TRaCK
Tropical Rivers and Coastal Knowledge

Indigenous socio-economic values and river flows

Sue Jackson, Marcus Finn, Emma Woodward and Pippa Featherston | 2011

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TRaCK – *Research to support river and estuary management in northern Australia*

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

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Enquiries

Dr Sue Jackson
CSIRO Ecosystem Sciences
PMB 44 Winnellie NT 0822, Australia
Phone: 08 8944 8415
Sue.Jackson@csiro.au

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EXECUTIVE SUMMARY

The following report presents the results of a three year study of Indigenous Socio-economic Values and River Flows funded under the TRaCK (Tropical Rivers and Coastal Knowledge) program. Although environmental flow assessments and allocations have been practiced in Australia for nearly 20 years, to date they have not effectively incorporated Indigenous values (Finn and Jackson 2011). Indigenous values associated with river systems and water tend to be poorly understood by river managers and water planners, and some are difficult to relate explicitly to particular flow patterns and to address in water allocation decisions.

When TRaCK formed, CSIRO researchers were aware that the socio-economic impacts of increased water use were under-researched, even though wild resource use is known to contribute to the customary economy so valued by traditional owners (Altman 2004). The project team wanted to improve the scientific understanding of the impacts of changing water use patterns on Indigenous communities, as well as effect of new water management institutions and practices such as environmental flow assessments. We were particularly interested in examining how to adapt environmental flow assessments to better account for linkages and dependencies between people and rivers in the northern catchments, where earlier preliminary work had revealed significant relationships between Indigenous communities and their water bodies (Jackson 2004, Jackson 2006a).

An earlier scoping study of Indigenous interests in tropical river management for Land and Water Australia (Jackson and O'Leary 2006) had identified the need to:

- Document the significance of water and riverine systems to Indigenous communities, particularly to Indigenous cosmology and environmental philosophy;
- Gain a better understanding of the direct economic benefit derived from Indigenous use of wild resources found in or reliant upon rivers and wetlands;
- Assess the impacts of potential changes to flow regime on Indigenous communities;
- Collaborate with Indigenous land management agencies to improve participatory monitoring of flow regime changes and wild resource use; and
- Develop collaborations and information to enhance the capacity of researchers and managers in northern Australia to incorporate social assessments in water allocation decisions and planning.

To those ends, the *Indigenous Socio-economic Values and Rivers Project* conducted research in two TRaCK focal catchments, the Fitzroy River of Western Australia and the Daly River of the Northern Territory. Working with two communities in each catchment, the project team combined qualitative and quantitative methods to understand the spatial and temporal pattern of resource use, its social, cultural and economic significance to local communities and their economies, and the eco-hydrological dependencies of the wild aquatic resources consumed by Indigenous households. A significant effort was devoted to recording local ecological knowledge; reproduced in the multiple forms including seasonal calendars with a strong focus on resource availability during different seasons (Woodward et al. in press). In addition, a one-year trial of a monitoring program with four Indigenous land management groups enhanced local capacity for wetland and river monitoring. Results from these activities will be published in reports available from CSIRO and in journal publications.

The aim of this report is to present the quantitative results from the economic component of the project in order to estimate the value of aquatic resource use to participating communities and to assess the impacts of potential flow alteration on those values. The exploratory nature of this research should be noted. Indigenous societies and their cultural practices are diverse across northern Australia, and limitations to the spatial and temporal scope of research is unavoidable given resource and time constraints. The research was conducted in a number of communities over a two-year period. The results are applicable to the communities involved, and given the climatic, social and environmental conditions encountered during 2009 and 2010. Much additional research is required to gain a fuller understanding of the value of Indigenous resource use throughout the region, and whether our results are typical and therefore can be extrapolated to other similar contexts.

During our study, an initial resource mapping exercise gathered data on the spatial and temporal distribution of Indigenous resource use, allowing potential relationships between important sites and flow to be determined. To quantify Indigenous resource use a total of 82 households were surveyed twice every three months over a two year period. A variety of methods was used to obtain the information required for the quantification of wild resource harvest and included direct observation, household surveys, resource use diaries, and doorstep accounting. The economic value of resources consumed by households was calculated using the replacement goods method (Altman 1987) where the market price of a proxy or substitute is used for products that do not have their own market value.

In the absence of a market for wild fish and game, estimating a dollar value presents significant challenges, and perhaps the most objective measure for comparison is instead the nutritional or energy value of a food (Buchanan et al. 2009). Gray et al. (2005) for example used the cost at local market to value harvested fish species. They did not add species with no market value to their total economic valuation (e.g. Eastern Grey Kangaroo, *Macropus giganteus*). Many of the species harvested by our research participants did not have a market value, but were still harvested in large numbers, including Long-necked Turtle and Magpie Geese. For our valuation to be as comprehensive as possible, we needed to account for popular aquatic species harvested by research participants.

Our choice of substitute goods attempted to reflect their nutritional equivalence, and Indigenous perceptions of the replacement item as being “similar’ in type to the non-market item. Our choice of replacement item for fish, for example, was relatively straightforward. Fish we observed as being perceived as “high value” such as Barramundi were allocated a value of $39.45/kg; the price of Yellowtail Kingfish from an online store[1]. Long-necked Turtle, a commonly eaten species of turtle, was allocated the price of T-bone steak ($20.69) from the same online store, while Pig-nosed Turtle (often viewed as "special") was allocated the more expensive value of fillet steak ($35.50)[2].

These values were, by necessity, defined by the researchers. It is critical to note that the exercise was not an attempt to derive the complete value of these species. As noted by Toussaint (2010; p.22) fish and fishing in Indigenous societies has multiple values: "what constitutes value…cannot be understood by adopting a singular or fixed form of comparison". What our replacement valuation does do, however, is to allow the relative contributions of aquatic species to household incomes to be broadly estimated. In particular, it allows the species that make the largest contribution to be identified, encouraging more specific consideration of their environmental flow requirements.

The following results represent a series of highlights from reported findings:

- In the Daly River catchment harvesting sites radiate from Nauiyu community along the Daly River. Additional harvesting sites were indicated along tributaries and low lying floodplain areas downstream of the community. River use mapping conducted with residents from Pine Creek and Kybrook Farm showed a cluster of sites around Claravale Crossing at the upstream limit of sites, extending downstream for a substantial distance.

- In the Fitzroy River catchment, customary harvest trips were distributed well upstream and downstream of the Fitzroy Crossing communities where river use mapping took place.

- Comparison of river use mapping data and household survey data suggests that access to fishing locations can play a substantial role in controlling where people go and the frequency of the trips that can be undertaken.

- A comparison of results from river use mapping and the household survey site distribution shows that the two methods will not yield the same information. The use of river mapping methods to indicate important sites for customary use will need to take into account the tendency for people to discuss sites that while important and readily recalled, may be remote and visited infrequently.

- The frequency of harvest trips per household ranged from 0.49 trips per fortnight for survey respondents from Pine Creek (Daly), to an average of 2.7 trips per fortnight by survey households in Muludja.

[1] www.colesonline.com.au

[2] It should be noted that there has been no conversion factor allocated to these values to account for higher prices paid in remote and regional areas. The cost of products from an online store is typically less than would be found in the shopfront itself and the cost of food products in regional and remote stores can be much higher than the cost of the same products in cities. For all these reasons our valuation should be considered to be a very conservative, absolute lower bound valuation.

- Overall, surveyed households from the Daly River tend to undertake more harvesting trips (1.52 trips per fortnight) than surveyed households from the Fitzroy River (1.37 trips per fortnight).
- The seasonal pattern of harvesting effort is different between the Daly River and Fitzroy River survey respondents. The data suggests that this difference is related in part to the number of harvesting trips undertaken in the Wet season.
- The frequency of harvesting trips is at its lowest in the Daly catchment during the Wet season, while the frequency of harvesting trips is at its highest during the Wet season in the Fitzroy. This is likely to be related to differences in access to harvesting locations in the two catchments.
- There are substantial differences in the way survey respondents in the Fitzroy and Daly river catchments use aquatic habitats. Harvesting activities in the Fitzroy River are largely focussed on use of the main river channel. Visits to the main river channel make up more than 70% of all trips in the Fitzroy, regardless of the season.
- Harvesting activities in the Daly, however, showed a clear switch from use of the main river channel during the Wet season to billabongs becoming the focal point of activities as the dry season continued. By the late dry season, 70% of all Daly trips are to billabongs, whereas at the same point in time in the Fitzroy, billabongs account for only 10% of trips.
- Two of the five highest value species in the Daly catchment (calculated according to the replacement method) are readily caught from billabong habitats - Long-necked Turtle and Magpie Geese.
- Long-necked Turtle are the species harvested and consumed in the highest numbers in the Daly catchment, reflecting the frequent and widespread use of billabong habitat.
- Four of the top five species harvested in greatest numbers in the Daly catchment are non-fish species, with Black Bream the only fish species to be harvested in numbers high enough to make the top 5.
- Four of the five species harvested in the highest numbers in the Fitzroy catchment were fish species. Two of these fish species, Bony Bream and Spangled Perch, are small bodied species predominately used as bait for catching other fish.
- The survey question that quantified “harvest” recorded the entire catch obtained from each trip in which the survey household was involved. As such, it can include the catch of more than one household. The survey question that quantified “consumption” included only those individuals of a species that were directly used by the survey household.
- The consumption of a household includes the immediate on-site use of a species for food, or as bait or burley. It also includes later use (such as for food) by people who live in the surveyed household when they return home. In addition to including the amount harvested by non-survey households on a trip, the difference between trip harvest and household consumption reflects the amount of sharing that occurs between households, families and communities.

- A comparison of the harvest and consumption rates of various species suggests that some are more commonly shared than others. In particular, Long-necked Turtle are capable of surviving for long periods out of water, making it an ideal species to be shared and gifted outside of the group involved in the hunting trip. In contrast, smaller bait species like Spangled Perch tend to be used almost immediately.
- Species making the largest contribution to replacement value in the Daly River were:
    - Long-necked Turtle;
    - Short-necked Turtle;
    - Barramundi;
    - Black Bream; and
    - Magpie Geese.
- Species making the largest contribution to replacement value in the Fitzroy River were:
    - Black Bream;
    - Fork-tailed Catfish;
    - Freshwater Sawfish;
    - Barramundi; and
    - Cherabin.
- More than 90% of the total replacement value derived by our survey households was represented by the top 5 species in each catchment.
- In contrast, the replacement value of species harvested was distributed across a large number of locations. The top 5 sites contributed only 63.9% of the total replacement value in the Daly River catchment, and 29.9% in the Fitzroy River catchment.
- This suggests that, while a subset of important species can be a useful representation of total replacement value, a subset of important sites represents a relatively small proportion of the total replacement value of resources obtained locally.
- Comparison of our data with the semi-quantitative assessment of the relative risks of freshwater fish to dry season water extraction in the Daly River (Pusey & Kennard 2009, Kennard et al. 2009), suggests that 3 of the 10 most valuable species in the Daly, and 4 of the 10 most valuable species in the Fitzroy, could be considered at high risk of impact under dry season water extraction scenario.
- These species are:
    - Daly River
        - Black Bream;
        - Barramundi; and
        - Mullet.

- Fitzroy River[3]
    - Black Bream;
    - Barramundi;
    - Bony Bream; and
    - Sleepy Cod

- Under the water extraction scenario used in the Bayesian Belief Network of Chan et al. (2011), the probability of an extremely low abundance of Barramundi increased from 36% to 43% and for Black Bream from 25% to 43%. Both of these species make a significant contribution to the total replacement value of Daly River harvest.
- In assessing the life history of key Indigenous harvest species, and the potential impacts of flow alterations, this report summarises existing knowledge and suggests new Australian life history charts for Cherabin and Freshwater Sawfish.
- Species harvested in high numbers in our study tended to be common and widespread.
- The only species with a national conservation status making the top 5 species contributing to replacement value was the Freshwater Sawfish in the Fitzroy River. While Freshwater Sawfish were harvested in relatively small numbers, their large body size provided a substantial (and economically valuable) food source. Freshwater Sawfish populations in Australia appear to be relatively healthy, particularly in Western Australia (Phillips et al. 2008).
- A clear calculation of the potential changes in Indigenous harvest associated with altered flow regimes was problematic. This was in part due to incomplete ecological knowledge of flow requirements of some harvest species, and in particular due to the limited nature of information on customary fisheries harvest at different species' population densities.
- The "Hybrid Economy" (Altman and Branchut 2008, Altman 2001, 2006), describes a three-sector economy relevant to remote Indigenous contexts (State (e.g. welfare), Market (e.g. private businesses), and Customary (e.g. wild resource harvest)). The customary sector that our household harvest falls into is largely ignored in an Australian policy context, including water resources management policy.
- Recent TRaCK research (Stoeckl et al. 2011) suggests that Indigenous people will be largely excluded from any increases to the market sector brought about by water resource development (because of a "disconnect" between Indigenous and non-Indigenous economic sectors). Stoeckl's results suggest that, given the current structure of Indigenous and non-Indigenous economies, the benefits of economic stimulus to go to Indigenous people represent only 0.5% of regional economic stimulus, and 1% of the total flow on effects.
- A very general assumption of a 50% reduction in aquatic resource harvest in the Daly River catchment may lead to a 2.5% decline in Indigenous household incomes. Given that increases to the regional market economy are unlikely to flow through to

[3] The risk assessment of Kennard et al. (2010) was conducted using data from the Daly River. We extrapolated Daly River results to those species found in the Fitzroy River.

Indigenous households, the potential influence of water resource extraction could be an increased reliance on welfare (State sector) by Indigenous households.

- So, while gaps in our knowledge and quantitative understanding limit our ability to define the impact of flow alterations on the replacement value of aquatic wild resources, it is apparent that the customary sector is a crucial component of Indigenous economies. Our investigations suggest that access to species, and the aquatic habitats that support them, is critical to maintaining a vibrant customary economy.

Acknowledgements

TRaCK project 2.2, '*Indigenous socio-economic values and rivers flows'*, drew on the knowledge, expertise and assistance of a broad group of people over a four year period. The project relied on the generosity and goodwill of a large number of people, many of whom who were not paid or reimbursed for the time they gave to the project. Foremost, and key to the success of the project, was the involvement of Indigenous research participants who contributed to the household economic surveys, the river mapping, the socio-economic documentation of water values and the participatory monitoring program.

One hundred and fourteen Indigenous residents from ninety-four households participated in the surveys in the Fitzroy and Daly catchments. The survey participants aren't identified here to protect their anonymity; however, their commitment to the project was integral to the project's continuation and completion. This group of people provided household harvesting data to the project team over a two year period with no financial or other immediate return.

Four Indigenous groups participated in the community-base participatory monitoring program. In the Daly River catchment we would like to thank Biddy Lindsay, Rita Pirak, Francis Miljat and Rob Lindsay from the MalakMalak Ranger group and Lenny Liddy, Jabal Huddleston, Laurie Corrigan, Patrick Huddleston, Mavis Allengale, Daphne Huddleston, Lizzy Sullivan, Andrew McMah, Nelly Huddleston, Teresa Banderson, Ivy Huddleston, Arthur Muggleton and Des Grainer, Cynthia Coyne and Kate Maltby from the Wagiman Ranger group.

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A committed group participated in the documentation of socio-cultural attachment to water in both catchments. In the Daly this included: Biddy Lindsay, Helen Kuwarda, Frances Miljat, Rita Pirak, Kitty Waliwararra, Patricia Marrfura McTaggart, Molly Yawulminy, Catherine Ariuu, Dorothy Daning, Kitty Kamarrama, Benigna Ngulfundi, Maureen Warrumburr, Mercia Wawul, Aaron McTaggart, Kieren McTaggart and Kenneth Mingun.

In the Fitzroy this included: June Davis, Helen Malo, Mervyn Street, Topsy Chestnut, Isaac Cherel, Joy Nuggett, Amy Nuggett and Nancy Bangu. Many people contributed to the report on Indigenous fishing by Sandy Toussaint from UWA (2010) and these people are acknowledged in that report.

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Two secondary schools were closely involved in the research project. In the Daly River, St Francis Xavier School participated in the Photovoice project and engaged with researchers in river workshops. We thank Maj O'Neill for engaging with and supporting the project. In the Fitzroy, Kulkarriya Community School at Noonkanbah Station was strongly engaged with the project, participating in PhotoVoice projects and regular classroom activities organised by visiting researchers. This engagement was championed by teacher Luke Royes, and the team will thoroughly miss the school visits.

This research project drew on the knowledge and skills of a Research Advisory Committee. We would especially like to thank the following members of the Committee: Professor Jon Altman (ANU CAEPR), Mr Tony Griffiths (NRETAS; Biodiversity North), Ms Kelly Howitt and Ms Leonie Williams (NRETAS; Water Resources), Dr Anna Straton (CSIRO), Associate Professor Sandy Toussaint (UWA) and Ms Susie Williams (WA Department of Water).

We wish to thank the WA Department of Water, Kununurra office, and the Water Resources section of the NT Department of Natural Resources, Environment, Tourism, Art and Sport (NRETAS) for their interest and support for the project, particularly Ian Lancaster, formerly the NT's Water Controller. Thanks are also due to Murray Radcliffe of the National Water Commission and Brendan Edgar, formerly of Land and Water Australia. We also thank the WA Department of Agriculture and Food for the use of their donga in Fitzroy Crossing during extensive periods of fieldwork.

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Lastly, team members regularly spent lengthy periods away from home during this research project, and we wish to acknowledge the support we received from family and friends during this time.

1. INTRODUCTION

1.1 Background

Indigenous people value aquatic ecosystems in a number of inter-related ways; they provide bush foods, art and craft materials and medicines; they are part of a socially and culturally significant landscape, and have the potential to sustain future water-related businesses and employment. The customary rights of Indigenous Australians to natural resources have been accorded greater recognition by state management systems since the *Native Title Act 1993*. Notwithstanding this formal recognition there has been relatively little quantitative research on the use of resources by Indigenous people in Australia (see Altman 1987, Gray et al. 2005, Venn and Quiggin 2007; Meehan 1982). Further there have been relatively few attempts to value non-traded goods and services in Indigenous societies (see Straton and Zander 2009).

National water policy proposes the allocation of water to meet certain Indigenous requirements: for direct Indigenous use, to sustain landscape features of heritage or religious value and native title. In northern Australia, given the significance of the size of the Indigenous population, its land holdings and attachment to customary estates, the need for water planning to identify and address Indigenous interests and values is considerable. But Indigenous values associated with river systems and water tend to be poorly understood by river managers and water planners, and some are difficult to relate explicitly to particular flow patterns and to address in water allocation decisions (Jackson 2008).

Implementing the NWI's provisions relating to Indigenous people will require comprehensive effort encompassing a number of policy domains, and not all of them, such as the native title arena, will be concerned with the scientific evaluation of water requirements and incorporation of values in water planning. Nonetheless, within water management policy and practice, resource assessment techniques capable of addressing Indigenous values are in their infancy (Jackson and Morrison 2007, Schofield et al. 2003), and water resource managers face conceptual and technical difficulties in calculating and allocating water to meet the needs identified in the NWI. Preliminary consideration of the issue (Jackson and Altman 2009, Jackson and Morrison 2007) reveals the need for greater clarity in conceptualising the nature of Indigenous water uses or needs, and for quantitative methods to assess flow requirements necessary to sustain Indigenous values.

Australian studies of the significance of water to Indigenous societies provide a rich account, narrative and qualitative in style, but provide little guidance to water planners seeking to understand the contribution of flow to Indigenous *use* of rivers, water-bodies and resources. Water planners require a specification of some flow or range of flows that optimise, permit, or do not irrevocably harm the human (and other) uses reliant on flow. For instance, South African environmental flow research demonstrates the need to make clear the link between direct human resource use and flow regime, achieved through studies of resource use patterns and their dependence on flow, quantification of harvested resources and spatially explicit information on harvesting rates (Finn and Jackson 2011; Pollard 2000). This report seeks to contribute to the current gap in socio-economic assessments of water resource development in Australia (Hussey and Dovers 2007).

1.2 Project Objectives

The project was designed to:

1. Document the significance of water and river systems to Indigenous communities, particularly to Indigenous cosmology and environmental philosophy;

2. Survey Aboriginal households to quantify the direct economic benefit derived from Indigenous use of wild resources found in or reliant upon rivers and wetlands;

3. Assess the impacts of changes to flow regime on Indigenous communities;

4. Collaborate with Indigenous land management agencies to develop and trial a participatory monitoring program for flow regime changes and wild resource use; and

5. Develop collaborations and information that will enhance the capacity of researchers and managers in northern Australia to incorporate social assessments in water allocation decisions and planning.

1.3 Project Approach

The project was implemented in stages (see Figure 1) to ensure adequate time to build relationships with research participants. The first stage of the project involved a river use mapping exercise aimed at gathering information on the sites people used, the species found at those sites, and the social and cultural significance of sites, species and activities such as fishing. The river use mapping exercise also allowed researchers to familiarise Indigenous households with the types of information we would be seeking during repetitive surveys, and the potential uses of that information.

During this stage, the project team interviewed Indigenous experts to document ecological knowledge relating to resources use and aquatic environments. Information was used to produce a series of seasonal calendars, representing Indigenous ecological knowledge relating to seasonality, meteorological conditions and interrelationships with species availability.

The second stage of the project centred on the quantification of aquatic resource use by Indigenous households, and subsequent economic valuation. This stage involved two years of household surveys; asking Indigenous households how often they hunt and fish, which sites they had been to recently, and information on the species harvested, used and shared. The replacement method was selected to value the economic contribution of wild resource use (see section below on these methods for more detail).

Stage three involved analysis of the quantification of harvest to assess the potential impacts of flow alterations. At this point, a number of species that contribute substantially to Indigenous household incomes were investigated further to assess their flow requirements. This information was then used to assess the potential effects of flow alterations on Indigenous use of aquatic wild resources. Three modelling approaches provided information on the potential effects of flow alterations. Firstly, a semi-quantitative risk assessment on fish species from the Daly River (Pusey & Kennard 2009, Kennard et al. 2009) was used to provide information on the relative risk of dry season water extraction on a range of fish species. Secondly, quantitative risk assessments (using Bayesian Belief Network predictive models) conducted on the Barramundi (*Lates calcarifer*) and Black Bream (*Hephaestus fuliginosus*) (Chan et al. 2011), was used to provide information on the response of those species to potential flow alterations in the Daly River. Finally, data on Indigenous harvest and effort was included in a Management Strategy Evaluation (MSE) model constructed by another TRaCK project (1.4).

Alongside other project components, a participatory monitoring trial was completed with two Indigenous groups from Daly River catchment and two groups from the Fitzroy River. This monitoring program aimed to trial the use of Indigenous indicators of “healthy river country” in a participatory fashion, whilst building capacity for ecological monitoring amongst Indigenous groups. Results from the monitoring trial are reported separately.

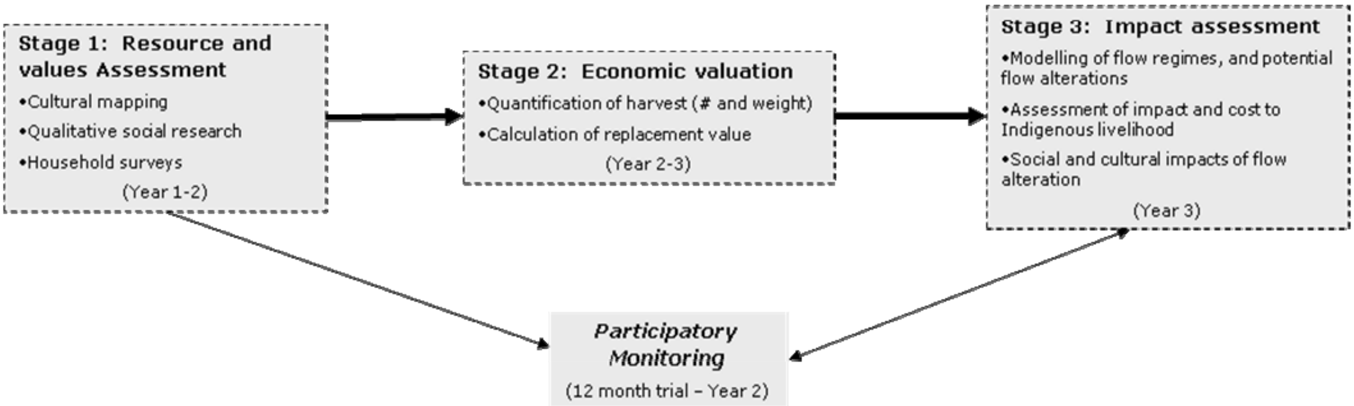


Figure 1: Stages of project, outlining the different components to information gathering, relationship building and analysis.

The exploratory nature of this research should be noted. Indigenous societies and cultural practices are diverse across northern Australia, and limitations to the spatial and temporal scope of research is unavoidable given resource and time constraints. This research was conducted in a number of communities in two northern Australian catchments, and over a two-year period. The results are applicable to the communities involved, and given the climatic, social and environmental conditions encountered during 2009 and 2010. However, much additional research is required to gain a full understanding of the value of Indigenous resource use, and to help understand whether our results are typical in a broader context.

1.4 Study Sites

Northern catchments are characterised by a distinct spatial pattern where most Indigenous people are located in relatively small settlements, invariably remote, while the vast majority of the non-Indigenous population resides in larger urban centres or cities (Taylor 2003). In some regions, Indigenous people comprise the majority of the population; for example, in the

Kimberley they form 50% of the population and 90% of all people living outside major Kimberley towns (Bergmann 2006)

The study focuses on the Daly River (Northern Territory) and the Fitzroy River (Western Australia) (Figure 2). There are extensive tracts of Aboriginal land in these TRaCK focal catchment areas. There is existing water extraction in both catchments, with a potentially large future demand for water resources in the Daly. Water resource planning has begun in the two catchments (Tindal aquifer WAP; Oolloo aquifer draft WAP), but the processes have not yet reached completion.

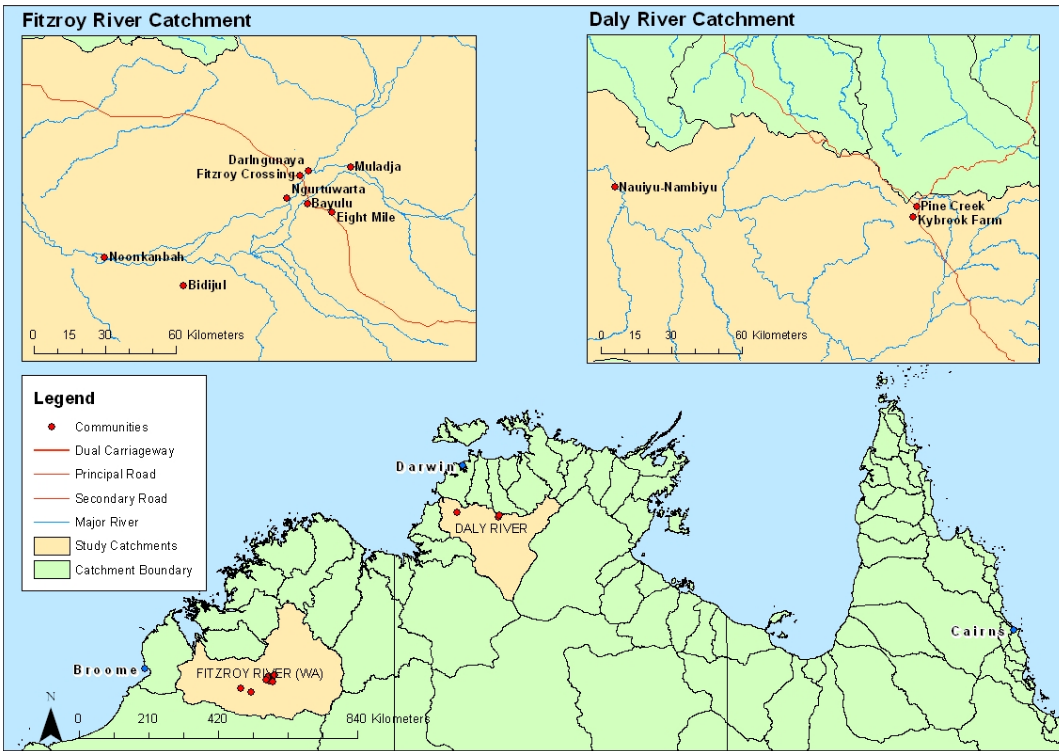


Figure 2: Northern Australia, showing the study catchments (Fitzroy River, WA, and Daly River, NT) and the focal communities for household surveys.

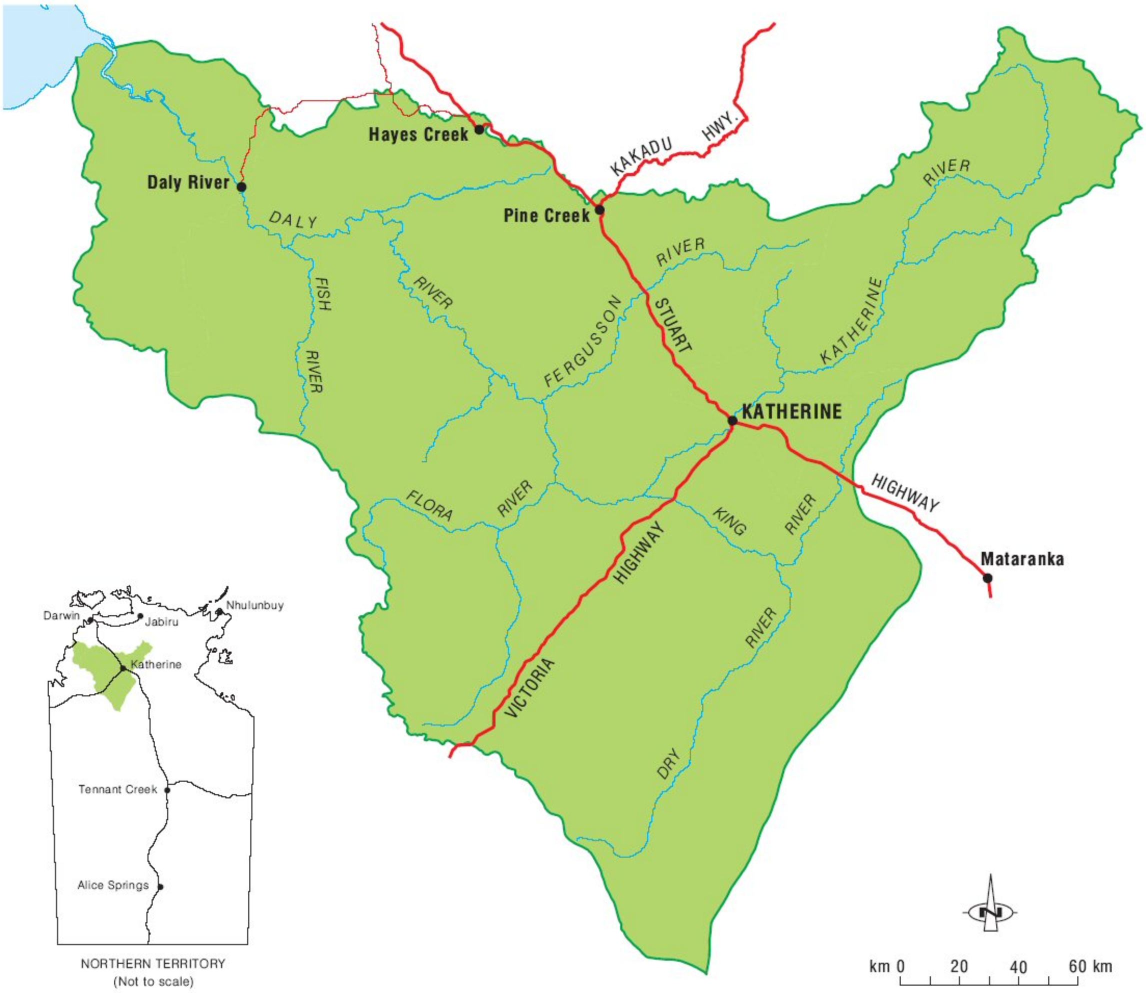
1.4.1 The Daly River region

The perennial Daly River rises near Katherine and flows in a north-westerly direction into the Timor Sea. The catchment of 53000km² receives 700-1300mm/year. It is fed exclusively by groundwater in the dry season and recharge to these groundwater systems is driven by climatic variability. Most of the region is subject to inundation during the Wet season, and swamps, lagoons and billabongs are a major feature in the landscape.

The catchment is recognised for its high ecological value, and the estuary and lower floodplains have been assessed as satisfying waterbird-based criteria for listing as a Wetland of International Importance under the Ramsar Convention (1971) (Chatto 2006). The Daly also supports the greatest number of species of freshwater turtles found in any Australian river, and the largest population of Pig-nosed Turtle in Australia. It is also one of only a few rivers in northern Australia where Freshwater Sawfish (*Pristis microdon* and *P. clavata*) and estuarine/freshwater Whiprays (*Himantura* sp.) are known to survive. River habitats and their associated creeks, springs and billabongs support a high diversity of resources, for food, medicine and other uses. Mammals, fish, birds, reptiles and a myriad of plant species contribute to the diet of many Aboriginal people living along the River, and contribute significantly to its social and cultural importance. The Daly River also holds a national reputation for recreational fishing; being the fifth most popular area to fish in the NT and accounting for 5% of the recreational fishing effort in the Territory (Daly Region Community Reference Group 2004). The most popular section of the Daly River for recreational fishing has been recorded as being the tidal freshwater reaches between the Daly River Crossing and Moon Billabong.

The Daly River catchment includes the major townships of Katherine, Daly River, Pine Creek and a number of smaller Aboriginal settlements (see Figure 3). These settlements include Nauiyu Nambiyu, Kybrook Farm, Pine Creek town camp, Binjari, Eva Valley and Barunga. Katherine is the largest town in the catchment and has a population of about 10 000. During the period 1996-2006 the population of the Daly Collection District consisted on average 67% non-Indigenous and 33% Indigenous residents, with no reported population growth. However, the Daly region is forecast to experience 40% growth over the next 20 years (Carson et al. 2009).

Figure 3: The Daly River Catchment, Northern Territory, Australia. Source: Department of Natural



Resources, Environment, Arts and Sport, Northern Territory Government 2008.

The Daly River catchment is one of several focal areas for agricultural development and intensification in northern Australia. The region is also considered to hold the greatest potential for agricultural development in the Northern Territory (Daly Region Community Reference Group 2004). Approximately 200,000 ha of land have been cleared in the catchment, which equates to about 4% of the total area. An additional 110,400 ha of land has been identified by NT Government agencies as being potentially suitable for clearing and agricultural development with additional water extraction proposed from both surface water systems and groundwater (Blanch et al. 2005). The Daly Basin currently has one water allocation plan for the Tindall Limestone Aquifer (Katherine) and the Oolloo aquifer plan is in development. The Daly Region Community Reference Group and the Daly River Aboriginal Reference Group are the formalised avenues for community representation in the development of water allocation plans in the region.

The Daly Region Aboriginal Community Reference Group identified four key risks to their Daly Focus Area following consideration of issues raised by community members and examination of available literature (Daly Region Community Reference Group 2004):

- Loss of perennial streamflow;
- Sedimentation of the River;
- Habitat degradation; and
- Decline in Indigenous values (see also Jackson 2006b).

There are numerous Aboriginal groups that maintain customary rights and interests in the Daly River catchment where the language group is the most common principle of land tenure (Table 1).

Table 1: Aboriginal groups of the Daly River (adapted from Jackson 2004).

Aboriginal Group	Area of interest
Wadjigan/Kiyuk	Daly estuary and surrounds
Malak Malak and Kamu	Lower Daly, Nauiyu and surrounding floodplains
Ngen’giwumirri, Maramanindji, Maranunngu	Western area of Daly Catchment including part of Port Keats Land Trust
Wagiman	Middle reaches of the Daly and Douglas area
Wardaman	Flora River region
Dagoman	North-Eastern section of the Daly Catchment and the Katherine area
Jawoyn	Katherine area

1.4.2 The Fitzroy River region

The Fitzroy River system is characterised by a braided channel, anabranching and billabongs on the floodplain, and significant lowland floodplain storage. Deep permanent pools occur along its whole length separated by shallower reaches. The river flows are highly unpredictable and ecological processes follow ‘boom and bust’ cycles that correspond with the wet and dry periods (Storey et al. 2001a). Wetlands of the Fitzroy River catchment, apart from the main Fitzroy River channel and the estuary, include large floodplain wetlands, small seasonal wetlands and permanent pools and billabongs. The country surrounding the river and its tributaries is also dotted with natural springs and permanent water sources which are culturally significant to local Aboriginal people (Yu 2005).

The pastoral industry and irrigated agricultural operations are the major contributors to agricultural production in the Kimberley region. Irrigated agricultural production has increased significantly over the last ten years and was valued at $53.6 million in 2004/05. This activity is based predominantly on horticultural and broad-acre crops grown in the Ord area near Kununurra as well as smaller agricultural holdings near Broome and Derby.

Attention focused on the water resources of the Fitzroy River catchment during the mid 1990s when cotton farming was proposed for the Fitzroy Valley and Broome region. Development scenarios included a dam at Dimond Gorge above Fitzroy Crossing and groundwater extraction from the La Grange Basin, southwest of Broome. Proposals to pipe water from the Fitzroy to meet Perth’s growing demand further focused attention on water resource use and social and environmental impacts associated with intensifying water extraction. A number of cultural studies were undertaken in collaboration with the then Water and Rivers Commission during this period of heightened interest in water resources (Toussaint et al. 2001, Yu 2000).

The Department of Water has produced a Kimberley Water Strategy and is currently preparing to undertake a regional water plan. According to Straton (2009), the water resources of the region are considerable, holding 80% of Western Australia’s fresh, surface water resources in over 100 rivers, creeks and streams. The Fitzroy, largest in terms of flow, contains 35 of the region’s 43 species of fish, 18 of which are endemic to the region (Storey et al. 2001b).

The Estimated Resident Population of the Kimberley in 2005 was 35,748 and is projected to reach 70,400 by 2031**.** From 1995 to 2005, the region's population increased at an average rate of 3.6 per cent per annum, making it the second fastest growing region in Western Australia. Major developments in aquaculture, irrigated agriculture, tourism and mining are likely to provide employment and investment opportunities that will significantly influence population projections (KDC website).

Aboriginal people form a significant proportion of the population in the region with the Fitzroy Valley crossing seven ethno-linguistic areas. In the 2001 Census 47.3% of the Kimberley resident population were recorded as being of Aboriginal or Torres Strait Islander descent, in comparison to a state-wide proportion of around 3.5%. While there are many common features, the study area is not culturally, linguistically or politically homogenous (Toussaint et al. 2001). The Fitzroy Valley includes Nyikina, Mangala, Ngarinyin, Bunuba, Gooniyandi, Walmajarri and Wangkajunga speakers. These groups retain affiliations to land and water in the area, with some groups arriving in the region more recently as desert migrants (Toussaint et al. 2001). As at Sept 2006, native title has been recognised in numerous claims: Wanjina-Wungurr Wilinggin NT Determination No 1, Rubibi, Tjurubalan People, Miriuwung-Gajerron (WA Area 1), MG (WA Area 2), MG #4, Karajarri People (Area A and B), Martu and Ngurrara, and the Bardi and Jawi Native Title Determination area. These areas cover approximately 120,000 sq kms, which is about 30% of the region.

1.5 Research ethics and Indigenous engagement

The project was conducted in accordance with the terms of human ethics clearance provided by Charles Darwin University and research agreements between the Kimberley Land Council and the Wagiman Association (through the Northern Land Council). The project also sought to fulfil the objectives outlined in the TRaCK Indigenous Engagement Strategy.

2.2.1 Research Ethics

The key terms and conditions of Charles Darwin University's human ethics clearance include:

- That all potential research participants are provided with sufficient information about the project and data confidentiality, including potential risks to the participant given their involvement, prior to the commencement of research. Also that participants will be provided with a project information sheet with the contact details of the Executive Officer of the ethics Committee as well as a local contact in case of questions or concerns;
- That written permission is obtained from each research participant before the collection of research information, and that the participant specifies the permission they give for the future use of that information;
- That permission will be sought from knowledge holders before non-confidential information relating to the significance of rivers or wetlands is released or reproduced; and
- That written consent is obtained prior to the release of images of people.

The key terms and condition of the Kimberley Land Council and Northern Land Council (with the Wagiman Association) agreements are similar and relate primarily to the protection of 'Confidential Information', Indigenous knowledge and Intellectual Property, through a process of checking all relevant research data before it is published.

During the life of the project 142 Indigenous participants were engaged directly in the research, often through the fulfilment of one or more of the following roles:

- Senior community members assisted CSIRO to engage a greater proportion of the community through introductions, championing the research and/or translation assistance;

- Participating in resource mapping to reveal spatial and temporal patterns of visitation to river and wetland sites and the range of resources collected from these areas;

- Participating in documentation of socio-cultural attachment to water, through the planning and recording of historical narratives about river use, the documentation of Indigenous ecological knowledge and construction of seasonal calendars, and through community photography and river education projects;

- Participating in household surveys on river and wetland resource use and harvesting effort;

- Participating in the community-based river monitoring component of the project, or

- Co-authoring presentations at conferences.

In the Daly catchment 32 households participated in the resource use survey and in the Fitzroy catchment, approximately 50 households. Several groups in the Daly and Fitzroy regions were also engaged in the participatory monitoring program, with approximately 32 individuals involved. Further, approximately 45 individuals were involved in the documenting of socio-cultural attachment to water.

2. INDIGENOUS USE OF AQUATIC WILD RESOURCES

2.1 Introduction

Indigenous people hold distinct cultural perspectives on water, relating to identity and attachment to place, environmental knowledge, resource security, and the exercise of custodial responsibilities to manage inter-related parts of customary estates (Jackson 2005, Jackson and Altman 2009, Jackson and O'Leary 2006, Langton 2002, Toussaint et al. 2001). In the belief systems of Australian Indigenous peoples, water is a sacred and elemental source and symbol of life (Langton 2006) and aquatic resources constitute a vital part of the non-market Indigenous customary economy as much as they inspire everyday experiences.

Few studies have attempted to determine the relative importance of food derived from aquatic environments prior to colonial contact. However, one study in the lower Murray River suggested that 30-40% of dietary protein was sourced from freshwater fish and shellfish (Pate 2000, cited in Humphries 2007). The number of species harvested by Indigenous people from aquatic habitats is substantial and ranges beyond fish. For instance, it has been suggested that historically the rhizome of Cumbungi (*Typha* sp.) could have been considered a staple food for Indigenous people in southern Australia (Gott 1999, cited in Humphries 2007).

Aquatic species continue to comprise an important part of the livelihoods of Indigenous peoples throughout Australia. Customary fishing, hunting and harvesting activities contribute substantially to Indigenous household income and diet (Altman 1987, Jackson and Altman 2009). The National Recreational and Indigenous Fishing Survey of 2003 revealed a 92% fishing participation rate for the surveyed Indigenous population in northern Australia. Approximately 38,000 Indigenous fishers participated in 420,000 fisher days harvesting almost 3 million fish in total (Henry and Lyle 2003). In parts of northern Australia, non-fish species such as Magpie Goose (*Anseranas semipalmata*), Long-necked Turtle (*Chelodina rugosa*) and Lotus Lily seeds (*Nelumbo nucifera*) make up a major component of the aquatic foods harvested by Indigenous people (Finn and Jackson, unpublished data).

Harvesting of wild resources for food and other purposes falls into what Altman (2006) terms the “customary” sector of a hybrid economy (Figure 4). The hybrid economy is a representation of a three-sector economy relevant to remote Indigenous contexts where attention needs to be given to the customary sector in addition to the “state” and “market” sectors of more conventional economic models (Altman 2006). Altman’s customary sector is usually defined from a production point of view rather than the consumptive, as we largely deal with in this manuscript, and is broader than the hunting, gathering and fishing activities that we have quantified (Altman 2001). A distinctive feature of the customary economy is that it is not monetised in the same manner as the state and market sectors, and has been largely unrecognised and unquantified (Altman 2001).

Importantly, the customary sector is not some pristine, pre-contact hunter-gatherer economy (Altman 2004). It is active in a modern sense, using modern tools and methods (Altman et al. 2011), and is strongly interrelated and partly dependent on the market and state sectors of the economy (Altman 2009b). The 2008 National Aboriginal and Torres Strait Islander Social

Survey (NATSISS) asked a number of questions about cultural practices including the harvest of wild resources. The survey results suggested that Australia-wide, approximately 60% of Indigenous people over 15 had participated in the harvest of wild resources in the past 12 months, and in remote communities that number increased to 72% of the population (Altman et al. 2011). The 92% fishing participation rate recorded in the 2003 National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) further suggests extensive contemporary involvement in the customary economy. Although quantifications of this harvest, and attempts at recording it value are rare, it is clear that the customary sector is a significant part of the Indigenous economy.

Partly due to its absence from mainstream, orthodox economic theory (Altman 2004) there is a lack of recognition of the customary economy in policy and management discourse and decisions. From a water resource management perspective, the ‘hidden’ nature of the value of wild resources to Indigenous households can mean that assessments of environmental flows may not lead to adequate protection of species that provide a significant contribution to the Indigenous economy (Finn and Jackson 2011). Water is important to Indigenous people in both customary and commercial economic activities, including the customary harvest of wildlife and floral species (Altman et al. 2009). Public policy, including water resource policy will need to account for the role of the customary economy, and will need to quantify in some manner the value of Indigenous wild resource use and the requirements of maintaining Indigenous access to important species. Native title legislation also mandates similar consideration (Jackson and Altman 2009).

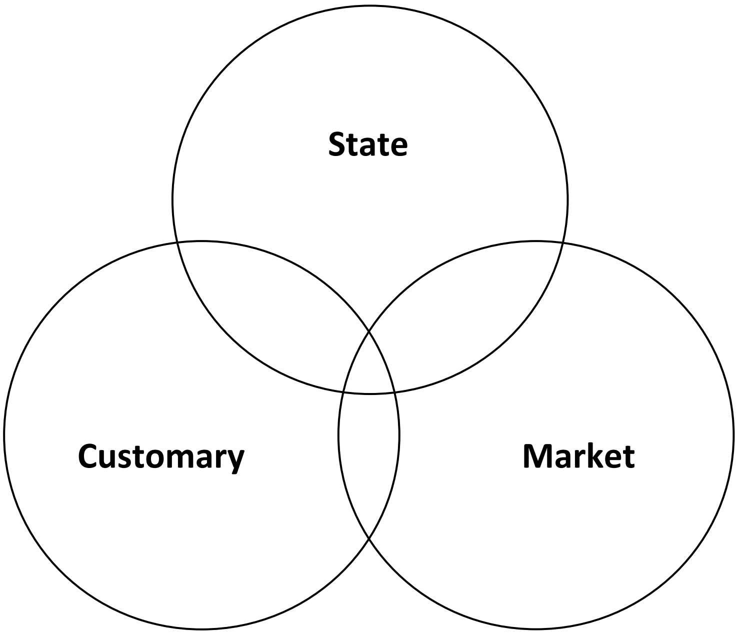


Figure 4: Representation of Altman's "Hybrid Economy", highlighting the contribution of the customary sector to the broader Indigenous economy.

Altman's (1987) comprehensive research on the contribution of customary use of wild resources to the small Kuninjku community at Mumeka on the Mann River in Western Arnhem Land in the Northern Territory (NT) made explicit the contribution of customary use of wild resources to Indigenous people and their economy. However, it did not discuss in detail the species used or the habitats hunted. The region and work was revisited more recently by Altman and Griffiths with a greater ecological focus on species and habitats. Results showed that although aquatic and semi-aquatic habitats (floodplains, swamps and streams) made up only 15% of the regional area, they were the locus of 79% of all hunting and gathering trips. Returns per hunting trip ranged from 2 – 7.5 animals in aquatic habitats as opposed to <1 animal per trip in terrestrial habitats (Griffiths 2003). Given the contribution that customary use makes to household incomes and diets and the prevalence of resident species in customary harvest, aquatic habitats could be considered high value areas.

Research in northern Australia has suggested that approximately 80% of Indigenous protein intake is derived from the customary (non-market) sector (Altman 1987; Asafu-Adjaye 1996). Likewise, the contribution of customary harvest to Indigenous household incomes has been found to range from 64% (Altman 1987) in remote Arnhem Land through to 2.9% - 8.2% in a regional community on the central coast of NSW (Gray et al. 2005) when the imputed value of harvested game is quantified. It is highly likely that the contribution of customary harvest to Indigenous household incomes in many regions of northern Australia would currently fall at the mid to high end of this range, although there are undoubtedly variations across the region, depending on the history of colonisation affecting attachment to land and access to resources, as well as the productivity of local environments.

The value of natural systems to humans is often broken into the two categories: use values and non-use values. A full economic valuation of a river to people would require both use values and non-use values to be calculated (Gray et al. 2005). Use values include commercial gains from utilising species and subsistence production, while non-use values include things such as aesthetic value and socio-cultural importance.

Water management usually targets a series of social, ecological and economic objectives that stakeholders wish to see achieved, and these objectives reflect society's values and preferences. Indigenous interests have not yet been well addressed by Australian water planning (Jackson and Altman 2009; Rural Solutions 2009; Jackson and Morrison, 2007) and it is rare to see a water plan that specifies Indigenous water use requirements for example (National Water Commission 2010).

The *Native Title Act (1993)* recognises Indigenous rights of customary use of resources for sustenance. Implicit in the right of customary use is a need to maintain Indigenous people's access to river resources (and so the direct-use value they can derive), an issue that the National Water Initiative (NWI) also seeks to address (Jackson 2008). This project assumes that a principal indicator for assessing the health of a water body is its productivity and the food and other materials extracted by Indigenous people. The project therefore focuses on quantifying the direct use (subsistence) value of aquatic resources to Indigenous people and tries to redress the relatively small amount of research into the economic value of the use of wild resources by Indigenous people in Australia (Gray et al. 2005). The results below will also serve as a baseline for long term monitoring of changes to water resources in the regions under study.

2.2 Aquatic resource use

There are a large number of interacting factors that affect the spatial and temporal pattern of Indigenous consumption of wild resources. These factors include land tenure, economic considerations such as the availability of vehicles and harvesting technology, the historical settling of people in various locations, social and cultural prerogatives and the amount of time available for the activity after other commitments such as family and work are met. Aboriginal people's access to wild resources will also depend heavily on the availability of plants and animals in the areas they use. The amount of wild resources harvested from an area will depend on the amount of effort invested, the efficiency of that effort, as well as the catchability and population size of the species being targeted.

Plants and animals are not distributed evenly across the landscape. Their distribution is defined by the availability of the habitat that sustains them, and the resources that make their existence in an area possible. In the case of species that live in aquatic habitats such as wetlands and river systems, many plants and animals depend on specific flow events during some stage of their life-cycle. Barramundi (*Lates calcarifer*) require linkages to coastal habitats to spawn, while Long-necked Turtles (*Chelodina rugosa*) require annually flooded wetlands to lay and hatch their eggs. Both of these species are commonly used by Aboriginal people as a source of food, so alterations in the flow regime that affect these species will also affect the ability of Aboriginal people to access and harvest them.

To assess the potential impact of flow alterations on Indigenous use of aquatic resources, we need to know where each species is harvested and its life history. The impacts of flow alteration on Aboriginal harvest of aquatic species could either be direct, or indirect. An example of a direct impact of flow alteration on Aboriginal harvest could be the truncation of the "run-off" by excessive harvesting of water as river flows decline after the Wet season (Dec-Mar). Barramundi often feed voraciously as river flows decline post- Wet season, and are commonly targeted during this time. Reducing discharge more rapidly over this period could shorten the amount of time that Barramundi can be caught in large numbers, reducing the annual catch. A more indirect impact could occur through the draining and diversion of flows around coastal floodplain habitats for agriculture. The loss of coastal floodplains would reduce Barramundi spawning and nursery areas, reducing its total population size. While this impact affects a life history stage of Barramundi that Indigenous people do not harvest, it could have a substantial impact on its population size in later years, ultimately reducing catch rates and affecting the value Indigenous people derive from its use. The potential for both direct and indirect impacts to result from flow alterations make it particularly important to understand where and when Indigenous harvest occurs (to be able to assess direct impacts), as well as understand the life history of commonly targeted species (to be able to assess indirect impacts). Section 6 will address in more detail the flow ecology of the harvested species and consider ways in which alterations to flow regime may affect Indigenous aquatic resource use.

2.3 Methods

Our project worked in a number of Indigenous communities along the Daly and Fitzroy Rivers. The criteria for the selection of communities to be involved in this study were:

- Communities needed to be in an area undergoing current water resource use or where future demands for water were likely to be substantial. This was to ensure that the information gathered by this study had immediate value;
- The community needed to be interested in being involved in the study and permission to work in the community for a number of years needed to be gained from relevant groups and community leaders;
- Community cohesion and the existence of structures such as Aboriginal ranger groups also made it more likely that a community would be selected. These attributes would make the research more likely to succeed and encourage capacity building, uptake of information and the persistence of the participatory monitoring program;
- A large and a small community in each catchment were selected to increase the likelihood of covering the range of variability in resource use.

The communities selected for the household surveys are shown in Table 2.

Table 2: Characteristics of communities selected for household surveys. Population characteristics from the 2006 census (ABS, 2007).

	DALY RIVER		FITZROY RIVER	
	Pine Creek/ Kybrook Farm	**Nauiyu - Nambiyu**	**Noonkanbah**	**Fitzroy Crossing**
Population	127 (Indigenous) 345 (total)	351 (Indigenous) 395 (total)	266 (Indigenous) 288 (total)	625 (Indigenous) 928 (total)
Language Groups	Wagiman Jawoyn	MalakMalak Kamu Maranunngu Ngen'giwumirri	Walmajarri Nyikina	Nyikini Mangala Walmajarri Gooniyandi Bunuba
Water resource development	Demand increasing with horticultural growth.	Demand increasing with horticultural and forestry growth.	Negligible increase in demand although potential mineral development	Negligible increase in demand although potential mineral development
Rainfall (mean annual)	1162 mm Douglas River	1354 mm Mango Farm	842.8 mm Curtin	540.5 mm
Wettest month	Feb (281 mm)	Jan (333 mm)	Feb (212 mm)	Jan (153 mm)
Driest month	Aug (1.3 mm)	Jun (0.4 mm)	Sep (0.1 mm)	Aug (1.4 mm)
Mean min. temp.	19.6 °C	20.6 °C	21.1 °C	19.2 °C
Mean max. temp.	34.2 °C	34.1 °C	35.5 °C	35.6 °C

2.3.1 Resource use mapping

Resource use mapping or "river mapping" was undertaken during the early stages of the project at all survey sites. The aim of this activity was to gather data on the spatial and temporal distribution of Indigenous resource use, allowing potential relationships between important sites and flow to be determined. It was one of the first components of the project to be implemented and had the added advantage of allowing strong relationships to be built between Indigenous participants and researchers. This information was derived using two methods. Firstly, Rapid Rural Appraisal (RRA) methods (Chambers 1994) were used during group sessions or with individuals where they were more comfortable working outside of the group session. Household surveys provided a second source of information on the spatial distribution of resource use. Household surveys are outlined in more detail in section 5.3.2 below.

River mapping sessions were undertaken in small groups. In the Daly catchment, a total of thirty-two people from Nauiyu Nambiyu, Kybrook Farm and Pine Creek Town Camp participated in river mapping sessions. Forty-three informants from several communities, including Bayulu, Muludja, Gillarong, Eight Mile, Junjuwa and Ngurtuwarta, participated in the river mapping exercise in the Fitzroy catchment. Often it was necessary to conduct a number of separate sessions with different language and family groups in each community to obtain a more complete picture of Indigenous use of flow-related plants and animals. Sessions remained relatively informal, with 1:100,000 scale maps of the local area and identification guides for local plants and animals used to prompt the group for information. In addition to the maps of the area, photographs of plants and animals that might be harvested and used by were shown to prompt further discussion. Specific care was taken at the outset of each exercise to explain to participants that the information given was confidential (i.e. it would not be released at a level of detail that would identify individuals and in some cases, specific locations) and that participants could decide at any time they no longer wished to be involved and their information could be removed from the map. Participants in the mapping exercise were paid a nominal fee for their time and information.

Along with the geographical locations of key sites/areas, information on the values of each site was recorded including the use of sites for hunting, fishing and collection of resources for medicines, art and craft or tools, or for other social or cultural reasons. Information was also gathered on people’s knowledge of the abundance of species at sites; which species are favoured for harvest; how harvest is related to seasonal change; whether harvest is related to social or cultural activity; whether informants have witnessed change in distribution or abundance, and whether there are inter-generational differences in value attributed to species. The information will be further analysed in journal publications arising from this report.

To date, information collected during the river mapping process has been used to:

- Construct seasonal calendars. The calendar format assisted researchers to collect and frame traditional ecological knowledge (TEK) on specific species and their life histories. It also assisted researchers to understand when specific species were available, or were targeted by Indigenous hunters. Seasonal calendars (and related information) also gave insights into the temporal pattern of use of aquatic resources (see Woodward et al. in press);

- Create maps of the spatial distribution of resource use. These maps assisted researchers understand which habitats and locations were most commonly used.

2.3.2 Seasonal calendars

Indigenous knowledge of aquatic ecosystems was documented and analysed through the production of a series of seasonal calendars. Creating seasonal calendars progressed naturally out of discussions that revealed the depth of phenological knowledge held by Indigenous experts. Phenological knowledge encompasses all biological seasonality, including the observation of life cycle changes in specific plant or animal species to indicate the timing of the onset of growth stages in other species, linguistic references to phenological events, conceptions of time as they relate to seasonal change, and spiritual beliefs about cause and effect relationships of seasonal change (Lantz and Turner 2003).

Phenological indicators can be thought of as stable biological timepieces that respond to seasonal variation between years (Lantz and Turner 2003). Phenological events generally occur in consistent order, with the arrival of one event predicting the imminence of another. Phenological knowledge is a significant aspect of many Indigenous knowledge systems, given the typical reliance on subsistence resource use. Increasingly, phenological knowledge is attracting interest worldwide as a monitoring tool for environment change, specifically climate change. Indigenous groups are closely monitoring the potential impacts of environmental change on wild resources (Gordon et al. 2007, Guyot et al. 2006) with Inuit people from the Arctic, for example, interpreting environmental indicators and determining animal behaviour with their traditional knowledge of currents and sea ice (McDonald et al. 1997)

The documentation of phenological knowledge, particularly of those events that correspond with the life-cycle of key food resources, has been documented elsewhere in northern Australia. Russel-Smith et al. (1997) report on the seasonal availability of staple foods collected by Gundjeihmi language speakers in the Kakadu region of the Northern Territory. Referring to the Gundjeihmi seasonal calendar, and its six distinct seasons, the authors identify the weather events that indicate the changing of seasons, and the accessibility of those habitats that support bush food staples. For example, yam species occupying floodplain and riverine habitats are generally unavailable through the Wet season given flooding conditions, so attention turns to lowland jungle habitats that provide a small, but highly significant source for yams during this period of the year…' (p167). They also identified that while a large number of species were utilized only occasionally or eaten more in the manner of snacks (e.g. many fruits), the major regional staples comprise 11 plant species and 19 animals species.

The TRaCK project compiled four seasonal calendars across the two catchments. These calendars can be viewed and downloaded from CSIRO's website at the addresses below:

http://www.csiro.au/resources/Ngangi-Seasonal-Calendar.html

http://www.csiro.au/resources/MalakMalak-Plant-Knowledge-Seasons-Calendar.html

http://www.csiro.au/resources/Gooniyandi-Seasons-Calendar.html

http://www.csiro.au/resources/Walmajarri-Fishing-Calendar.html

Three of the four seasonal calendars were strongly focused on ecological knowledge of floodplain and other aquatic ecosystems, so the patterns of resource use displayed might under-represent species from woodland and other terrestrial habitats.

Two of the seasonal calendars were created with two language groups in the Daly River catchment and resulted in production of the 'Ngan'gi Seasons' calendar and the 'MalakMalak and Matngala Plant Knowledge' poster. The other two calendars were created with representatives of the Gooniyandi and Walmajarri language groups in the Fitzroy River catchment, resulting in the 'Gooniyandi Seasons' calendar and the 'Walmajarri words from the riverside' calendar.

The Ngan'gi Seasons calendar emerged from and evolved through participatory action research with Indigenous research participants of Nauiyu community. The calendar took ten months to produce and initially involved the documentation of Indigenous ecological knowledge and seasonal indicators. It ultimately evolved into a calendar that depicted the thirteen recognised seasons of the Ngan'gi set of Aboriginal languages, known as Ngan'gikurunggurr and Ngen'giwumirri. On seeing the Ngan'gi Seasons calendar, MalakMalak traditional owners of land surrounding Nauiyu community sought to work with project team members to also document resource use, with a focus on valuable plant resources.

The Gooniyandi and Walmajarri calendars emerged from and evolved through participatory action research with Aboriginal research participants at Muludja community, Go-Go Station and Fitzroy Crossing.

2.3.3 Household surveys

Household surveys were conducted over a 2 year period to quantify the use and economic value of aquatic resources to respondents. "Aquatic species" were those for which a key feature of their life history depended entirely on aquatic habitats. While many species living on the floodplain and along river corridors such as the Agile Wallaby (*Macropus agilis*) may be affected by flow alterations and subsequent loss of habitat, our surveys focused on those that were considered as obligate aquatic.

The most basic list of information required to estimate the net economic value of wild resources is (Gray et al. 2005):

- The average amount of each species harvested;
- The number of people harvesting each species;
- The market price of each type of wild resource; and
- The cost of harvesting wild resources.

The gross economic value of wild resource harvest or consumption can be estimated without accounting for the costs of harvesting. While other authors have estimated the expenditure involved in obtaining wild resources to obtain a net replacement value, in many cases these are only a partial estimate of costs (e.g. fuel costs, Buchanan et al. 2009). While we could also partially estimate costs based on our household survey (e.g. fuel costs based on distance to site), many costs such as the opportunity cost time spent hunting could not be accurately assessed from our survey. The replacement values presented in this report are gross replacement values, in part because we wanted to minimise our use of a survey response we consider variable at best, and in part because we wanted to use a straightforward calculation, preserving the easily understandable nature of the replacement value method (Buchanan et al. 2009).

We estimated the gross replacement value of the harvest and consumption for each species using:

$$GRV = (aWt*aTN*aV) + (bWt*bTN*bV) + (cWt*cTN*cV)$$

Where:

- *GRV* = Gross replacement value;
- *aWt; bWt; cWt* = mean weight in grams or a species for the large (a), medium (b) and small (c) size classes;
- *aTN; bTN; cTN* = total number of individuals of a species harvested or consumed in the large (a), medium (b) and small (c) size classes;
- *aV; bV; cV* = “shop value” of the replacement item for a species in the large (a), medium (b) and small (c) size classes (Table 3).

A variety of methods have been used by practitioners to obtain the information required for the quantification of wild resource harvest, including direct observation, household surveys, resource use diaries, and doorstep accounting. Each of these methods differs in the scale to which they can be applied, the quality of information returned, and the cost of applying the method.

Intensive methods such as direct observation, where the researcher accompanies people on food quests (Altman 1987), and doorstep accounting, where the researcher enumerates catches as people return to their homes (Godoy et al. 2000, Sheil and Wunder 2002), are likely to provide accurate and detailed information. However, they are expensive to apply at larger spatial and longer temporal scales and the presence of observers may influence the frequency and location of food quests. Less intensive methods such as diaries of resource use that are filled out by hunters (Gram 2001), or periodic household surveys that interview people on what they have taken in the recent past (Gray et al. 2005), can cover much larger scales. However, these methods may underestimate resource use because of poor participant recall (Gram 2001, Gray et al. 2005) or may return inaccurate information if respondents revise their statements up or down depending on their perception of the questions and the broader context in which the research is set (Sheil and Wunder 2002).

We used repeated household surveys to calculate the quantity of wild resources Indigenous households were taking from rivers and wetlands. Surveys were implemented during a semistructured interview, with participants being asked to recall a period of hunting activity over the preceding 2 weeks. Interviews were repeated twice in a month to allow for longer temporal coverage (i.e. 1 month) while reducing the overall recall period (i.e. 2 weeks). The monthly surveys were conducted quarterly for 2 years to provide information on the seasonal and inter-annual variability of resource use.

During each household interview, participants were asked to separately discuss each trip in which wild resources were harvested. This allowed researchers to calculate the probability of each species being harvested. Participants were also asked to provide:

- the location of the trip;
- the method of travel;
- the number of men, women and children participating;
- the species captured and their quantities;
- the method of capture;
- the final use of the species; and
- how the wild resources were shared.

Interviewers also encouraged participants to discuss:

- how river flows might impact on their trip (e.g. was this flow a good one for catching Barramundi?); and
- whether they had noticed any change to the quality or quantity of resources related to climate or flow.

We realise these last two questions are leading, but found them necessary for the capture and recording of qualitative information that would assist us link patterns of resource use to specific flow conditions.

Households participating in the research were not selected at random. Due to the frequent timing of interviews and their potentially intrusive nature, we asked participating communities to nominate a number of households who would be interested in participating in the study and who would be considered to fit in the high, medium and low resource use categories. Households initially chosen for participation in the surveys were then asked to suggest another household that may be interested in talking to researchers. In this manner, the selection of households was similar to the snowball sampling technique (Goodman 1961), although we did not attempt to control the number of households we asked to be recommended, as is required under a strict implementation of the Goodman method. To minimise the prevalence of high resource users in our sample, we specifically asked participants to recommend households they thought would be interested in talking to researchers, rather than households they thought frequently participated in fishing and hunting activities.

2.3.4 Sample size

As there is little existing information on flow related resource use by Indigenous communities, we could not use power analysis or any similar method to choose a sample size prior to beginning our household surveys. Instead, we reviewed the international literature to calculate the sample sizes in projects reported in peer-reviewed publications. In general, we aimed at a sample size that was as large as logistically possible given resource and time constraints, and that reflected the published literature.

We aimed for a minimum of 5 households surveyed in each community. Where 5 households represented more than 20% of the entire community it was used as the sample size. For larger communities (i.e. more than 25 houses) sampling aimed to interview 20% of households. Our sampling strategy broadly reflects the sample sizes used in the international literature. These sample sizes include 20% for large communities (more than 200 households) (Turner 1998), 10% in one community and 20% in another community (Shackelton et al. 2007), a range between 18% and 72% (Shackleton et al. 2002) 3.3% of Indigenous people in a catchment (where the authors acknowledge small sample size) (Gray et al. 2005), and an intensive survey that covered 9% of households in one village and 6% of households in another (Bari et al. 1998).

Our final coverage of households was variable. In the Daly River catchment, the mean number of households surveyed each season declined as the research continued over the two year period (Figure 5). The average number of households surveyed during our sampling trips in the Daly River was 24; a sample size of approximately 23% of Indigenous households in our survey communities (ABS, 2006). The number of households we were able to survey in Fitzroy River communities also declined as the research continued (Figure 6). The average number of households surveyed in the Fitzroy River was 36; a sample size of approximately 20% of Indigenous households in survey communities (ABS, 2006).

The decline in households surveyed reflects a combination of the availability of households to be involved in the surveys during each trip and withdrawal of a number of household during the project.

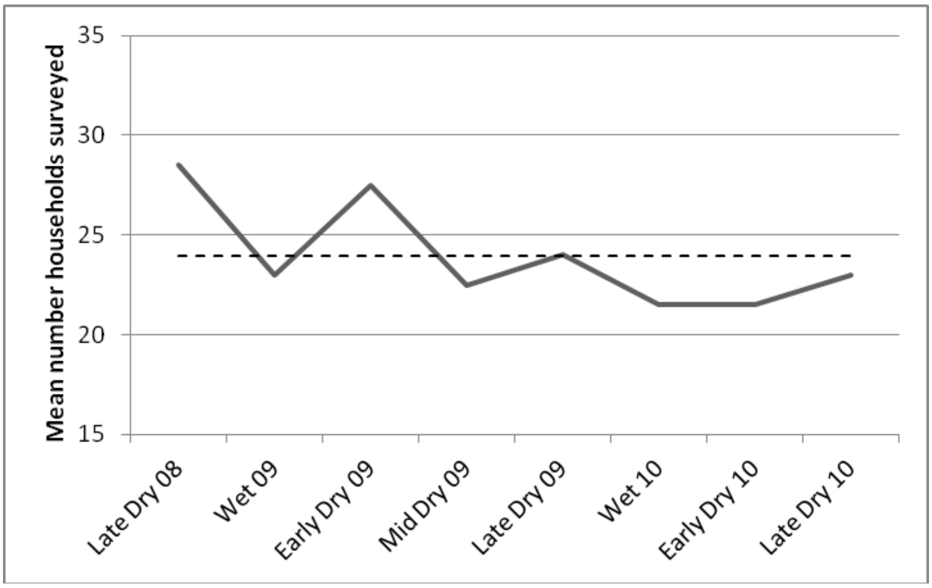


Figure 5: Mean number of households surveyed in the Daly River catchment during each sampling trip (solid line). The dotted line shows the mean number of households surveyed over the life of the project.

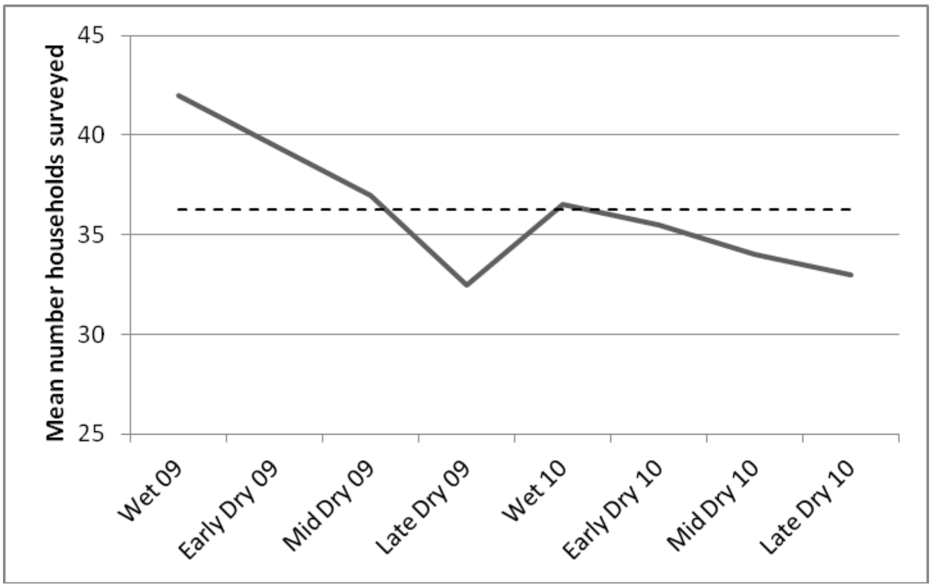


Figure 6: Mean number of households surveyed in the Fitzroy River catchment during each sampling trip (solid line). The dotted line shows the mean number of households surveyed over the life of the project.

2.4 Statistical analysis

2.4.1 Calculating replacement value – assumptions and data management

Survey respondents could not always align the total number a species harvested with the numbers that fell into different size categories. For example, it was not unusual for a survey respondent to recall that the group had caught eight Long-necked Turtle (*C. rugosa*), but only be able to recall that "two were really big ones, the rest were all sizes". Incomplete recall needed to be accounted for when assessing replacement value, as the total harvest of species was broken into size categories: large, medium and small. Where survey respondents had incomplete recall of the make-up of size categories, unallocated catch was placed in the "medium" category, effectively given the un-sized catch the average for that species. The number of individuals consumed in each size category was taken to be proportional to the number harvested, unless the survey respondent informed us otherwise.

It was necessary to ascertain the mean length of individuals of a species for each size category (large, medium and small). This allowed the "numbers of individuals harvested" to be converted to "weight of harvest" using length-weight regressions from the literature and other TRaCK research (Table 3). During 2009 surveys, respondents were asked to indicate the size of individuals that fell into each size class with their hands as opportunities presented themselves. At the end of 2009, the results of this were reviewed to indicate whether we had a large enough sample for a given precision. The number of samples required to provide a 90% confidence that our mean was within 10% of the real mean was calculated using:

$$n = \left(\frac{z\sigma}{m} \right)^2 \qquad \text{Equation 1}$$

Where:

n = number of samples required

z = t distribution critical value for a 90% confidence interval (1.645)

σ = standard deviation of existing sample

m = our accepted margin of error (10% of mean of existing sample)

In all cases where there were more than 10 existing samples with which to estimate the population mean and standard deviation, the number of samples required to meet our criteria was less than 20. In 2010 we attempted to ensure that a minimum of 20 samples were collected for each species recorded as harvested. The mean of these records were then used as the size of that species for each size category. Not all species were harvested in high enough numbers to allow the estimation of 20 individuals for each size category. Where fewer than 20 individuals had their size estimated, we used the data we had to estimate the mean.

It is important to note that the mean sizes we arrived at are the mean sizes that survey respondents considered to fall into each size category. For example, a mean size for a large Barramundi (*L. calcarifer*) of 83 cm represents the opinion of our survey respondents. This allowed us to convert responses like "I caught two Barra, and they were both big ones" to an estimated catch of two 83 cm Barramundi. This could then be converted to an estimated weight using our length-weight regressions (Table 3), and used to estimate the total replacement value of those fish.

2.4.2 Resource valuation

Wild aquatic resources consumed by Indigenous people are not traded in a market and therefore their economic value is difficult to estimate. Non-market valuation is increasingly being undertaken as a means of revealing 'hidden' values and brings to light the importance of resources or environments not exchanged in market transactions but nonetheless are of benefit to human societies (Emerton 2005). Although increasingly popular, there are numerous limitations that have been well documented in the literature on valuation.

There are two reasons for attempting to estimate the value of the aquatic specific harvested by Indigenous people:

1. to quantify one type of cost that Aboriginal people may experience as a result of water use decisions, either at the local or regional scale, and

2. to assist water managers who have limited resources and knowledge to target areas of greatest economic value to Aboriginal people.

The economic value of resources consumed by households was calculated using the replacement goods method (Altman 1987). Even where wetland goods and services have no market themselves, they often have alternatives or substitutes that can be bought and sold. The method uses the market price of a similar product as a proxy for wetland resource and ecosystem values (Emerton 2005). It is used relatively widely and was considered by Altman (1987) in a north Australian study to provide quite accurate values. It is only a partial economic value, focussing entirely on the "consumptive direct use value" component of total economic value (Figure 7).

It also does not attempt to account for the indirect or non-use cultural and social values associated with wild resource harvesting which are reportedly significant (Jackson 2006a, Toussaint et al. 2001). Altman and Branchut (2008) for example, found in the Maningrida region an 'overarching Aboriginal view that water is a resource with inseparable cultural and economic values, significant water places have high religious and livelihood values' (2008: 2).

The valuation nonetheless provides useful information on the likely lower-bound value of Indigenous flow-related resource use to the customary economy. However, it has been criticised for a number of reasons including:

- it relies on comparisons between dissimilar or incommensurate items (e.g. wild meat may be more 'valuable' to Indigenous hunters that the market value of domestic meat would suggest);
- conceptualising plants and animals as an economic resource may obscure or marginalise the importance of harvesting and fishing practices to social and cultural life in water use decisions (Toussaint 2010); and
- it is anchored in current pricing and therefore does not allow easily allow for predictions of value (Haener et al. 2001).

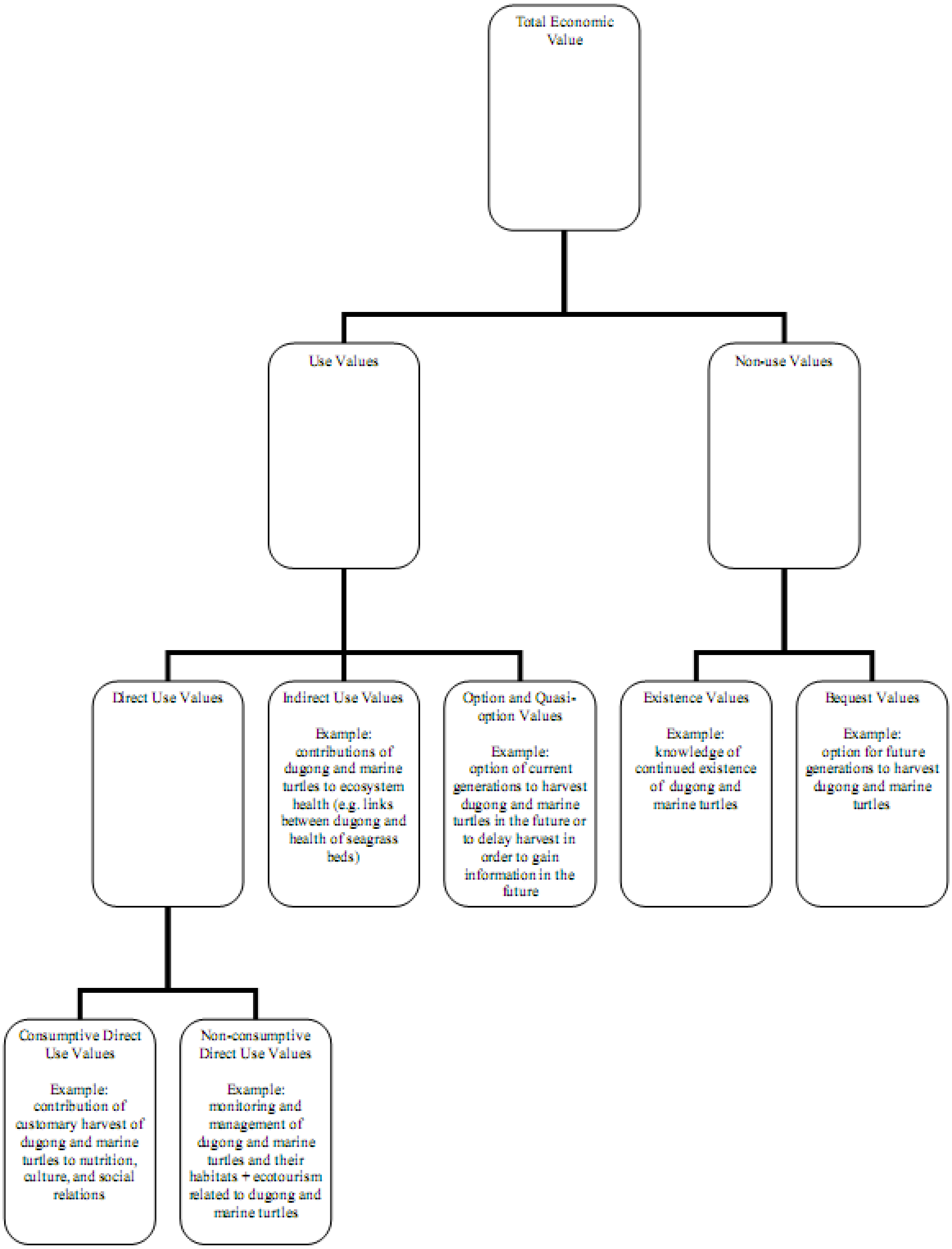


Figure 7: Components of total economic value (Source: Buchanan et al. 2009)

During this research, replacement items were chosen to reflect the predominate use of the species they were to replace (e.g. food, bait, art materials; see Table 3). Further consideration was given to whether the item was considered a “high value” item or a “lesser value” item. This proved difficult, as individuals involved in the research often had conflicting opinions on what items would be considered preferable. Indeed, Toussaint (2010) finds that although some species were well desired, the "type of fish sought, caught, cooked and eaten was not a priority". Toussaint also mentions that Black Bream were a generally preferred species, but seemingly in large part because they were easily caught, and could be immediately cooked and eaten on the spot. This makes the specific preferences and the acceptability of proxies difficult to elucidate. The shop items used for replacement values are shown in the table below, and were designed to:

1. Generally reflect the type of food item the species represent (e.g. turtles were given values representing the cost of meat from a shop, fish were given replacement values representing the cost of fish from a shop); and

2. Reflect the general preferences for species that were made apparent to researchers through the project. For example, Pig-nosed Turtle were considered a prized species by Indigenous survey respondents and so were given a more expensive "fillet steak" value. Long-necked Turtle were usually treated as a more general food source, and so were given a less expensive "t-bone steak" value.

These values were, by necessity, defined by the researchers. It is critical to note that the values are not an attempt to derive the complete value of these species. As noted by Toussaint (2010; p.22) "what constitutes value…cannot be understood by adopting a singular or fixed form of comparison". What the valuation in this study reveals however, is one way of measuring the relative contributions of aquatic species to household incomes. In particular, it allows the species that make the largest contribution to be identified, encouraging more specific consideration of their environmental flow requirements, and an assessment of a set of costs that might be incurred by households if flow alterations adversely affected these species.

The replacement values reported here represent the harvest and consumption of survey households over the two year period of data collection. Reporting at a higher level is not required for the purposes of informing water resource management; therefore, no attempt has been made in this report to assess the replacement value derived from the direct use of aquatic resources at the level of an entire community or catchment. It is possible however that aggregated figures at a community level, if treated carefully, might inform water policy decisions as governments consider trade-offs.

Our method of calculating replacement value outlined here therefore represents only a proportion of the total economic value of aquatic species to Indigenous people (see for example Straton and Zander (2009) for results on Indigenous non-use values relating to tropical rivers). The valuation data provided within this report allows the ranking of species by the relative level of their economic contribution to Indigenous households. This allows a subset of economically important species to be identified, and their flow requirements assessed. Likewise, it allows a relative ranking of the economic contribution harvesting sites make to Indigenous households; information that clarifies how resource use, and the contribution it makes to Indigenous households, is spread across the landscape.

Table 3: Table of characteristics of aquatic species used for replacement value calculations.

ID	Species	Latin name	Big (cm)	Med (cm)	Small (cm)	Big (g)	Med (g)	Small (g)	Equation	Source for length-weight relationship (or mean weight)	Replacement item	$/kg
1	Long-neck Turtle	*Chelodina rugosa*	32.5	25.9	21.8	1960	1029	631	$Wt(g) = 0.2CL(cm)^{2.839}$ [multiplied by 0.5 for meat recovery]	Featherston, unpub. data from Honours research	T-bone steak	$20.69
2	Barramundi	*Lates calcarifer*	71.5	53.6	37.5	2975	1324	485	$Wt(g) = 0.0229TL(cm)^{2.81}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Yellowtail Kingfish	$39.45
3	Magpie Goose	*Anseranas semipalmata*				1707	1707	1707	Mean Wt (g) = 2438 [multiplied by 0.7 for meat recovery]	Frith and Davies, 1961 (n=761)	Frozen chicken	$5.25
4	Mullet	*Liza ordensis*	40	30	20	555	269	97	$Wt(g) = 0.0637LCF(cm)^{2.52}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Imported Barramundi	$17.82
5	Pig-nosed Turtle	*Carettochelys insculpta*	40	35	23	3350	2281	681	$Wt(g) = 0.163CL(cm)^{2.88}$ [multiplied by 0.5 for meat recovery]	Georges and Kennett, 1989	Fillet steak	$35.50
6	Short-neck Turtle	*Emydura tanybaraga/victoriae*	34.2	27.2	18.9	3009	1542	533	$Wt(g) = 0.2CL(cm)^{2.9194}$ [multiplied by 0.5 for meat recovery]	Featherston, unpub. data from Honours research - *E. victoriae*	T-bone steak	$20.69
7	Black Bream	*Hephaestus fuliginosus*	30.7	23.6	16.7	450	199	68	$Wt(g) = 0.138LCF(cm)^{3.10}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Yellowtail Kingfish	$39.45

Table 3 cont.

ID	Species	Latin name	Big (cm)	Med (cm)	Small (cm)	Big (g)	Med (g)	Small (g)	Equation	Source for length-weight relationship (or mean weight)	Replacement item	$/kg
8	Lotus Lilies	*Nelumbo nucifera*				40	40	40	2g per seed; mean = 20 seeds per head (calculated from 10 x photos)	Shen-Miller et al., 2002 - 2g per wetted seed	Macadamia nuts	$49.81
10	Wood Duck	*Chenonetta jubata*				577	577	577	Mean weight of male and female across different seasons x 0.7 for meat recovery	Briggs et al., 1991	Frozen chicken	$5.25
12	Whistling Duck	*Dendrocygna arcuata*				368	368	368	Mean weight x 0.5 for meat recovery	http://birdsinbackyards.net/species/Dendrocygna-arcuata	Frozen chicken	$5.25
14	Pandanus leaves	*Pandanus aquaticus*				33	33	33	Estimate of approximately 30 leaves per kg	Personal estimate in absence of other data	Linen rug warp	$99.84
17	Spangled Perch	*Leiopotherapon unicolor*	16.1	8.8	5.1	74	12	2	$Wt(g) = 0.0204LCF(cm)^{2.95}$	Bishop et al., 2001	Imported Barramundi	$17.82
18	Catfish	*Neoarius graeffei*	36.3	28.4	18.3	697	319	78	$Wt(g) = 0.00921LCF(cm)^{3.19}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Imported Barramundi	$17.82
19	Snapping Turtle	*Emydura dentata*	34.5	32.7	15	2692	2275	197	$Wt(g) = 0.08CL(cm)^{3.1395}$ [multiplied by 0.5 for meat recovery]	Featherston, unpub. data from Honours research	T-bone steak	$20.69
20	Cherabin	*Macrobrachium rosenbergii*	20.4	13.7	11.2	45	40	38	$Wt(g) = 36.99TL(cm)^{0.298}$ [multiplied by 0.5 for meat recovery]	Kuris et al., 1987	Prawns (Food quality)	$20.89

Table 3 cont.

ID	Species	Latin name	Big (cm)	Med (cm)	Small (cm)	Big (g)	Med (g)	Small (g)	Equation	Source for length-weight relationship (or mean weight)	Replacement item	$/kg
21	Sleepy Cod	*Oxyeleotris selheimi*	34	31.7	15	396	318	30	$Wt(g) = 0.00769TL(cm)^{3.14}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Imported Barramundi	$20.69
23	Saratoga	*Scleropages jardinii*	80	60	40	4964	1866	470	$Wt(g) = 0.0021TL(cm)^{3.4}$ [multiplied by 0.8 for meat production]	Bishop et al., 2001	Imported Barramundi	$20.69
25	Bush Turkey	*Ardeotis australis*				3325	3325	3325	Average of male and female weights (4750g) [multiplied by 0.7 for meat recovery]	Ziembicki, 2010	Frozen chicken	$5.25
26	Wallaby	*Macropus agilus*				7525	7525	7525	Average of male and female weights (Wet and Dry seasons - 15050g) [multiplied by 0.5 for meat recovery]	Stirrat, 2003	T-bone steak	$20.69
27	Red-Face Short-neck Turtle	*Emydura tanybaraga/victoriae*	34.2	27.2	18.9	3009	1542	533	$Wt(g) = 0.2CL(cm)^{2.9194}$ [multiplied by 0.5 for meat recovery]	Featherston, unpub. data from Honours research - *E. victoriae*	T-bone steak	$20.69
28	Kangaroo	*Macropus agilus*				7525	7525	7525	Average of male and female weights (Wet and Dry seasons)	Stirrat, 2003	T-bone steak	$20.69
30	Shark	*Carcharhinus leucas*	100	75	50	5779	2148	796	$Wt(g) = (6165.14 - 21.741TL(mm)) + (0.0228TL(mm)^2)$ [multiplied by 0.8 for meat recovery]	Thorburn, 2006	Imported Barramundi	$17.82

Table 3 cont.

ID	Species	Latin name	Big (cm)	Med (cm)	Small (cm)	Big (g)	Med (g)	Small (g)	Equation	Source for length-weight relationship (or mean weight)	Replacement item	$/kg
31	Jewfish	*Neosilurus ater*	30	23	15	193	86	23	$Wt(g) = 0.0073TL(cm)^{3.04}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Imported Barramundi	$17.82
32	Barred Grunter	*Amniataba percoides*	10	7.5	5	21	9	3	$Wt(g) = 0.0185LCF(cm)^{3.06}$	Bishop et al., 2001	Pilchards	$8.00
35	Bony Bream	*Nematalosa erebi*	17.5	12.4	7.6	92	31	7	$Wt(g) = 0.0122LCF(cm)^{3.12}$	Bishop et al., 2001	Pilchards	$8.00
38	Freshwater Mangrove										Panadol Tablets 12 pack	$2.19
39	Stingray	*Himantura dalyensis*	60	40	20	5321	1731	254	$Wt(g) = 0.0789WD(cm)^{2.7702}$ [multiplied by 0.8 for meat recovery]	FishBase	Imported Barramundi	$17.82
41	Freshwater Crab					12	12	12	Mean value of Spangled Perch (bait)		Prawns (Frozen)	$13.92
42	Mouth Almighty	*Glossamia aprion*		12.5		33	33	33	$Wt(g) = 0.0109LCF(cm)^{3.17}$	Bishop et al., 2001	Pilchards	$8.00
43	Archerfish	*Toxotes chatareus*	28.3	14	10	431	53	20	$Wt(g) = 0.021LCF(cm)^{2.97}$	Bishop et al., 2001	Pilchards	$8.00
44	Giant Gudgeon	*Oxyeleotris selheimi*	34	31.7	15	396	318	30	$Wt(g) = 0.00768TL(cm)^{3.14}$ [multiplied by 0.8 for meat recovery]	Bishop et al., 2001	Imported Barramundi	$17.82

Table 3 cont.

ID	Species	Latin name	Big (cm)	Med (cm)	Small (cm)	Big (g)	Med (g)	Small (g)	Equation	Source	Replacement item	$/kg
45	Tarpon	*Megalops cyprinoides*		27.5		287	287	287	Wt(g) = 0.0242LCF(cm)$^{2.83}$	Bishop et al., 2001	Pilchards	$8.00
46	Longtom	*Strongylura krefftii*		40		131	131	131	Wt(g) = 0.00098LCF(cm)$^{3.2}$	Bishop et al., 2001	Pilchards	$8.00
47	Sawfish	*Pristis microdon*	212.5	116.43	75	16170	2596	682	Wt(g) = 0.0017TL(cm)$^{3.040}$ [multiplied by 0.8 for meat recovery]	FishBase	Yellowtail Kingfish	$39.45
49	False-spined Catfish	*Neosilurus pseudospinosus*	30	23	15	193	86	23	As per *Neosilurus ater*	Bishop et al., 2001	Imported Barramundi	$17.82
54	Water Lily	*Nymphaea sp.*				40	40	40	Makes value as per *Nelumbo nucifera*		Macadamia nuts	$49.81

3. RESULTS

3.1 Spatial distribution of resource use

River use mapping was undertaken as a precursor to the household surveys. The river use mapping exercise provided an understanding of the distribution of harvesting sites and the species that could be obtained from those sites. Critically, it also enabled the researchers to establish relationships with Indigenous participants, and the community more broadly, before the two-year program of household surveys began.

River use mapping sessions gathered information on:

- the location of harvesting sites, fishing and sites of social or cultural importance;
- the species that could be taken from harvesting and fishing sites; and
- seasonal information on species availability, and in some cases, site hydrology (e.g. where a site along the river was a permanent waterhole).

The sessions used 1:100,000 topographical maps to locate areas of interest. Notes were taken on the topographical maps and recorded in notebooks.

In the Daly River catchment, river use mapping at Nauiyu Nambiyu suggested that harvesting sites radiate from the community along the Daly River (Figure 8). Additional harvesting sites were indicated along tributaries and low lying floodplain areas downstream of the community. River use mapping conducted with residents from Pine Creek and Kybrook Farm (a nearby community) showed a cluster of sites around Claravale Crossing at the upstream limit of sites, extending downstream for a substantial distance (Figure 8).

Likewise, the information obtained during the river use mapping exercise suggested that customary harvesting trips were distributed well upstream and downstream of the Fitzroy Crossing communities where river use mapping took place (Figure 9).

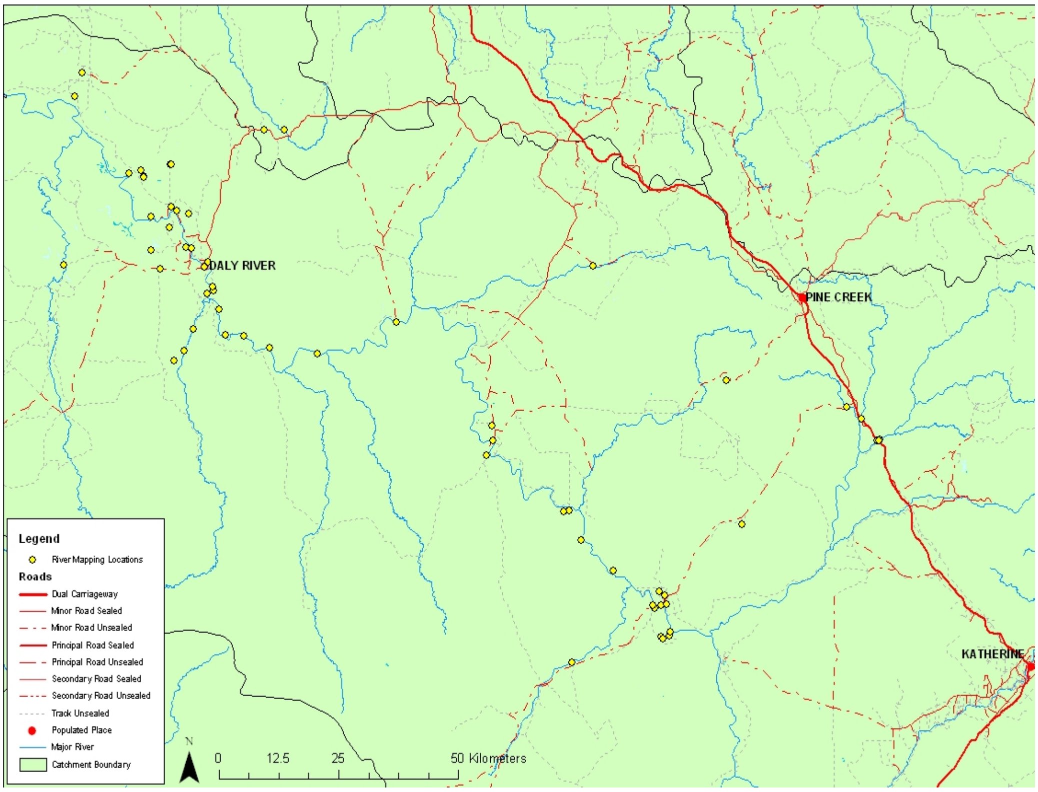


Figure 8: Locations recorded during river use mapping sessions in the Daly River catchment. River mapping sessions were conducted with Indigenous people from Nauiyu (Daly River) and Pine Creek/Kybrook Farm.

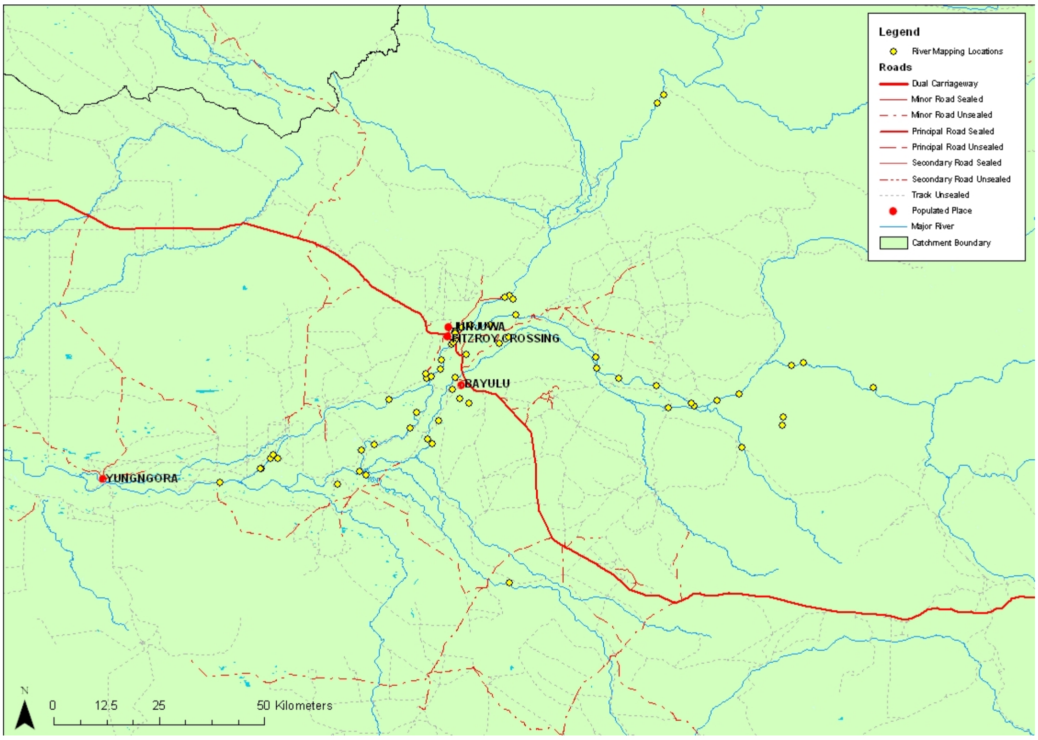


Figure 9: Locations recorded during river use mapping sessions in the Fitzroy River catchment. River mapping sessions were conducted with Indigenous people from several communities in and near Fitzroy Crossing including Bayulu, Muludja, Gillarong, Eight Mile, Junjuwa and Ngurtuwarta.

Overlaying harvesting and fishing effort data from household surveys on maps generated from river use mapping sessions indicated substantial differences in the information obtained using the two methods. In the Daly River catchment, the locations people visited differed from those identified during the river mapping sessions (Figure 10). Many of the sites indicated as places where target species could be harvested were not visited during the eight months recorded by household surveys (Figure 10). In particular, the sites located upstream of Nauiyu, along the main river channel of the Daly River and Chilling Creek, and the sites indicated during river mapping in the area downstream of Claravale Crossing were largely not recorded as being visited during our household surveys (Figure 10). Sites upstream of Daly River crossing are difficult to access for Indigenous residents of Nauiyu as access usually involves the use of a boat to travel upstream; there are few roads that travel along this section of the river.

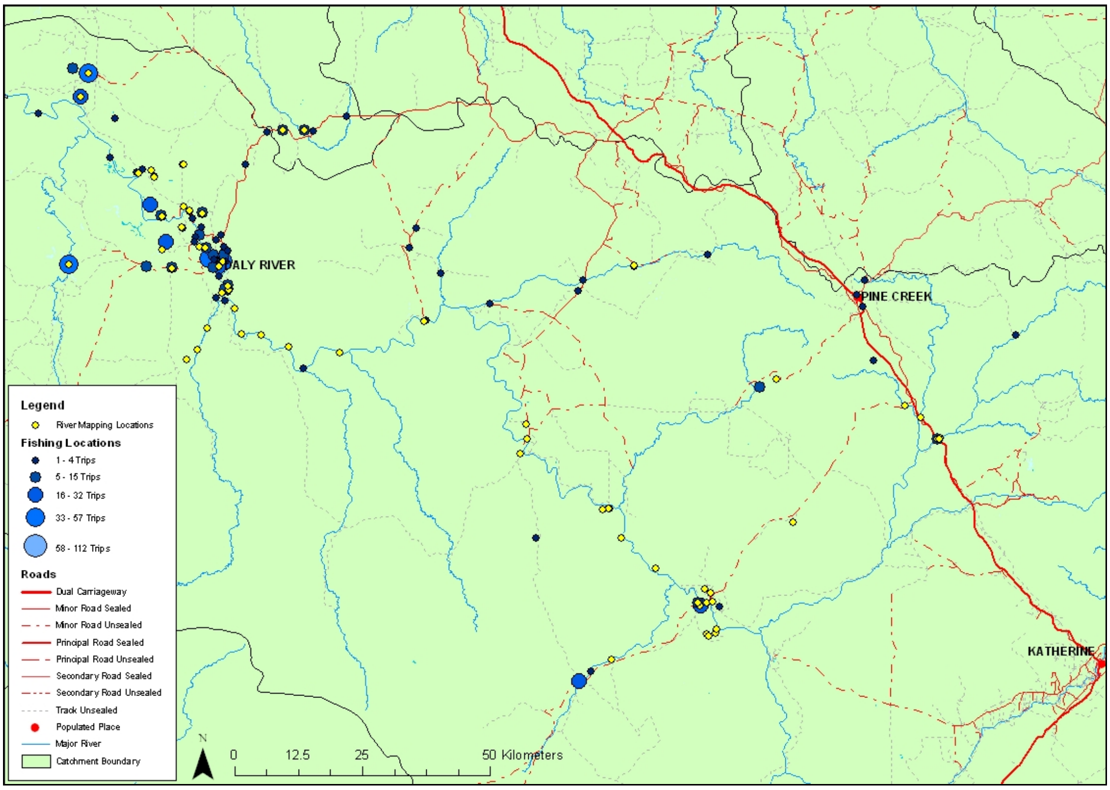


Figure 10: Location of sites indicated by river use mapping participants (yellow points), and harvest sites as recorded during two years of household surveys (blue circles) in the Daly River catchment. The size of the blue circles indicates the number of trips taken to the sites as recorded by household surveys.

In the Fitzroy River catchment, river mapping and fishing locations tend to align more closely than in the Daly River. Sites that were indicated during river use mapping but were not recorded as visited during our household surveys tended to be in areas well upstream of the communities where river use mapping exercises were conducted. Likewise, there is a small cluster of sites on the downstream end of the Cunningham River (a little more than halfway between Fitzroy Crossing and Yungngora) that we did not record as being visited during household surveys (Figure 11). This, at least in part, can be attributed to a group of

Indigenous research participants who were involved in the river use mapping exercise, but declined to be involved in the household surveys. The unvisited area on the Cunningham River is an area they would traditionally use.

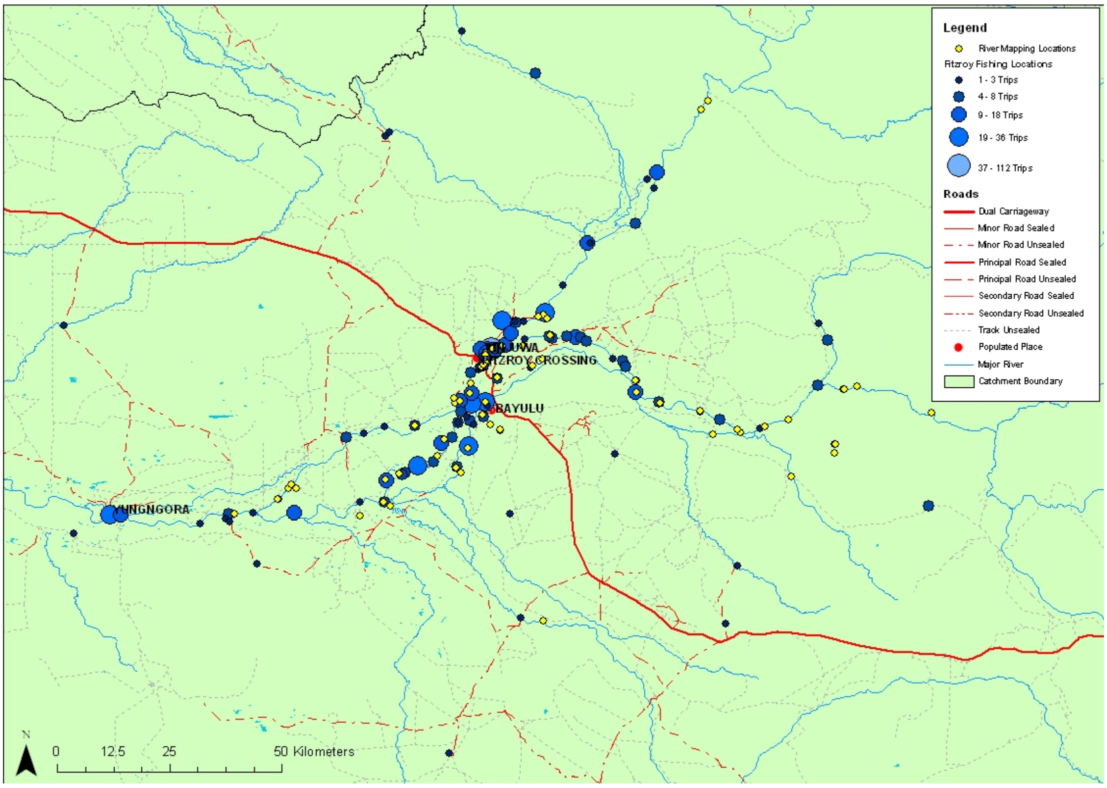


Figure 11: Location of sites indicated by river use mapping participants (yellow points), and harvest sites as recorded during two years of household surveys (blue circles) in the Fitzroy River catchment. The size of the blue circles indicates the number of trips

It is clear from overlaying the results of our river use mapping exercise, and the visitation data from our household surveys, that there are substantial differences in the information obtained. There were a number of locations indicated during our river use mapping exercise that were never recorded as being visited during two years of household surveys. There are a number of reasons this could have occurred:

- visits to locations indicated during river use mapping may have occurred outside of the period of the household survey;
- People not included in our household surveys may have visited these sites; and
- Sites that were not recorded as being visited by household surveys tended to be more remote and difficult to visit than those that occurred in both datasets. The distribution of household survey data suggests that sites with easier access were more likely to be visited. Our river use mapping exercise included no such access constraints.

Comparison of river use mapping data and household survey data suggests that access to fishing locations can play a substantial role in controlling where people go and the frequency of the trips that can be undertaken. The clearest indication of this is the difference between the distribution of sites indicated by the Wagiman people of Pine Creek (Daly) during river use mapping, and the visits to those sites during household surveys. A number of sites downstream of Claravale Crossing on the Daly that were indicated during river use mapping but were not recorded as being visited during household surveys. There are no formed roads to these sites, vehicular access is impossible during the Wet season, and even in the Dry season driving to these sites requires many hours of travel over rough terrain; a sturdy 4WD is required.

A comparison of our river use mapping and household survey site distribution shows us that the two methods of data gathering will not yield the same information. The use of river mapping methods to indicate important sites for customary use will need to take into account the tendency for people to discuss sites that while important and readily recalled, may be remote and visited infrequently. Likewise, the use of household surveys to indicate important sites for customary use will need to account for the likelihood that site visits will not be recorded in time periods between surveys as well as by people not involved in the research.

3.2 Household survey responses – Daly River

Sites recorded as being used by our survey respondents over the two years of household surveys appeared to be clustered around Nauiyu (Figure 12). However, we accessed a larger number of survey households in Nauiyu (21) compared to Pine Creek/Kybrook Farm (16), and Nauiyu community is situated right on the banks of the Daly River, while Pine Creek is approximately 80km by road from the accessible part of the river.

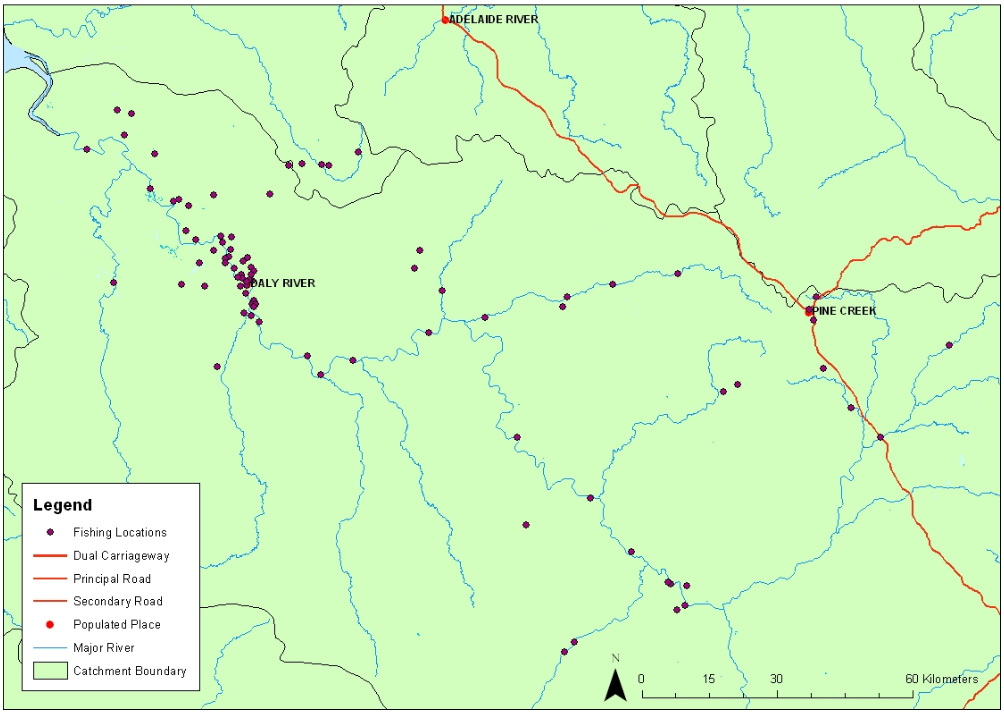


Figure 12: Locations where Indigenous harvest was reported during two years of household surveys in the Daly River catchment. Surveys were undertaken with Indigenous people from Nauiyu (Daly River) and Pine Creek.

The number of trips taken to each site also reflects the higher level of accessibility in Nauiyu (Figure 13). There were a larger number of sites with frequent visits over the two years in Nauiyu, many of those sites being floodplain billabongs like Moon Billabong (to the northwest of the community) and billabongs on Elizabeth Downs Station (to the west of the community). These locations were favourite places for the capture of Long-necked Turtle (*Chelodina rugosa*) and Magpie Goose (*Anseranas semipalmata*). The locations frequently visited by survey households in Pine Creek and Kybrook Farm, while being distant from those communities (approx. 80km to 110km by road), were located on Wagiman Land Trust (held under inalienable freehold title), and were frequented by the Wagiman-Guwardagun Rangers who worked in the area.

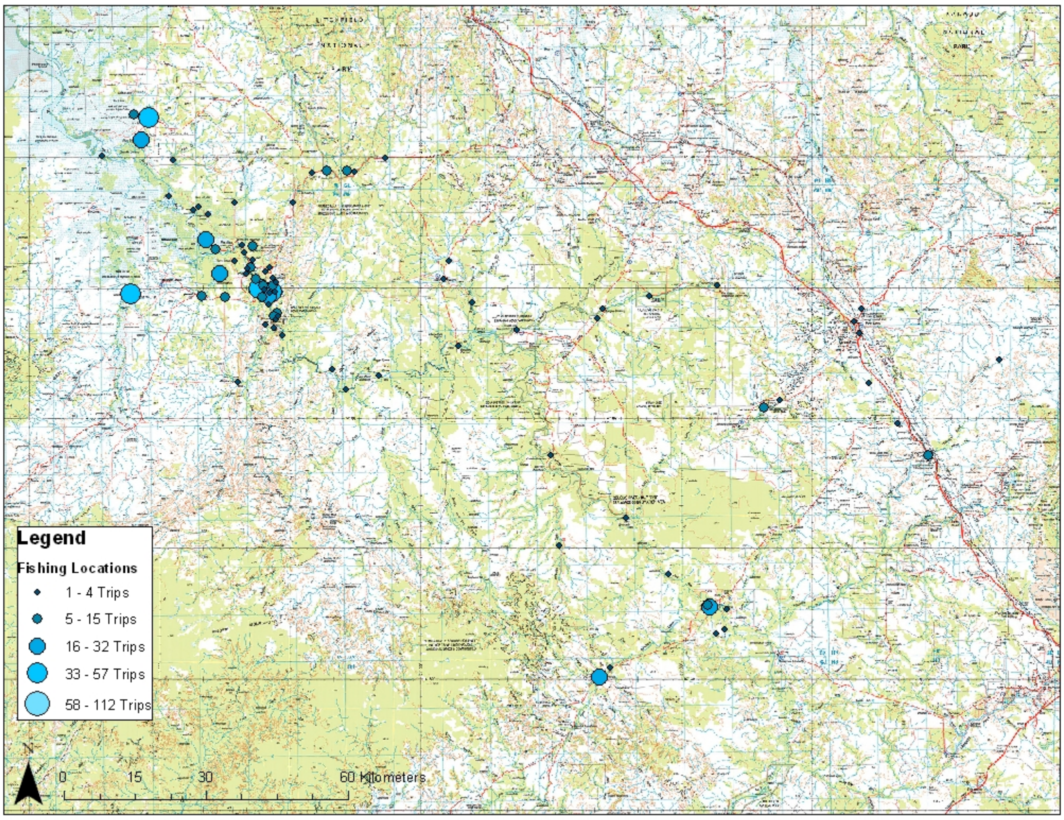


Figure 13: Number of harvesting trips taken to locations in the Daly River catchment. The locations in this map are the same as location in Figure 12.

3.3 Household survey responses - Fitzroy River

Locations of harvest of survey respondents in the Fitzroy were distributed along a long section of the Fitzroy and Margaret Rivers (Figure 14). The number of sites visited over the survey period tended to be slightly higher around the survey communities (Fitzroy Crossing and Yungngora). The slightly lower number of sites seen between Yungngora and Fitzroy Crossing reflects its distance from survey households.

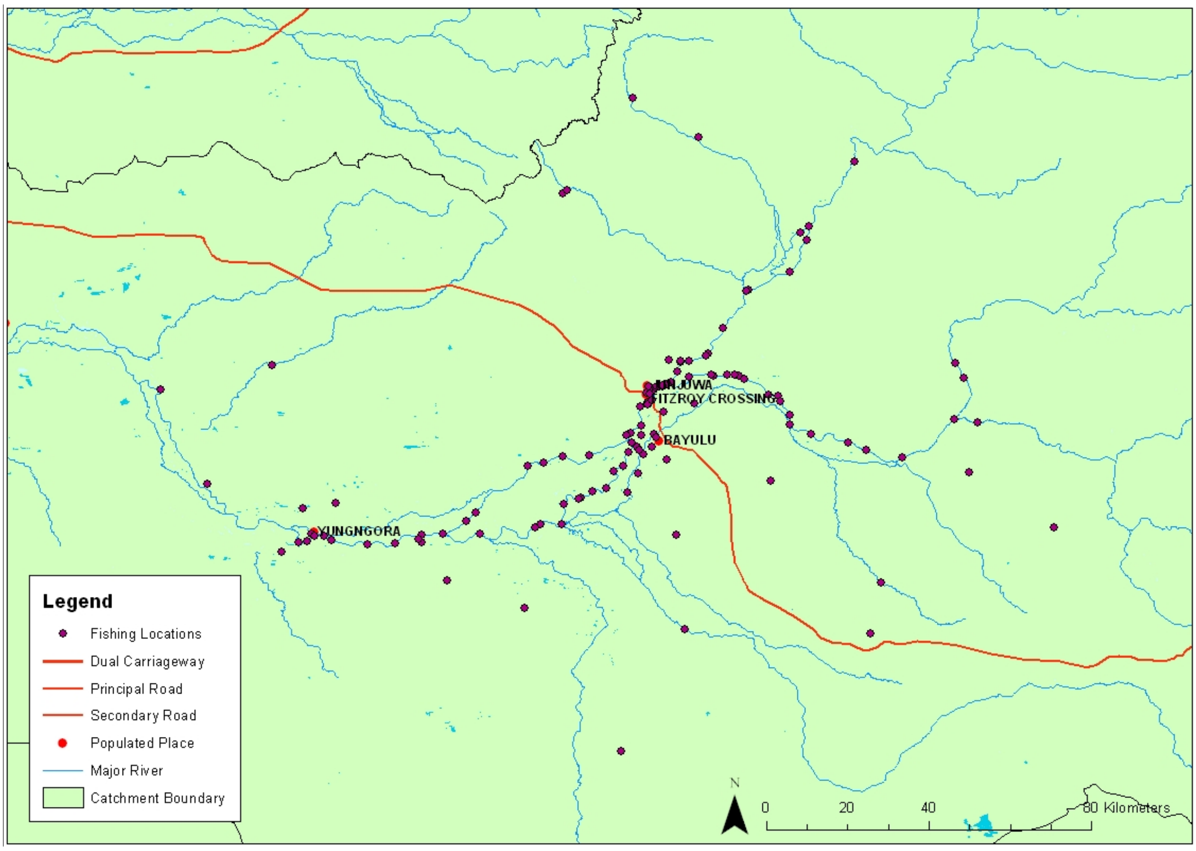


Figure 14: Locations where Indigenous harvest was reported during two years of household surveys in the Fitzroy River catchment. Surveys were undertaken with Indigenous people from Fitzroy Crossing (and small communities within 15 km) and Yungngora.

The frequency of visits to sites over the two year survey period (Figure 15) clearly shows that sites closer to survey households were visited on a more frequent basis than sites distant from those households.

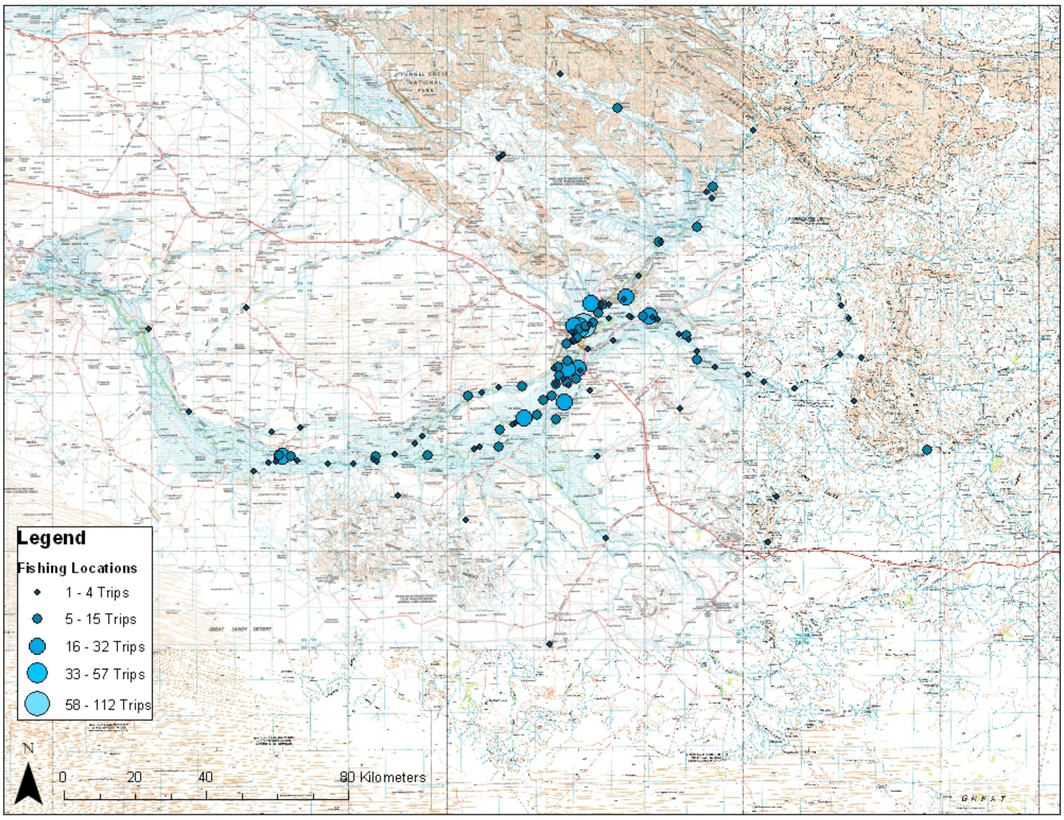


Figure 15: Number of harvesting trips taken to locations in the Fitzroy River catchment. Locations are the same as those shown in Figure 14.

3.4 Annual pattern of resource use from seasonal calendars

3.4.1 Daly River catchment

The Ngan'gi Seasons calendar

- reflects the seasonal cycles of resource availability – and access to sites to hunt and gather, and
- depicts the ecological cues that signal to that people when to start hunting or collecting specific resources.

In contrast to following pre-set calendar dates found in the Gregorian calendar, Ngan'gi seasons are defined by one or more indicative events, which herald the arrival of a new season. These events, or seasonal indicators, can be a combination of ecological, meteorological or metaphysical observations. These key events are known by expert Ngan'gi speakers to indicate the availability of specific food resources. For example:

- When Speargrass (panangalan) seeds begin to shoot people know that the Bush Potato (misyawuni) is available for gathering;
- The appearance of dragonflies (ayiwisi) heralds the beginning of the Dry season, and tell people it's a good time for Barramundi (atalmerr) fishing, and

- The emergence of Red Kapok flowers (yeninggisyi) indicate that it is time to collect Freshwater Crocodile eggs, but once the pods of the same tree turn brown and crack, the crocodile eggs are hatching.

The Ngan'gi Seasons calendar, which depicts one language group's knowledge from the Daly River catchment, has 4 to 5 seasons that fall within the Wet and 8 to 9 seasons that fall within the Dry. This is indicative of the diversity and extent of resource-related events that occur during the Dry, with the key events named as seasons. During the Wet period Indigenous residents of Nauiyu have limited access to hunting sites due to flooding or inundation, and animal species also disperse within the flooded landscape, making them more difficult to hunt. Less availability of food resources results in fewer phenological events, and fewer season names for this part of the seasonal calendar.

According to the seasonal calendar, hunting and gathering of resources starts in earnest toward the end of the Wet season with the collection of fruits during wudupuntyurrutu, when the river rises following heavy rains. During this time Saltwater Crocodile, Echidna and Rock Python are also actively hunted.

The Dry season is coming when the Speargrass stalks start to die and turn a reddish colour while the big Wet is subsiding. This season is known as wurr wirribem filgarri, and is when people actively hunt for Prawns in the river and creeks.

The Dry season has started when the wind blows from the east and Spear grass seeds have turned brown and start falling to the ground. This season is known as wurr bengim miyerr. It is the Dragonflies that indirectly bring the wind in the early Dry, as their arrival wakes the big Black Kangaroo (agurri) that lives in the hills who then sings the wind, blowing it from the east. The Dragonflies indicate to people that it's time to fish for Barramundi. This seasonal observation by Ngan'gi speakers is clearly reflected in the household survey data. As shown in Figure 27, Barramundi harvesting strongly peaks in the Early Dry before reaching the lowest levels of harvest in the late Dry. Data collected by the TRaCK Fish and Flows project over a five year period clearly indicates that Barramundi are more abundant in the early Dry season (June) than they are in comparison to later (September/October) (B. Pusey *pers. comm.*)

Wurr bengin derripal is a season name that literally translates to 'it's knocked the grass into a bent over position.' It refers to the times of the year when storms push the Spear grass over. It is still raining, and is a good time for harvesting Magpie Goose eggs, so there is still a fair amount of water around to support the floating nests. This time might be thought of as the Late Wet/Early Dry season. This time of the year is known to be good for Catfish, but not yet time for hunting other fish.

Resource collection starts to ramp up with the arrival of Wirirr marrgu. The Dry season is in full-swing, and the Spear grass is being burnt and black ash is on the ground. People are clearly influenced by the temperature as they have a 'good feeling' about going hunting and looking for turtle at this time as one doesn't get too hot. It is now time to fish for Black Bream, Archer Fish, Mullet, Cherabin and Prawns, and target Barramundi living in the creeks. As shown in Figure 28 the greatest numbers of Black Bream were harvested in the Early Dry and Mid Dry surveys, as described in the sequential seasonal events of the calendar.

As the billabongs levels have dropped significantly since the beginning of the Wet, a range of lilies can now be accessed along the margins of billabongs and swampy areas. Water dependent species targeted now include *Nymphaea macrosperma* (Waterlily), *Nulumbo nucifera* (Red Lotus Lily) and *Eleocharis dulcis* (Water Chestnut). *Horsfieldia australianum* (Native Peanut), found in monsoon vine forests, and *Marsdenia viridiflora* (Bush Banana) are also collected now. With the water levels lower, it is also much easier to collect mussels and crabs on the now-exposed edges of billabongs, creeks and springs.

During this season, as the muddy margins of billabongs become exposed with the drop in water level, turtle hunting begins. According to the Ngan'gi Seasons calendar turtle hunting will intensify over the coming seasons (and months) as the water retracts further. The heating and drying experienced over the coming season will create increasing areas of drying billabong margins. This soft mud will be searched with crow-bars and feet in an attempt to find hibernating animals. It is said to be the best time for hunting turtles hiding under the mud, when the seasons of Ngunguwe and Lirrimem are occurring. During this period it is very hot and humid and there are mirages on the horizon and the river water is warm. This knowledge of harvesting time is reflected in Figure 25. The graph shows a distinct increase in harvesting rates for Long-necked Turtle from the Wet to the Late Dry.

During this very hot part of the year the bark of the Ghost Gums starts peeling, and this indicates that shark are fat and ready to catch. The river is really low now and it is a good hunting time for Stingray and Sawfish.

There is also a seasonal name (or sub-seasonal same) that describes the time of the year that Pig-nosed Turtle are known to be laying eggs. Memenyirr is the season name that literally translates to both 'hot burning sand' and the Pig-nosed Turtle lifting her feet to cool them as she lays her eggs in the hot burning sand. It is interesting to note that no data emerged from the household surveys about the collection of turtle eggs as a resource, although Pig-nosed Turtles were hunted as a resource. This phenological observation falls into a rare category of not directly informing resource use, however it is possible that this important observation (as indicated by it being termed a 'season') may historically have told people when to hunt Pig-nosed Turtle eggs.

With the first rains of Kudede Green Tree Ant queens are ready for eating and the turtles start moving after hibernating through the Dry. The turtles are said to still be fat at this time and still good hunting if you can find them.

MalakMalak and Mangala plant knowledge

The seasonal calendar undertaken with senior MalakMalak language speakers focused on significant plant species and their use and availability throughout the seasons.

MalakMalak speakers identify seven seasons that describe the annual cyclical rain and wind patterns within their country on the Daly River. MalakMalak phenological knowledge of plants is rich, but as much of the information does not relate specifically to water dependent species, and therefore river flows, it will not be discussed in detail here.

Some points to consider however are:

- The flowering of *Cochlospermum fraseri* (Yyety) signals that Freshwater Crocodile eggs are ready to be collected and eaten;

- *Dioscorea transervsa* (Nimir), is found in jungle patches and is dug up during the season of kaleykaley – the time at the beginning of the Dry season when the refreshing wind called kaleykaley begins to blow;

- *Dioscorea bulbifera* (palaty) is the yam that you dig up when you hear the 'cheeky yam grasshopper' also called palaty singing out to let you know it is ready.

While MalakMalak people are the recognised traditional owners of country in the vicinity of Nauiyu community, Nan'gi language speakers, whose country is toward the mouth of the Daly River, have grown up in Nauiyu and surrounding areas and also hold intimate knowledge of phenology and seasons in this area, as shown in the Ngan'gi Seasons calendar.

3.4.2 Fitzroy River catchment

Gooniyandi Seasons Calendar (Mingayooroo – Manyi Waranggiri Yarrangi)

Gooniyandi country is found in the vicinity of the Margaret River, a major tributary of the Fitzroy. There are three defined seasons recognised by Gooniyandi language speakers:

1. Yidirla: Wet season time when the river runs;
2. Moongoowarla: the overarching season of cold weather which is subdivided into two seasons:
    a. Ngamari: female cold weather time, cold days and cold night, and
    b. Girlinggoowa: the milder male cold weather time; and

3. Barrangga: very hot weather season.

The rain, winds and storms that arrive in Goonyiandi country from four different directions are generated by four different snakes of four different skins. These weather events are strongly tied to ecological observations and phenological knowledge that both describes and reveals key resource events. There is a strong focus on resource events that are tied to the river (Margaret River), rather than billabongs or springs.

Rain, wind and river levels are explained by Gooniyandi as a complex cycle of linked events. For example:

- Barndiwiri is the first rain storm of the Wet season. It is associated with the Jangala snake and arrives from the North. People know that this storm will make the rivers run.

- When the river runs for the second time several different fruits are ripe (including *Flueggea virosa* and *Ficus coronulata*) are washed into the water, feeding the fish and turtles.

- When the river and creeks are running it is good fishing for catfish and the bigger fish – Black Bream, Barramundi, Sawfish, Stingray and turtles. The household survey data supports these observations, as the highest numbers of Catfish were taken by residents in the Fitzroy during the Wet and Early Dry data collection periods, when the river and creeks are running (Figure 31), and Barramundi was also reported to have the highest harvesting numbers for the Early Dry survey period (Figure 33).

- Fish are said to shut their mouths when the Moongoowarla wind starts blowing from the East and the weather cools.

- As the west season rains finish the wind changes direction and the Garrawoorda blows from the South. The water is high and this is a good time for catching Sawfish. The appearance of red Dragonflies at this time also tells you Sawfish are fat.

- March-flies will arrive during Moongoowarla when all of the fish are fat and when Freshwater Crocodiles are laying their eggs – as the Marchflies are said to protect them during this time. This is a particularly good time for Bony Bream, Catfish, Long-necked Turtle, Barramundi and Spangled Perch.

- During Barrangga (the hot period at the end of the Dry) the pools in the river channel continue to dry and get smaller. When fishing these pools, trapped sawfish and Barramundi won't bite, while Catfish and Bream will run for the bait. To catch Barramundi and Sawfish people have to target the larger, deeper river pools. According to the household data, catfish were caught more in the Late Dry than the Mid Dry and this might reflect the harvesting success of this species in small remnant pools (Figure 31).

- At the very end of the Dry season when it is very hot, Black Bream, Catfish and Longtom will stop biting and start carrying and laying eggs. As shown in Figure 30 there was a slight decrease in the number of Black Bream harvested per trip between the Mid Dry and the Late Dry survey periods, which might be explained by this seasonal observation.

Walmajarri Words from the Riverside (Walmajarrijarti Wangki Martuwarra Kadaji)

Walmajarri people originate from desert country and have migrated into the river area from southern desert locations during the last 50 years (Toussaint 2010). The Walmajarri research participants who worked on the Walmajarri fishing calendar grew up with Gooniyandi people along the river, and became keen and proficient fishers, learning seasonal indicators and other resource harvesting cues. The Walmajarri calendar combines Walmajarri seasonal names with knowledge of both desert and river country. In compiling the calendar, and discussing river country, the participants consistently sought to qualify their observations by asking that we check with Gooniyandi speakers, as they felt they weren't qualified to provide such information.

Three main seasons are identified by Walmajarri speakers:

1. Parranga: hot weather time
2. Yitilal: raining time

3. Makurra: Cold weather time

The following seasonal information from the Walmajarri calendar contributes to the discussion on Indigenous knowledge of water-dependent resource use:

Parranga:

- This is the best time to catch Catfish, Barramundi, Bony Bream, Spangled Perch, Archer Fish and Cherabin. The Burrowing Sand Frog is used as bait to catch Catfish. Each of these species, except for the Archer Fish, is listed in the top ten species, by number of individuals caught, for the Fitzroy region. Catfish are listed as the fourth most numerous species caught, with frogs, a popular bait for a number of fish including Catfish, being the eighth most common 'species'.
- The Walmajarri calendar states that small Bony Bream and Spangled Perch are used as bait, and these are the two most commonly caught species in the Fitzroy.
- Freshwater mussels can be used or bait in place of red meat. When the paperbarks are flowering it is a sign to collect mussels – as the nectar from the flowers, and droppings from the flying fox fall into the water feeding the mussels.
- The white flowers of *Atalaya hemiglauca* indicate that Freshwater Crocodiles are laying their eggs, and it is time to collect them.
- Water Chestnuts (from the roots of the water lily) are collected more easily during parranga when the water is low.

Yitilal:

- Two figs, *Ficus racemosa* and *Ficus coronulata* grow along the banks of creeks and rivers. Heavy rain washes the ripe figs into the water, feeding the fish and making them fat. If there is a poor Wet season the fruit don't wash into the river and the fish stay skinny as they only have weed to eat.
- When the water is high you can fish for Bony Bream, freshwater crabs and the big brown frogs found in the billabongs.
- After the rain, when people can access the river again, the first thing they seek is bait. Meat on a hook will attract freshwater crab. People will fish the billabongs to catch Bony Bream, which is used as a berley as well. The small fish are crushed and put on the side of the bank at the waterline - so it slowly washes away and attracts bigger fish. According to survey data, Bony Bream was the number one species harvested (according to numbers of individuals), supporting the idea that Bony Bream is targeted in high numbers as a bait fish, as described in the calendar.

Makurra:

- During the cold season it is a challenge to catch fish, but larger bony bream are targeted with a special bait of salted beef. Other fish don't like salted bait so Bony Bream can be targeted in this way. Catfish sometimes bite during the cold weather if they are hungry.

- Shallower pools in the river channel as well as creeks and billabongs are the main focus of fishing during makurra (the cold weather time).
- Archer Fish can be caught at this time, using the tail end of a grasshopper or frogs legs as bait. It is difficult to catch Cherabin during the day, so people try harvesting them in the afternoons and evenings.

Both the Gooniyandi and Walmajarri calendars reported that during the cool season it is hard to catch fish. However, this observation is not reflected in the "harvest per trip" rate data. Interestingly, the surveys show a reduced number of trips being undertaken in the cool season, presumably as a result of people's knowledge that fishing is harder. However, it is possible that the "harvest per trip" rates stays high because the more knowledgeable and therefore successful fishers are those who persist and those that don't go are those who are usually unsuccessful. Further analysis into individual household fishing effort and success during the cool periods would clarify this issue.

3.5 Household surveys

3.5.1 Frequency of trips by community

The frequency of harvest trips undertaken by survey respondents ranged from 0.49 trips per fortnight by residents of Pine Creek, to an average of 2.7 trips per fortnight by residents of Muludja (Figure 16). Overall, survey respondents from the Daly River tend to undertake more harvesting trips (1.52 trips per fortnight) than survey respondents from the Fitzroy River (1.37 trips per fortnight).

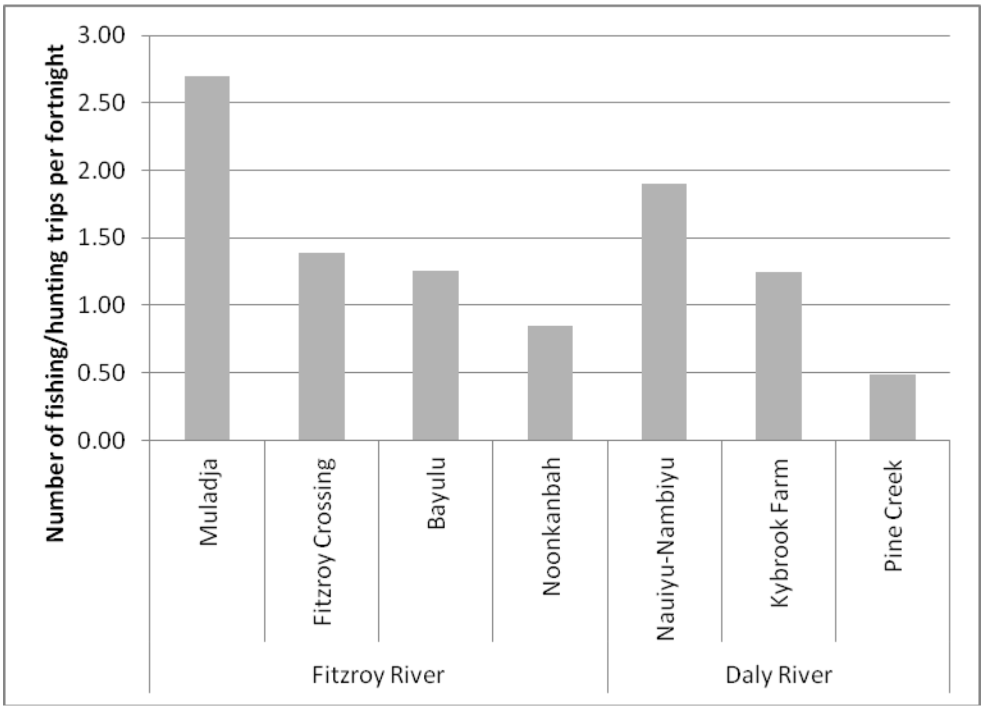


Figure 16: Number of trips per household survey (per fortnight) undertaken by survey respondents in communities in the Fitzroy River and Daly River catchments.

3.5.2 Seasonal pattern of trips

The seasonal pattern of harvesting effort is different between the Daly River and Fitzroy River survey respondents. Figure 17 suggests that this difference is related in part to the number of harvesting trips undertaken in the Wet season. The frequency of harvesting trips is at its lowest in the Daly catchment during the Wet season, while the frequency of harvesting trips is at its highest during the Wet season in the Fitzroy.

This is likely to be related to the flow regime differences and its effect on access to harvesting locations in the two catchments. In the Daly River catchment, the locations in which our survey respondents live tend to become completely isolated by floodwater during the Wet season. Survey respondents can do some fishing in the floodwaters surrounding their communities, but much of the country they usually visit for harvesting activities is either completely inundated, or cut off by flooding. During our household surveys at the height of the Wet season in 2009 and 2010 in the Daly River, 45% of respondents mentioned they had not been fishing because "the water is too high", "too boggy' or the river was "running too hard", compared to a similar response from only 8% of survey respondents in the Fitzroy.

While harvesting locations are also isolated by floodwaters in the Fitzroy catchment, flooding in the Fitzroy and Margaret rivers stays largely within the river channel. This allows our survey respondents, most of whom live within walking distance of the river channel, ready access to the river for fishing (as shown in Figure 7 below). This period in the Fitzroy is also well known as an excellent time to catch Barramundi and Catfish at locations where flooded creeks are running back into the river. Fitzroy River survey respondents often commented on people "going mad for Barramundi" at this time, and so the fishing effort was substantial, as the following graph illustrates.

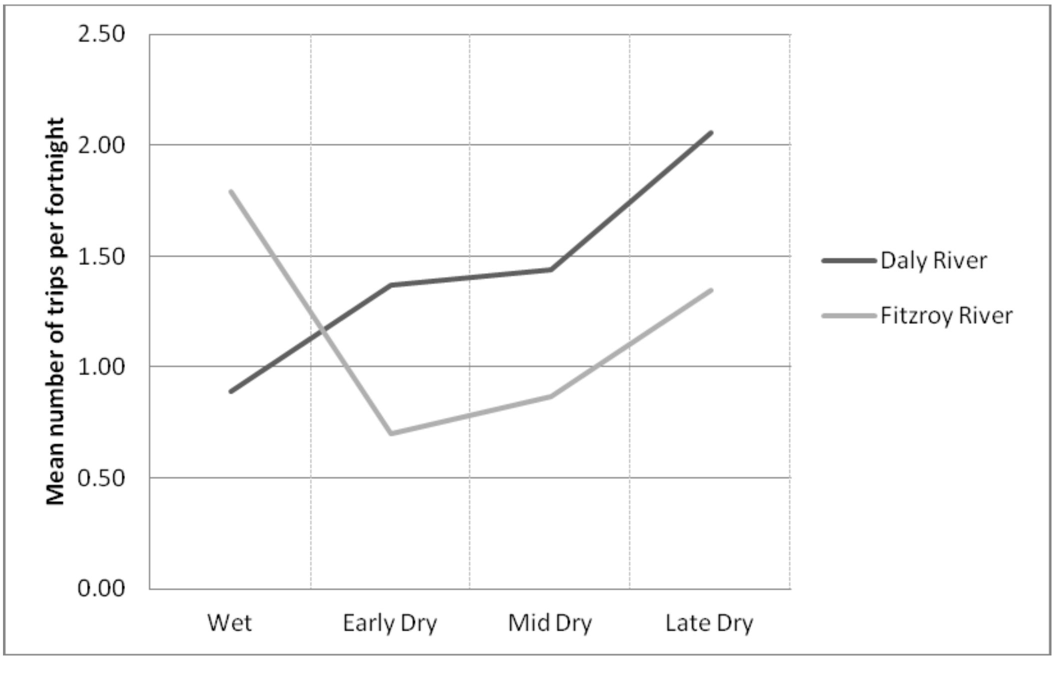


Figure 17: Mean number of trips per survey (per fortnight) for survey households in the Fitzroy River and Daly River catchments.

3.5.3 Frequency of trips by habitat

There are substantial differences in the way survey respondents in the Fitzroy and Daly river catchments use aquatic habitats. Harvesting activities in the Fitzroy River are largely focussed on use of the main river channel (Figure 18). Visits to the main river channel make up more than 70% of all trips in the Fitzroy, regardless of the season. Harvesting activities in the Daly however, showed a clear switch from use of the main river channel during the Wet season, to billabongs becoming the focal point of activities as the Dry season continued (Figure 18). By the Late Dry season, 70% of all Daly trips are to billabongs, whereas at the same point in time in the Fitzroy, billabongs account for only 10% of trips.

The Daly River catchment contains much more seasonally inundated floodplain and billabong habitat than the Fitzroy catchment. Two of the five highest value species in the Daly catchment are readily caught from billabong habitats. Long-necked Turtle are found buried in the mud of drying billabongs using long sticks before being dug up and eaten. Magpie Geese are also very abundant late in the Dry season as they move into drying billabongs to feed. Aboriginal people shoot and eat them in large numbers at this time of year, and so it is a popular time to undertake harvesting trips to billabong habitats.

Another notable difference between the catchments is the relative difference in effort directed towards harvesting from spring-fed habitats in the Daly. At their most popular in the mid-Dry season, spring-fed habitats account for 11% in the Daly, whereas in the Fitzroy they only account for 4%.

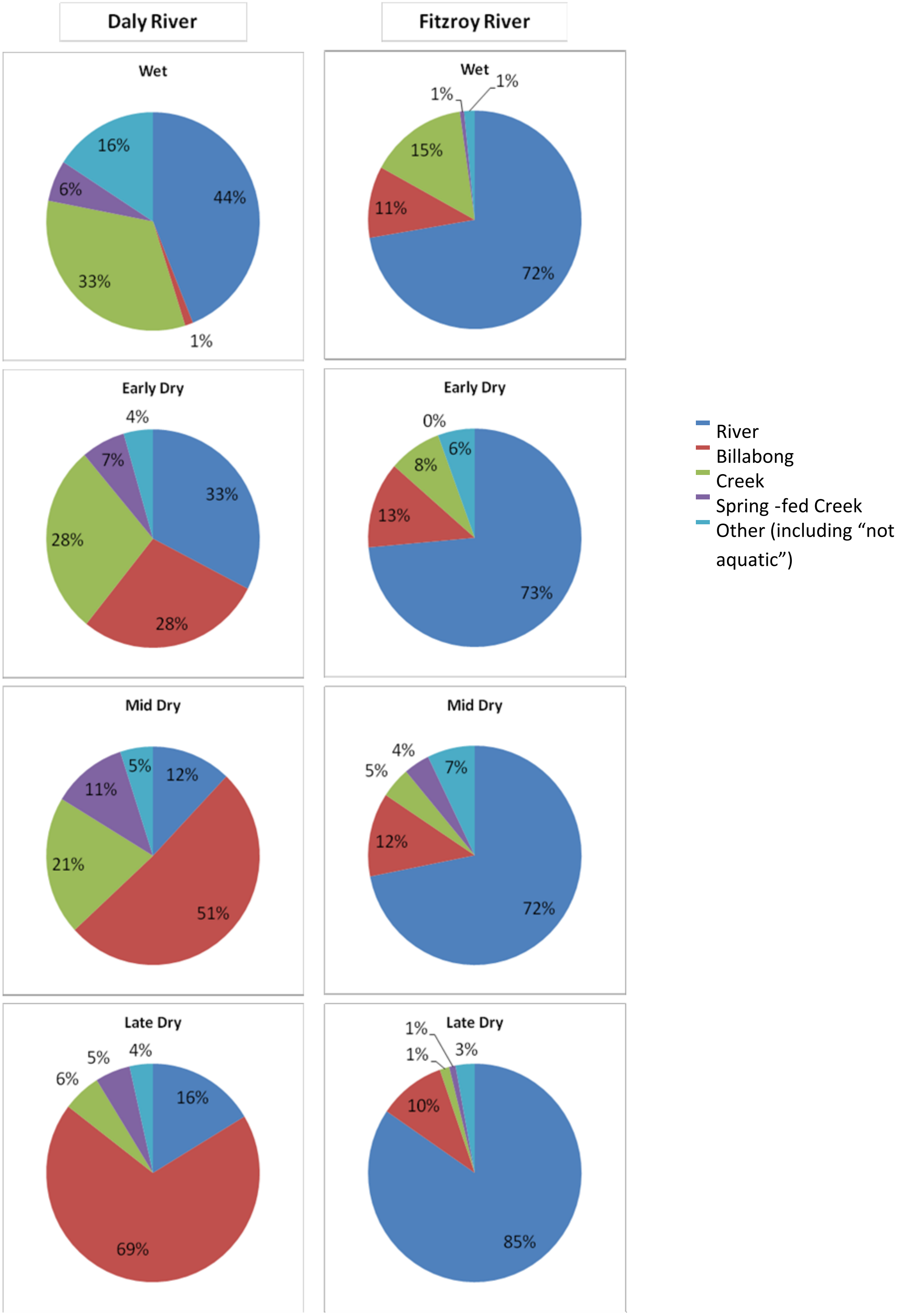


Figure 18: Percentage of trips visiting habitats in the Daly and Fitzroy River catchments.

3.5.4 Species caught and consumed in highest numbers[4]

Long-necked Turtle (*C. rugosa*) are the species harvested and consumed in the highest numbers in the Daly catchment (Figure 19). Four of the top five species harvested in the Daly catchment are non-fish species, with Black Bream (*H. fuliginosus*) the only fish species to be harvested in numbers high enough to make the top 5. This reflects the frequent, and widespread use of, billabong habitat in the Daly catchment. Much of the harvesting effort in the Daly focuses on billabongs (Figure 18), and as a result species like Lotus Lily, Magpie Goose and turtle are taken in high numbers. These results confirm the importance of billabongs to Indigenous resource use in the Daly and highlight the need to sustain required flows.

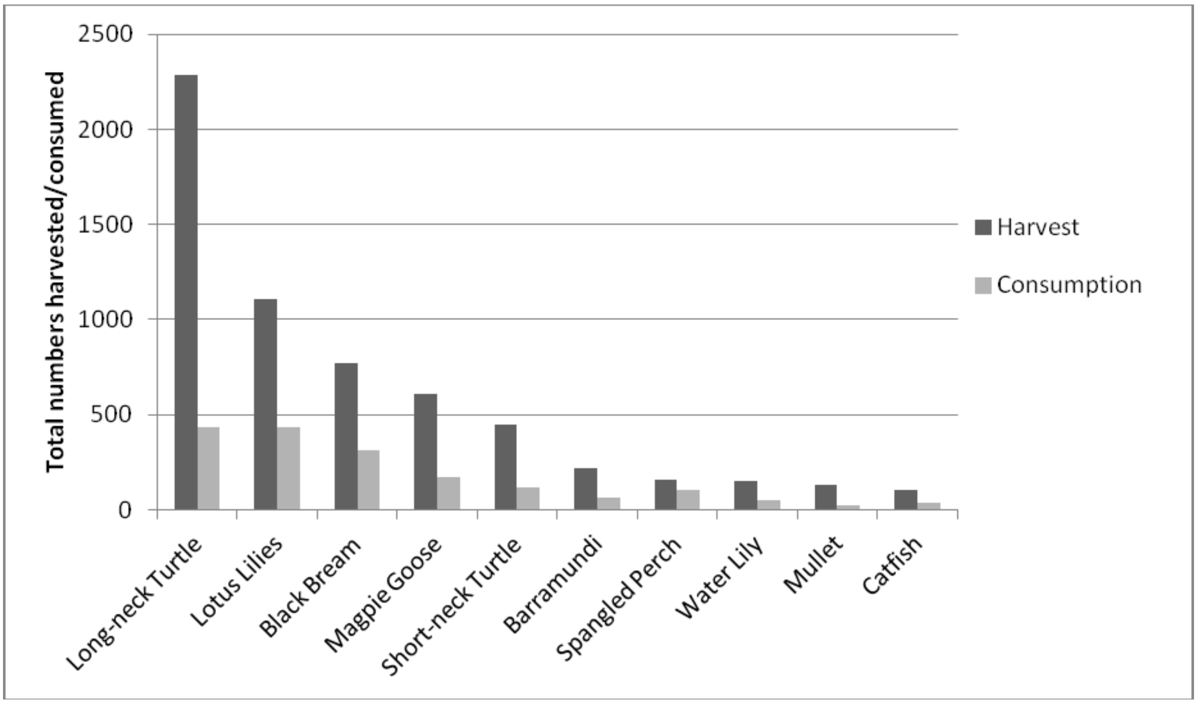


Figure 19: Harvest and consumption of the ten species captured in the highest numbers by survey households in the Daly River catchment. "Harvest" is the total number of individuals of a species harvested by all people involved in the trip, while "consumption" represents the number of species taken home and consumed by the survey households.

[4] A brief note on Figure 19 and Figure 20 is relevant here, as the presentation of both "harvest" and "consumption" numbers can cause confusion. "Harvest" is the total numbers of a species caught by all households involved in a trip. The data was collected by asking survey respondants to "tell us about everything that was caught on your trip". This "harvest", could be taken home by non-survey households involved in the trip, or shared amongst the community at a later time.

"Consumption" on the other hand, represents the numbers of a species *actually used or consumed by people living in the survey household*. It is particularly important to note that the difference between harvest and consumption does not represent discards, or waste. Rather, it represents that amounts caught on a trip, as opposed to the share obtained by the survey household. There was very little waste – one of our survey response categories for "sharing" was "discarded or thrown back"; and this represented only 5% of our survey responses.

Four of the five species harvested in the highest numbers in the Fitzroy catchment were fish species (Figure 20). Two of these fish species, Bony Bream and Spangled Perch, are small bodied species predominately used as bait for catching other fish. Black Bream (*H. jenkinsi*) and Catfish (*Neoarius* spp.) are two popular food species, and were harvested in relatively high numbers. These results are supported by Toussaint's qualitative data on fishing in the Fitzroy (2010) where Black Bream is 'regularly caught if not always actively sought' because they are easily hooked and can be cooked and consumed on the spot. Cherabin (*M. rosenbergii*), also known as freshwater prawns, are a large-bodied decapod crustacean that is captured from rivers and billabongs. Smaller sized Cherabin are used for bait, while the larger bodied individuals are eaten. Cherabin are found in much larger sizes later in the Dry season.

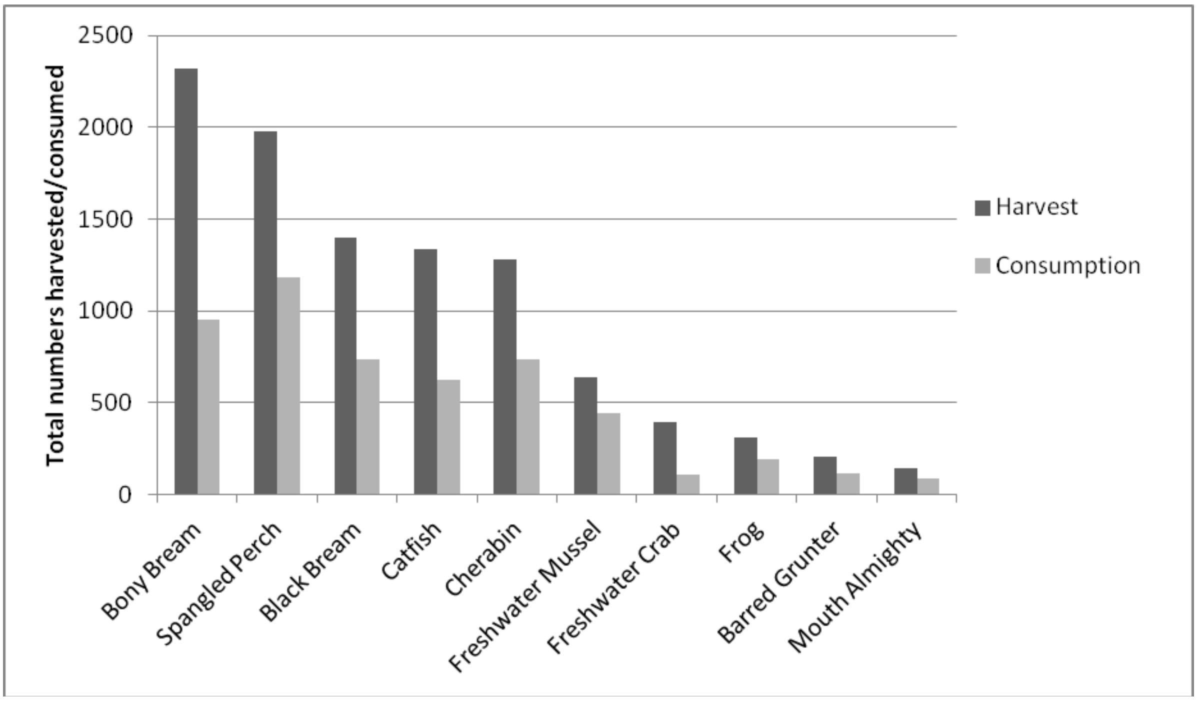


Figure 20: Harvest and consumption of the ten species captured in the highest numbers by survey households in the Fitzroy River catchment. "Harvest" is the total number of individuals of a species harvested by all people involved in the trip, while "consumption" represents the number of species taken home and consumed by the survey households.

The results show that the household consumption of species was always lower than the amount harvested. "Harvest" accounted for all individuals captured during the harvesting trip, and as such could account for the effort of more than one household. In addition to this, "consumption" of a household included only those individuals of a species that were used by the survey household. This use could include the immediate use of a species as bait or burley by a household or later use (such as for food) when people returned home.

The difference between trip harvest and household consumption also reflects the amount of sharing that occurs between households, families and communities. Although it is not possible to completely distinguish the effect of multiple households on a trip from the amount of harvest shared outside of the trip, investigation of a number of species suggests sharing in many cases is substantial.

This is indicated clearly in the Daly River (Figure 19). Long-necked Turtle for example are a popular species, harvested in large numbers late in the Dry season as billabongs begin to dry. Because it is an air-breathing species capable of surviving for long periods out of water, turtle stays alive (and fresh) well after it is harvested. This makes it an ideal species to be shared and gifted outside of the group involved in the harvesting trip. In contrast, Spangled Perch are a small bodied fish most commonly used for bait. They survive for short periods of time outside of water, are only eaten when they approach their maximum size, and so the common use is as bait to catch larger species of fish. As can be seen in Figure 19, 66% of Spangled Perch harvested in the Daly River are consumed by the survey household, while only 19% of harvested Long-necked Turtles are consumed by the survey household. Many larger species, particularly species capable of surviving after capture such as Long-necked and Short-necked Turtle, and iconic species such as Barramundi and Magpie Goose, are shared extensively. Black Bream appear to fill an intermediate role, where some sharing is common, but they are also immediately eaten. As noted by Toussaint (2010), the smaller size of Black Bream is appealing to people as they can each have their own around the campfire “just sitting on the lap”.

3.5.5 Species with greatest replacement value (entire harvest)

With the exception of the Lotus Lily, the species that made the largest contribution to replacement value in the Daly River (Figure 21) were also the species that were harvested in the greatest numbers (Figure 19). The five species with the highest replacement value (harvest) in the Daly River accounted for 91.6% of the total replacement value.

Most of the species harvested in large numbers in the Daly River were relatively large-bodied species, with the bait species commonly harvested in the Fitzroy River (Figure 20) not being harvested in great numbers in the Daly River. This can be attributed to the target species and fishing methods utilised. The main harvesting methods for Long-necked Turtle (searching drying billabongs) and Magpie Goose (shooting) do not involve the use of fishing lines and bait. Black Bream and Catfish, although harvested using baited fishing lines, are most often targeted in the Daly River using “meat bait”: flesh from a wallaby, kangaroo, pig or store bought meat. Barramundi is often caught using lines baited with small fish, but is often targeted using artificial lures. Given the species targeted and the methods used, the use of cast nets for gathering bait species was not as common in the Daly River as in the Fitzroy River, and so small bait-sized fish species such as Bony Bream and Spangled Perch did not feature as predominately in catches.

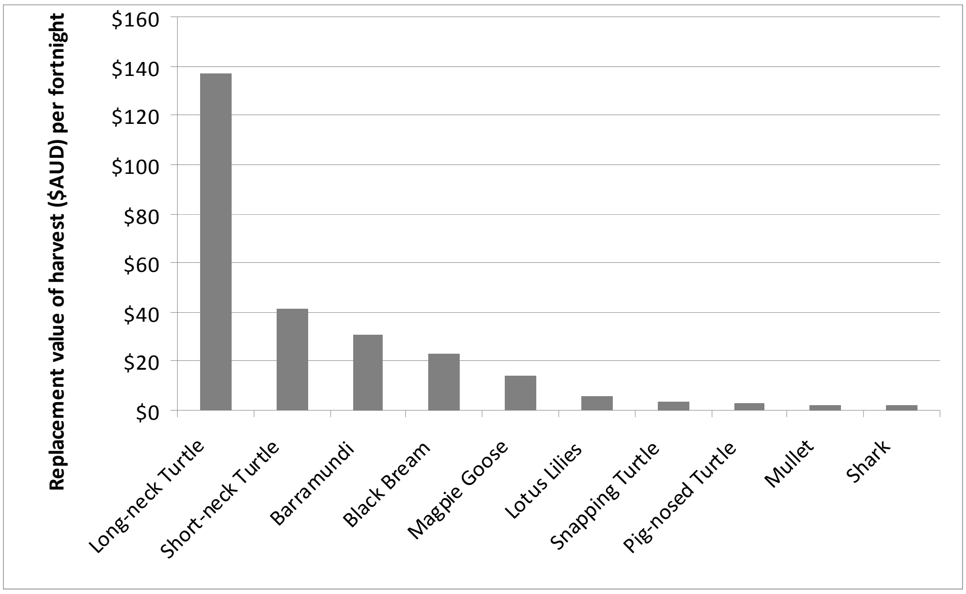


Figure 21: Fortnightly replacement value of aquatic species harvested on trips by survey households in the Daly River between October 2008 and September 2010. Figure shows only the ten most valuable species.

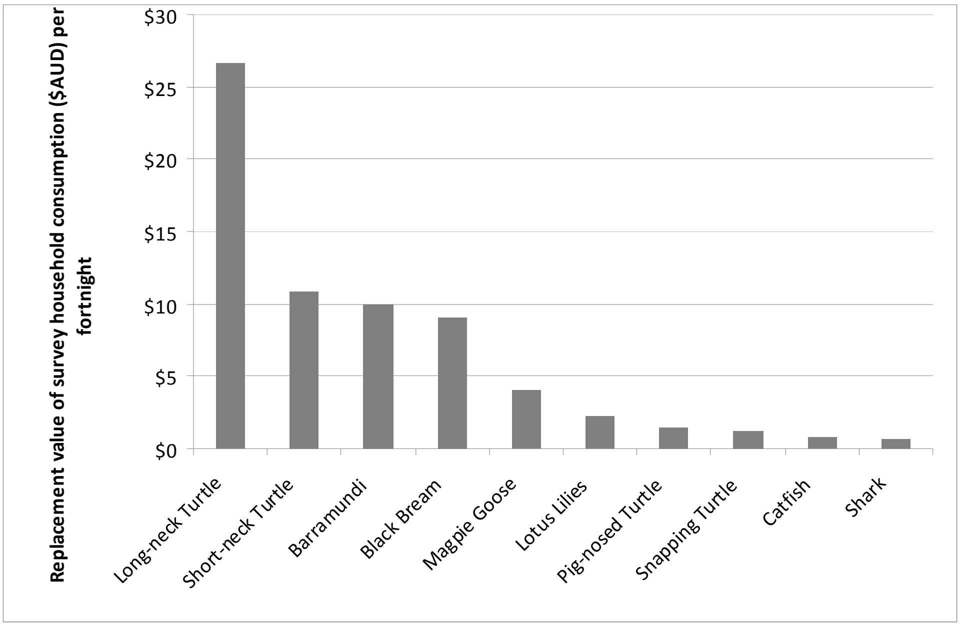


Figure 22: Fortnightly replacement value of aquatic species consumed by survey households from the Daly River, in the two years between October 2008 and September 2010.

Bony Bream and Spangled Perch, the two species harvested in the highest numbers in the Fitzroy River (Figure 20), did not feature in the five species making the largest contribution to replacement value. The five species with the highest replacement value (harvest) in the Fitzroy River accounted for 91.7% of the total replacement value.

Black Bream and Catfish made a large contribution to replacement value, as they were harvested in relatively high numbers, and are larger bodied fish species that make them an ideal food supply (Figure 23). Toussaint (2010: 6) argues that Black Bream is favoured because the comparatively small size means that ‘everyone can be around a campfire and have a fish of their own just sitting on the lap’. Sawfish and Barramundi were harvested in lower numbers than many other species, but their large size (up to 2m long for Sawfish, and to 1m long for Barramundi) mean that each individual has a high replacement value.

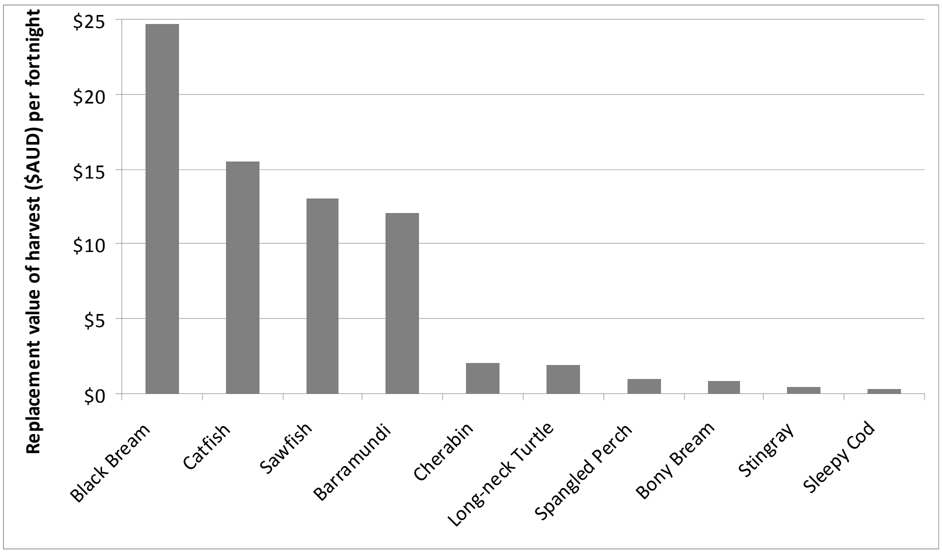


Figure 23: Replacement value of aquatic species harvested on trips by survey households in the Fitzroy River between February 2009 and November 2010. Figure shows only the ten most valuable species as defined by this method of valuation.

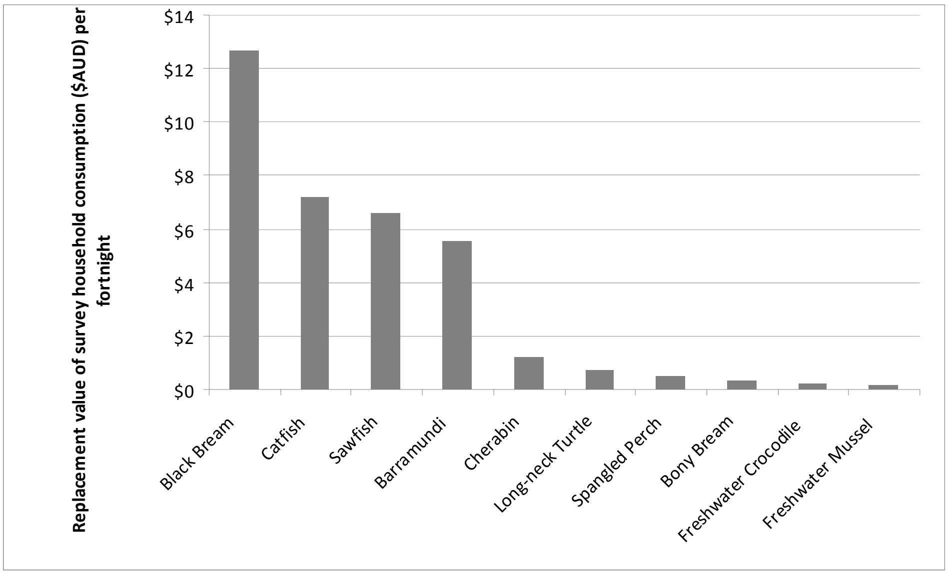


Figure 24: Replacement value of aquatic species consumed by survey households from the Fitzroy River, in the two years between February 2009 and November 2010.

3.5.6 Daly River: Seasonal harvest patterns for the top 5 ranked species

Long-necked Turtle (Chelodina rugosa)

Long-necked Turtle were harvested in much higher numbers late in the Dry season (Figure 25), during which time many of the seasonally inundated billabongs in the Daly begin to dry. Adult Long-necked Turtle aestivate in the mud of drying billabongs until the following Wet season. During this period, people search the billabongs, pushing long, narrow sticks into the mud until the feel a turtle shell. Turtles are then dug out of the mud and can be cooked immediately, or kept alive for a period of time and shared with relatives and other families.

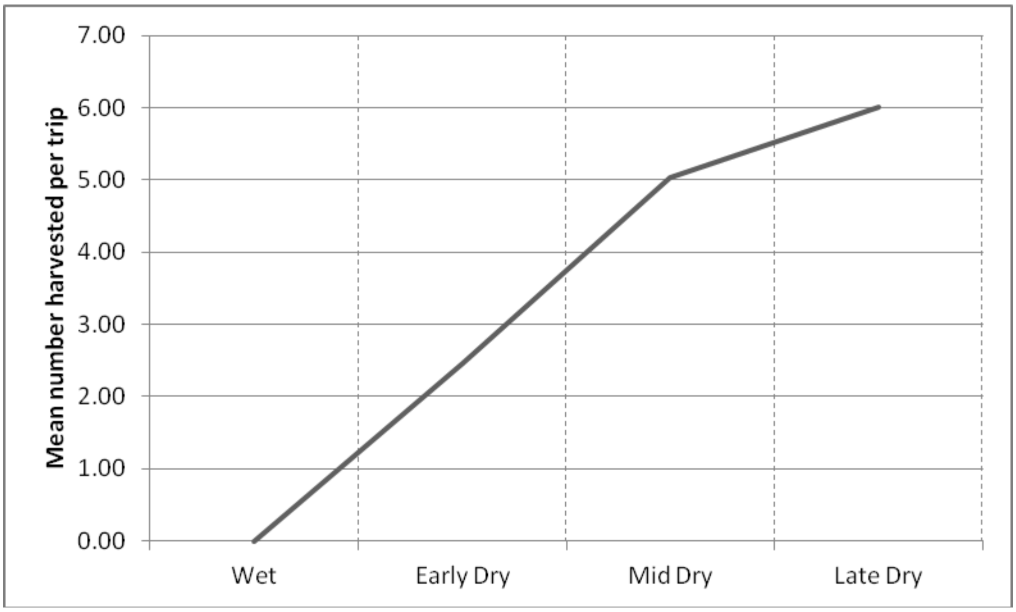


Figure 25: Mean number of Long-necked Turtle harvested per trip undertaken by survey households in the Daly River catchment.

Short-necked Turtle (Emydura tanybaraga/victoriae)

Short-necked Turtle were harvested in the greatest number in the Early- and Mid-Dry seasons (Figure 26). Short-necked Turtle were most commonly harvested from creeks (75%) using fishing lines (86%). So, while the main harvest of Long-necked Turtle depended on the drying of their billabong habitats late in the Dry season, the harvest of Short-necked Turtle was most intensive when creeks were full and accessible for fishing in the Early- and Mid-Dry season. It is not clear from our data whether a lack of habitat availability drove the decline in fishing success for Short-necked Turtle, or whether effort later in the Dry season focussed on the high seasonal availability of Long-necked Turtle and Magpie Geese.

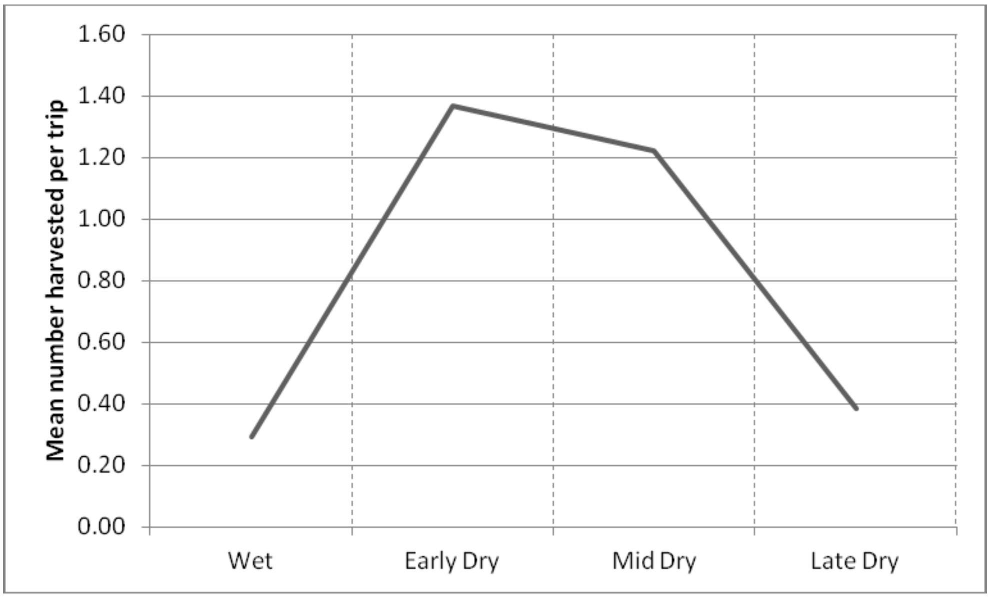


Figure 26: Mean number of Short-necked Turtle harvested per trip undertaken by survey households in the Daly River catchment.

Barramundi (<u>Lates calcarifer</u>)

Harvest success for Barramundi is highest in the early Dry season (Figure 27). This is a time of year when Barramundi are extensively targeted because the feed voraciously as the Wet season flood waters drain from the floodplain into the main river channel.

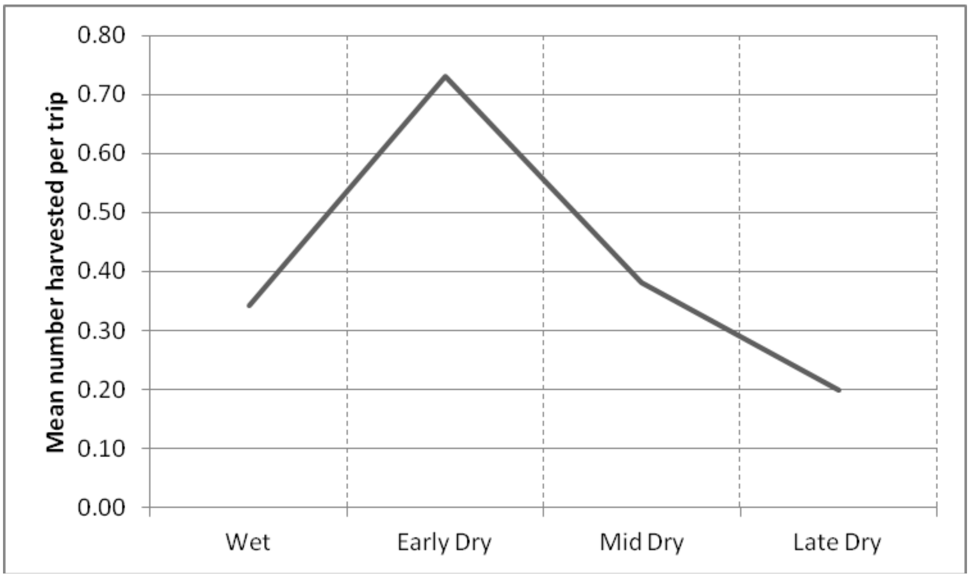


Figure 27: Mean number of Barramundi harvested per trip undertaken by survey households in the Daly River catchment.

Black Bream (<u>Hephaestus fuliginosus</u>)

Black Bream catch peaks in the early Dry season with a steady decline in catch throughout the lLate Dry (Figure 28). It is possible that the main driver of this decline in the number of

Black Bream harvested per trip is a change in the focal species as Magpie Geese and Long-necked Turtle become relatively available. Additional evidence of this is supplied by the Black Bream harvest in the Fitzroy River (Figure 30). While the Black Bream from the Daly River (*H. fuliginosus*) and Black Bream from the Fitzroy River (*H. jenkinsi*) are different species (Pusey et al. 2004), they appear to fill a similar functional role and maintain similar habits. In the Daly River, the number of Black Bream captured per trip declined late in the Dry season, while in the Fitzroy River the harvest of Black Bream in the Late Dry season occurred at similar levels to that occurring in the Early- and Mid-Dry season. This reduced the likelihood that a lack of availability or a reduction in catchability is the reason for the decline in catch per trip in the Daly River.

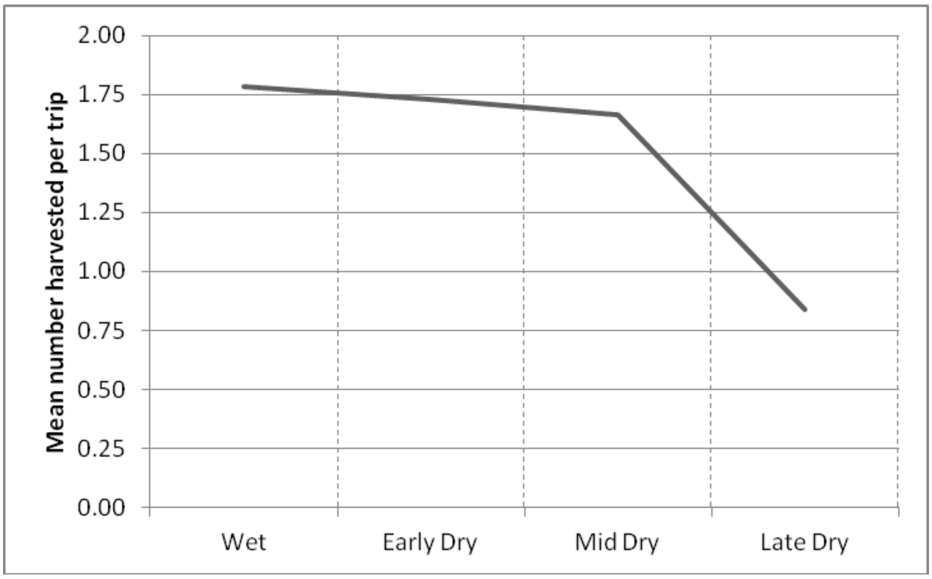


Figure 28: Mean number of Black Bream harvested per trip undertaken by survey households in the Daly River catchment.

Magpie Goose (<u>Anseranas semipalmata</u>)

Magpie Geese were caught in their greatest numbers in the Late Dry season (Figure 29). Magpie Geese migrate from their nesting areas on flooded wetlands to feeding areas late in the Dry season, and “arrive” at many of the billabongs along the Daly River during this period of time. The massive increase in harvest per trip of Magpie Geese reflects their availability at harvest sites.

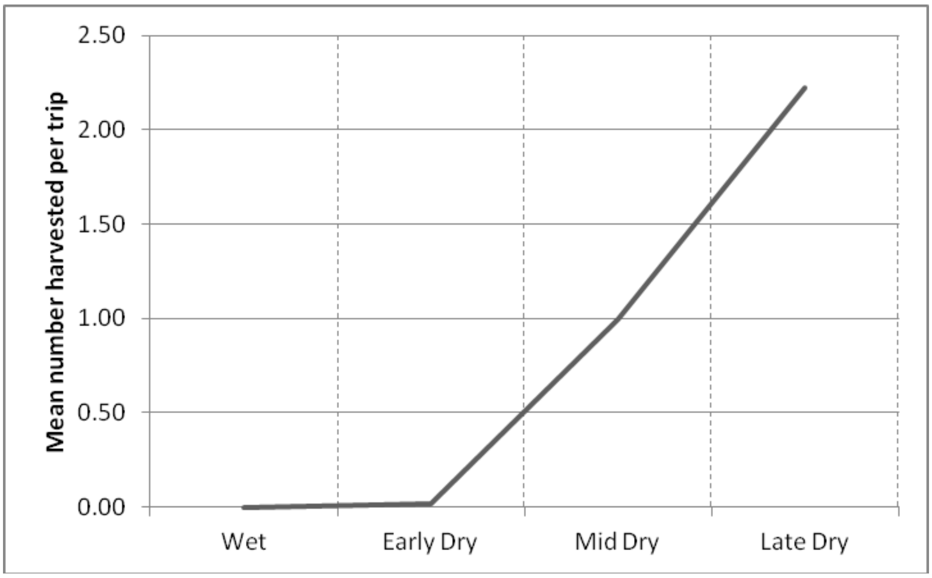


Figure 29: Mean number of Magpie Goose harvested per trip undertaken by survey households in the Daly River catchment.

3.5.7 Fitzroy River: Seasonal harvest patterns for the top 5 ranked species

Black Bream (Hephaestus jenkinsi)

Black Bream were harvested in the highest numbers per trip in the Early- and Mid-Dry seasons (Figure 30). There was little Black Bream harvest in the Wet season, and it is possible that this is due to Catfish being the focal species at this time.

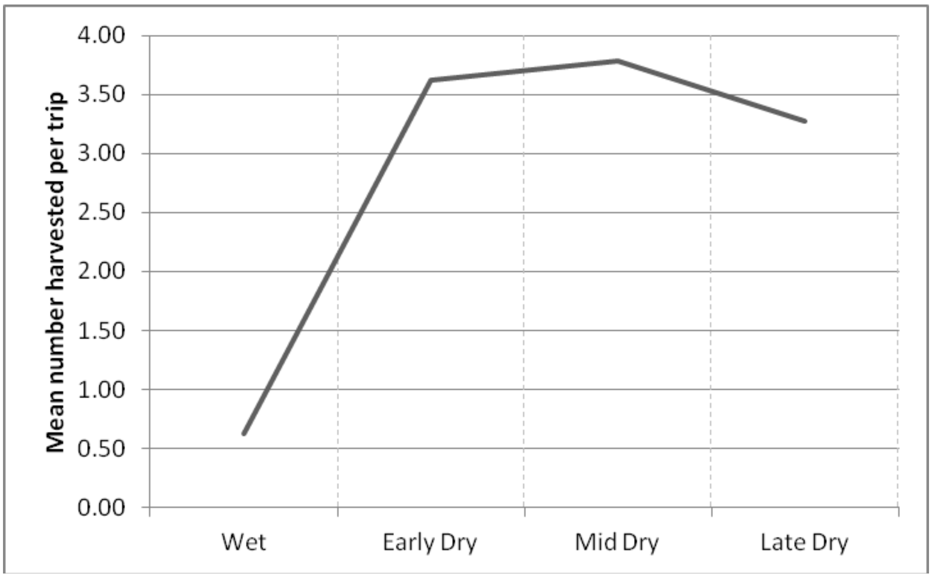


Figure 30: Mean number of Black Bream harvested per trip undertaken by survey households in the Fitzroy River catchment.

Fork-tailed Catfish (Neoarius spp.)

Catfish were taken in the highest numbers in the Wet season, and early Dry season (Figure 31). It is at this time of the year that Indigenous people consider Catfish to be "fat" and a more attractive catch for food. Catfish often form the basis for a stew or curry served with damper and potatoes or rice (Toussaint 2010).

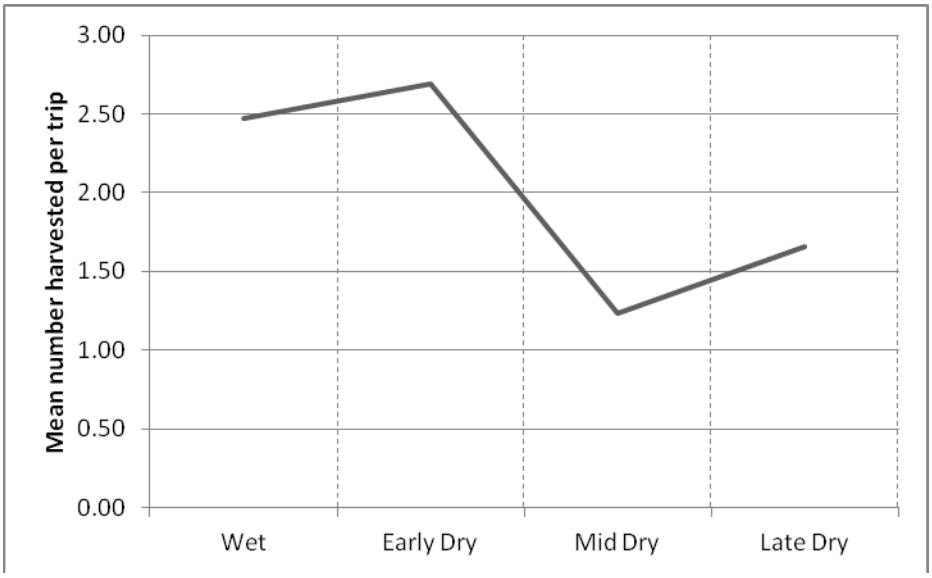


Figure 31: Mean number of Catfish harvested per trip undertaken by survey households in the Fitzroy River catchment.

Freshwater Sawfish (Pristis microdon)

The number of Freshwater Sawfish being caught per harvest trip peaked in the Mid-Dry season, but otherwise remained relatively consistent throughout the year (Figure 32).

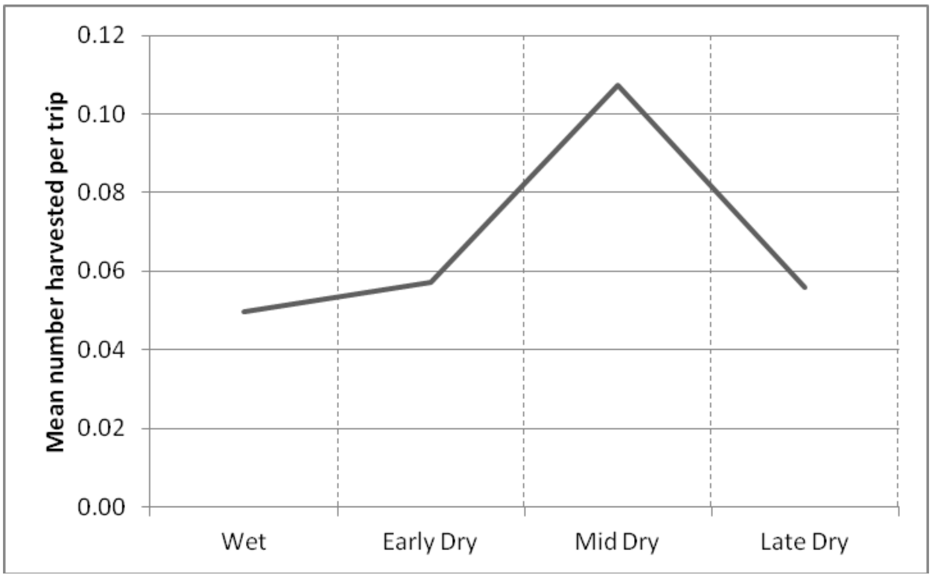


Figure 32: Mean number of Freshwater Sawfish harvested per trip undertaken by survey households in the Fitzroy River catchment.

Barramundi (Lates calcarifer)

Barramundi catch per trip peaked in the early Dry season in the Fitzroy River (Figure 33), as it did in the Daly River (Figure 27). During the early Dry season, many of the seasonally running creeks in the Fitzroy catchment are draining back into the main river channel. These locations are heavily targeted by Indigenous fishers as favoured locations to capture Barramundi. Toussaint (2010: 6) explains that Barramundi fishing is valued for the elaborate cooking process (wrapped in paperbark and cooked in a 'bush oven') and the time that both catching and cooking allow for social interaction.

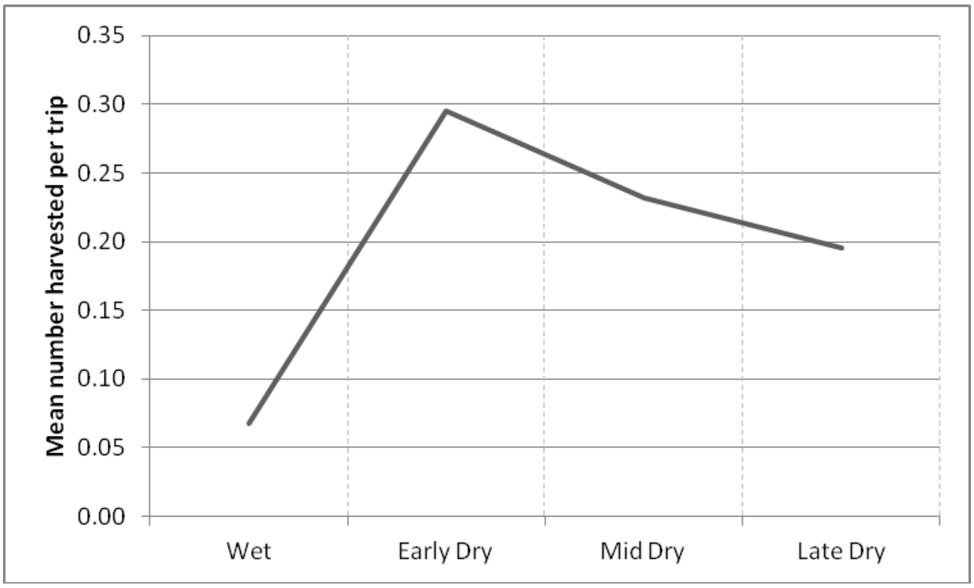


Figure 33: Mean number of Barramundi harvested per trip undertaken by survey households in the Fitzroy River catchment.

Cherabin (Macrobrachium rosenbergii)

Cherabin are mainly captured in the Fitzroy River during the Dry season (Figure 34). There is a substantial increase in the capture of Cherabin per trip late in the Dry season, as they are much larger at this time and become a favoured food source. Later in the Dry season it is common for Indigenous people to target Cherabin in rivers and billabongs by throwing a handful of chicken feed pellets into the water, waiting for the Cherabin to gather on the pellets to feed, and then throwing a cast net over the same area to trap them.

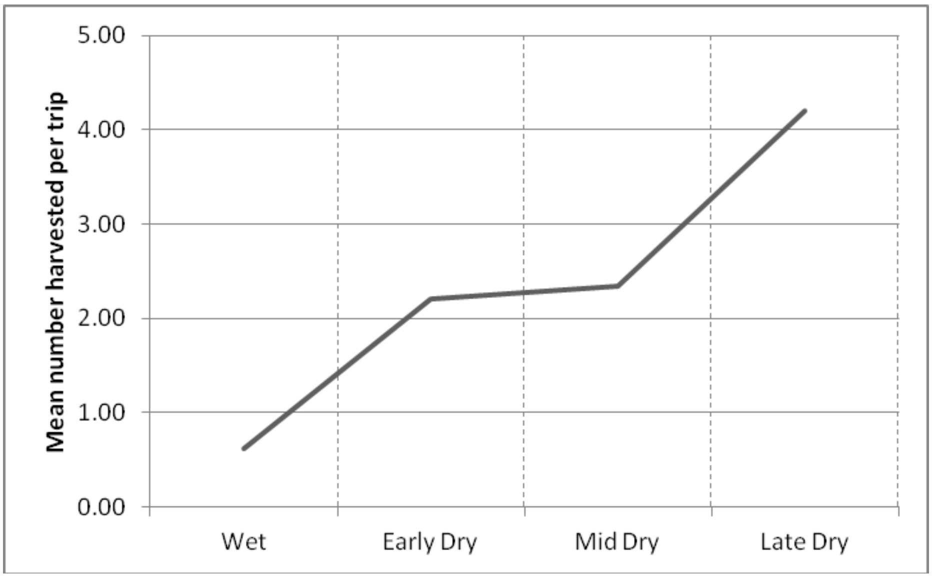


Figure 34: Mean number of Cherabin harvested per trip undertaken by survey households in the Fitzroy River catchment.

3.5.8 Sites contributing high value – Daly River

While the five species with the highest replacement value represented more than 90% of the total replacement value recorded in our surveys, the same was not true when data was analysed by site. The five sites providing the highest value of harvest during our household surveys in the Daly River (Table 4) provided 63.9% of the total replacement value. If that list was expanded to include the ten sites providing the highest harvest value, 74.6% of the total replacement value was represented. Within sites however, the five species contributing the highest replacement value at that site represented more than 99% of the total value derived from that site (Table 4).

Table 4: Five sites contributing the largest replacement value (harvest) in the Daly River catchment. The five species (where available) contributing the largest value to each site are shown. The total replacement value that those five species represented over the two years of surveys is shown, with the percentage of the entire replacement value derived from that site in brackets.

Site name	Number of trips	Species	Replacement value
Elizabeth Downs	57	Long-necked Turtle	$27,849
		Barramundi	$3,802
		Short-necked Turtle	$1,971
		Magpie Goose	$1694
		Shark	$38
		Total	**$35,354 (99.9%)**
Litchfield Station Creek	34	Long-necked Turtle	$15,662
		Short-necked Turtle	$3,425
		Whistling Duck	$6
		Total	**$19,092 (100%)**
Dorisvale (Bradshaw Creek)	23	Short-necked Turtle	$2,517
		Black Bream	$974
		Snapping Turtle	$377
		Catfish	$121
		Barramundi	$117
		Total	**$4,106 (99.9%)**
Moon Billabong	19	Long-necked Turtle	$2,718
		Magpie Goose	$780
		Whistling Duck	$160
		Lotus Lilies	$40
		Tarpon	$18
		Total	**$3,717 (100%)**
Red Lily	51	Lotus Lily	$1,369
		Long-necked Turtle	$1,057
		Magpie Goose	$798
		Water Lily	$94
		Short-necked Turtle	$32
		Total	**$3,349 (99.8%)**

3.5.9 Sites contributing high value – Fitzroy River

The ability of a subset of sites to represent total replacement value was even more limited in the Fitzroy River catchment. The five sites representing the highest replacement value of harvest during our household surveys (Table 5:) represented only 29.9% of the total replacement value obtained over two years of surveys. When the list of sites was expanded to the ten sites with the highest replacement value of harvest, 44% of the total replacement value was represented.

As was true in the Daly River catchment, the five species contributing the highest replacement value within a site represented well over 90% of the total replacement value at that site (**Table 5:**). This suggests that while a subset of sites poorly represents the total replacement value of harvest in our survey communities, a subset of species within sites, and for a catchment overall, is able to represent more than 90% of the total replacement value. These results will have implications for water planners with scarce resources available to devote to research and monitoring.

Table 5: Five sites contributing the largest replacement value (harvest) in the Fitzroy River catchment. The five species (where available) contributing the largest value to each site are shown. The total value that those five species represents is shown, with the percentage of the entire replacement value derived from that site in brackets.

Site name	Number of trips	Species	Replacement value
Old Fitzroy Crossing	112	Catfish	$1,101
		Black Bream	$1,019
		Barramundi	$365
		Cherabin	$191
		Bony Bream	$129
		Total	**$2,805 (92.6%)**
Fitzroy River (down from Noonkanbah airport)	11	Freshwater Sawfish	$1,914
		Black Bream	$390
		Catfish	$263
		Long-necked Turtle	$162
		Barramundi	$52
		Total	**$2,781 (97.8%)**
Pigeon Creek	13	Freshwater Sawfish	$1,048
		Black Bream	$941
		Barramundi	$366
		Catfish	$50
		Short-necked Turtle	$43
		Total	**$2,447 (97.6%)**
Ngukurti	7	Freshwater Sawfish	$843
		Black Bream	$758
		Barramundi	$274
		Catfish	$172
		Spangled Perch	$83
		Total	**$2,130 (94.5%)**
Noonkanbah Crossing	32	Black Bream	$1,072
		Catfish	$376
		Barramundi	$274
		Long-necked Turtle	$106
		Freshwater Sawfish	$81
		Total	**$1,909 (91.3%)**

4. ASSESSING THE IMPACTS OF FLOW ALTERATION ON INDIGENOUS RESOURCE USE

4.1 Introduction

Heightened water resource pressures world-wide have elevated the role of flow regime in sustaining aquatic ecosystem health and, as a result, the scientific discipline of instream or environmental assessment has emerged (Richter et al. 1997, Tharme 2003). During recent years there has been increased appreciation of environmental, aesthetic and recreational values provided by rivers (Poff et al., 2003) as global water resource pressure increases and greater effort is devoted to meeting human development goals under sustainable development frameworks. Thus there is now a pressing need to adapt environmental flow assessment (EFA) to embrace a wider set of socio-economic concerns than previously addressed (King & Brown 2010).

In Canada, for example, specific river regulation controversies have served to highlight how poorly understood were the non-consumptive uses and 'that this hindered comprehensive river resource management' (Rood et al., 2003: 123). A similar situation is evident in northern Australia, where Indigenous wildlife harvesting can be dependent on river flows, but economic activity in the non-market sector (including subsistence resource use) is largely unquantified, and unrecognised in management decisions (Altman et al. 2009). In New Zealand, significant steps have been taken to develop methods to protect Maori instream values using methods that capture objective and subjective data (Tipa pers. comm.). In Canada, Indigenous resource rights are constrained only by conservation limits, driving governments and water managers to carefully consider whether water allocations may affect customary harvest and ensuring Indigenous subsistence needs are not impacted (Durette 2008).

A key element of the Australian COAG water reform agenda was a national water resources policy which made provision for defining water rights for the environment, stating that:

> *… environmental requirements, wherever possible, should be determined on the best scientific information available and have regard to the inter-temporal and inter-spatial water needs required to maintain the health and viability of river systems and groundwater basins…* (cited in Cottingham et al. 2005).

Environmental flows can also be referred to as instream flow needs (IFN): 'flows that were required particularly for environmental aspects such as fisheries, water quality, and riparian ecosystems' (Rood et al., 2003: 123).

Notwithstanding the policy shifts, EFAs undertaken by water resource agencies have made little attempt to understand the pattern and significance of Indigenous resource use and its role in the flow ecology. As a result, the choices made in the selection of target species and management objectives reflect priorities and values of non-Indigenous scientists, conservation agencies and dominant user groups such as recreational fishers. These dominant non-Indigenous priorities and values can differ from those held by Indigenous groups, and it is these differences that need to be explicitly addressed in EFAs, rather than being overlooked on the assumption that environmental flows will serve as a surrogate for the protection of Indigenous instream values (NRETAS 2009, NWI 2004).

The term 'flow regime' refers to the way in which the flow varies daily or seasonally. It defines much of the character of the river, how frequently it floods and whether it is subject to long periods of low flow, or even no flow. Flow regime influences the physical condition (depth, velocity, width) which supports instream values. There are a number of important characteristics of flow regimes when considering the effect of activities on instream values:

- seasonal aspects, including low flow
- frequency and duration of low flows
- frequency and magnitude of floods
- 'average' flow conditions (mfe, 1998: 40).

In the section to follow, we examine the flow requirements of some of the key species contributing to Indigenous household incomes.

4.2 Potential impact of flow alterations

There are two recent sources of information on the potential impacts of flow alterations on Daly River fish species: the semi-quantitative assessment of risk from the *Fish and flows* project (Pusey & Kennard 2009, Kennard et al. 2009), and the quantitative assessment of impact of specific extraction scenarios using Bayesian networks (Chan et al. 2011). We comment on both of these sources of information with respect to the species making a significant contribution to the replacement value of Indigenous harvest, before moving on to describe the potential impact of flow alterations on species for which there is no existing source of information.

4.2.1 Qualitative risk assessment – Daly fish species

A semi-quantitative assessment of the relative risks of freshwater fish to Dry season water extraction in the Daly River has been undertaken using a conceptual model of the potential impacts of Dry season extraction within a pressure-vector-response framework (Pusey & Kennard 2009, Kennard et al. 2009). The likely effects of Dry season water extraction (pressure) on a range of vectors over 13 categories were investigated. These vector categories included the loss of riffle habitat, the exposure of bank-side habitat and refugial areas, the loss of spawning and feeding areas and a reduction in longitudinal and lateral connectivity. The relative risk of changes to each species (response) was ranked against each vector category using 3 risk categories; high risk, moderate risk and low risk. Forty fish species were including in the risk assessment (Figure 35).

Many of the fish species included in the risk assessment were harvested by Indigenous people over the period of our household surveys. In particular, Barramundi, Black Bream and Mullet were within the top ten species in the Daly River, according to replacement method of valuation (Figure 35).

- Black Bream – high risk (30);
- Barramundi – high risk (28); and
- Mullet – high risk (27).

It could be expected, but is not confirmed by our research, that many of the species included the qualitative risk assessment for the Daly River will have similar flow requirements in the Fitzroy River. The species from the Fitzroy River that fall within the top 10 species include (Figure 35):

- Black Bream – high risk (30);
- Catfish – low risk (18);
- Barramundi – high risk (28);
- Spangled Perch – medium risk (23);
- Bony Bream – high risk (24);
- Sleepy Cod – high risk (26).

Out of the ten species in each catchment making the largest contribution to Indigenous household income, three species in the Daly River and four in the Fitzroy River are listed as at high risk from Dry season water extraction.

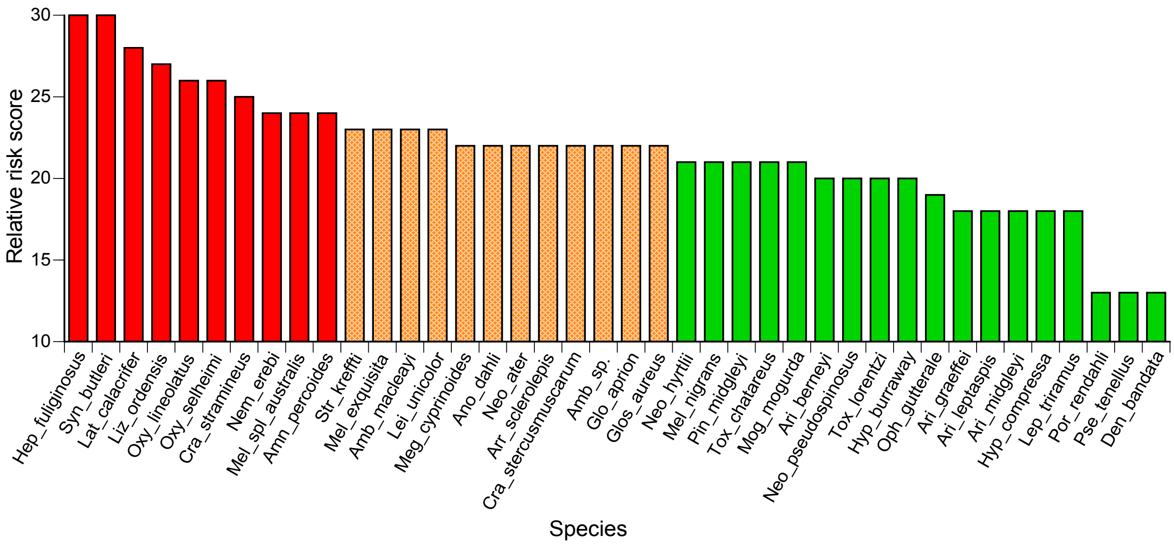


Figure 35: Relative risk to fish species in the Daly River of Dry season extraction (from: Pusey & Kennard 2009, Kennard et al. 2009). Fish species providing high replacement value to Indigenous people in the Daly River include Black Bream – *H. fuliginosus* (Hep_fuliginisus), Barramundi – *L. calcarifer* (Lat_calcarifer), and Mullet- *Liza ordensis* (Liz_ordensis).

4.2.2 Bayesian Belief Network – Black Bream and Barramundi

A quantitative assessment of the potential impact of flow alterations using Bayesian Belief Network predictive models has been completed by Chan et al. (2011). Black Bream and Barramundi were the ecological endpoints for the Bayesian Belief Network (BBN), which linked Dry season flows to various aspect of the biology of these species (Chan et al. 2011). The Dry season extraction models used in the BBN suggested that there would be substantial hydrological impacts on Dry season flows under the range of models assessed, but that the relative impacts on Dry season discharge would decline downstream (Figure 36).

One of the outputs of the BBN was the probability of an “extremely low” abundance of Black Bream or Barramundi under each of the flow alteration scenarios tested (Figure 37). This output suggests that the probability of extremely low abundances of both Black Bream and Barramundi would increase under all of the Dry season extraction scenarios tested. In particular, the probability of extremely low abundances under the full use of current water entitlements increased from a natural probability of 25% to a probability of 43% for Black Bream, and from a natural probability of 36% to an impacted probability of 43% for Barramundi (Figure 37). The full use of existing water entitlements is predicted to reduce mean Dry season discharge by 45% (Figure 36).

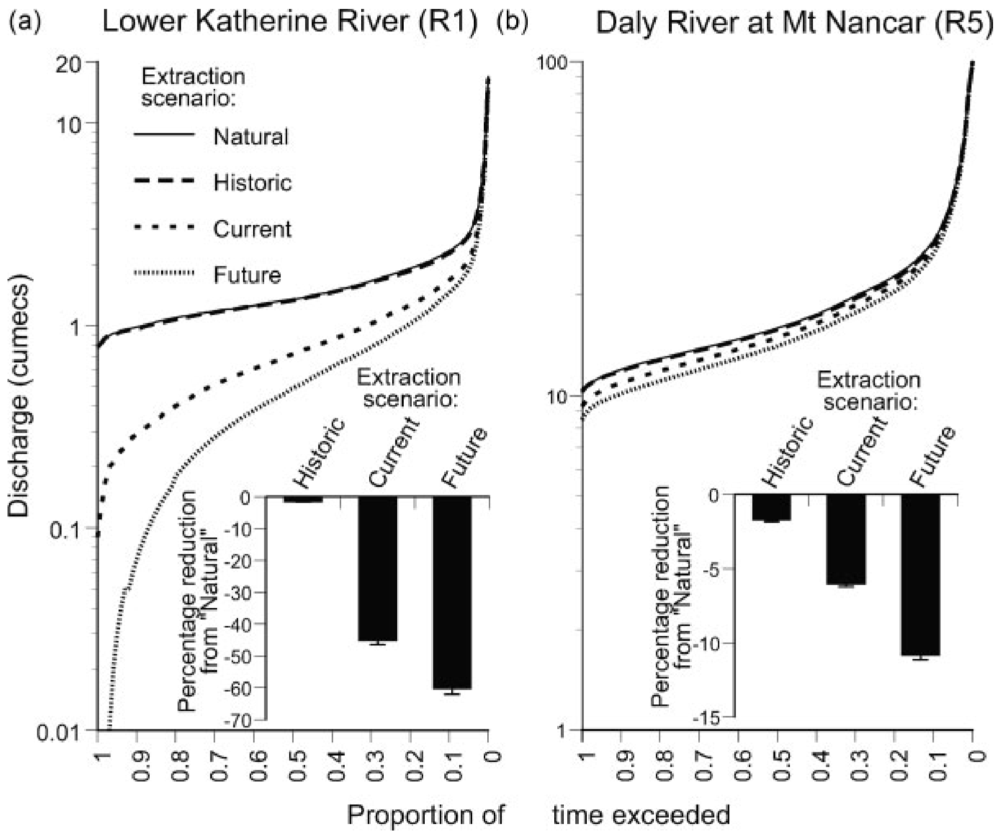


Figure 36: Dry season flow duration curves, and modelled reduction in median Dry season discharge on the lower Katherine River and Daly River at Mt Nancar (Source: Chan et al. 2011). The “percentage reduction from natural” graphs show the declining nature of the impact in a downstream direction, with the lower Katherine River site being well upstream of Mt Nancar.

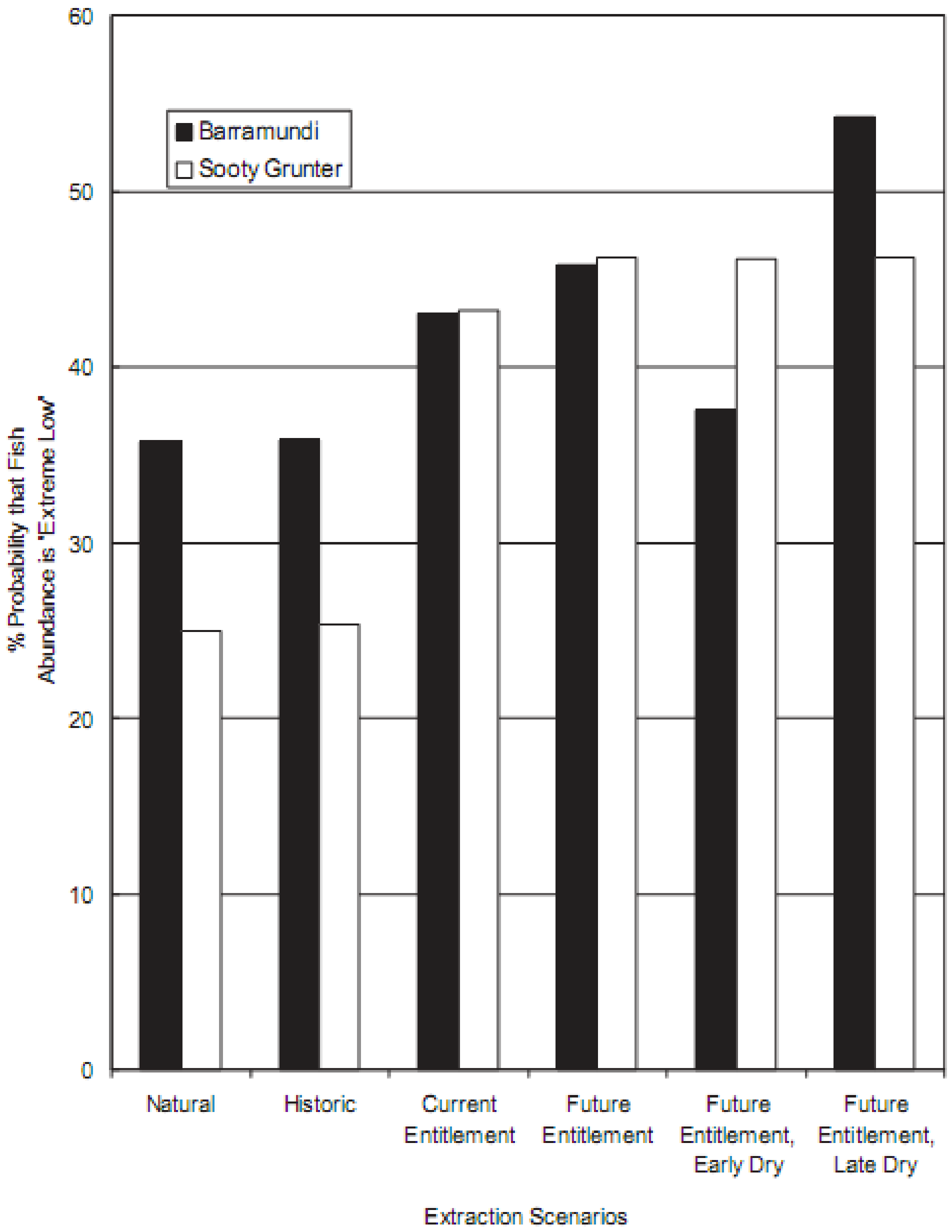


Figure 37: Probability of "extreme low" abundance of (a) Black Bream and (b) Barramundi, under the flow extraction scenarios at Dorisvale shown in Figure 36 (Source: Chan et al. 2011).

4.2.3 Qualitative assessments of flow requirements – top 5 species

Barramundi (Lates calcarifer) flow requirements

Barramundi are a large, iconic northern Australian fish that also occur in eastern Africa, Papua New Guinea, and many countries in south-eastern Asia (Allen et al. 2003). It is a large, predatory fish that sits at (or very near) the top of the food chain (Staunton-Smith et al. 2004). It is catadromous, migrating from freshwater to saltwater to spawn (Allen et al. 2003), and is distributed from Shark Bay (WA) north to the Mary River (Qld) (Figure 38). Barramundi are one of the most important recreational and commercial fish in Australia (Keenan 1994) and although they are capable of tolerating marine conditions and distributing between rivers, populations in the NT usually remain within their own river catchment and do not make move great distances to other systems (Keenan 1994).

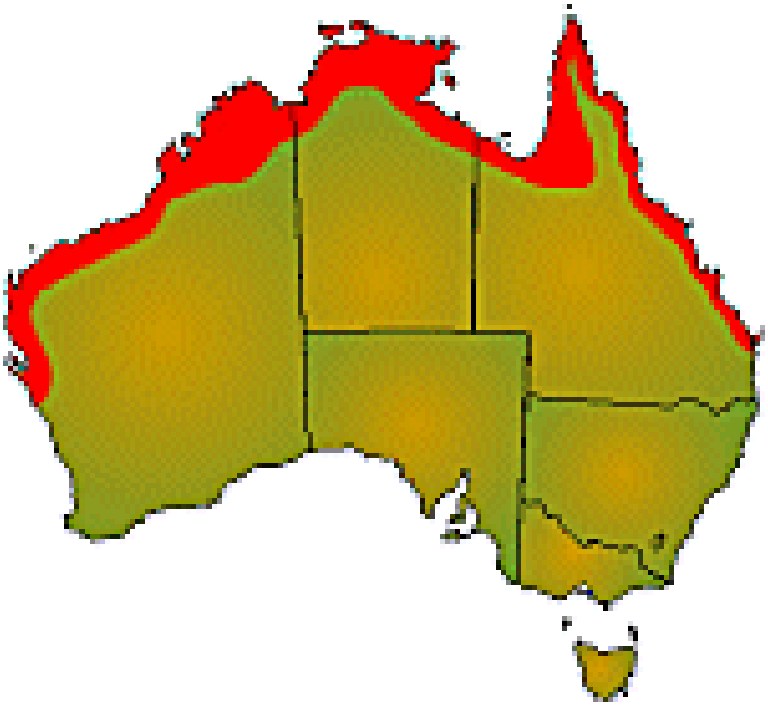


Figure 38: Australian distribution of Barramundi (*L. calcarifer*) (Source: www.nativefish.asn.aus)

Barramundi spawn in near-marine salinities (28—32 pps) at the mouths of tidal rivers and estuaries (Keenan 1994). They spawn in coastal areas before and during the Wet season (Staunton-Smith et al. 2004), and often do this on the spring (large) tides when flooding can fill temporary coastal nursery swamps and provide large amounts of larval habitat (Milton et al. 2008).

Post-larvae use estuarine wetlands as nurseries, and depart these areas at the end of the Wet season (Milton et al. 2008). By the 15th day after hatching, juvenile Barramundi can tolerate completely freshwater and will move to exploit flooded wetlands adjacent to river mouths. Such rapid larval development is unusual for a fish species (Keenan 1994).

Juveniles will migrate upstream into freshwater within the first year when possible otherwise they will remain in tidal creeks until they can migrate (Staunton-Smith et al. 2004). It would seem that most juveniles would migrate to freshwater in the NT, but in the regulated Fitzroy River in Queensland, much of the estuarine Barramundi population had not spent time in the freshwater above a major barrage (Milton et al. 2008).

Sub-adult Barramundi migrate upstream into freshwater reaches until they mature. Barramundi have increased growth and survivability in freshwater, but it does not appear critical for their survival (Milton et al. 2008) and individual Barramundi can complete their entire life-cycle in marine and estuarine water (Staunton-Smith et al. 2004).

Barramundi will migrate to saltwater during floods once they have reached sexual maturity (Staunton-Smith et al. 2004). The maximum size of Barramundi is approximately 180cm, and they are commonly captured up to 120cm long. They change sex from male to female when they are approximately 80cm long (Allen et al. 2003). In Australian rivers, it appears that mature Barramundi do not return to freshwater once they have migrated downstream to spawn (but may remain in the estuary for a number of years) (Staunton-Smith et al. 2004).

Northern Territory populations do not undertake extensive movements between river systems (Keenan 1994). Although Barramundi can complete their life-cycle in saline water, good connectivity between fresh and saltwater systems appear critical for healthy populations. Flooding of coastal wetlands provide extensive habitat for larvae and juveniles, and strong connectivity allow juveniles to migrate to upstream areas where they grow faster. Barramundi populations are most vibrant in the Gulf of Carpentaria and the Northern Territory where longitudinal connectivity of rivers is good, and there is extensive seasonal flooding of coastal wetlands.

Extensive flooding of coastal wetlands will ensure abundant spawning habitat. Preservation of longitudinal connectivity will allow bidirectional migrations to continue, and protection of freshwater habitats (billabongs, wetlands etc.) will ensure a continued population of maturing fish to move downstream and spawn upon flooding.

Black Bream (Hephaestus fuliginosus/jenkinsi) flow requirements

Black Bream are a solid perch-like fish that lives in freshwater habitats in northern Australia (Figure 39). It is also commonly called Sooty Grunter. It is abundant in the freshwater areas of coastal catchments from the central Queensland to the Daly River, NT (Allen et al. 2003). Black Bream are found in a wide range of freshwater habitats in the NT, and are caught from waterholes in creeks, spring-fed creeks, billabongs and the main river.

Figure 39: Translocated Black Bream (*H. fuliginosus*) electrofished from the Fitzroy River, Queensland (Photo: Marcus Finn).

Black Bream spawn exclusively in freshwater (Hogan and Nicholson 1987). The spawning habitat in low gradient rivers (rivers like the main channel of the Daly etc.) is unknown (Pusey et al. 2004), but as they spawn in the Wet season flowing water microhabitats will nearly always be available (Pusey et al. 2004). The spawning migration is upstream in most rivers, but has been observed to be in a downstream direction in the Alligator rivers region (Pusey et al. 2004).

Black Bream spawn in summer in response to monsoonal rains (Wet season) (Allen et al. 2003), and rising water levels have been suggested to trigger spawning (Pusey et al. 2004). Black Bream have demersal eggs that sink into crevices in sediments, and are slightly adhesive which may help prevent them being swept downstream (Pusey et al. 2004). Bream feed for the first time 3 days after they hatch (Pusey et al. 2004).

Adults are found in a wide range of aquatic (lentic and lotic) habitats and appear quite hardy, surviving in a water pH as low as 4, and water temperatures ranging from 12 ^{o}C to 34 ^{o}C (Allen et al. 2003). However, annual Wet season flooding (even in habitats well away from rivers and creeks) would appear essential for a strong population. Longitudinal connectivity may also be important for upstream and downstream spawning migrations.

Long-necked Turtle (Chelodina rugosa) flow requirements

The Long-necked Turtle is a relatively large freshwater turtle that lives in both billabongs and rivers, and is distributed across tropical Australia, from Cape York (Qld.) across to the Kimberley (WA) (Figure 40). The Long-necked Turtle is abundant in seasonally inundated floodplain swamps and wetlands, and has an elongated neck that allows it to be largely predatory, catching fish from ambush positions (Kennett and Tory 1996). The Long-neck Turtle is the only reptile known to lay its eggs underwater (Kennett et al. 1998).

Turtles lay their eggs in shallow water at the edge of seasonally inundated wetlands at the end of the Wet season. The eggs don’t develop until they dry out during the Dry season (Kennett et al. 1993). They develop through the Dry season and hatch when the first Wet season rains soften the soil; this allows the hatchlings to emerge from the nest at a time when it is more likely there will be water nearby (Kennett et al. 1993). Long-neck Turtles lay multiple clutches of eggs over the Wet season in a ‘scattergun’ approach that means at least some eggs should be viable when the next Wet season starts (Kennett 1999). The flooding of nests is not facultative; it is a requirement for the survival of embryos and emergence of hatchlings (Fordham et al. 2006).

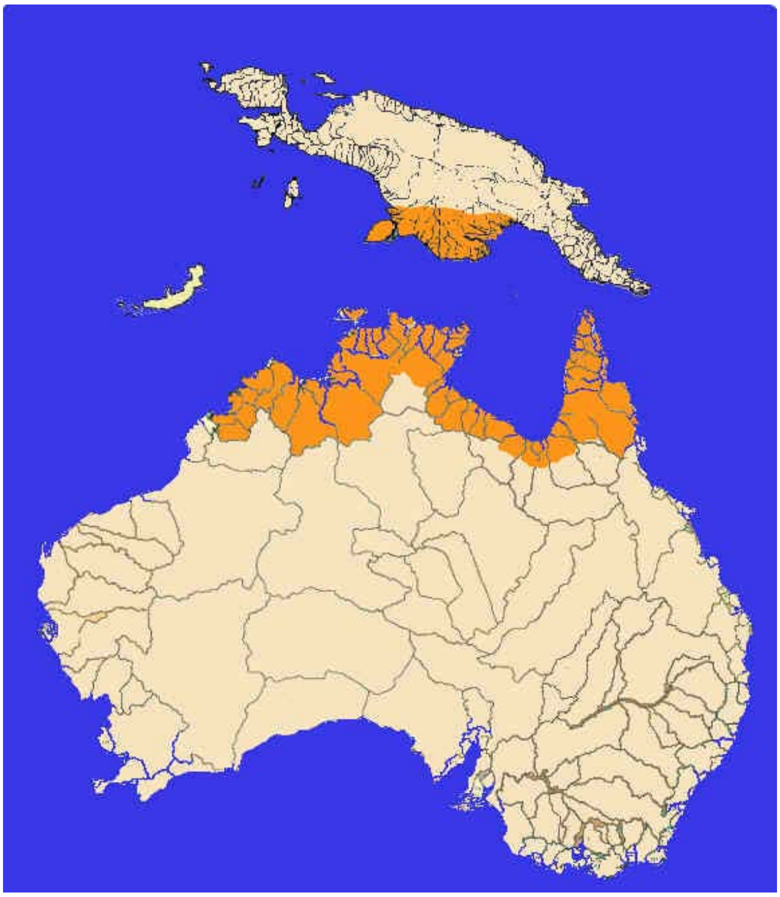


Figure 40: Distribution of Long-necked Turtle (C. rugosa).

As wetlands dry, adult Long-necked Turtles will bury themselves in the mud to aestivate until the next Wet season. In very wet years when water remains in the billabong, turtles do not aestivate (Fordham et al. 2007). However, it appears that even when turtles do not aestivate (i.e. remain swimming in the water column) they stop feeding at the end of the Dry season.

Long-neck Turtles depend on the seasonal wetting and drying of wetlands and billabongs for their breeding. Eggs that are not held underwater suffer the same high mortality as those that are held under water for too long (>25 weeks) (Fordham et al. 2006). So, while aestivation is facultative (not absolutely necessary), the inundation and drying of nests appears critical.

Magpie Goose (Anseranas semipalmata) flow requirements

Magpie Geese are large, black and white birds that grow a prominent hump on their heads as they mature. The Magpie Goose is not a duck or a goose, but is considered a primitive relative (www.threatenedspecies.environment.nsw.gov.au). Magpie Geese are very common in the wetlands of the Northern Territory, which supports the world's largest population (Parks and Wildlife Commission of the Northern Territory nd). It was originally distributed into southern Australia, but had essentially disappeared from its southern range by 1920 (Nye et al. 2007) (Figure 41).

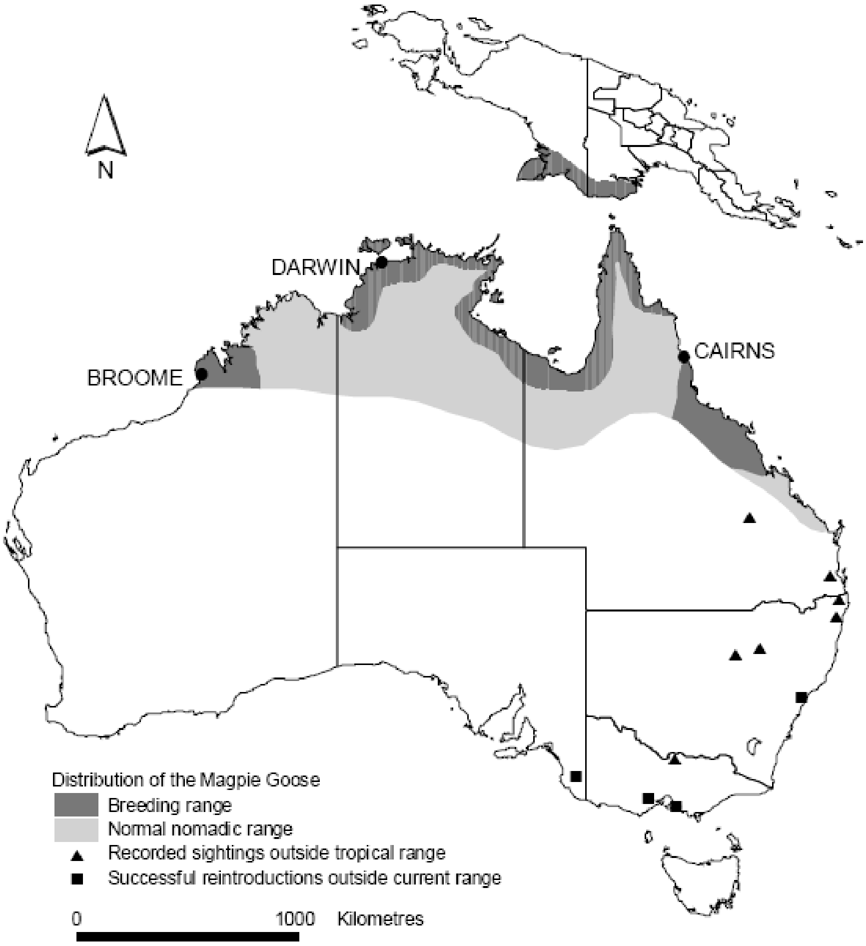


Figure 41: Distribution of Magpie Goose (*A. semipalmata*) (Source: (Parks and Wildlife Commission of the Northern Territory nd)

Magpie Geese move between Wet season breeding sites and Dry season feeding sites, and aggregate in vast colonies during the Wet season (Brook and Whitehead 2005) to build nests in moderately dense stands of Spike Rush (*Eleocharis* spp.) and Wild Rice (*Oryza meridionalis*) (Corbett et al. 1996). Nesting occurs during the Wet season from about December to April on coastal floodplains. Research suggests that nest density (and so the total number of eggs laid and hatched through a breeding season) is much higher when the first Wet season rains begin earlier in the year (Whitehead and Saalfeld 2000). There are probably more nests and eggs when the rains start earlier because this allows the food supply for geese to grow earlier, increasing their body condition and allowing more animals to nest (Whitehead and Saalfeld 2000). Eggs hatch after 24-25 days of incubation (Corbett et al. 1996).

Magpie Geese depend on coastal wetlands for breeding, and much of their food supply. While the timing of the first Wet season rains seems to define how many geese nest, flooding makes nesting habitats available. The strongest relationships between river flows and Magpie Goose populations appear to be:

(a) A requirement for the flooding of coastal wetland habitats for nesting; and

(b) Food supply availability in seasonally filled wetlands.

Fork-tailed Catfish (Neoarius spp.) flow requirements

Six species of the large Ariidae family regularly occur in freshwater habitats in northern Australia, of these *A. graeffei*, *A. leptaspis* and *A. midgleyi* are most likely to be encountered. These species are medium to large in size and occur in freshwater and estuarine habitats, with *A. midgleyi* occurring exclusively in freshwater. The three species utilise off-channel floodplain habitats, indicating a preference for clear waters, and are tolerant of a moderate range of pH levels (Pusey et al. 2004).

The three species begin breeding prior to the onset of the Wet season, although where spawning takes place is unknown. Spawning occurs in the late Wet/early Dry season for *A. graeffei* and the late Dry/early Wet season, preceding flooding, for *A. leptaspis* (and perhaps *A. midgleyi*). The timing of spawning could be the result of an increase in temperature, day length and enhanced production in the river systems (Pusey et al. 2004). The species exhibit a high degree of parental care of their young with *A. graeffei* and *A. midgleyi* males inhabiting deeper water during incubation.

Movement is an important part of the life history of *Neoarius* species. *Neoarius midgleyi* embarks upon small scale migration to deeper water during incubation (Kailola and Pierce, 1988 in Pusey et al. 2004) and may move onto floodplains during times of inundation. The movement of *A. leptaspis* is also relatively unknown although it is believed likely to move between its estuarine habitats and upstream areas (Pusey et al. 2004).

The most detailed movement biology exists for *A. graeffei*, which has been researched in numerous fishway studies (for example: Kowarsky and Ross, 1981; Russell, 1991; Stuart, 1997; Stuart and Mallen-Cooper, 1999; and Broadfoot et al., 2000; in Pusey et. al., 2004). These studies show *A. graeffei* moves upstream through fishways at a temperature range between 18 – 29˚C. In the Fitzroy River (Camballin) barrage in Western Australia fish mostly moved at temperatures above 23˚C and in numbers of around 1000 fish a day when water temperature surpassed 27˚C. The studies also showed migration occurring at a wide range of discharge and flow conditions although times of low discharge recorded the highest fish movements. Migration upstream occurred throughout the year although studies found it to be greatly reduced in the cooler months of July and August. The studies also make note that larger *A. graeffei* are more successful at ascending fishways than smaller individuals and that a higher number enter the structures than are able to reach the top.

Substantial migrations of Fork-tailed Catfish suggest that reductions in longitudinal connectivity may restrict these movements. Given the high biomass of catfish that have been observed moving up the Fitzroy River (12.7 tonnes per month (Stuart 1997 in Pusey et al., 2004)) river regulation that restricts movement along the river channel may have a substantial effect on Indigenous harvest. More generally, river regulation and flow alterations that reduce the frequency of flooding and the area inundated, or reduce longitudinal and lateral connectivity in river systems, is likely to impact the three catfish species considered here (Pusey et al. 2004).

Short-necked Turtle (Emydura tanybaraga/victoriae) flow requirements

The Northern Yellow-faced Turtle (*E. tanybaraga*) and Northern Red-faced Turtle (*E. victoriae*) inhabit permanent water bodies including large rivers, waterholes, billabongs and floodplains. The geographic range of *E. tanybaraga* and *E. victoriae* are 210,313 km^2 and 430,109 km^2 respectively (Buhlmann et. al., 2009). The exact areas that *E. tanybaraga* occupy are not well described but the species is known to occur in the rivers and tributaries of the Fitzroy and Isdell Rivers in Western Australia, the Daly, Finnis, South Alligator and McKinley Rivers in the Northern Territory and the Mitchell and Walsh Rivers in Queensland. *Emydura victoriae* inhabits northern Australia from the Fitzroy River in Western Australia to the Daly River in the Northern Territory (Georges and Thomson, 2003 in Snyder and Tkach, 2006), and from the Daly River to the Mitchell River in Queensland (Georges 1994). Both species are found in areas that experience monsoonal Wet and Dry seasons. Flooding is common during the summer monsoonal wet with some tributaries drying back to intermittent pools during the Dry season. These events reduce river flow affecting the distribution of turtles, often resulting in a greater concentration in remaining permanent water bodies (Kennett 1999).

It is likely that *E. tanybaraga* is an opportunistic omnivore like other northern Australian *Emydura* species. The genus typically feeds upon fish carrion, freshwater invertebrates, submerged aquatic plants, algae, and terrestrial insects. Freshwater mussels, snails, crustaceans and terrestrial plant matter can also be present in their diet. *E. victoriae* is also an opportunistic omnivore, feeding on available invertebrate prey and wind-blown terrestrial insects as well as supplementing its diet with molluscs, aquatic and terrestrial plant matter, filamentous algae and sponge (Featherston 2008). The females of both species may also have a tendency toward macrocephaly, which is an enlargement of the muscular tissue between the eye and the jaw (Cogger 2000). This increased musculature allows them to extend their food range and Welsh (1999) reports *E. victoriae* from the Daly and Douglas Rivers in the Northern Territory display an increasing consumption of molluscs in their diet as macrocephaly develops. Faulks (1998) suggests the freshwater turtles in the Daly River are dependent, especially during the Dry season, on the resources provided by the riparian vegetation and on undisturbed banks and bars for nesting sites.

Little is known about the life history and reproductive biology of tropical freshwater turtles in Australia and around the world, even basic information such as egg and clutch size is scarce (Kennett 1999; Judge 2001). Limited information has been published on the breeding biology of *E. victoriae* (Gaikhorst et. al., 2011), and has since thought to be related to *E. tanybaraga* (Cann 1998). The nesting behaviour of the two species depends on the timing of the monsoonal Wet and Dry seasons, bringing with it changes in temperature, humidity, precipitation and water level. Northern Territory *Emydura* species are reported to lay eggs from late August to early November (Legler 1985). It is believed nesting at this time allows the eggs to hatch with the arrival of the first rain; increasing the survival chances of hatchlings due to an abundance of water (Doody and Welsh 2005).

Weather and climate are often linked to the reproductive cycle, such as the initiation of the breeding season, nesting behaviour and other events within the season, the timing of which are critical for fitness (Bowen et. al., 2005). Kennett (1999) suggests rainfall may be more important in determining the seasonality of reproduction than temperature in highly seasonal areas such as the wet-dry tropics. Seasonal rainfall results in floodplain inundation and subsequent drying and annual fluctuations in the availability of aquatic habitats, that are often large and unpredictable (Kennett 1999; Bowen et. al., 2005).

Cherabin (Macrobrachium rosenbergii) flow requirements

The bulk of the literature regarding Cherabin involves investigations relating to their potential as an aquaculture species. Research into Cherabin, their life history and flow requirements is particularly sparse in northern Australia; probably as extensive commercial fisheries have not been developed as they have in areas such as India (e.g. Kurup and Harikrishnan 2000, Raman 1965).

Cherabin are commercially important worldwide, and migrate to estuaries to spawn as larvae require brackish water for survival and development (de Bruyn et al. 2004). In India, Cherabin breed after the monsoonal rains, with larvae dying within a few days if kept in fresh or marine waters, instead of brackish water habitats (John 2009). They are a fast growing species, with females attaining a length of 180 – 200mm in one year (Raman 1965).

Post-larval and adult Cherabin appear to grow more rapidly in freshwater than they do in brackish water (Thanh Huong et al. 2010). After spending an approximately 1 month-long larval development stage in brackish water (Thanh Huong et al. 2010), juveniles migrate back upstream (Lee and Fielder 1979).

Due to the lack of information on the life history of Cherabin in northern Australian rivers, we constructed two "potential" life cycles. The first is based on information derived from northern hemisphere literature on the species (Figure 42). If Cherabin follow the same pattern in Australia as the species in the northern hemisphere, berried females will occur in the lower reaches of rivers and estuaries shortly after the Wet season (March – April). We suggest that adult female Cherabin make a downstream migration to deliver eggs to brackish areas required for larval development based on the description of this as a more likely scenario than egg drift in large rivers for a similar species (*M. ohione*) in the US (Rome et al. 2009).

Peak numbers of berried females should be encountered in May, June and July, with most females being mature or berried by June. Presumably spawning occurs between May and July, as by August the number of berried females encountered is much reduced (Figure 42). Larvae appear to head back upstream in September, although the relatively disconnected nature of the Fitzroy River at this time suggests that the life cycle in some areas may differ.

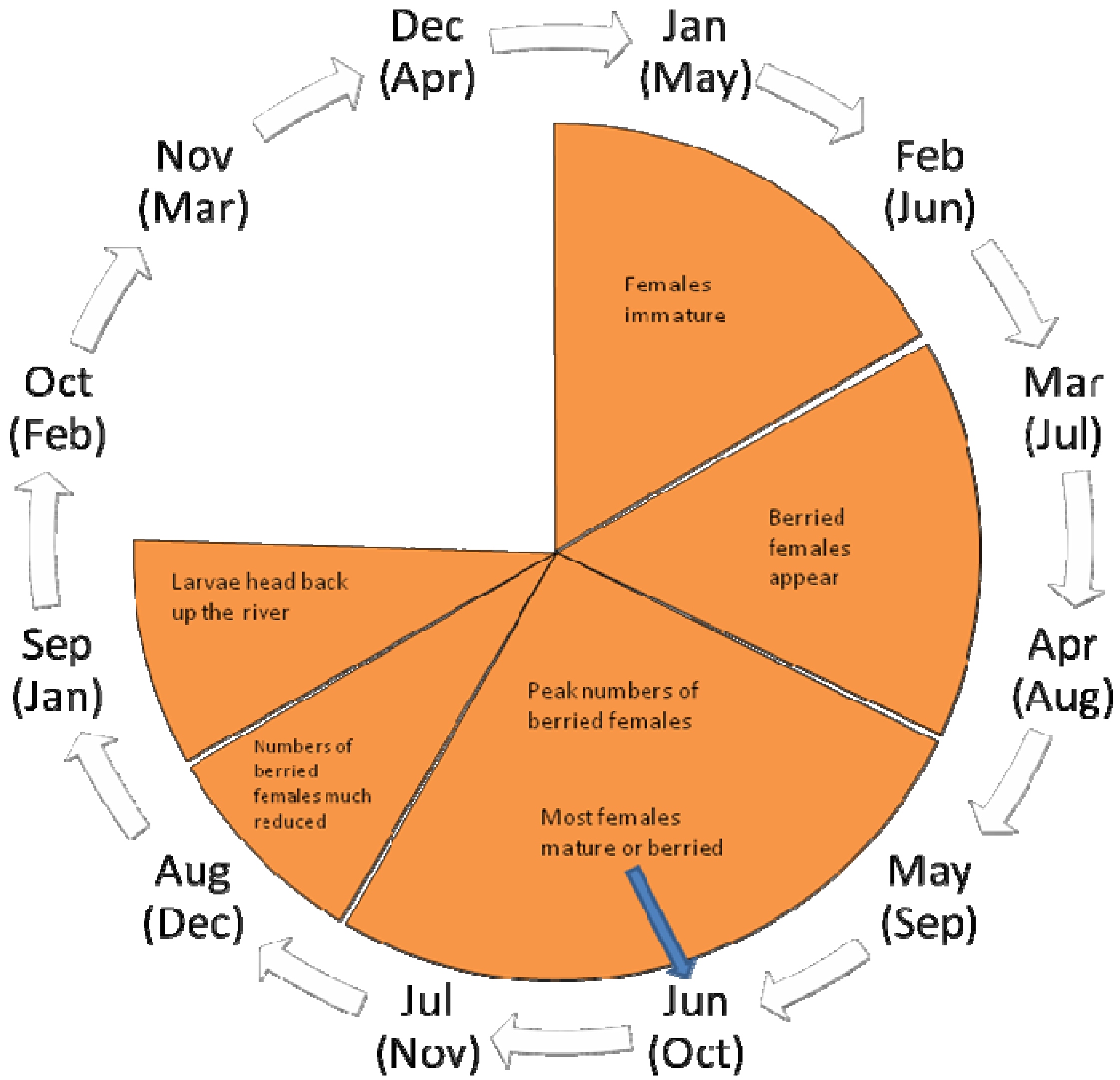


Figure 42: "Potential life cycle" of Cherabin in northern Australia. Information is sourced from northern Hemisphere literature (particularly Raman 1965, and Kurup and Harikrishnan 2000). Months have been "matched" using the peak monsoonal season mentioned in the literature used, with the northern Australian equivalent shown outside of the brackets.

The second "potential" life cycle (Figure 43) takes into account the prevalence of Cherabin in many northern Australian rivers that cease to flow during the mid to late Dry season (approximately July to December). Research on the movements of Cherabin in India suggests that juveniles migrate back upstream around September (Figure 42) (Raman 1965). However, in many northern Australian river systems there is limited or no connectivity at this time. Observations of movements of juvenile palaemonid crustaceans including Cherabin (*M. rosenbergii*) have been made in April in the Daly River (P. Novak pers. comm.). April appears a much more likely period for juvenile Cherabin to be migrating back upstream. Peak discharge in most northern Australian rivers is February, so April will often represent a recession flow from the Wet season peaks. This would maximise connectivity at a time when flow velocities are declining, and migration upstream at this time would avoid Cherabin juveniles being trapped in downstream estuarine sections as salinity increases towards marine levels during the Dry season. Under our second scenario, Cherabin would spawn around the height of the Wet season, when brackish water habitat is likely to be maximised due to freshwater inflows into estuarine reaches. Juveniles would then migrate back upstream soon after the Wet season as flow velocities decline, but while connectivity is maximised (Figure 43). A similar pattern of juvenile migration was observed for *M. ohione* in the US, where upstream migration occurred as discharge and flow velocity declined soon after Wet season maxima (Bauer and Delahoussaye 2008). We suggest that this second life cycle is a more likely life history pattern for Cherabin in northern Australia.

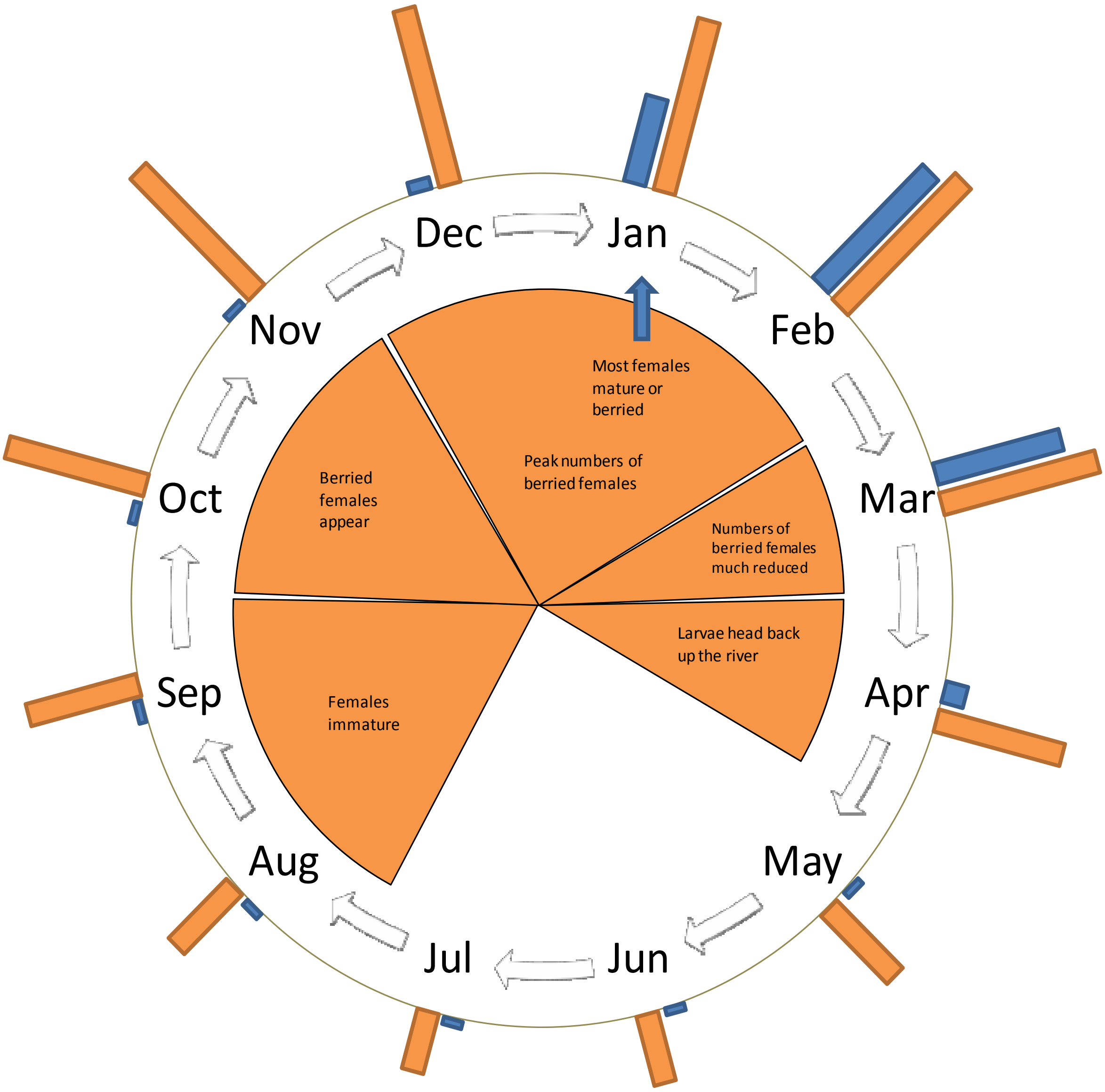


Figure 43: Potential life cycle of Cherabin in northern Australia. Timing of onset of the stages has been modified to fit with observations of juvenile decapods moving up the Daly River in April (P. Novak, pers. comm.). Blue bars on the outside of the diagram show the relative mean monthly discharge, orange bars show the relative monthly mean minimum temperature.

Flow alterations that result in a reduction of connectivity of systems, and those that affect the amount of brackish habitats in lower rivers and estuaries are likely to have a substantial impact on Cherabin populations. Dams and impoundments on the lower Ohio River in the US resulted in the virtual extinction of a similar species, *M. ohione,* once abundant there

(Rome et al. 2009). It would also appear that relatively minor reductions in the time for which longitudinal connectivity is available may have substantial impacts on population sizes. Reductions in the “closure period” of a salinity barrage on an Indian river from 160 days to 106 days resulted in a 3-fold increase in the commercial harvest of Cherabin (Kurup and Harikrishnan 2000). Water extractions, even in unregulated systems, that reduce longitudinal connectivity at critical times of the year could reduce the Indigenous harvest of Cherabin substantially.

Freshwater Sawfish (Pristis microdon) flow requirements

Although there is limited information available about Freshwater Sawfish, they appear to be a catadromous species. Juvenile Freshwater Sawfish appear to be confined to freshwater environments (Stevens et al. 2005), and the mouth of the Fitzroy River in Western Australia has been suggested to be a nursery area for the species (Whitty et al. 2008).

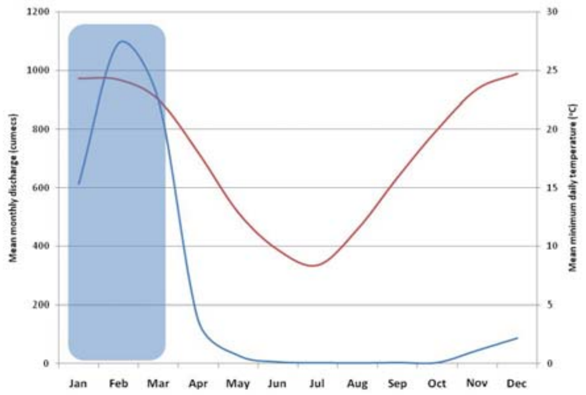
There are few records of adult Freshwater Sawfish in Western Australia (Whitty et al. 2008), although relatively recent research in the Fitzroy River has provided some insight into their likely life cycle. Figure 44 provides a generalised life cycle of Freshwater Sawfish summarised from available scientific information. Additional information was sourced from anecdotal evidence provided by the Indigenous participants.

Adult sawfish appear to pup in the vicinity of the Fitzroy River mouth in the late Wet season, and there may be some level of synchronisation of the timing of this event (Whitty et al. 2008) to coincide with high discharge. Given the widespread distribution of juvenile sawfish in pools of the Fitzroy River to up to 400km upstream (Whitty et al. 2008), as well as their presence in flood-filled billabongs isolated from the river channel, juveniles must migrate up the river system during periods of high discharge. It is also likely, given the suspected timing of pupping in the late Wet season, that the initial movement of juvenile sawfish through the system is supplemented by further movements during subsequent Wet seasons. Freshwater Sawfish in the Fitzroy River appear to reach maturity sometime between 4-7 years of age, and 2400 mm total length (TL) for males and 2800 mm TL for females (Whitty et al. 2008). At this point they migrate back out of the river (only possible during elevated Wet season flows), and into high salinity conditions for the remainder of their adult lives. Little is known of the habitat requirements of Freshwater Sawfish in WA (Whitty et al. 2008), although research involving the capture of WA species in the same genus (*P. clavata* and *P. zijsron*) suggested adults spend much of their time in shallow water near or within intertidal areas (Stevens et al. 2008).

Figure 44: Life-cycle of Freshwater Sawfish.

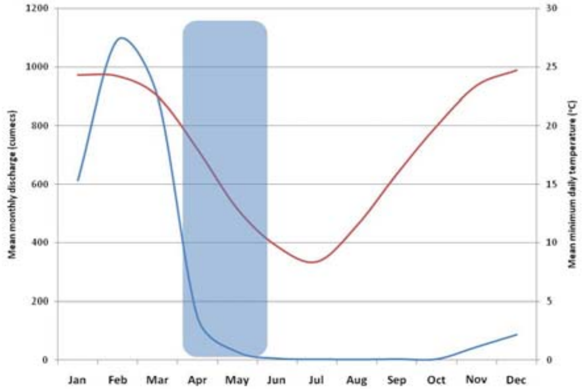
A significant correlation has been shown between the mean discharge of the Fitzroy River in April and the recruitment of Freshwater Sawfish (Whitty et al. 2008). This suggests that flow alteration scenarios that reduce the discharge at this time of year are likely to reduce the recruitment success of sawfish. River discharge in April usually represents the drawdown period from the Wet season floods. It is possible that a longer or larger Wet season, resulting in a larger mean discharge in April, may increase longitudinal connectivity at a time when juveniles are migrating into upstream river reaches, provides greater access to upstream habitat areas.

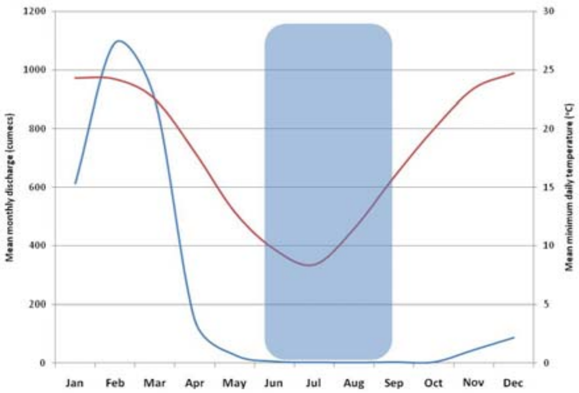
Table 6: Key flow requirements for main species during "flow seasons" - Wet, Early Dry, Mid Dry and Late Dry season. A generalised hydrograph (blue line), with mean minimum monthly temperature (red line) show the conditions prevalent during each season being considered. “Flow seasons” were defined by the authors to represent conditions: Wet season = high discharge, high temperature; “Early Dry” = declining discharge, declining temperatures; “Mid Dry” = baseflow, minimum temperatures; “Late Dry” = baseflow (some freshets), temperatures increasing towards maximums.

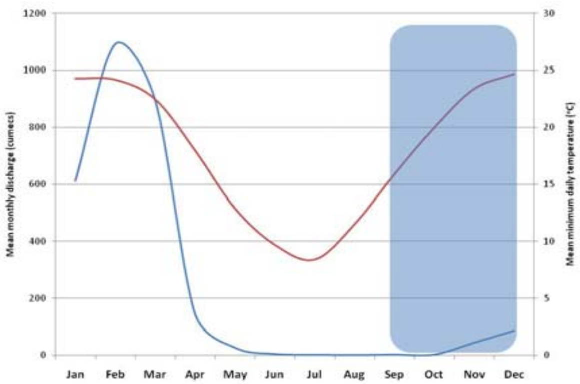
Flow season	Generalised annual hydrograph	Species	Flow Requirements	Potential Impacts[5]
Wet		Black Bream	Spawn in response to monsoonal rains and in response to rising water levels Annual Wet season flooding appears critical for strong population Provision of connectivity may be critical for upstream/downstream spawning migrations	Loss of longitudinal connectivity by structures affecting spawning migrations Removal, or delay, of “rising water level” spawning signal Reduction in seasonally inundated stream area will reduce habitat utilised by recruits and juveniles
		Catfish	Spawn during, or near the Wet season Likely to access floodplain habitats during floods	Reductions in flood frequency and floodplain inundation may reduce productivity and populations size
		Freshwater Sawfish	Pup during the Wet season in estuarine conditions near river mouth	Loss of freshwater input could remove spawning signal (unknown)
		Barramundi	Flooding fills coastal nursery swamps, wetlands and floodplains	Reduction in flooding likely to reduce recruitment success Reduction in Wet season discharge may reduce population size, and possibly

[5] Much of the information on impacts listed in this table is synthesised in Pusey and Kennard (2009).

				productivity Water uses that reduce the extent or volume of flooding likely to will reduce abundance
		Cherabin	Downstream migration to brackish habitats for spawning may occur on early Wet season flows Discharge into estuaries likely to provide extensive brackish habitats – required for larval Cherabin to move from Stage 1 to Stage 2 and beyond	Reductions in Wet season discharge may increase salinity in spawning areas, reducing larval survival
		Long-necked Turtle	Inundate eggs, triggering hatch Fill billabongs Lays eggs (underwater) on the edge of drying wetlands (multiple nesting)	Reduction in flooding will reduce billabong habitats where turtles nest Eggs require rewetting to hatch. This function can be fulfilled by rainwater, but extensive flooding will increase habitat availability for juveniles
		Short-necked Turtle	Not yet complete	
		Magpie Goose	Fill billabong and floodplain nesting areas Aggregate in vast colonies to build nests in moderately dense stands of Spike Rush and Wild Rice	Reduction in flooding will reduce breeding habitats

Early Dry		Catfish	Likely to move during these flows, particularly in the Fitzroy River when connectivity is good, and water temperatures are still high	More rapid drawdown may affect movement Higher numbers moving at higher water temperatures, so cold water releases from impoundments could affect movement
		Freshwater Sawfish	Juveniles moving upstream to freshwater	Reduction in length of Wet season drawdown will restrict upstream movement
		Barramundi	Juveniles moving upstream to freshwater	Reduction in length of Wet season drawdown will restrict upstream movement
		Cherabin	Possibly a critical time for upstream movement of young-of-year (YOY) juveniles in northern Australian systems	More rapid drawdown could reduce connectivity at a time of Cherabin migration
		Long-necked Turtle	Lays eggs (underwater) on the edge of drying wetlands (multiple nesting)	Drying necessary for embryo development
		Short-necked Turtle	*Not yet complete*	

<table>
<tr><td rowspan="3">Mid Dry</td><td rowspan="3">
</td><td>Catfish</td><td>Cold water temperatures reduce movement</td><td></td></tr>
<tr><td>Barramundi</td><td>More rapid growth and increased survivability in freshwater habitats</td><td>Reduction in riverine discharge may restrict short-term connectivity, and availability of feeding habitats

Extraction from pools and billabongs may reduce growth and survivability</td></tr>
<tr><td>Short-necked Turtle</td><td>Not yet complete</td><td></td></tr>
<tr><td rowspan="2">Late Dry</td><td rowspan="2">
</td><td>Catfish</td><td>Probable spawning period for A leptaspis and A. midgleyi

Possible period of extensive movement, as water temperatures increase and early storms provide connectivity</td><td>Reductions in water temperature by impoundment releases may reduce fish movement, and remove or delay spawning cues</td></tr>
<tr><td>Black Bream</td><td>Juveniles prefer flowing water habitats when available</td><td>Excessive extraction that takes rivers to “cease to flow” levels will affect juvenile habitats</td></tr>
</table>

		Barramundi	Sexually mature adults congregating near river mouths and coastal headlands Rising water temperature increases feeding activity and growth	
		Cherabin	Potentially the time at which downstream migration of sexually mature males and berried females occurs in northern Australia A chance that increasing water temperatures are a cue for egg and sperm development, and early Wet season storms provide downstream connectivity and brackish water habitat	Reductions in water temperature by impoundment releases may remove or delay spawning cues Capture of early Wet season flows, or reductions in connectivity at this time, could affect downstream migration
		Long-necked Turtle	Drying of nests and eggs critical for egg development, survival and recruitment success Adults will aestivate in mud as billabongs dry Even when not aestivating, they appear to stop feeding	

		Short-necked Turtle	*Not yet complete*	
		Magpie Goose	Drying billabongs and stands of native grasses used as feeding areas, fattening geese for breeding season	

4.3 Management Strategy Evaluation model

A Management Strategy Evaluation (MSE) framework is being constructed for the Daly River. The model uses much of the TRaCK research, and will provide an integrative system of models allowing stakeholders to view the potential outcomes of management decisions on a wide range of factors.

The data presented in this report is in the process of being integrated into the MSE (Figure 45). The effects of alterations to surface and groundwater hydrology through water extraction scenarios will be linked to our Indigenous replacement value information both directly, and through an indirect link mediated flow ecology relationships between fish and other species (Figure 45). The inclusion of our data into the MSE should allow an assessment of how Indigenous replacement value will be affected by management decisions.

The MSE model is still in the process of being constructed, so further analysis will be completed once outputs from the model are received.

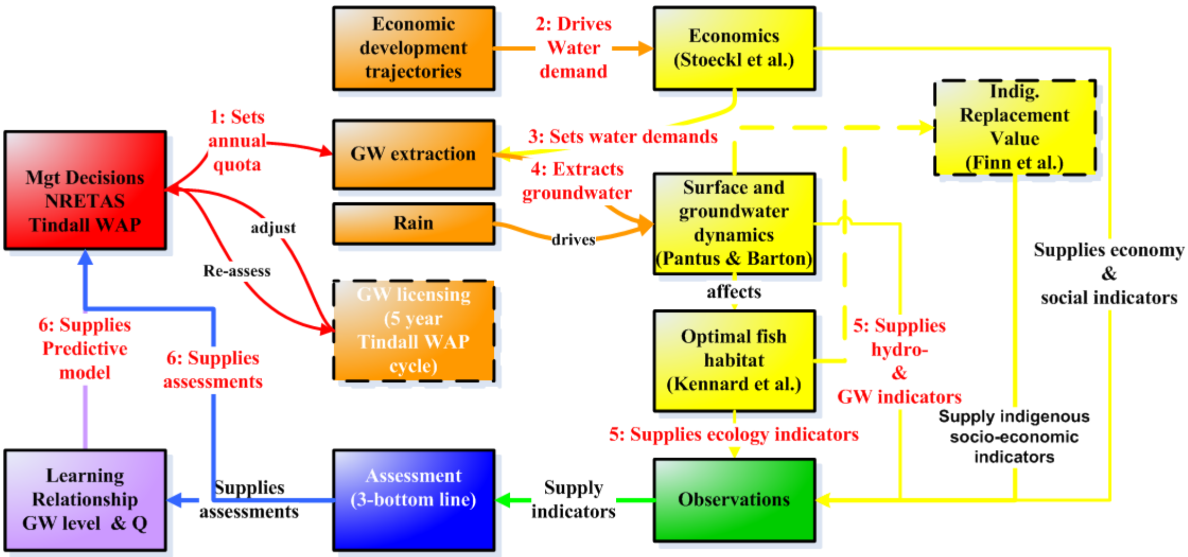


Figure 45: The structure of the Management Strategy Evaluation tool, showing where data from the current report ("Indig. Replacement Value" box) is integrated.

5. DISCUSSION

5.1 Patterns of Indigenous harvest

The species harvested by Indigenous people in our study in the greatest numbers were relatively abundant and widespread species. This was also an observation of early work on bush foods in Aboriginal diets in the Northern Territory, where species harvested in the "least prolific season" of *Dharratharra* (approximately May to July) were all assessed as being common or abundant (Rae et al. 1982). This suggests that the common and widespread nature of these species is, at least in part, critical to their current and continued contribution to household incomes. This harvest of wildlife makes a contribution to people's wellbeing and livelihood and, while largely unaccounted for, is a key feature of Indigenous people's economic strategy, particularly in remote areas (Altman 2009b). Flow allocations that reduce the abundance or spatial distribution of a species while maintaining the biological sustainability[6] of a population could therefore still result in a reduced Indigenous harvest, affecting Indigenous livelihoods.

The calculation of replacement value multiplied the number of a species harvested by body size and shop value. So, the list of "valuable" species in terms of their replacement value was different to the list of the species harvested in high numbers. Most of the species that ranked highly in terms of replacement value were common and widespread species. However, Freshwater Sawfish (*P. microdon*) in the Fitzroy River catchment showed the third highest replacement value. Freshwater Sawfish are listed as vulnerable nationally under the *Environment Protection and Biodiversity Conservation (EPBC) Act (1999)* and in the Northern Territory under the *Territory Parks and Wildlife Conservation Act (2000)*. Their vulnerable listing suggests there is at least a 10% probability of the species becoming extinct in the "medium-term future" (within 100 years)[7]. However, Stevens et al. (2005) note that populations of Freshwater Sawfish in Australia appear to be healthy, particularly in Western Australia, and as the species appears to have limited migration between disparate populations (Phillips et al. 2008), fishing in other countries and regions is unlikely to have an impact on Australian populations (Stevens et al. 2005).

The species with the five largest contributions to replacement value in each catchment made up more than 90% of the total replacement value we quantified during our household surveys. This suggests that a subset of species could easily be targeted during flow assessments as indicator species, particularly if there was an interest in the economic contribution of the direct use of species[8].

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[6] We use "biological sustainability" in the general manner of Bue et al. (2008); a population of a species that, while harvested or impacted, has a spawning population that does not decline over time. So, the population (and distribution) may be reduced, but the species is self-sustaining.

[7] http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=66182#public_guidelines_loop

[8] Some care will need to be taken when assessing a subset of "high value" species. In one of the Indigenous language groups we worked with, the death of a man whose totem was the Magpie Goose led the restriction of Magpie Goose consumption for a substantial mourning period. Substantial variability in harvest, and the contribution that species can make to household incomes, can arise from such events.

In contrast, the five sites in each catchment with the highest replacement value represented a relatively small amount of the total replacement value. These sites accounted for only 63.9% of the total replacement value in the Daly River catchment, and 29.9% of the total replacement value in the Fitzroy River catchment. This suggests that while a subset of species can give a relatively complete indication of how the total replacement value might be affected by flow alterations, the contribution of sites is more evenly spread, so a larger number of sites will be required to assess the effects of flow alterations.

The use of aquatic habitats during harvesting trips differed substantially in each catchment, and there was a clear seasonal change in the habitats used in the Daly River. The main habitat used during harvesting trips across all seasons was the main river channel. However, while the main river channel was the focal point of harvesting trips in the Daly River catchment during the Wet season and Early Dry season, more than 50% of all trips in the Mid and Late Dry season were to billabong habitats. This seasonal pattern of change in the Daly River catchment is likely to be driven by a combination of habitat availability, and the seasonal abundances of target species.

The Daly River catchment has extensive areas of floodplain billabong habitat, while the Fitzroy River has much less. However, the change in habitat use across seasons also appears to be related heavily to site access, species abundances and feeding patterns. The heavy use of the main river channel during the Wet season and Early Dry season occurs when many of the billabongs are still inundated by floodwater or inaccessible. However, it is also a known time to target Barramundi and Black Bream in the Daly River. As billabongs dry during the Mid and Late Dry season, Long-necked Turtles begin to bury themselves in the mud to aestivate. Aboriginal people at this time walk the drying billabongs, poking long poles into the mud to feel the turtles so they can be dug up and eaten. Late in the Dry season Magpie Geese move into their feeding grounds in preparation for the Wet season and nesting. At this time they are very abundant, and are shot and eaten in large numbers.

What is clear given the seasonal nature of habitat use, and the difference observed between catchments, is that Indigenous harvest trips are substantially driven by species availability and the availability of aquatic habitats. This provides further validation to the hypothesis that Indigenous harvest of aquatic species is strongly linked to existing flow regimes, and is likely to be substantially affected by flow alterations that modify habitat availability and species distributions.

5.2 Potential impacts of flow alterations

The potential impacts of flow alterations were assessed using a variety of data sources during this project. These sources include a semi-quantitative risk assessment (Pusey & Kennard 2009, Kennard et al. 2009), a quantitative BBN (Chan et al. 2011), and by reviewing the literature on the flow requirements of the species making the most substantial contribution to replacement value. We also considered the potential influence of flow alterations at four "flow seasons" in the annual hydrograph (Table 6). These seasons, selected for their temperature and discharge characteristics, were the "Wet", "Early Dry", "Mid Dry" and "Late Dry".

It is worth noting at this point, that the potential for water extraction to affect discharge during each of these seasons is quite different. Currently, there is no water infrastructure in our study catchments that would allow the capture of high Wet season discharges. The peak of the hydrograph occurring in the Wet season cannot be altered, nor can the higher discharge occurring on the receding limb of the Wet season hydrograph occurring in the Early Dry season. Models of current and future water extraction scenarios in the Daly River show that the bulk of impacts to discharge occur during the Mid and Late Dry seasons (Chan et al. 2011); a situation we expect is relevant to other northern catchments. However, we discuss the potential for impact on important Indigenous harvest species during the Wet season as there is some potential for infrastructure projects and capture of higher flows in the future. In 2011, Western Australian Premier, Colin Barnett, highlighted his thoughts on the inevitability of a large water capture and transport project in the Fitzroy River at some time in the future: "*I have not lost my desire, my interest to see water to come south…I think it is inevitable that, over time, and it might be over the next 20 years, there will be an integrated water system across the state*"[9].

The environmental flow risk assessments for fish in the Daly River (Pusey & Kennard, 2009; Kennard et al. 2009; Chan et al. 2011) focused on the impacts of Dry season water extraction. Given the current lack of water infrastructure such as dams on the rivers of our focal catchments, there is currently no ability for water resource development to manipulate high flows, and Dry season impacts are the most likely over the short to medium term.

The semi-quantitative risk assessment (Pusey & Kennard 2009, Kennard et al. 2009) suggested that a number of species providing a substantial contribution to Indigenous household incomes could be severely impacted by Dry season water extraction. These species included Black Bream, Barramundi and Mullet in the Daly River, and Black Bream, Barramundi, Bony Bream and Sleepy Cod in the Fitzroy catchment. Spangled Perch and Catfish in the Fitzroy catchment presented lower levels of risk. The assessment of Chan et al. (2011) further shows Barramundi and Black Bream at risk from substantial impacts from Dry season water extraction.

Of the ten species that contributed most to replacement value in each catchment, those that are highlighted as being at high-medium risk of late Dry season water extraction make up 21% of the total replacement value in the Daly River, and 53% of the total replacement value in the Fitzroy River. It is difficult to quantify what this level of risk might mean to total replacement value, but if water extraction resulted in a significant reduction in the harvest of these high risk fish species, the contribution that customary harvest makes to Indigenous households could decline substantially. If, for example, Dry season water extraction reduced the Indigenous harvest of those high and medium risk species by 50%, their contribution to the total replacement value we calculated is halved. This would result in our calculated replacement value declining by 11% in the Daly River and 27% in the Fitzroy.

While the environmental flow risk assessment work focused on Dry season water extractions, our summary of the life histories and flow requirements of the five species contributing most to replacement value suggests that flows occurring immediately after the Wet season (the receding limb of the Wet season hydrograph) may be important to many species. There is some potential for alteration of these flows early in the Dry season as heavy extraction of water into off-stream storages as Wet season flows decline could limit

[9] http://au.news.yahoo.com/thewest/a/-/national/9145907/water-will-come-south-barnett-says/

the extent and duration of downstream flooding (Pusey et al. 2004) and increase the rapidity of drawdown substantially.

Barramundi spawn in saline conditions near the mouths of rivers during the Wet season (Staunton-Smith et al. 2004). Larvae spend a short amount of time in flooded, saline coastal habitats before moving into freshwater (Keenan 1994). When possible, Barramundi juveniles make their way upstream into freshwater, where they grow faster and have a higher survivability (Milton et al. 2008). The large Wet season flows would appear critical for the maintenance of the flooded coastal habitats used by juveniles, while a substantial period of connectivity during the early Dry season would allow 0+ year class Barramundi to move upstream into the more productive freshwater habitats.

Freshwater Sawfish appear to have a similar life history to Barramundi; pupping in estuaries (Whitty et al. 2008), with the juveniles moving upstream and spending their pre-maturity lives in freshwater habitats (Stevens et al. 2008). Water extractions on the drawdown of the Wet season may reduce the amount of time that longitudinal connectivity is available, limiting the ability of juvenile Freshwater Sawfish to move upstream. This is particularly true of the Fitzroy River, which dries back to a series of disconnected pools in the Dry season, and has a human-made barrier (Camballin Barrage) and natural barrier (an upstream rockbar) along its main channel. While there is the potential to improve connectivity across human-made barriers by using fishways, there is no information available to suggest Freshwater Sawfish use such structures (Doupe et al. 2005, Morgan et al. 2005). A significant correlation has been found between discharge in the Fitzroy River in April and Freshwater Sawfish recruitment (Whitty et al. 2008), suggesting that water extractions affecting discharge over this period will have a clear impact on this species.

As for Freshwater Sawfish and Barramundi, Cherabin appear to rely heavily on the longitudinal connectivity made available by higher discharge periods. Cherabin spawn in brackish water near estuaries, and after approximately a month of development (Thanh Huong et al. 2010), make their way back upstream to freshwater habitats (Lee and Fielder 1979). Given that marine salinities kill Cherabin larvae (John 2009), and that post-larval and adult Cherabin grow faster in freshwater (Thanh Huong et al. 2010), connectivity appears to be a key feature of the productivity of Cherabin populations. This is especially true in many northern Australian rivers that dry to (or close to) disconnected pools later in the Dry season. Cherabin have been observed and sampled moving upstream in April in northern Australia (P. Novak, pers. comm.), suggesting that juveniles take advantage of the receding Wet season flows to move back upstream to more productive habitats.

Periods of high discharge, the floods of the Wet season, are currently relatively unchanged in our study catchments. The unimpacted nature of Wet season flows is likely to continue in many northern catchments, as the ability to capture and store water using impoundments is highly constrained by topography and climate in northern Australia (CSIRO 2009). However, there is certainly ongoing political pressure to develop water storage and transport schemes in some of our study catchments. Additionally, the potential for Wet season flows to be impacted by anthropogenic or natural changes to climate and precipitation is currently poorly known due to the variability in predictions for northern Australia, and the tendency for the best estimates to show little future change (CSIRO 2007).

Should Wet season flows be altered, there would be substantial impacts to some of the key species harvested by Indigenous people in our focal catchments. Long-necked Turtle lay their eggs under water along the edges of seasonally inundated billabongs (Kennett et al. 1998). The eggs need to dry, then rewet for development and hatching (Fordham et al. 2006, Kennett et al. 1993). Long-necked Turtle alone make up 51% of the total replacement value in the Daly River catchment. So, any flow alterations or changes to land management that impact Long-necked Turtle are likely to have a substantial effect on Indigenous household incomes.

Magpie Goose also depend on floodplain habitat for nesting, and aggregate in vast colonies during the Wet season (Brook and Whitehead 2005). Like Long-necked Turtle, any reduction in the area of floodplain inundated would have a substantial effect on Magpie Goose populations, and this impact would likely reduce Indigenous harvest. Wet season discharge to estuaries is also likely to create extensive brackish water habitats required for the successful spawning and larval development of Cherabin (de Bruyn et al. 2004). Reductions in Wet season discharge could reduce or remove these brackish spawning habitats, and reduce the Cherabin populations highly valued by Indigenous people.

While the significance of impacts of alteration to Wet season discharge is not as clear cut in the Fitzroy River catchment due to the smaller contribution of Long-necked Turtle and Magpie Goose to harvest, both Barramundi and Freshwater Sawfish have life history stages dependant on Wet season discharge. Barramundi populations have been shown to be positively correlated to Wet season discharge (Staunton-Smith et al. 2004), while Freshwater Sawfish recruitment has been shown to be positively correlated to late Wet season (April) discharge (Whitty et al. 2008). Reductions in Wet season discharge would likely reduce the population size and Indigenous harvest of these species, which make up 34% of the total replacement value of Indigenous harvest.

A clear calculation of the reduction in the total replacement value of Indigenous harvest associated with flow alterations is problematic. Published information on quantified relationships between many of the species harvested and riverine discharge is limited, although this is steadily improving as demonstrated by recent advances in knowledge relating to Daly River fish and Freshwater Sawfish referenced in this report.

5.2.1 The hybrid economy and flow alteration impacts

Gaps in empirical knowledge constrain our ability to precisely quantify the potential effect of flow alterations on the economic value of Indigenous wild resource harvest. But conceptual models of the Indigenous economy can assist in considering the likely influence of impacts on Indigenous livelihoods. A central question is ‘What is the role of customary economic activity and is it a critical feature to be accounted for in management decisions?’ The work of Altman on hybrid economies provides a conceptual framework within which to consider possible environmental changes associated with water resource development.

While conventional economic frameworks largely consider two sectors, private (market) and public (state) (Altman 2006), the hybrid economy includes a third sector - the customary. The customary sector accounts for the non-market economic contribution that activities such as subsistence hunting make to Indigenous production (Altman 2001, Jackson 2008). The three sector hybrid economy is a more complete description of economies in remote Indigenous communities, and Altman (2001) suggests that conventional two sector economic models are a fundamentally wrong economic framework to be applying to remote Indigenous communities.

The customary economy can make a substantial contribution to Indigenous households. Work in Indigenous outstations near Maningrida in the late 1970's and early 1980's found that production for subsistence use was the mainstay of the economy, with the imputed subsistence income making up more than 60% of the total household incomes (Altman 1987). A study of *Kuninjku* speakers in West Arnhem Land in 2002-2003 suggested that the customary sector made up 32% of the local economic activity. Work on Indigenous harvest this region of Arnhem Land has continued since 1948 (Altman 2009a) and over that extensive period of time, has continued to highlight the significance of harvest to Indigenous households.

Likewise, our work focussing on the household consumption of aquatic species suggested the replacement value derived from that use by surveyed households equates to 5.1% of the median household income in the Daly, and 2.9% in the Fitzroy (Table 7). As the survey focussed on aquatic species it did not include many species that Indigenous people harvest on a relatively frequent basis, a more complete analysis of the contribution of the customary economy (that included, for example, wallabies and feral pigs) would certainly increase our figures. Our work was also largely done in townships. The economic contribution the customary sector makes to Indigenous households can change depending on the location, and harvest in outstations and remote areas is generally higher than in townships and larger centres (Altman et al. 2011). Our focus on aquatic species, the conservative nature of our valuation, and the township-based nature of most of our survey households suggests that the replacement values we have calculated are an absolute lower bound figure.

Table 7: Replacement value of harvest and household consumption per surveyed fortnight in the Daly and Fitzroy Rivers. Median household income for the purposes of this comparison is the average of the surveyed communities (ABS 2006).

	Daly River			Fitzroy River		
	Harvest	*Consumption*	*Household consumption as % median income*	*Harvest*	*Consumption*	*Household consumption as % median income*
Top 5 species	$245.83	$60.66	4.5%	$67.24	$33.26	2.7%
Top 10 species	$262.11	$67.11	5.0%	$71.62	$35.24	2.9%
All species	$268.25	$69.17	5.1%	$73.36	$35.92	2.9%

Therefore, a substantial component of the Indigenous economy in our study regions is provided by the customary sector (Jackson 2008). A likely trajectory of change under a future development scenario in northern Australia would result in some removal of water from aquatic systems for the irrigation of crops, and other commercial uses. Theoretically at least, the aim of this form of development would be to increase commercial production by growing the region's market sector. And, presumably, any impacts on customary activities would be taken into account under the native title regime (see Jackson and Altman 2009; O'Donnell 2011).

Recent research in northern Australia calls into question the likelihood of Indigenous people benefiting from orthodox agricultural development. According to Stoeckl et al (2011), despite their significant numbers, Indigenous people will be largely excluded from the benefits of such economic stimulus, receiving only 0.5% of the total regional stimulus, and 1% of the total flow on effects. As a result of a disconnect between the Indigenous and non-Indigenous market economic systems identified by Stoeckl et al. (2011), agricultural expansion is unlikely to result in increased Indigenous incomes. But is there likely to be any impact on the state sector from increased consumptive water use? Altman argues that the level of state intervention in the Indigenous economy has peaked (Altman 2001) and so it is unlikely that water resource development and flow alterations will have a direct influence on the state sector of the hybrid economy.

The Indigenous market sector may be affected by water decisions in other ways that are not yet amenable to quantification, given our current knowledge of the Indigenous regional economy. Flow alterations may affect species that are indirectly used by Indigenous people. For example, a decline in Barramundi, which is a very popular recreational fish species, may adversely affect any sports fishing enterprises owned by Indigenous people or other parts of the tourism sector that Indigenous people may either own or contribute their labour to. Revenues flowing through Indigenous –owned tourist accommodation in the Fitzroy Crossing area for example, may be affected by water allocation decisions that adversely impact on fish species or aquatic landscapes valued by tourists. The strength of the effect will again depend on the extent to which Indigenous people participate in water-based market commercial activities and are beyond the current analysis of direct use of aquatic resources.

The above analysis is of course predicated on the assumption that property rights in water remain unchanged. As Altman and Branchut (2008) argue in relation to water governance at Maningrida in the NT, property rights in water are locally contested:

> *While the state asserts crown ownership of water, this is not a view that is shared by traditional owners of the land. Legally, Native Title law guarantees traditional owners unfettered customary rights in water. However, the relationship between land rights and fresh water rights remains unclear and legally untested (2008: 2).*

Should the state change the existing property rights regime to the benefit of Indigenous land owners, for example by providing land owners with alienable water rights, trading of water may be brought about between Indigenous land owners and commercial water users. If this were to occur, increased water use may then result in an expansion of the market sector of the Indigenous economy beyond the pattern of growth assumed in Stoeckl et al's (2011) analysis.

When one accounts for the economic circumstances facing most Indigenous communities the impacts are brought into relief. Indigenous populations show a greater need for low-cost means of sustenance offered by the consumption of wild resources. As Altman et al, noted elsewhere:

> *The economic and nutritional importance of customary food sources becomes even more pronounced when viewed alongside the relatively low levels of cash income, the*

> *lack of formal employment opportunities, and the expense of fresh and nutritious store foods (2009).*

According to Brimblecombe (2007), traditional foods are generally recognized by researchers to contribute significantly to contemporary Aboriginal peoples' social and cultural well-being. Brimblecombe's research on nutrition in Arnhem Land reports that poverty is a key determinant of Indigenous well-being and that:

> *In 2002, 77.4% of Indigenous people in the NT aged 15 years and over reported financial stress. This proportion was significantly higher for Indigenous people in remote areas than in non-remote areas (84.2% and 43.7% respectively) (2007: 6).*

Emerging research clearly suggests that flow alterations under future development scenarios could have a substantial impact on populations of species that contribute to the Indigenous customary economy (e.g. Pusey & Kennard 2009, Kennard et al. 2009, Chan et al. 2011 this text) and this could put greater pressure on household budgets. For example, if we made the very general assumption that extensive flow alterations reduced the consumption of aquatic resources by 50%, and all other factors such as effort remained constant, the result could be a 2.5% reduction in household incomes in the Daly River catchment (representing approximately $35.00 per fortnight).

Given that increased commercial and agricultural production supported by this water use in the largely non-Indigenous sector is currently unlikely to result in benefits to Indigenous households (Stoeckl et al. 2011), their economic status would almost surely decline. Such a result would be antithetical to much government policy directed towards stimulating Indigenous economic opportunity (Altman 2006). It is also possible that the effect of extracting water to stimulate agricultural activity could result in additional burdens on the state sector, requiring increases in direct payments via the welfare system to prevent a decline in Indigenous people's economic status. Implications such as these reinforce the importance of understanding the Indigenous customary sector's reliance on water and the linkages between this and the other sectors. Conventional two-sector economic models might suggest that an increase in commercial agricultural production may increase the market sector, thereby reducing household reliance on the state sector. However, the inclusion of the customary sector as an important part of the economy, along with recent advances in our understanding of how regional economic stimulus may (or may not) flow on to Indigenous households (Stoeckl et al. 2011), suggests that efforts to increase the regional market sector, if they adversely reduce Indigenous access to aquatic resources, may simply result in a decline in the customary sector's contribution, and a corresponding need for the state to increase its support to Indigenous households.

5.3 Conclusion

It is clear that aquatic resources make a substantial contribution to household incomes in our study catchments. This contribution, currently unaccounted for in mainstream metrics of Indigenous household economies, provides a means for Indigenous households to supplement their incomes (Buchanan et al. 2009).

A relatively large proportion (>90%) of the gross replacement value that we calculated for aquatic species, was made up of a relatively small subset of high value species. In contrast, the replacement value of species harvested was distributed across a large number of locations. This is an important feature to note for water resource management, particularly when attempting assessments of environmental flows. While a relatively small subset of species will encompass a large proportion of the replacement value, a subset of aquatic sites will not. Scoping for Indigenous values and flow assessments should aim to be spatially inclusive, but can focus on small subsets of key species.

Substantial gaps in knowledge remain, ranging from the flow requirements of species harvested by Indigenous people to the relationship between species' population dynamics and Indigenous harvest success. These gaps mean that clear calculations of changes in the replacement value of aquatic species associated with flow alteration scenarios remain problematic. However, the substantial contribution of the customary economy to Indigenous livelihoods makes Altman's (2001) hybrid economy a useful conceptual framework within which to consider impacts.

Our quantification of value focuses only on the consumption of aquatic species. If the broader range of productive activities contributing to the customary economy such as hunting, fishing, gathering, art, craft, and caring for country activities (Buchanan et al. 2009) were included, the "value" of the customary sector would be much larger than the figures reported here.

Indigenous participation in harvest and cultural production activities Australia-wide was about 60% in the 2008 National Aboriginal and Torres Strait Islander Social Survey (NATSISS) (Altman et al. 2011). In remote areas, the percentage of Indigenous people over the age of 15 participating in harvesting of wild resources was 72% (ibid.). Although NATSISS 2008 never quantified the harvest obtained during these activities, nor attempted to assess the economic value of such harvest, it is clear that the majority of Indigenous Australians involve themselves in harvesting activities that contribute to the value of the customary economy.

Based on our valuation of aquatic resource consumption as a proportion of median household income, we would suggest that a 50% reduction in catchability of aquatic species would result in 2.5% shrinkage of Indigenous household incomes in the Daly River catchment[10]. Presumably the use of this water would grow the regional market economy via commercial production, but it is unlikely that more than 0.5% - 1% of these benefits would

[10] This, of course, does not account for the impact of land use changes on terrestrial species that also make up a significant proportion of Indigenous harvest. The full value of wild resource use will be higher than our valuation as it will include terrestrial species. A full valuation of the customary economy will be higher again, as it will include the value of other components of the customary economy such as land management, and environmental benefits such as feral animal reduction and carbon storage (Altman et al. 2011).

filter to Indigenous people (Stoeckl et al. 2011). So, water resource extraction would likely lead to a decline in the contribution that the combined market and customary sectors make to Indigenous households, resulting in a larger dependence on the state sector and welfare if the status quo of Indigenous household incomes is to be maintained. This response to water extraction in northern Australia is perhaps unexpected, reaffirming the value of considering a hybrid economic model in Indigenous Australia.

So, while gaps in our knowledge and quantitative understanding limit our ability to define the impact of flow alterations on valued aquatic wild resources, it is apparent that the customary sector is a crucial component of Indigenous economies. Our investigations suggest that access to species, and the aquatic habitats that support them, is critical to maintaining a vibrant customary economy. Assessing the impacts of water resource development on key species, and allocating or protecting flows to minimise Indigenous impacts, cannot occur effectively without a clear understanding of the Indigenous values associated with aquatic resources, and the flow requirements of supporting these. The scientific determination of Indigenous water requirements will be essential if governments are to fully implement national water policy and fulfil their obligations under the *Native Title Act* to guarantee traditional owners customary rights in water.

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