of which has changed over time in response to economic factors worldwide. The development and growth of South East Asian and Middle Eastern markets for live cattle exports is significant for the pastoral industry of northern Australia. In 2003-04, for example, slowing economic growth in parts of these markets plus a higher Australian dollar and competition from Brazil and India resulted in decreased exports (Mackinnon *et al.* 2008).

Land and water uses and practices

Land and water uses are primarily determined by what is possible given the natural resources of a region, driven by the ecology, landscape and water cycle, and by the net economic returns available. However they are also driven and guided by values and attitudes, policies and other institutions, and other social and economic processes (such as demographic change and increasing demand from China for Australia's natural resources, for example). In turn, land and water uses and practices on the ground in the tropical rivers region are directly responsible for many impacts on tropical river systems and the provision of ecosystem services.

The first non-Aboriginal people entered the Daly River region in the 1860s, being mainly explorers, surveyors and workers on the Overland Telegraph Line (Northern Land Council and Aboriginal Areas Protection Authority 2004). Small gold field ventures were established in 1872, Springvale Station was stocked with sheep in 1876, the first cattle enterprise was established in the Daly River catchment in 1881 (Northern Land Council and Aboriginal Areas Protection Authority 2004), and copper was found in 1882 (Stanley 1985). An influx of non-Aboriginal people, mainly male Chinese, to work on mines is reported to have had a significant impact on the Aboriginal population (Pearce 1983; McGrath 1985; Stanley 1985; Aboriginal Land Commissioner 1991), for example, through the introduction of alcohol and opium causing depopulation and general instability (Aboriginal Land Commissioner 1991).

There are similar stories about the early development of pastoralism and mining in the Fitzroy River region of the Kimberley (Grey 1814, in Head 1999; ACIL Tasman Pty Ltd and Worley Parsons 2005) and in Mitchell River region in north Queensland (Jack 1921). Early pastoral ventures across the tropical rivers region often failed due to inadequate understanding of the challenges of operating in a tropical environment (Speck *et al.* 1964). Some of the negative impacts of pastoralism that exist today had their roots in the practices of these early years. The prohibitive cost of sinking bores in the early 1900s meant that cattle were allowed unfettered access to rivers (J. Woinarski, pers. comm.). This impacted negatively on Aboriginal people (through competition for water resources and degradation of important places for ceremonial activity) (McGrath 1987), and on river ecosystems, causing erosion on river banks (Symanski 1996). Attention has been drawn to the problems of overstocking and the degradation of river frontages since 1945 (Burnside 1979).

The discovery of gold drove the establishment of townships such as Hall's Creek and Fitzroy Crossing in the Fitzroy River catchment, which then went on to become bases to service the pastoral industry (Moller *et al.* 2002; ACIL Tasman Pty Ltd and WorleyParsons 2005). Aboriginal people worked on cattle stations (Chase and Meehan 1983; Wilson 1999; Yuco Pty Ltd 2003), cropping ventures (Northern Land Council and Aboriginal Areas Protection Authority 2004) and in the pearling industry (Monaghan 2004), however, many stories about the impact of these new social and economic conditions on Aboriginal people are of murder and displacement and the introduction of diseases, drugs and alcohol (Pearce 1983; Stanley 1985; Aboriginal Land Commissioner 1991; Monaghan 2004; Northern Land Council and Aboriginal Areas Protection Authority 2004). Various missions were established with the aims of providing education and health care to Aboriginal people, but often involved the discouragement of Aboriginal dancing, art and other customary activities (Stanley 1985). The policies of assimilation and new forms of tenure further discouraged mobility and modified customary land use (Monaghan 2004).

The small-scale ventures and market gardens that often developed around mines and missions prompted consideration of the suitability of the region for larger-scale horticulture (Northern Territory Government 2003). Some crops developed in the early 1900s included tobacco, sugar cane, banana, cereal and vegetables (Northern Land Council and Aboriginal Areas Protection Authority 2004). Agricultural and experimental farms were developed and settlements for agriculture increasingly taken up, with varying degrees of success (Northern Territory Government 2003). There were trials of a range of crops, including peanuts and cotton, but the challenges of the operating environment persisted (Millington 1979; Stanley 1985).

This development and experimentation cycle of the early 1900s was repeated mid-century with the first formal investigation of cropping potential in the Daly River catchment (Northern Territory Government 2003), the establishment of the Katherine Research Station in 1948 (O'Gara 1998), and the conducting of irrigation experiments in the Ord region in the 1940s (Greiner and Johnson 2000). Land resource survey reports in the NT noted that the Daly region had the most potential for further development of agriculture (Christian and Steward 1953), however, in the early to mid 1980s, a combination of low grain yields, low investment in research and development, high input prices and inexperience lead many agriculturalists to sell out to pastoralists (F. O'Gara, pers. comm.). Pastoralism remains the largest land use by area and horticultural land use now accounts for approximately 2% of the total area of the tropical rivers region, 8% of horticultural activity in Australia and 5% of the national horticultural yield (van Dam *et al.* 2008).

Agricultural experimentation, the introduction of feral animals, and grazing practices in northern Australia have all impacted on local ecosystems through their influence on erosion, native vegetation and the fire regime (Whitehead 2003). Water buffalo and feral pigs, introduced in the 1800s, contribute to erosion and the degradation of floodplains and native vegetation (Bayliss 1985; Bowman and McDonough 1991). Grazing by these feral animals and cattle modifies the abundance of grass species and impacts on fire behaviour. These impacts on fire behaviour, and the sub-optimal management of fire have impacted negatively on plant and animal abundance and seedling recruitment (Williams *et al.* 2002) and on production profits (Dyer and Stafford Smith 2003). Poor management of grazing lands, including overstocking, lack of fencing riparian zones and poor fire management has been found to contribute to decreased native vegetation, compacted and eroded soil (especially on riverbanks), increased turbidity, and increased weeds (Froend *et al.* 1998; Rangelands NRM Coordinating Group 2004; Lawford 2006; Lindsay and Commander 2006).

Agricultural experimentation included the introduction of several new plant species in attempts to improve pastures for cattle (Cook and Dias 2006). Many of these introduced species went on to become weeds (Lonsdale 1994), which have outcompeted other plants that provide food for native fauna and contributed to altering fire behaviour. The impacts of these and other land and water use practices are surveyed by Woinarski *et al.* (2007), as are other processes, including the unfolding impacts of the invasion of northern Australia by the cane toad, which is having significant and negative impact on native fauna (Burnett 1997), including aquatic species with high conservation, ecological, cultural and economic value such as the pig-nosed turtle (Doody *et al.* 2006).

While land uses and practices have impacted on tropical river systems and ecosystem services, the impact of water use to date has been smaller by comparison, except for in the Ord River catchment, where the dam and water delivery system have significantly impacted on the local social-ecological system (Stanley 1975; Storey and Trayler 2006). Ultimately the proportion of water that can be extracted from rivers in northern Australia is relatively low compared to those in southern Australia. The contingent rule for the allocation of groundwater in the NT is that "at least 80 per cent of annual recharge is allocated as water for non-consumptive use, and extraction from consumptive uses will not exceed the threshold level (equivalent to 20 per cent of annual recharge)" (National Water Commission 2005, p.9.5). Provisions in the Mitchell Water Use Plan ensure that total water use from existing and future entitlements do not amount to more than 1 per cent of the average or median annual discharge of the Mitchell River to the Gulf of Carpentaria (Queensland Department of Natural Resources and Water 2006). Until such time as these caps on extraction are reviewed, and there are shifts in values, attitudes, policy and other institutions, the main impacts of land and water uses and practices appear to be more on water quality than quantity. Some of these impacts have been briefly discussed above and are further summarised below. Of particular note is the impact of mine disturbance and runoff from mines in operation from the 1870s to the early 1900s on nearby aquatic habitats. The relative lack of environmental management principles and standards at the time has resulted in soil disturbance, acid mine drainage and the high concentration of heavy metals from many of the now abandoned mines (Burrows 2004).

The daily water use practices of some users in the north may be more problematic than the potential for larger-scale water extraction, at least in the short term. The daily water use rates and attitudes expressed about rights of use by Darwin residents mentioned earlier are reflected in the use of 65% of Darwin's household water in watering gardens (Power and Water Corporation 2006). Similarly, a study with mango growers in the Katherine region found that some farmers believe there is "plenty of water" and are strongly opposed to paying per unit of water, citing that the costs of sinking and running a bore are high enough and often prohibit investment (Straton *et al.* 2006). This study also revealed a range of irrigation water use practices, with some growers being up to date with the most efficient irrigation technology and others having limited funds to invest in such infrastructure (Straton *et al.* 2006).

Other relevant land and water uses driving conditions and dynamics in the tropical rivers region are pearling and fishing, and conservation. Pearling ventures were established in the Kimberley region and Cape York Peninsula in the 1860s and 70s (Monaghan 2004). Commercial barramundi and prawn fishing began in the Gulf of Carpentaria in the 1960s and have grown to become the main commercial fisheries of the tropical rivers region. Fisheries production is reliant on freshwater flows from Australia’s tropical rivers (Robins *et al.* 2005; Robins *et al.* 2006). The Mitchell River system contributes to Gulf of Carpentaria fisheries, which are worth between $35 and 78 million per year (Economic Associates Pty Ltd 2006).

Since the National Strategy for Ecologically Sustainable Development of 1992 and a range of subsequent policies, reforms and pieces of legislation, provision has been made for planning for biodiversity conservation. As such, there are several Nature Parks, State Forests, National Parks and Conservation Areas in each of the three catchments, managed for their biodiversity, recreational, tourism and cultural values. Native title legislation and land claims also impact on land and water use practices. The advent of new approaches to environmental and wastewater management on pastoral stations (Tredwell and Nelson 2006) and practices such as conservation tillage (T. West, pers. comm.), sustainable farming and grazing systems (O'Gara 1998), and sustainable grazing management (Petty *et al.* 2007) are impacting on land and water use practices at the farm scale.