Tilapia in north Queensland waterways: Risks and potential economic impacts

Report prepared for the Australian Centre for Tropical Freshwater Research, James Cook University, Townsville

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Executive Summary

This main purpose of this report is to provide an attempt at estimating the economic impact of tilapia in north Queensland. The assessment is based on a desk-top review of existing information and a limited empirical investigation involving key waterway managers and recreational fishers. The report lays important conceptual foundations for an integrated economic assessment by explaining the direct and indirect costs—economic, environmental and social—associated with tilapia and differentiating between use and non-use values of waterways. In the process of deriving economic impact estimates, this report also reassesses the various risks that tilapia pose in a north Queensland context.

The common name 'tilapia' refers to a group of tropical freshwater fish in the family Cichlidae (*Oreachromis*, *Tilapia*, and *Sarotherodon* ssp). Tilapia are native to Africa and the southwestern Middle East. Following their introduction to Australia for ornamental purposes, they found their way into natural waterways about three decades ago. Significantly, infestations, particularly in north Queensland, have been spread by people over the past thirty years—whether inadvertently or deliberately is not known. Based on the scant scientific data that are available on the ecological impacts of tilapia on native biodiversity in waterways of countries where they have been introduced, tilapia are thought to pose a significant risk. Based on the potential risk that they pose, tilapia are a declared pest fish in Queensland.

Tilapia pose a risk to the ecology and water quality of waterways because of their fecundity, ability to prosper under a wide range of ecological conditions, and aggressively territorial behaviour. These characteristics enable tilapia to outcompete and displace native fish species and have earned tilapia the title of 'cane toads of the waterways'.

There are several regions across Australia with established tilapia populations in waterways, of which one is north Queensland, where tilapia are established in rivers within the Great Barrier Reef catchment from the Burdekin River south of Townsville to the Endeavour River near Cooktown. Tilapia has the potential to "take over tropical rivers in much the same way carp has done to the Murray-Darling" (ABC, 2005).

The direct costs associated with monitoring, management and prevention of tilapia amounted to nearly $900,000 during 2006/07. The Queensland Government, through the DPI&F, incurred the bulk of expenses for prevention and management related measures, principally for production and dissemination of information material for public education. DPI&F bore 67% of the total direct costs of tilapia in the financial year 2006/2007. Some NRM groups were assisting in the dissemination of these materials, as were local governments. Significant prevention costs were incurred by SunWater (approximately $230,000), which had installed and was maintaining fish exclusion screens in the Mareeba-Dimbulah Irrigation Area. The principal purpose of the screens was to prevent the spread of tilapia into the Gulf of Carpentaria catchment. Region-wide monitoring costs were also principally borne by DPI&F, with NQ Water undertaking substantial monitoring

efforts in Townsville water supplies. Management costs, through electro-fishing, were also incurred, mainly by DPI&F.

Focus group discussions and interviews with recreational fishers and members of fish restocking groups confirmed anecdotally many findings from the international literature, e.g. that poor health of waterways contributes to relative abundance of tilapia. Catch of native target fish appears unaffected, particularly in artificially stocked waterways. Tilapia cause anglers to collect bait fish in non-affected streams and the behaviours dictated by the noxious fish legislation impact on enjoyment of recreational fishing. Knowledge that waterways are infested causes a decline of associated non-use values. However, in the absence of a non-market valuation study, this research found no empirical basis to quantify these economic impacts.

In a north Queensland context, the report classified the following risks:

- Risk of tilapia causing a decline in water quality in water reservoirs (specifically Ross River Dam) to the effect that water is not safe for human consumption: High—Extreme
- Risk of tilapia affecting the non-use values of north Queensland waterways: Moderate—High
- Risk of tilapia causing a decline in Queensland commercial fisheries: Moderate
- Risk of tilapia impacting on recreational and tourism values of north Queensland: Low—Moderate

Based on a series of assumptions, this report provides some “least cost” and “highest cost” cost estimates for various cost items. The bandwidth of potential costs is high and cannot be narrowed based on current information. Potentially, assuming that the risks to commercial fisheries and freshwater supplies manifest, the economic impact may be in the 10s of millions of dollars. Thus, potentially the economic impact of tilapia in north Queensland may be similar to the cost generated by carp nationally, but for different reasons. In addition, the decline of non-use values of waterways may also be high.

On the basis of the high risk ratings and high cost estimates, the findings support the precautionary approach taken in Australia in declaring tilapia a noxious fish, developing public education campaigns, and installing fish barriers where catchments are interlinked. However, the report recommends that research and monitoring be undertaken to (1) better understand the ecological impact of tilapia on waterways and aquatic ecosystems and (2) develop an inventory of use and non-use values associated with waterways. In combination, this information could support a more precise estimate of economic impact and support the design of efficient policy and management responses by providing a foundation for a cost-benefit analysis.

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Acronyms

ABARE – Australian Bureau of Agricultural and Resource Economics

ACTFR – Australian Centre for Tropical Freshwater Research

BRICMA – Barron River Integrated Catchment Management Authority

BRS – Bureau of Rural Sciences (Commonwealth of Australia)

CRC – Cooperativre Research Centre

CRCTREM – Cooperative Research Centre Tropical Rainforest Ecology and Management

DAFF – Department of Agriculture Fisheries and Forestry (Commonwealth of Australia)

DPI – Department of Primary Industries

DPI&F – Department of Primary Industries and Fisheries (Queensland), formerly QDPI

FAO – United Nations Food and Agriculture Organisation

GBR – Great Barrier Reef

GoC – Gulf of Carpentaria

HSC – Herberton Shire Council

ICM - Integrated Catchment Management

IUCN – International Union for Conservation of Nature

MRWMG – Mitchell River Watershed Management Group

NRM – Natural Resource Management

1 Introduction

The common name 'tilapia' refers to a group of tropical freshwater fish in the family Cichlidae (*Oreachromis*, *Tilapia*, and *Sarotherodon* ssp). Tilapia are native to Africa and the southwestern Middle East. Following their introduction to Australia for ornamental purposes, they have found their way into natural waterways where infestations, particularly in north Queensland, have spread significantly over the past three decades. Other infestations have been reported in Victoria, south-east Queensland and Western Australia. While there is little scientific information on ecological impacts of tilapia, particularly in Australia, tilapia are thought to pose a significant risk to aquatic ecosystems and have been declared noxious fish in Queensland.

Tilapia, once established in a waterway, tend to become a dominant fish species. They demonstrate biological and ecological characteristics shared by many successful invasive fish species (Canonico *et al.*, 2005). Invasive freshwater species generally reduce water species abundance through predation, hybridization, parasitism or competition. They may alter community structure and ecosystem processes, such as nutrient cycling and energy flows (Arthington,1991).

Tilapia are now widely established in north-east Queensland east of the Great Dividing Range. They occur in waterways between the Burdekin River in the south and the Endeavour River (Cooktown) in the north, where they were first reported in 2007. There is concern that tilapia may cross the watershed of the Great Dividing Range and become established in the rivers that drain into the Gulf of Carpentaria (Stephen, 2008). It is feared that tilapia may alter significantly the ecology of aquatic ecosystems of waterways in the Gulf and cause a decline in key fisheries in the Gulf of Carpentaria, specifically barramundi and prawn. In January 2008 a tilapia infestation was reported in Eureka Creek in the upper reaches of the Mitchell River catchment. A swift and comprehensive control response was enacted to eradicate what was hoped to be a localised population (Stephen, 2008). However, the success or the eradication activity is as yet uncertain. Failure would likely result in an infestation across the entire Gulf of Carpentaria region (Butts, 2008).

Through their impacts on aquatic ecosystems, tilapia are affecting the uses and values that society, both as individuals and industries, derives from these ecosystems (Morgan *et al.*, 2004; QDPI, 2001; Webb, 2003; Webb *et al.*, 2007a; Webb *et al.*, 2007b). Yet despite their rapid expansion and status as noxious fish, little is known about the (socio) economic impacts of, and risks associated with, tilapia in Australia.

This report addresses some of the existing knowledge gaps. In particular, the report pursues the following objectives:

- It compiles and integrates existing information and data relevant to the topic.
- It conceptualises the impacts of tilapia on uses and values of waterways.
- It scopes and quantifies, where possible, the economic impacts of tilapia.
- It re-assesses the risks that tilapia pose from an economic perspective.

This report is structured into six sections.

Section 2 provides a literature review of the biology and ecology of tilapia as it relates to their presence and potential impacts in north Queensland. This includes a history of tilapia introduction and expansion in Australia and the rationale for declaring tilapia pest fish.

Section 3 describes the conceptual framework adopted for this research. It develops the research approach and details the research methods.

Section 4 describes the results of the research.

Section 5 offers discussion and interpretation of the results. It integrates the new data with existing information through an expanded risk assessment of tilapia with a focus on north Queensland. It also provides quantitative economic impact estimates based on a series of explicit assumptions.

Section 6 contains concluding comments and recommendations for future research.

2 Biological, ecological, historical and institutional context of tilapia in Australia

The common name ‘tilapia’ refers to a group of tropical freshwater fish in the family Cichlidae (*Oreachromis*, *Tilapia*, and *Sarotherodon* ssp), that are native to Africa and the southwestern Middle East.

For the purpose of this report, we focus on two species in particular, *Oreochromis mossambicus*, the Mozambique mouthbrooder, and *Tilapia mariae*, commonly referred to as black mangrove (or niger) cichlia.

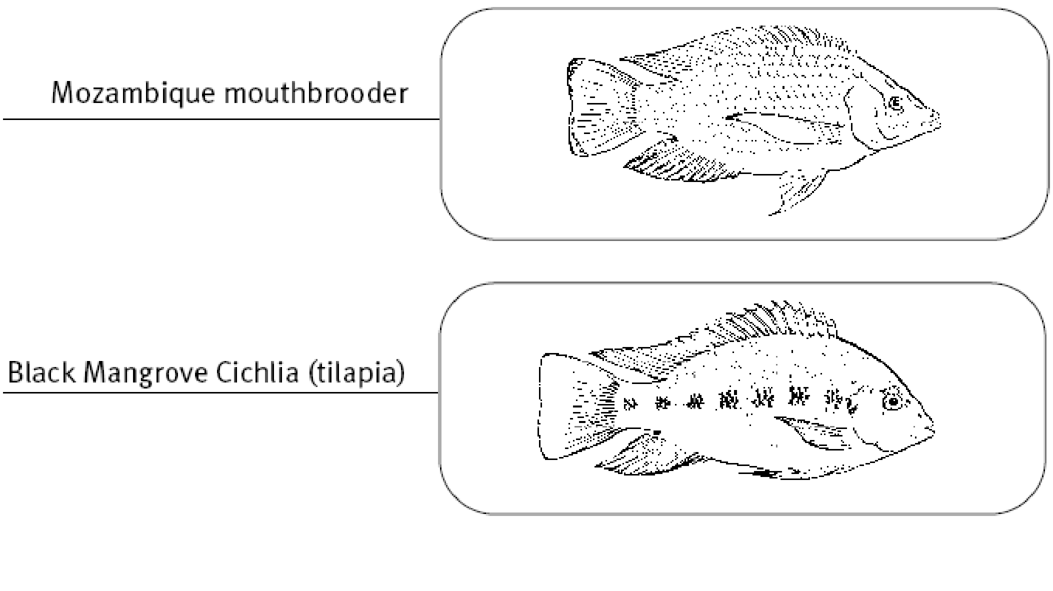
Over the past century, tilapia have been intentionally dispersed worldwide for the biological control of aquatic weeds and insects, as baitfish for aquaculture, as food fish and for aquaria (Canonico *et al.*, 2005; Fortes, 2005). According to Canonico *et al*. (2005, p. 465) most introductions of tilapia into new countries have been for aquaculture purposes because they offer an affordable high-yield source of protein that can be raised easily in a range of environments. Aquarium trade, however, was the reason for their introduction to Australia.

2.1 Biology of tilapia

Oreochromis mossambicus (Mozambique mouthbrooder) and *Tilapia mariae* (black mangrove cichlia) have distinct morphological features, as shown in Figure 1.

Figure 1: Appearance of tilapia

Source: QDPI, 2001, p. 7



Oreochromis mossambicus (Mozambique mouthbrooder) is a deep bodied fish with almost symmetrical dorsal and anal fins and with a prominent concave upper jaw line in males. The size for adults is usually from 30-44cm for males and 25-33cm for females under 'normal' conditions (Webb *et al*., 2007a). This species can exhibit stunting involving sexual maturation at small sizes to reduce the effects of population pressures on abiotic and/or biotic resources in the water body.

Tilapia mariae (black mangrove) is a smaller fish with a highly compressed, oval-shaped body, large eyes, and three anal spines. Colouring is from olive green to light yellow with several dark blotches along the sides of the body (Webb *et al*., 2007b).

Oreachromis mossambicus becomes reproductively active at and above 23 degrees Celsius (Webb, 2003). This means that sexually mature individuals in north Queensland are active for 9-10 months of the year normally and produce 4 to 5 broods per year for most females (Webb, 2003). Females can produce up to 1200 eggs per year (QDPI, 2001) with a survivorship of between 50—90% under laboratory conditions (Webb, 2007 9 /id). In comparison, Carp (*Cyprinus carpio*) produces 80,000 to 1.5 million eggs per spawning season in Australia albeit with very high juvenile mortality (QDPI. 2001). Mortality in *Oreachromis mossambicus* is low because they are mouth brooders, i.e. the female protects eggs and larvae by rearing them in her mouth until they are old enough to compete effectively in the wild (Webb, 2007b). An implication of this strategy is that the translocation of a single female mouthbrooder, carrying young in her mouth, can lead to the colonisation of a new environment. *Tilapia mariae* are nest builders who contribute to reduced juvenile mortality by vigorous defence of their nests.

2.2 Ecology of tilapia

The ecological impacts of invasive fish species can be grouped into eight general categories (Canonico *et al*., 2005): alteration of hydrological regime; alteration of water chemistry regime; alteration of physical habitat; alteration of habitat connectivity; impacts on the biological community; impacts on specific populations; genetic impacts and alteration of ecosystem structure and processes. Many of these apply to tilapia. In particular, tilapia are highly invasive, display persistence under a very wide range of conditions, have prolific breeding strategies and display competitive behaviour (Canonico *et al*., 2005; Morgan *et al*., 2004; QDPI, 2001; Webb *et al*., 2007a).

Tilapia are generally considered herbivores, detritivores or planktivores (Canonico *et al*., 2005). The diet of *Oreachromis mossambicus* consists of aquatic macrophytes, benthic algae, phytoplankton, zooplankton, detritus, periphyton and fish larvae (El-Sayed, 2006). *Tilapia mariae* has a similar diet to *Oreachromis mossambicus* that can be described as planktivory (Webb *et al*., 2007b). However, both species have been documented to consume the eggs and larvae of other fish species (Canonico *et al*., 2005; Burrows, 2008; Webb, 2003; Webb *et al*., 2007a; Webb *et al*., 2007b).

Oreachromis mossambicus and *Tilapia mariae* are both highly tolerant of anoxic conditions, saline water, poor water quality and low levels of available nutrients. Linde *et* *al*. (2008) found an association between the relative abundance of juvenile tilapia in a Brazilian river and habitat degradation. Combined with high fecundity, these tolerances predispose tilapia to a higher probability of successful establishment in areas that are beyond their natural range (Canonico *et al*., 2005).

The natural distribution for *Oreachromis mossambicus* in Africa is from 17°S to 33°S (Webb *et al*., 2007a). A comparison of this range with Australia suggests that tilapia have a potential climatic range distribution that extends south almost to Sydney. Below 27°S, tilapia are only observed to inhabit saline or brackish waters in their native range (Webb *et al*., 2007a).

Tilapia prefer slow moving streams or estuaries and still water (Webb, 2003; Webb *et al*., 2007a; Webb *et al*., 2007b). They can survive and breed in fresh or saline water and may show some preference for slightly saline water in terms of their thermal tolerances.

Oreachromis mossambicus is listed by the IUCN as one of the world's worst 100 invasive species (Lowe *et al.,* 2000). The key reasons for their proliferation are their ability to survive and prosper under conditions that are toxic to most other fish, the high survival rate of their young due to mouth breeding, their aggressive behaviour towards other fish and their predation on eggs and young of native fish.

2.3 History of tilapia in north Queensland

Tilapia species that have infested north Queensland waterways include the Mozambique mouth brooder (*Oreochromis mossambicus*) and the black mangrove or niger cichlid (*Tilapia mariae*). Other cichlids with small isolated populations in Queensland include the three-spot cichlid (*Cichlasoma trimaculatum*), red devil (*Amphilophus citrinellus*), oscar (*Astronotus ocellatus*) and Victoria Burton's Haplochromine (*Haplochromis burtoni*; DPI&F, 2008).

Of the two tilapia species that have established self-maintaining populations in North Queensland waterways, *Oreachromis mossambicus* is the most widely distributed and has the widest temperature tolerance. It is found in the Gascoyne-Lyons catchment in Western Australia, dams and some rivers in south-east Queensland and in a range of rivers and waterways around Townsville, Cairns and the Atherton Tablelands (Canonico *et al*., 2005). There are two distinct strains of *Oreachromis mossambicus*; the Townsville and south-east Queensland strain being 'pure' and the strain found around Cairns considered to be a hybrid between *O. mossambicus, O. aureus and O. niloticus.* Hybridisation is likely to have taken place in capativity prior to the release of specimens into natural waterways (Canonico *et al*., 2005; Webb *et al*. 2007a).

The introduction of *Oreachromis mossambicus* to open aquatic systems of north-east Queensland is believed to have first occurred in Townsville in 1978. It is thought that tilapia specimens were released into ponds in Anderson Park, from where they escaped and established themselves in the Ross River during subsequent floods (DPI&F, 2008). The exact time and nature of introduction of *Tilapia mariae* is unknown.

Dispersal of many invasive freshwater species in Australia is predominantly through human vectors (Lintermans, 2004). Species that have had their spread facilitated by humans include *Oreachromis mossambicus, Gambusia holbrooki* (Eastern Gambusia), and *Cyprinus carpio* (Carp). Mechanisms include "bait bucket introductions", escapes from outdoor ponds or farm dams and deliberate legal or illegal introductions or releases (Lintermans, 2004). Similarly for tilapia, it is thought that introductions to other waterways in north Queensland were through human vectors, either inadvertently or deliberately. Tilapia were first reported in a tributary of the Barron River in 1986 and then again in another tributary in 1995. Anecdotal evidence suggests that a pond in a resort golf course in Port Douglas, into which a few tilapia specimens had been released in 1989, yielded 13 tonnes of tilapia biomass only three years later (IACRC, 2008). Tilapia were first sighted in the Endeavour River (Cooktown) in 2007. The most recent new sighting was in January 2008 in Eureka Creek in the upper reaches of the Mitchell River catchment, which drains into the Gulf of Carpentaria. In this case, a swift and comprehensive control response was enacted to eradicate what was hoped to be a localised population (Stephen, 2008). However, the success or the eradication activity is as yet uncertain. Failure of the eradication effort would result in the likely infestation across the entire Gulf of Carpentaria region (Butts, 2008).

2.4 Potential impacts of tilapia in (north) Australia and its status as a pest species

Tilapia are one of 16 species of exotic fish that have formed significant self-maintaining populations in Queensland waters (EPA, 2003). There are two principal impacts of tilapia that are of concern in a north Australian context. The first is their ability to displace native fish species. Displacement results mainly from prolific breeding and aggressive competition for habitat. The second concern refers to their potential impact on water quality, also resulting from prolific breeding and the ability to accumulate substantial biomass with its associated waste products.

2.4.1 Displacement of native fish through competition

It is unlikely that tilapia will impact on native fish species in Australia through competition for food or predation. Rather, they may displace native species through aggressive behaviour during mating periods when the males vigorously defend their display pits (Moran *et al*., 2004). Arthington and McKenzie (1997) demonstrated that *Oreochromis mossambicus* keep indigenous species out of their breeding territories.

The behavioural competitive impact of tilapia may specifically affect barramundi (*Lates calcarifer*), an important commercial fish species as well as a prized recreational target fish. "Tilapia are capable of having severe impacts on native fish populations, including [..] icon species such as barramundi" (Gribb, 2008).

The value of wild-caught commercial barramundi fisheries in Queensland in 2005/06 was over $6.7 million (ABARE, 2007), with the majority of harvest originating from the Gulf of

Carpentaria. Figure 2 shows a time series of the value of barramundi catch in the GBR or GoC waters. Recreational fishing is an important past time for people in Queensland. Approximately one quarter of the Queensland population (5 years and older—equivalent to 785,000 persons) goes recreational fishing, crabbing, or prawning in Queensland every year (Henry and Lyle, 2003). Recreational fishers target barramundi in natural streams and in stocked impoundments including the Burdekin Falls Dam and Lake Tinaroo, both of which are infested with tilapia (Webb *et al.*, 2007a; 2007b). Despite their prevalence in key recreational fishing areas, tilapia do not rate a mention in key fishing guides for north Queensland (e.g. Explore Australia 2006; North Australian Fish Finder 2007).

In Queensland, the vast majority of recreational anglers go saltwater fishing exclusively (Figure 3). Fewer than 10% fish only in freshwater and about a quarter fish in both ecosystems. Recreational fishers in far north Queensland show a particularly high preference for saltwater fishing (DPI&F, 2008b). Freshwater fishers increasingly favour fishing in dams and impoundments relative to rivers (Figure 4).

Figure 2: Commercial harvest and value of wild-caught barramundi in the GBR region and Gulf of Carpentaria (QLD section) waters

Source: DPI&F, 2008b

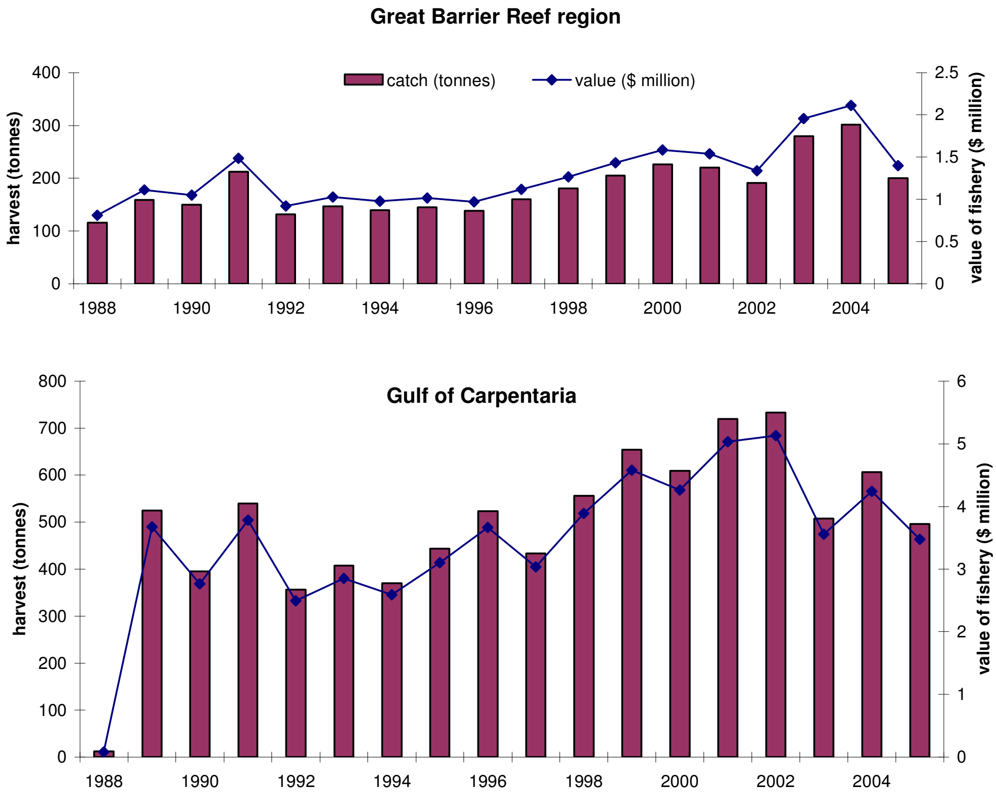


Figure 3: Types of recreational fishing in Queensland

Source: DPI&F, 2008b.

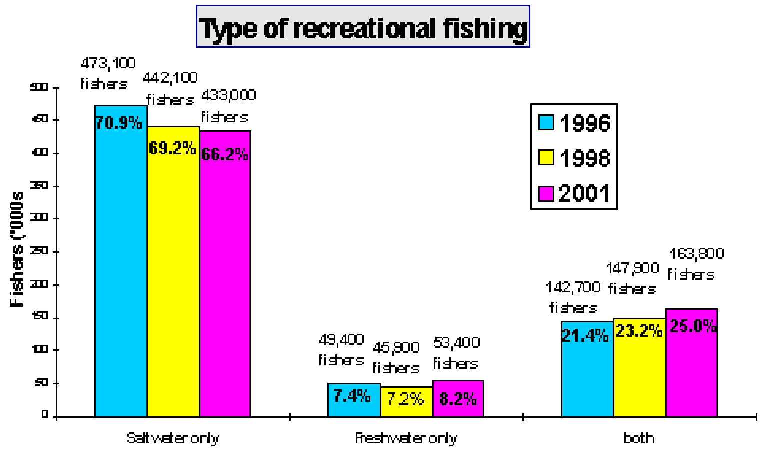
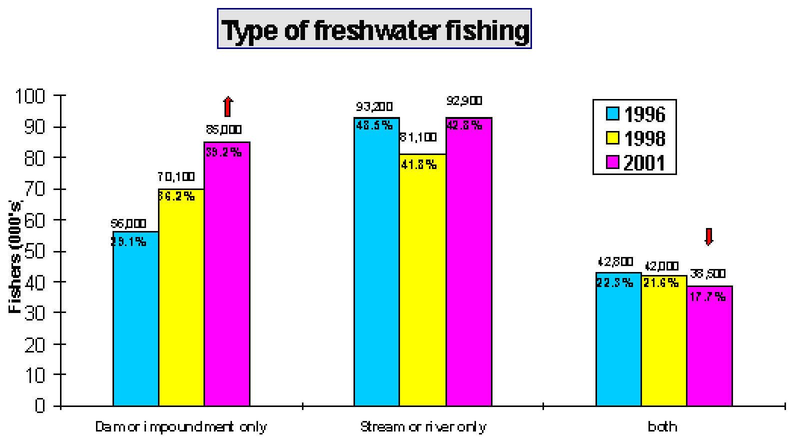


Figure 4: Preferred freshwater fishing localities

Source: DPI&F, 2008b.



Barramundi are more commonly caught by recreational anglers in inland waterways than in coastal or offshore locations. According to the National Recreational and Indigenous Fishing Survey (Henry and Lyle, 2003), 88% of barramundi were caught in inland waterways including estuaries (49%), rivers (36%) and lakes/dams (3%). During 2005, residents of the Far North and Northern Statistical Divisions in Queensland caught approximately 39,636 and 43,655 barramundi, respectively, but released most of them back into the environment keeping only 14,462 and 9,975 specimen, respectively (DPI&F, 2008b). Across Queensland, 51,159 barramundi were harvested by Queensland residents, which is 27% of the total catch (DPI&F, 2008b). These estimates are based on telephone surveys. They do not include those fish caught and/or harvested by interstate or overseas visitors.

Queensland fishers spend approximately $1000 each year on fishing activities, including the costs of tackle, boats, travel and accommodation (NLWRA, 2002). Using these estimates, the contribution to the Queensland economy from individual fishers is approximately $880 million with about $528 million of this attributable to fishers in estuaries (NLWRA, 2002). The value of recreational fishing for barramundi in Queensland has been estimated at $15 million annually (Robinson, 2001).

2.4.2 Eutrophication of water and competition for abiotic resources

The second key issue surrounding impacts of tilapia is regarding water quality. Tilapia have been observed to cause eutrophication. They have the capacity to impact on the water quality of water bodies they inhabit through a build-up of biomass leading to increased consumption of food and subsequent release of nutrients into the water. Increased levels of bioavailable nutrients have an associated increased risk of algal blooms that may cause fish die-off.

Several workers have found evidence that the presence of large populations of tilapia can contribute to severe degradation of water quality, particularly in isolated water bodies (Canonico *et al*. 2005; Webb 2003; Webb *et al*. 2007a). For example, in Lago Paranoá in Brazil, excretion of wastes as well as bioturbation by tilapia from the consumption of benthic algae have been linked to increased nutrient recycling, leading to enriched levels of bioavailable phosphorus and free chlorophyll *a* (Starling *et al*., 2002, in Canonico *et al*., 2005). Increased populations of cyanobacteria (blue-green algae) were also found and associated directly with the effects of tilapia activity on nutrient levels.

Increased levels of organic material in waters, as a result of algal blooms thriving in enriched nutrient environments, can lead to suffocating, anoxic conditions that may be fatal to fish. Tilapia themselves are tolerant of anoxic conditions (Canonico *et al*., 2005), allowing them to survive fish die-off episodes where other species may be affected.

Tilapia may be compared with carp. Environmental impacts generally result from the bottom-feeding behaviour of carp (McLeod, 2004, p.31). Bioturbation for carp is expected to be greater since sediment is inhaled and sifted through the gill rakers in an activity knows as ‘mumbling’ and can increase turbidity, release sediment nutrients and destroy aquatic plants.

The presence of tilapia in water storage structures where the water is used both for recreational purposes and human consumption is therefore a cause for concern.

2.4.3 Risk assessment

The likelihood of establishment of tilapia in tropical waters is extremely high (Canonico *et al.*, 2005). Currently, infestations in the tropical parts of northern Australia are geographically limited (Figure 2). The potential range of tilapia is thought to be much larger, covering most of Queensland and the northern parts of the Northern Territory and Western Australia (Figure 2).

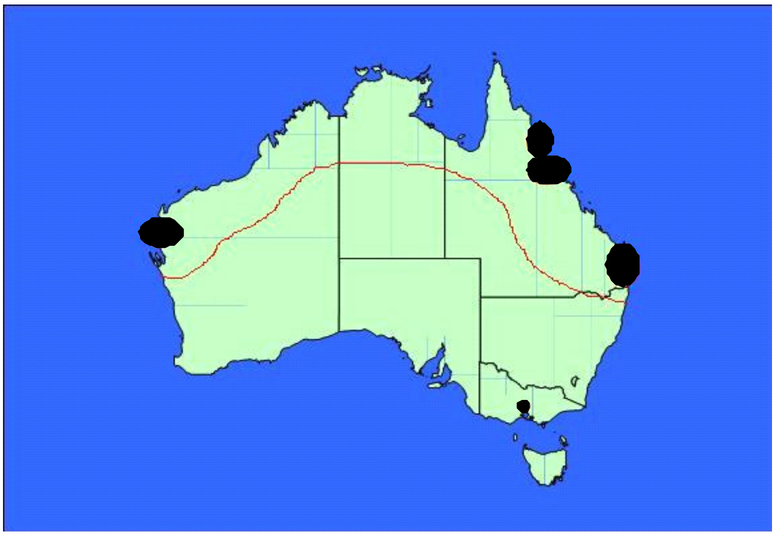
Even under moderate climate change scenarios and associated increases in temperatures, tilapia could potentially spread across the vast majority of the Australian continent (IACRC, 2008). Warmer waters may also see tilapia sexually active all year round in many sites, resulting in an even higher number of annual broods.

Tilapia, carp (*Cyprinus caprio*) and gambusia (*Gambusia holbrooki*) are considered to be posing the greatest threat to the health of Queensland waterways (EPA, 2003). Because of the (potential) impacts from tilapia combined with the high level of difficulty to control them, tilapia are rated in the top 10 pest animals of the Wet Tropics (CRCTREM, 2002). Other exotic fish rated similarly are gambusia and guppy (Figure 6).

Figure 5: Expected extent of spread of tilapia under current climatic conditions

Source: http://www.invasiveanimals.com. Accessed 17th March 2008.

Black circles indicate current infestations; red line indicates southern climatic boundary



On the basis of the potential ecological risk they pose, *Oreachromis mossambicus* and *Tilapia mariae* are declared pests in Queensland, New South Wales, Victoria, South Australia and the Northern Territory (Queensland Government, 1994). The supporting risk assessment for Queensland is provided in Table 1.

Figure 6: Current major animal pests of the Wet Tropics (Australia)

Source: Harrison and Congdon (2002)

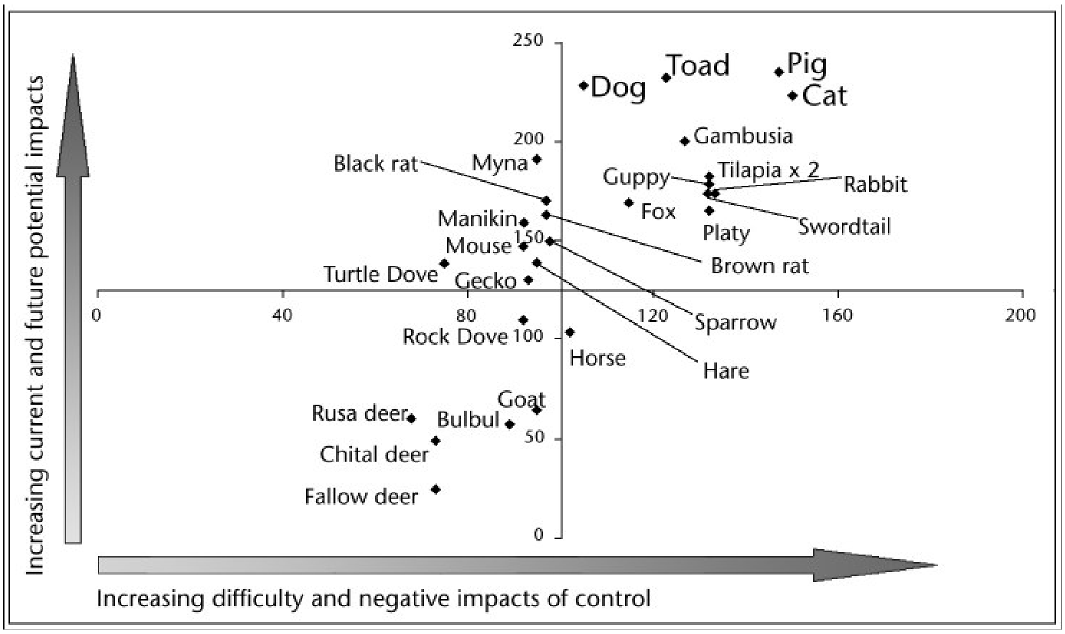


Table 1: Species assessment supporting the pest fish declaration of tilapia

Source: DPI (2001)

	Oreochromis mossambicus	Tilapia mariae
Based on the growth and reproductive characteristics of the species, what is the likelihood of it displacing local native species?	High	High
What is the likelihood of the species becoming a significant predator of exhibiting aggressive behaviour towards native species?	Medium – aggressive	High – very aggressive
What is the likelihood of the species altering the physical environment in potential receiving waters?	Medium	Medium
What is the likelihood of the species destabilising plant communities in the receiving waters?	Low	Low
What is the likelihood of the species hybridising?	High – with other Oreochromis species	High – with other tilapia species
What is the likelihood of the species utilising degraded habitats?	High	High
What is the likelihood of the species withstanding a broad range of environmental conditions?	High – broad environmental tolerances	High – very broad environmental tolerances

Under Queensland law (The Queensland Freshwater Management Plan 1999), *it is an offence to possess tilapia alive or dead. Tilapia cannot be kept, hatched, reared or sold; nor can they be taken home for eating or any other purpose. Penalties of up to $150,000 apply for possessing tilapia* (DPI&F, 2008c).

The occurrence of tilapia in the upper Barron River and Tinaroo Dam is of major concern as these are connected via irrigation channels to the Mareeba-Dimbulah irrigation system, which lies in the Mitchell River catchment and therefore in the Gulf of Carpentaria catchment (EPA, 2003). This cross-catchment hydrological connection opens a series of potential translocation paths for tilapia into the Gulf of Carpentaria catchment (BMTMG, 2001). The discovery of tilapia in Eureka Creek in January 2008 underscores the near certain risk of such cross-basin translocation.

3 Methodology

3.1 Economic impact of pest species: conceptual foundation and examples

There are many pest animal species in Australia that cause economic impacts. The traditional understanding of economic impact refers to the financial value of reduced (agricultural) productivity associated with a pest species. Modern impact assessments take a 'triple bottom line' approach and report on economic (financial), environmental and social impacts (McLeod, 2004).

Economic impact assessment typically involves three steps (Mcleod, 2004).

- Estimating the distribution of the pest;
- Identifying the value of (agricultural) production within the range of the pest; and
- Calculating the reduced value of production as a result of the pest and/or the increased cost of production.

For example, dingos and wild dogs cause losses in the grazing sectors. On the basis of their distribution and assumptions regarding livestock kills, production losses have been estimated to be approximately $48 million annually (Mcleod, 2004). In addition, there are costs to farmers associated with wild dog control (labour and materials for management and fencing) that amount to $16 million annually. A further $1.5 million annually is invested in wild dog-related research, taking the direct economic impact of the wild dogs to approximately $66 million annually. However, this estimate does not take into account the environmental and social costs, for example the impact to biodiversity and recreational use values of landscapes.

With tilapia, as with other pest fish, estimating economic impact is more difficult and complex for two reasons:

- There is a lack of scientific evidence to support cost estimates both in terms of lost production of any sector and in terms of increased costs of production.
- The causal relationships between the presence of tilapia and impacts are uncertain and quantification relies on a series of assumptions.

McLeod (2004, p.31) estimated the annual impact of carp in Australia to the community to be approximately $12 million—compared to management costs of $2 million annually. He justified this estimate on the basis of the bottom-feeding behaviour of carp, which caused increased water turbidity, reduced the abundance of invertebrates and aquatic plants and possibly displaced other fish species. The principal components of this cost are reduced recreational fishing value and costs caused by water turbidity.

- "*If carp were contributing to a 30% decline in prized fish species, then a social cost of $9 million per year could be attributed to the impact of carp on recreational fisheries*" (McLeod, 2004, p. 32), assuming
  - 600,000 Australians may use carp-infested waterways for recreational fishing and
  - in the absence of carp, fishers would have satisfactory water quality and greater abundance (and catch) of prized native fish.
- Attributing 10% of the annual cost of water turbidity and the cost of sedimentation to the presence of carp, the water quality cost of carp is about $2.8 million per annum.

It is thought that tilapia may impact on some native fish species that have commercial value, e.g. barramundi, although a clear causal relationship has not been scientifically established to date. While there is the possibility that barramundi breeding may be impeded by tilapia behaviours and that juvenile barramundi may be eaten by tilapia, there is also evidence to suggest that barramundi may eat tilapia (e.g. Webb, 1994). In addition, commercial catch, of for example barramundi, is influenced by many natural factors (e.g. river flows) as well as institutional factors (e.g. fishing regulations) and fluctuates accordingly. This means that it is almost impossible to calculate potential losses that tilapia may cause to the commercial barramundi fishery.

Estimating losses to the recreational fishery would include not only an assessment of reduced catch of recreational target species due to tilapia, but also a suite of amenity and other values associated with angling as a recreational activity. Further costs of tilapia are associated with a potential decline in the environmental values of infested waterways. As none of these values are bought and sold in the market place, non-market valuation techniques are required to estimate their magnitude (Pearce and Turner, 1990). These methods measure people's revealed or stated preferences and include contingent valuation and willingness to pay (Allen and Loomis, 2006; Atkins and Burdon, 2005) and choice modelling (Alvarez-Farizo *et al.*, 2006; Bishop, 1982; Christie *et al.*, 2006; Hein *et al.*, 2006; Henry, 1987; Richards and Aitken, 2004; Smith, 1983).

In comparison, it is easy to calculate the direct costs associated with the presence of tilapia based on control and management expenses, as such costs are recorded as expenses by companies, organisations and agencies and are therefore more readily accessible.

It is thought that for many pest species the non-market impacts (social and environmental) may outweigh the direct costs and economic impacts. As discussed above, McLeod (2004) estimated the cost associated with the environmental impact of carp to be approximately 6-fold its management cost. Of the approximately $16 million total cost per annum, one quarter ($4 million) was attributed to economic impact with the environmental impact comparatively larger ($11.8 million). No estimate for the social impact of carp was provided.

For a more complete assessment of the economic (triple bottom line) impact of tilapia it is therefore important to understand the types of costs that tilapia are causing and the types of other impacts associated with tilapia infestations. Because of the uncertainty of causal relationships it is also important to cast the analysis within a risk assessment framework.

The EPA environmental values framework for assessment of water quality (EPA, 2006), shown in Table 2, was chosen as a principal framework for scoping the economic impacts for several reasons.

Table 2: Definition of Environmental Values in the Queensland Water Quality Guidelines

Source: EPA (2006)

	ICON	
Aquatic Ecosystems		The intrinsic value of aquatic ecosystems, habitat and wildlife in waterways and riparian areas – for example, biodiversity, ecological interactions, plants, animals, key species (such as turtles, platypus, seagrass and dugongs) and their habitat, food and drinking water. Waterways include perennial and intermittent surface waters, ground waters, tidal and non-tidal waters, lakes, storages, reservoirs, dams, wetlands, swamps, marshes, lagoons, canals, natural and artificial channels and the bed and banks of waterways. See below for details of three possible "levels of protection" contained in the Australian water quality guidelines (AWQG).
		High conservation value aquatic ecosystems (HCV) (Level 1) are largely unmodified or have undergone little change due to human activities and are often found within national parks, conservation reserves or inaccessible locations.
		Slightly to moderately disturbed aquatic ecosystems (SMD) (Level 2) have experienced some change from human activities but are not considered highly disturbed (see below). Aquatic biological diversity may have been affected to some degree but the natural communities are still largely intact and functioning.
		Highly disturbed aquatic ecosystems (HD) are degraded systems likely to have lower levels of naturalness but may still retain some ecological or conservation values.
Primary industries		**Irrigation:** Suitability of water supply for irrigation - for example, irrigation of crops, pastures, parks, gardens and recreational areas.
		Farm Water Supply: Suitability of domestic farm water supply, other than drinking water. For example, water used for laundry and produce preparation.
		Stock Watering: Suitability of water supply for production of healthy livestock.
		Aquaculture: Health of aquaculture species and humans consuming aquatic foods (such as fish, molluscs and crustaceans) from commercial ventures.
		Human Consumers of Aquatic Foods: Health of humans consuming aquatic foods - such as fish, crustaceans and shellfish (other than oysters) from natural waterways.
Recreation and aesthetics		**Primary Recreation:** Health of humans during recreation which involves direct contact and a high probability of water being swallowed - for example, swimming, surfing, windsurfing, diving and water-skiing
		Secondary Recreation: Health of humans during recreation which involves indirect contact and a low probability of water being swallowed – for example, wading, boating, rowing and fishing.
		Visual Recreation: Amenity of waterways for recreation which does not involve any contact with water - for example, walking and picnicking adjacent to a waterway.
Drinking Water		Suitability of raw drinking water supply. This assumes minimal treatment of water is required – for example, coarse screening and/or disinfection.
Industrial uses		Suitability of water supply for industrial use - for example, food, beverage, paper, petroleum and power industries. Industries usually treat water supplies to meet their needs.
Cultural and spiritual values		Indigenous and non-indigenous cultural heritage - for example: • custodial, spiritual, cultural and traditional heritage, hunting, gathering and ritual responsibilities; • symbols, landmarks and icons (such as waterways, turtles and frogs); and • lifestyles (such as agriculture and fishing).

- The framework was developed specifically to assess the values of waterways. As fish, tilapia are confined to waterways and their presence directly affects the values of waterways.
- The listing of direct, indirect and non-use values provided by the framework ensures that the study is cognizant of the various types of impacts that tilapia may have for different sections of the community.
- The framework was developed in the context of the Australian and Queensland governments developing and implementing policy for water quality improvement and protection. It represents an example of how concepts of environmental values are applied to a specific conservation issue and translated into the policy arena. It therefore appears useful to review this framework in the context of a theoretical framework of values of environmental goods and services.

3.2 The economic value of water and waterways

The sum of benefits that society derives from environmental goods (e.g. waterways free of tilapia) can be referred to as 'total economic value' (Hodge and Dunn, 2001) and the benefits as ' welfare contributions'. The total economic value approach is based on the identification and quantification of the linkages between the environmental condition (or change) and human activity. It establishes the link between an environmental function and the flow of environmental services which people value.

Figure 7 provides a stratification of uses and values. Non-use (or passive use) benefits are those that society derives from the landscape without actually using it. Table 3 illustrates how the framework can be applied to conceptualise the uses and values of water and waterways.

Figure 7: The components of total economic value

Source: Adapted from Hodge and Dunn (2001)

Aesthetic value	Non-consumptive use value	Direct use value	USE value	Total economic value
Recreational value				
Educational value				
Distant use value				
Consumptive use value				
Indirect use value				
Option value				
Existence value			NON-USE value	
Bequest value				
Philanthropic value				

Specific definitions include:

- Option value is the amount of money society would be willing to pay for retaining an option to use a good (e.g. an area, facility, species) that would be difficult or impossible to replace or for which no close substitute is available (Smith, 1983). This explains why demand may exist even when there is no current intention to use the good in question and the option may never be exercised (Henry 1987).
- Existence value is the amount of money that society would be willing to pay to know that a particular natural good exists (e.g. a native fish) exists in its natural habitat (Loomis *et al.*, 2000; Sharp and Kerr, 2005).
- Bequest value is the amount of money that society would be willing to pay today so that future generations will have good water quality or native fish in their natural habitat (Loomis *et al.*, 2000).
- Philanthropic value is the amount of money that society would be willing to pay today as a result of individuals' desire to improve the material, social, and spiritual welfare of humanity through the preservation of good water quality or native fish in their natural habitat.

Table 3: Total economic value of water and waterways

Source: adapted from Atkins and Burdon (2005)

Use Values			Non-use values
Direct use values	Indirect use values	Option values	Existence values
Drinking water Recreation, e.g. recreational fishing Commercial fishing Agriculture/industry Biodiversity value Research/education Tourism/ecotourism Human health	Recreation, e.g. water sports Landscape Biodiversity value Aesthetic values, e.g. appreciating the view of lakes and rivers Tourism/ecotourism Research/education Human health	Future uses as per direct and indirect use values	Water (of potable quality) and healthy waterways as objects of intrinsic value, as a gift to others, and as a responsibility (stewardship)

Bishop (1982) illustrates that because of the existence of option values, revenue obtained from current users is an insufficient indicator of total economic value. Loomis (2004) makes the point that while non-use benefits are often quite small per person, the non-rival nature of public good benefits (such as high water quality or preservation of species) results in simultaneous enjoyment by millions of people. Therefore, the total social benefits can be quite large and outweigh the use values.

Loomis (2004) provides numerical estimates of the composition of total value of water quality as established through a survey of US citizens, Of 100% total value, 37% was attributed to use values, and 63% to non-use values – including 26% bequest value, 21% option value and 16% existence value. Holmes (2002) claims that non-market values in Australia’s outback regions are very important, far outstripping their relative influence in more populated regions. Polome *et al.* (2005) discuss the issues of economic valuation; non-market benefits and benefit transfer between beneficiaries.

Non-use values may be disregarded or undervalued because they are not expressed in the market (Beare *et al.*, 2003), causing misallocation of resources. Inappropriate institutional arrangements or poorly defined property rights can further cause misallocation of resources (ABARE, 2001). Markets fail to allocate resources efficiently when the private costs and benefits of an individual’s actions diverge from those that accrue to the rest of the community. This is common when dealing with natural resources.

Non-use values may sometimes be expressed politically (Richards and Aitken, 2004) which may or may not take account of the full variety of viewpoints on natural resource issues (Bellamy, 2005). In many cases, sophisticated analysis is needed to produce any sort of quantitative value estimates that can be balanced against use values determined in the market or administratively. Biodiversity has value in itself which requires assessment (Christie *et al.*, 2006).

Wetlands, being one form of waterways, have a diversity of non-use functions and non-consumptive values (DEWHA, 2008). They protect shores from wave action, reduce the impacts of floods, absorb pollutants and provide habitat for animals and plants. Wetlands purify inflowing water and are important for recreational activities. They also form nurseries for fish and other freshwater and marine life and, because of this, are critical to Australia's commercial and recreational fishing industries.

Wetlands also bear historical significance with some having high cultural value. In particular, many wetland areas throughout Australia are important to Aboriginal people. Although this value is still relatively unexplored, it is known that wetlands have religious and historical values for many local communities. For example, in Australia, many wetlands have a cultural value to their Aboriginal Traditional Owners, in which they conduct ceremonies and semi-traditional hunting and gathering (Schuyt and Brander, 2005; Whitten *et al.*, 2002).

Few studies globally have been conducted into the environmental values of aquatic ecosystems. Table 4 provides a selection of relevant studies. These studies show that people value environmental services and impact. Even if the dollar amount that the average household is willing to pay for improvements in environmental quality is small, the aggregate value can be very large due to the number of households concerned.

Table 4: Selection of environmental values estimated for aquatic ecosystems

Source: Adapted from McLeod (2004; p. 6)

Study	Comments
Loomis (1987) in Young (1991) protection of Mono Lake's ecosystem	Each household would be willing to pay the equivalent of AUD $29 per year to preserve wetlands in current state
Water Research Centre Flood Hazard Centre (1989)	Each UK household would be willing to pay the equivalent of AUD $21 per year to improve water quality and fishing
Mitchell and Carson (1981)	Each household would be willing to pay the equivalent of AUD $82 per year to improve water quality and fishing in the USA
Van Bueren *et al.* (1993)	West Australian recreational anglers were willing to pay $5.50 per additional salmon caught
Burns *et al.* (1997)	South Australian recreational anglers were willing to pay $0.72 per additional whiting caught
Possingham *et al.* (2002) – protection of freshwater ecosystems	Willingness to pay was $0.08 per household for swimming and fishing for every 10 kilometres of degraded waterway that is restored (totalling approx $260,000 for all Australian households per 10 km of degraded waterway--$390 million over the length of the river system in the study).

3.3 Approach to estimating the economic impact of tilapia

The present approach to estimating the economic impact of tilapia was guided by the total economic benefit framework and moderated by the resource limitations of the study. There was no scope, for example, to design and undertake a non-market valuation study. Rather, the research needed to focus on scoping the issue of economic impact and illustrating impact areas. Two lines of investigation were pursued:

- Elicitation and collation of the direct/management cost of tilapia
- Scoping of the environmental and social costs associated with tilapia

These investigations provided new insights and information that was then used to revisit the risk assessment of tilapia—in the particular context of north Queensland—and to provide some broad cost quantification of impacts based on various assumptions.

To quantify the management costs associated with tilapia, a questionnaire was developed and distributed, together with a covering letter (Appendix 1) to relevant organisations and agencies in (north) Queensland. The list of organisations and contact officers was established in consultation with Dr Damien Burrows and Mr Vern Veitch of the ACTFR and is shown in Table 5. The questionnaire is shown in the Appendix 2.

Respondents were specifically asked to provide written consent for the information to be used and disclosed for the purpose of this study.

Table 5: Organisations and agencies involved in survey of management cost

Type of agency or organisation	Name of organisation	Responding officer (response mode: E=email; T=telephone; F=facsimile)
State Government	DPI&F	Dr Aafer Saraç (E)
Local Government	Atherton Shire Council	Tim O'Brien (E)
	Burdekin Shire Council	Trevor Williams (E)
	Cairns City Council	Russell Wild (E)
	Cardwell Shire Council	Damon Sydes (T)
	Cook Shire Council	Jason Carroll (E)
	Douglas Shire Council	Peter Logan (E)
	Eacham Shire Council	Troy Orchard (T)
	Herberton Shire Council	Gordon Malcolm (P)
	Hinchinbrook Shire Council	Susan Oswald (E)
	Johnstone Shire Council	Ken English (E)
	Mareeba Shire Council	Sid Clayton (F)
	Thuringowa City Council	Jasmine Oakes (T)
	Townsville City Council	Russell Warner (E)
Water Corporations	Sunwater	Brett Stevenson (E)
	NQ Water	Rob Hunt (E)
(Sub-) Regional NRM Groups	Terrain	Sam Pagano (T)
	Burdekin Dry Tropics NRM	Jenni Edmonds (T)
	South Cape York	Jason Carroll (E)
	Mitchell River Watershed Management Group	Deborah Easthop (E)

The questionnaire referred to costs incurred during the 2006/07 financial year but respondents were also asked to describe activities and associated costs in other years. The activities and associated costs were classified, on the basis of the intent of the activities, into monitoring, management and prevention activities.

- "Monitoring" included anything that organisations undertook to observe/measure the spread and/or impact of tilapia.
- "Management" included activities that were aimed at reducing/eradicating tilapia and/or its impact.
- "Prevention" included activities that were aimed at preventing the spread of tilapia. It included education and research activities, and infrastructure projects.

Additional questions were asked in relation to:

- The impacts that tilapia had on the organisation's stakeholder/s, e.g. the community or parts of the community. This formed the rationale for the organisation undertaking and funding the actions listed earlier;
- Likely future developments related to tilapia.

Based on the finding by McLeod (2004) for carp and discussions with fisheries scientists from the ACTFR, a working hypothesis was developed that suggested the costs to non-direct values of tilapia, predominantly associated with environmental and social impacts, would substantially outweigh management/direct costs. A sub-hypothesis postulated that a large part of the cost would be incurred by recreational fishers through a decline in use and non-use values associated with angling in tilapia - infested waterways.

The National Recreational and Indigenous Fishing Survey demonstrated that different motivational factors are important to Queensland anglers including aesthetic, sporting and social factors (Henry and Lyle, 2003). Based on their ecological features, tilapia have the potential to impact all three values - reducing enjoyment of fishing, reducing fishing activity and causing people to travel further distances to be able to fish in waterways which are not infested.

A series of scoping questions were developed (Appendix 3) to guide the focus group discussions with recreational fishing and fish restocking groups in Townsville and Atherton. Focus group discussions were of approximately 45-60 minutes duration. In addition, several semi-structured telephone interviews were conducted with other recreational fishing experts. Again, the selection of groups and experts was guided by ACTFR specialist advice. Table 6 summarises these data gathering activities.

Table 6: Focus group discussions and interviews with recreational fishers and experts

Method	Research respondents/participants	Date
Focus group discussions	Townsville Sport Fishing Club (Kirwan; 15 participants)	20 February 2008
	Twin Cities Fish Stocking Society (Kelso; 9 participants)	6 March 2008
	Tablelands Fish Stocking Association (Atherton; 3 participants)	20 March 2008
Telephone interviews	Warren Hughes (Cairns)	11 March 2008
	Graham Dalip (Atherton)	27 February 2008
	Michael Dawson (Yungaburra)	27 February 2008

The topics and issued covered included:

- Fishing: General, methods, frequency and demographics
  - How frequently and where did people fish (times per year; proportion in fresh/estuarine waters; proportion of boat versus land-based platforms)?
  - Who did people fish with (e.g. family/friends)?
  - How far did people travel away from home for fishing, and how often?
  - What attracted people to fishing?
  - What was their experience (years)?

- Catch of tilapia and observed impact of tilapia
  - How often, during the past year, did people recall catching a tilapia specimen?
  - Where did they catch tilapia?
  - With what gear/method did they catch tilapia?
  - Based on people's experience, were tilapia replacing their normal target species or were they caught in addition?
  - What were people doing with the tilapia they caught?
  - Had people noticed any change in the occurrence of tilapia and the frequency with which they were caught?
  - Had people noticed any differences between areas that had dense populations of tilapia and areas in which they were present but only in small populations?
  - How and to what extent were anglers changing their behaviour in areas that were infested by tilapia?
  - Had people noticed any changes to the ecosystems that they attributed to tilapia? If they had, had those changes affected anglers' behaviour?
  - To what extent had current management methods succeeded in controlling the population or spread of tilapia?
  - Had people observed any impacts of tilapia on commercial interests in the area, including commercial fishing and tourism? How were those interests affected? What were associated costs?

3.4 Risk assessment

The DPI risk assessment of tilapia, which formed the basis of its noxious pest declaration, is shown in Table 1. This assessment was conducted some years ago and in a whole-of-Queensland context. It was decided that with the new information generated by this research, the risk assessment should be revisited and further adapted to a north-Queensland context.

Risk assessments study vulnerabilities, threats (known and postulated), likelihoods, expected losses or impacts, and (theoretical) effectiveness of abatement measures. Risk assessment involves identifying a danger and estimating the probability of it occurring. Risk assessments integrate the likelihood of occurrence and the severity of the potential impact through a matrix, as shown in Table 7, and provide the resulting assessment of risk.

Table 7: Generic risk assessment metric

Likelihood	Consequences: Catastrophic	Major	Moderate	Minor	Insignificant
Almost certain	Extreme	Extreme	High	High	Moderate
Likely	Extreme	High	High	Moderate	Moderate
Possible	High	High	Moderate	Moderate	Low
Unlikely	High	Moderate	Moderate	Low	Low
Rare	Moderate	Moderate	Low	Low	Low

Likelihood asks about the expected probability of something happening:

- Almost certain: Expected to occur in most circumstances
- Likely: Will probably occur in most circumstances
- Possible: Might possibly occur at some time
- Unlikely: Could occur at some time
- Rare: May occur only in exceptional circumstances.

Consequences asks about the severity of expected impact (hurt, damage):

- Catastrophic: Death or large number of serious injuries to people will occur, environmental disaster; huge cost
- Major: Serious and/or extensive injuries to people will results, severe environmental damage; major cost
- Moderate: Injuries to people will result, contained environmental impact; high cost
- Minor: People may require first aid treatment, some environmental and/or financial cost
- Insignificant: No injuries, low environmental impact; no-low financial cost.

Risk management responses are recommended on the basis of the combined risk score.

- Extreme: Immediate action(s) required
- High: Action plan required, attention by key decision makers required
- Moderate: Specific monitoring or procedures required, management responsibilities must be specified
- Low: Manage through routine procedures

The risk assessment of tilapia is based upon data, anecdotal evidence and expert opinion obtained in the course of this research. There is also some additional literature, including a description of failed tilapia aquaculture projects abroad (Fortes, 2005), which may bear some relevance for tilapia in Australia.

4 Research results

4.1 Tilapia-related management costs and associated actions

There is a series of actions which agencies and organisations with a mandate for water and waterway management in north-east Queensland undertook in response to the presence of tilapia and to prevent tilapia from spreading further.

Direct costs are the expenses that are attributable to the presence of tilapia in waterways, including expenses for monitoring, management (reduction/eradication) and prevention measures. Table 8 provides a summary of direct costs by type of organisation/agency and cost category.

Table 8: Tilapia-related expenses incurred during 2006/07 in (north) Queensland

	Monitoring	Management	Prevention	TOTAL
Local governments	$939	$0	$8,387	$9,326
Water Corporations	$24,000	$10,000	$228,966	$262,966
QLD Government (DPI&F)	$213,000	$80,000	$303,860	$596,860
Regional NRM groups	$0	$0	$20,014	$20,014
TOTAL	$237,939	$90,000	$561,227	$889,166

Total expenses attributable to the presence of tilapia were approximately $900,000 for 2006/07. The bulk of these costs were borne by the Queensland Government (67%) and the water corporations (30%) while costs to local government and regional NRM groups were comparatively low (1% and 2%, respectively). A majority of expenses related to the prevention of tilapia spreading further (63%). Monitoring was the second largest cost component while eradication/reduction costs were minor.

The cost incurred by the Queensland Government, through the DPI&F, were for a new program called “Stop the Spread”, the total cost of which amounted to almost $600,000 during 2006/07.

- As part of this program, tilapia monitoring was carried out in 65 priority areas three times a year. Monitoring at all 65 locations lasted for a month. Monitoring was carried out by three field officers who were guided by pest fish biologists and fisheries scientists. The total cost, including salaries, vehicles and equipment, was $213,000.

- Electro-fishing was the major management method and was used predominantly in rivers, with some activity occurring in lakes, impoundments and private dams. Various types of nets and traps were also used. Rotenone was used to eradicate pest fish in small closed water bodies such as private dams. Salary and operating costs associated with management amounted to $80,000.
- The largest focus of the program was on prevention, mainly through a concerted public education campaign.
    - A major public communication program was carried out in north-east Queensland at a cost of $165,000 to raise awareness of the importance of exotic pest fish, particularly tilapia. Educational documents including a children's activity book, tilapia ID cards, leaflets, posters, and signage were developed and distributed. Radio messages were broadcast to increase public knowledge.
    - The DPI&F fisheries research centre based in Cairns developed a research project through the Invasive Pest Species CRC entitled "Development of management strategies for the control and eradication of feral tilapia populations in Australia". The project was carried out in the tilapia infested catchment of the Northern Region. The cost during 2006/07 was $139,000, the majority of which were operational.

The two water corporations, NQ Water and SunWater, had vastly different costs and expense profiles for tilapia (Table 9). Cost to SunWater was approximately ninefold the cost to NQ Water, with most of the SunWater costs directed at prevention of further spread.

Table 9: Tilapia-related expenses incurred during 2006/07 by water corporations in north-east Queensland

	Monitoring	Management	Prevention	TOTAL
NQ Water	$17,000	$10,000	$0	$27,000
Sunwater	$7,000	$0	$228,966	$235,966
TOTAL	$24,000	$10,000	$228,966	$262,966

SunWater manages the water supply for the Mareeba-Dinbulah Irrigation Area. To minimise the risk of tilapia using the irrigation channels to move from the Barron River catchment to the Gulf of Carpentaria catchment, SunWater installed screens/fish barriers.

- The investment cost for the screens was approximately $1.4 million in 2004 and an additional $100,000 was spent of screen cleaning equipment (2005). To derive at an annual cost, these investments were depreciated using Australian Taxation Office rules (ATO, 2006).

- According to Brett Stevenson of SunWater, these costs *"affect the corporation's ability to deliver water and reduce its operational cost efficiencies",* meaning that ultimately SunWater customers bear the costs through a higher price for water.

NQ Water spent approximately $17,000 on monitoring tilapia and a further $10,000 on the removal of tilapia from below the Ross River Dam wall following cessation of flows (removal used volunteers, staff and equipment hire). No preventative actions were undertaken.

The expenses incurred by local governments throughout north-east Queensland in relation to tilapia were minimal—most councils did not undertake any actions with respect to tilapia. As Table 10 shows, only three councils undertook any activities during 2006/07 that incurred costs, with approximately 90% of total costs spent by Herberton Shire council in the pursuit of preventing the spread of tilapia. Shire employees carried out weekly inspections of the integrity of Herberton Dam and simultaneously undertook visual examinations for tilapia. The HSC manager of engineering services had undertaken extensive discussions with DPI&F, consultants and JCU staff.

Table 10: Tilapia-related expenses incurred during 2006/07 by NQ local governments

Note: Local governments prior to 2008 amalgamation

	Monitoring	Management	Prevention	TOTAL
Atherton	$0	$0	$0	$0
Burdekin	$0	$0	$0	$0
Cairns	$0	$0	$400	$400
Cardwell	$0	$0	$0	$0
Cook	$0	$0	$0	$0
Douglas	$159	$0	$636	$795
Eacham	$0	$0	$0	$0
Herberton	$780	$0	$7,351	$8,131
Hinchinbrook	$0	$0	$0	$0
Johnstone	$0	$0	$0	$0
Mareeba	$0	$0	$0	$0
Thuringowa	$0	$0	$0	$0
Townsville	$0	$0	$0	$0
TOTAL	$939	$0	$8,387	$9,326

Douglas Shire undertook visual inspections of drains in Port Douglas in early 2007 on two separate occasions following alerts that tilapia had been sighted. Tilapia was not confirmed but printed material was distributed in the local area.

It is important to note that these costs provide a snap-shot only. For example, Burdekin Shire did not incur any costs during 2006/07, but supported the response following the discovery of tilapia in Keelbottom Creek some years earlier. Specifically, it provided meeting facilities, secretarial support and refreshments for the DPI&F co-ordinated meetings.

Among the (sub-)regional natural resource management (NRM) groups operating in north-east Queensland, only the Mitchell River Watershed Group stated they had incurred expenses of substance in relation to tilapia (Table 11). Terrain NRM stipulated they had incurred no expenses—they did not count research into tilapia, which is indirectly funding this project, as an expense.

Table 11: Tilapia-related expenses incurred during 2006/07 by regional NRM groups

	Monitoring	Management	Prevention	TOTAL
Mitchell River Watershed Group	$0	$0	$18,764	$18,764
Barron ICM	$0	$0	$0	$0
South Cape York ICM	$0	$0	$1,250	$1,250
TERRAIN NRM	$0	$0	$0	$0
Burdekin Dry Tropics NRM	$0	$0	$0	$0
TOTAL	$0	$0	$20,014	$20,014

4.2 Tilapia related impacts on non-monetary uses and values of waterways

The impacts of tilapia on social and environmental values are largely unknown both in Australia and elsewhere. To scope these indirect costs, at least partially, focus groups discussions and expert interviews were conducted. The key insights are summarised below.

- Recreational fishing in north-east Queensland: methods, frequency and demographics
  - Most participants in focus groups discussions were long-term residents of north-east Queensland with long-term angling experience in the region.
  - Fishing activity of the (vast) majority of recreational fishers on the north-east coast of Queensland was focused on saltwater environments.
  - Boats were the major fishing platform.
  - Generally, recreational fishers undertook little fishing, other than cast netting for bait, in freshwater systems. However, members of restocking groups frequently participated in freshwater angling, on most weekends.
  - Some anglers participated in freshwater fishing competitions organised by other clubs, e.g. in the Burdekin River.

  - Members of restocking groups undertook approved (re-)stocking activities with target fish species (sooty grunter, barramundi) to enhance recreational fishing experiences in modified freshwater systems. Modified systems included Tinaroo Dam and Ross River weirs.
  - Most recreational anglers fished with friends, commonly in groups of two to three and some were accompanied by family members.
  - Most commonly, recreational fishers undertook day trips, launching their boats within 20-100 kilometres of their home. For Townsville anglers, this included fishing the Bohle, Burdekin, Haughton and other, smaller, rivers.
  - Few (less than 20%) fishing trips involved distances to fishing locations of 100 kilometres or more. Favoured locations for Townsville-based anglers included waters around Hinchinbrook Island and the Gulf of Carpentaria.
  - Freshwater anglers mainly fished in restocked waterways and undertook infrequent fishing activity in unmodified streams (e.g. Keelbottom Creek).
  - The main motivations for fishing were relaxation and sport.
- How often were tilapia caught?
  - It was very rare for anglers in freshwater systems to catch tilapia.
  - Tilapia were caught on a small minority of freshwater angling trips (no more than 10%) unless targeted. On trips where they were caught, tilapia constituted a very small proportion of total catch.
  - The Lake Tinaroo Barra Bash had a “Tilapia” category for children. Catch in 2005 and 2006 was 86 and 59 tilapia specimens, respectively. In 2003 and 2004 the “Tilapia” category had also been open to adults and 14 and 198 fish were caught, respectively.
- How were tilapia caught?
  - Tilapia would not take lures or prawns as bait.
  - Fly fishing with small lures occasionally resulted in catching tilapia.
  - Tilapia needed to be specifically targeted with the use of small baited fish-hooks. Bread, worms and vegetables were said to be useful baits.
  - One respondent recounted purposely placing a lure amongst a school of tilapia—only to catch a sooty grunter.
  - The most effective method of catching tilapia was cast netting in infested waterways.
- Where were tilapia caught?
  - Key locations around Townsville included: Louisa Creek, Woolcock drains, The Lakes, Rowes Bay golf course, Town Common, Willows rotunda, Ross River weirs, and Fairfield Waters.
  - River systems where tilapia were caught included Burdekin River, Bohle Creek, Alligator Creek, Stuart Creek, Keelbottom Creek, Mulgrave River, and Barron River.

  - Most of the waterways where tilapia were most prolific were said to be "corrupted"—they were either highly modified or man-made and infested with weeds and other introduced fish species.
- Were tilapia having an impact on target fish species?
  - Respondents indicated that they had no evidence and did not feel that tilapia were impacting target fish species.
  - Respondents repeatedly stated that tilapia were predated on by barramundi, and hypothesised that this might explain "phenomenal" growth rates of tagged barramundi in Ross River weirs. Most respondents had personally seen evidence of barramundi predating on tilapia. They had seen barramundi "smashing" tilapia or found tilapia in the mouth or guts of caught barramundi.
  - It was suggested that tilapia biomass in estuarine systems was regulated by predation by native fish.
  - The Twin Cities Fish Stocking group mentioned that one reason for the commencement of barramundi stocking of Ross River weirs in 1992 was to control tilapia.
  - It was suggested that the health of waterways played a key role in the abundance of tilapia. Specifically, the extensive presence of aquatic weeds and poor water quality were thought to provide conditions that favoured tilapia. Tilapia were more tolerant to water pollution (urban water runoff draining into waterways) and weeds were providing them with shelter from predators.
  - It was suggested that tilapia acted as a food source for the large water bird population of Ross River and Ross River Dam.
  - One respondent thought that sooty grunter tended to be smaller in Mulgrave River, which "was teeming with tilapia", than in other tropical rivers. He was unsure whether there might be a causal relationship.
  - It was suggested that "tilapia do damage by sheer numbers". When allowed to build up, they "displaced native fish and took all the oxygen and food".
- What were people doing with the tilapia they caught?
  - The official response was that all tilapia caught were killed and buried or binned as legally required by their status as pest fish.
  - However, respondents noted that some anglers would throw them back in the water if they felt unobserved because of the hassle associated with proper disposal.
  - One respondent had observed children catching tilapia and taking them home.
  - Several research participants stated that tilapia tasted very good. "They have beautiful fillets and are beautiful to eat."
- Was there a noticeable change in the occurrence of tilapia and the frequency with which they were caught?

    - No change had been observed, other than the ongoing geographical spread of tilapia.
    - Tilapia in Stuart Creek were said to be particularly large, which was attributed to a lack of predators there.
    - Anglers were appalled by the spread of tilapia into previously unaffected streams. One participant expressed his “disgust and dismay” at finding tilapia in remote fishing locations where he did not expect them. “It ruins your day.”
    - Anglers were resigned to tilapia spreading further. They expressed a “feeling of helplessness”.
- Did anglers attribute any changes to the ecosystems to tilapia?
    - Many respondents had seen tilapia nesting sites generated by the males in shallow water.
    - Some respondents noted that tilapia was unlike carp in that they did not muddy the water.
    - One respondent had observed tilapia following platypus and eating some of the materials that they (platypus) had stirred up.
    - “The bottomline is that we don’t know what happens underneath the surface of the water.”
- How and to what extent were anglers changing their behaviour in areas that were infested by tilapia?
    - Anglers were not changing their angling activities in response to tilapia—they continued to visit the same places and fish the same way. Anglers were continuing to fish in tilapia infested waterways, principally because they did not perceive there to be an impact on target species and because they did not commonly catch any tilapia.
    - Some angler would choose different locations for collecting bait fish with cast nets because they could not legally use tilapia for bait.
- To what extent had current management methods succeeded in controlling the population or spread of tilapia?
    - Electro-fishing was said not to work very well for the control of tilapia because they were “hard to stun”.
    - Respondents were unanimous in their assessment that noxious fish legislation was ineffective because it did not encourage anglers to target tilapia and remove it from waterways. Anglers were particularly critical of the need to destroy caught specimen and the illegality of human consumption. Many respondents thought that if possession was legal, then anglers would be more inclined to target tilapia. However, it was also said that no level of recreational fishing of tilapia would be able to cause eradication of tilapia from infested waterways.
    - Good health of waterways was seen as critically important to controlling the spread and biomass of tilapia.

- Had tilapia had any impact on commercial interests in the area, including commercial fishing and tourism? How were those interests affected? What were associated costs?
    - Respondents had not observed or heard of any impacts.

4.3 Risks of tilapia

The pest status of tilapia is based on the perceived potential for tilapia to significantly impact on aquatic ecosystems—mainly through displacement of native fish, its large potential spread across north Australian waterways and the infeasibility of control or eradication with current methods.

According to the DPI&F (Zafer Saraç, research response) *"Once tilapia establishes itself in open water it is, under current knowledge and technology, impossible to remove."*

In a north Queensland context, the big, current questions are;

- Whether tilapia will spread into the rivers flowing in the Gulf of Carpentaria, and what might be the consequences of its dispersal west, particularly on commercial fisheries, environmental values including endangered species, and on social and cultural values of waterways?
- Whether tilapia has the potential to foul the freshwater reservoirs that it inhabits and to put town water supplies at risk?
- Whether tilapia can cause a substantial decline in other uses and values of north Queensland waterways?

Risk of tilapia spreading into Gulf of Carpentaria waterways

People have been the principal vectors of tilapia across catchment boundaries. According to the DPI&F (Zafer Saraç, respondent) *"Tilapia spread into new catchments or locations mainly due to people carrying them and releasing them into waterways. This will still be an issue in the future."* If introduced upstream, flooding speeds the dispersal of tilapia downstream, while the speed of dispersal in downstream waterways is regarded as slow due to their territorial lifestyle (QDPI, 2001). Tilapia were detected in a tributary of the Burdekin River, Keelbottom Creek, in 2004. Subsequent floods aided its rapid dispersal downstream (ABC, 2005). They are now entrenched throughout the Burdekin River and in Burdekin Falls Dam. In 2004, tilapia were discovered in the Endeavour River near Cooktown (DPI&F, 2007). In all these examples people are the probable vectors.

There is particular concern about tilapia infesting Gulf of Carpentaria waterways as its ecological characteristics may impact the highly valuable barramundi and northern prawn fisheries in Gulf waters (BRS, 2006; FAO, 2004). The concern is that, once established in one Gulf stream, tilapia may spread rapidly throughout the entire Gulf region (including the Northern Territory) aided by high volume river flows during the wet season. In

January 2008, tilapia were detected in Eureka Creek, a tributary to the Walsh River, that flows into the Mitchell River, which forms part of the Gulf catchment (DPI&F, 2008). While it is hoped that swift response action to what is thought was a localised infestation may have been effective, the outcome is as yet uncertain (Butts, 2008).

This latest case demonstrates that it is not only probable but almost certain that tilapia will expand their range into the Gulf of Carpentaria catchment. Damien Burrows (in an interview with the ABC 7:30 report (ABC, 2005) stated: *"It will happen. Tilapia will be put into one of those Gulf rivers, it's just a matter of when…".* It is, however, uncertain how tilapia came to be in Eureka Creek since precautions had been taken to screen irrigation channels that could have allowed tilapia to reach the Mitchell catchment. SunWater has been heavily involved in the installation of tilapia exclusion screens, which are up to 24 meters long, in the irrigation channels to minimise the risk of translocation of the pest fish through irrigation water. *"The prevention of tilapia spreading has cost SunWater well over $1.5 million in capital and ongoing costs in the area. It affects our ability to deliver water and reduces operational cost efficiencies"* (Charlie Martens, respondent).

<u>Risk of tilapia adversely affecting drinking water quality</u>

According to NQ Water (Rob Hunt, respondent) *"tilapia are a significant concern to raw water quality within the Ross Dam* [which forms the major potable water supply for Townsville]*. Recently conducted monitoring has indicated that tilapia populations have rapidly populated the Lake Ross environs and an increase in biomass is occurring. [..] The most significant concern is when RRD* [Ross River Dam] *levels reduce to below 10% – will tilapia biomass influence respiration rates and result in a fish kill? Would such an impact on raw water quality compromise NQ Water's ability to deliver potable water to its clients?"*

Tilapia populations exist in several key water storages in north-east Queensland, which supply not only water for irrigation but also for human consumption. These include the Lake Dalrymple (Burdekin Falls Dam), Ross River Dam, and Lake Tinaroo. Ecologically, these water bodies are highly modified with Lake Tinaroo and the Burdekin Falls Dam being stocked with translocated native fish species, specifically barramundi, that support important recreation and tourism values.

Due to their high fecundity tilapia have the potential for creating and contributing to a decline in water quality in isolated water bodies. Large populations of tilapia may start to impact by causing a decline in dissolved oxygen during dry periods. Reductions in dissolved oxygen may cause fish kills, that in turn may create reductions in water quality associated with rotting animal biomass and increasing nutrient (specifically phosphorous and nitrogen) loads. Depending on other seasonal conditions, algal blooms may occur (Canonico *et al*., 2005). Every step of the causal chain has potentially detrimental effects on the suitability of water for human consumption.

Risk of tilapia adversely affecting uses and values of north Australian waterways

While affecting the suitability of water for human consumption, dead fish, high levels of nutrients and algal blooms also impact on all other direct and indirect uses of waterways, including angling, swimming, boating and amenity, as well as non-use values.

According to NQ Water (Rob Hunt, response to survey*) "following flood released from RRD, large number of tilapia congregate below the dam stilling basins, rapidly reducing DO* [dissolved oxygen] *levels and causing fish kills. These fish have to be removed from the stilling basins and adjacent water holes to reduce public health concerns. The loss of tilapia is not of concern, but the loss of native species and the environmental (public) impact of large mass of decaying fish is undesirable".*

In mid March 2008, a collaborative effort between NQ Water, the Australian Centre for Tropical Freshwater Research, Thuringowa City Council and a number of volunteers removed a large number of tilapia from below the Ross River Dam.

According to Herberton Shire Council (Gordon K. Malcolm, research response) *"Council believes that over-reaction in this case is better than under-reaction and therefore request immediate increase in funds and resources to fight the fight before it becomes an established pest in a presently clean river system. As the damage done by this pest fish is not fully understood a more cautious and determined course of action is required now, not later"*.

5 Discussion

Tilapia were introduced to Australia as ornamental fish but have been released into natural waterways. They have attracted the status of declared pest fish in Queensland and other states because of the risk they pose to economic and environmental values of waterways. This policy approach adopts the precautionary principle which stipulates that *"… lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage"* (Commonwealth of Australia, 2007).

This research reinforces the risks that tilapia pose to environmental, economic and social values of waterways in north Queensland and beyond. The research demonstrates that management agencies, water providers, angling experts and other key stakeholders are acutely aware of the risks, derived from personal observations, (scant) scientific measurements, and knowledge of the biological and ecological characteristics of tilapia. However, there appears to be a gap between that knowledge and that of members of the general public, who are thought to be primarily responsible for the continuing spread of tilapia into previously 'clean' waterways and catchments.

Based on the research result, an expanded risk assessment of tilapia is offered in Table

The assessment retains the criteria used by the earlier DPI-based assessment (QDPI, 2001) but differs in that it (1) provides a combined assessment of both species (*Oreochromis mossambicus* and *Tilapia mariae*) and (2) explicitly assesses likelihoods and consequences of various aspects of risk. In doing so, the resulting risk categories are more readily interpretable. Consequences were rated on the basis of the scientific literature presented in this report and other supporting evidence obtained.

The resulting risk is deemed Moderate for the potential of tilapia to destabilise plant communities in receiving waters. In this, tilapia differs substantially from carp. However, there is a High—Extreme risk of tilapia withstanding a broad range of environmental conditions and a Moderate—Extreme risk of tilapia utilising degraded habitats. The 'Extreme' rating refers to waterways of poor health, where tilapia have a distinct competitive advantage over native fish due to their high ecological tolerance and/or ability to find shelter from predatory fish in weed infestations. An Extreme risk rating implies that there is a need for immediate action to improve the health of waterways, e.g. by reducing water pollution, removing weeds and re-establishing riparian vegetation. While improved health of waterways is unlikely to reduce the risk of infestation, it would appear critical to minimising the likely impacts of tilapia on the ecology of waterways.

To make the relevance and implications of the biological and ecological risks more tangible in a north Queensland context, Table 12 offers a risk assessment of tilapia in relation to the concerns held about its impact here, based on the empirical information gathered by this research. Criteria for the assessment are based on the use (direct, indirect) and non-use values of north Queensland waterways that are most likely at risk from tilapia.

Table 12: Risk assessment of tilapia

Source: based on the likelihood assessment by DPI (2001);
reclassified: high→likely; likely→almost certain; medium→possible; low→unlikely

	Likelihood	Consequences	Risk
Based on the growth and reproductive characteristics of tilapia, what is its potential impact on local native species through displacement?	Likely	Major	High
What is the potential of tilapia becoming a significant predator or exhibiting aggressive behaviour towards native species?	Possible—Likely	Moderate	Moderate—High
What is the potential of tilapia altering the physical environment in potential receiving waters?	Possible	Major	High
What is the potential of tilapia destabilising plant communities in receiving waters?	Possible	Minor	Moderate
What is the potential of tilapia hybridising?	Likely (among tilapia only)	Insignificant	Moderate
What is the potential impact of tilapia utilising degraded habitats?	Likely—Almost certain	Minor—Major	Moderate—Extreme
What is the potential impact of tilapia withstanding a broad range of environmental conditions?	Likely—Almost certain	Moderate—Major	High—Extreme

Table 12: Risk assessment of tilapia in the context of northern Queensland

	Likelihood	Consequences	Risk posed
Causing decline of Queensland commercial fisheries (e.g. barramundi)	Possible	Minor—Moderate (But could be major for some businesses and local industries)	Moderate
Causing water quality decline in water reservoirs (specifically Ross River Dam) to the effect that water is not safe for human consumption	Likely—Almost certain (have been shown to breed up to extremely high biomass)	Major (may not kill people but cause large costs and inconveniences)	High—Extreme
Effect on recreational and tourism values of north Queensland	Unlikely—Possible	Insignificant (for tourism)—Moderate (e.g. use of certain dams for recreational fishing)	Low—Moderate
Effect on non-use values of waterways (existence, bequest, philanthropic values)	Likely	Insignificant—Moderate	Moderate—High

Possible water quality decline in (drinking) water reservoirs as a direct consequence of tilapia biomass built-up and subsequent large-scale fish kills is rated as posing a High—

Extreme risk. Likelihood is rated as Likely—Almost certain given the demonstrated ability of tilapia to build up large biomass and the naturally varying water levels in reservoirs. The repercussions of an occurrence, most likely in the case of Ross River Dam, which supplies drinking water to most of Townsville, would be “dramatic” even though it is unlikely they would result in death of humans. Drinking water treatment facilities would be unable not cater for such an event (Rob Hunt, personal communication 17/04/2008).

Of Moderate—High risk are the effects of tilapia on the non-use values of waterways. The consequences are rated as Insignificant (if waterways are already of poor quality) to moderate (for near-pristine waterways). This is consistent with the findings by Loomis (2004) in the USA, where 63% of the total value of water quality referred to non-use values. In particular, it is evident from research respondents that the unexpected presence of tilapia in a waterway can greatly reduce their enjoyment of using the waterway, even though it may not necessarily lead to a change in use pattern. This associated cost could be measured using a non-market valuation approach.

The potential impact on commercial fishing is rated as ‘of Moderate risk’. Principally, this study found no compelling evidence to substantiate a direct link between tilapia and the abundance of barramundi. It would appear that in artificially stocked environments barramundi pray on tilapia, particularly if the health of waterways is good. However, tilapia threaten native species in virtually all situations where they have been introduced into waterways through disruptive spawning behaviour as well as trophic interactions (Canonico *et al.*, 2005). Thus, the ecology of tilapia is such that conceivably they can have a detrimental impact on barramundi and other native fish that share breeding and nursery areas. In the absence of scientific data the possibility of a (long-term) detrimental effect cannot be discounted.

For recreational fisheries, tilapia is rated as being ‘of Low—Moderate risk’. In addition to the possible impact on the abundance of target species it has been taken into consideration that tilapia are not commonly caught unless specifically targeted since they respond to fishing methods not used for native fish. This means that core angling activities remain largely unaffected. However, some recreational anglers are going to other locations (where tilapia are either absent or less abundant) to get bait fish. Also, if a tilapia specimen is caught it cannot be kept but must be disposed off in accordance with noxious fish legislation, which anglers clearly find annoying. Also, dead and rotting tilapia carcasses disposed close to preferred angling spots affects the amenity of these spots. Thus, tilapia do affect recreational fishing values in various ways—but these ‘costs’ are attributable to the institutional response that has been enacted (noxious fish legislation) and not necessarily the presence of tilapia in a waterway *per se*.

Respondents repeatedly pointed to an observed relationship between the abundance and prominence of tilapia in a waterway and the ecological health of waterways. This is consistent with the international literature, where it has been demonstrated that invasiveness in some cases is confounded by factors including habitat destruction or other non-native species introductions (Canonico *et al.*, 2005).

A key objective of this study was to attempt to translate the potential impacts of tilapia, as supported by international literature and new empirical data, into an assessment of potential economic impact for north Queensland. This research provided a first scope of (potential) economic impact, which is summarised in Table 13.

The cost items in Table 13 are structured to mirror the types of costs elicited, either quantitatively or qualitatively, in Section 4 of the report. The four categories and associated methods for estimation are:

- Direct/management costs (including monitoring, management and prevention costs) were obtained from the mail-back survey of agencies, NRM groups, local governments and water corporations.
- Costs to direct use values of waterways (including human consumption of water, irrigation water, recreational fishing, other recreation activities associated with waterways—eg. water sports, and amenity) were assessed qualitatively.
- The costs to indirect use values of waterways, principally commercial fishing, were quantified based on hypotheses and a lower and upper bound of potential cost estimated. Commercial fishing is an indirect use as the fisheries do not physically undertake harvesting activities in infested waterways—rather, the native fish which hatched in these waterways and spent part of their life cycle there are caught in offshore environments.
- Loss of non-use values associated with waterways are associated with reductions in bequest, philanthropic and ecological values of waterways and are assessed qualitatively.

For all cost categories and items a ‘current’ estimate is provided in Table 13 along with “future least cost” and “future highest cost” estimates of hypothetical economic impact. These estimates are based on a suite of assumptions, which are explained in detail in the associated footnotes.

It is important to note that the hypothetical cost components for least-cost-case and highest-cost-case are *not additive* because they are based on different and possibly conflicting assumptions. For example, a least-cost approach to management would be to do nothing about tilapia, thus incurring no direct costs. However, this “saving” may result in higher cost to direct and indirect use values by potentially accelerating the spread of tilapia and/or not mitigating their ecological impact.

The study quantified the direct/management costs, which various organisations and agencies incurred solely due to tilapia, to be approximately $900,000 during 2006/07. In all likelihood the real cost for the year 2006/07 was higher as at least one respondent did not include ongoing research costs into their cost figures. It is possible to reduce these costs by not doing anything about tilapia; however, it is more likely that direct costs in the future will be higher, possibly 3-fold current costs, in response to increased spread and increased need for research into the ecological dimensions of tilapia in (north) Australia.

Table 13: Estimated economic impact of tilapia in the context of northern Queensland

Note: numbers in columns 2 and 3 are NOT additive; refer to assumptions outlined below

Costs/Uses/Values	Current	Hypothetical Future Economic Impact	
	Observed ($ per year--2006/07)	Least Cost ($ per year)	Highest Cost ($ per year)
Direct costs			
Monitoring	$237,939	$0 4)	>$1 million 5)
Management	$90,000	$0 4)	>$1 million 5)
Prevention	$561,227	$0 4)	>$1 million 5)
Cost to direct use value of waterways			
Human consumption of water	$0	$0 6)	$10 million ++ 7)
Irrigation water	+ 1)	$0 6)	+ 8)
Recreational fishing	+ 2)	$0 6)	$3 million 9)
Other recreation	+ 2)	$0 6)	$3 million 10)
Amenity	+ 2)	$0 6)	+ 11)
Cost to indirect use values of waterways			
Commercial fishing	$0	$0 12)	$16 million 3)
Loss of non-use values associated with waterways (ecology, water quality)	no evidence	$0 13)	$ 1 million ++ 14)

1) Efficiency of delivery of irrigation water in the Mareeba Dimbulah Irrigation Areas is reduced due to tilapia screens. Associated cost to irrigators is unknown.
2) Recreational fishers are “dismayed and disgusted” when they find tilapia in unexpected locations. “Stench” of rotting tilapia carcasses on river banks. We have assumed that non recreational fishers would be similarly impacted when using waterways for recreation.
3) Assumes commercial obliteration of the GoC prawn and barramundi fisheries. Value of Northern Prawn Fishery for 2006/07 was $64 million. Assumption 50% of catch from GoC; Value of GoC barramundi fishery (QLD) for 2005/06 was $3.7 million. Future costs discounted to net present value.
4) Assumes that tilapia is wide spread and removed from noxious fish list—no further tilapia-specific activities.
5) Assumes that there is an intensified attempt at controlling tilapia, specifically through improving health of waterways, restoration of wetlands, more research and more education.
6) Assumes that tilapia is controlled to an extent where it does not have any impacts on direct use values; and, possibly, pest fish status is removed
7) Not an annual cost; net present value of a single event. Cost estimate is built on 20-days drinking water loss for Townsville (see body of text). *The incident of a mass fish kill in Ross River Dam would be unmanageable with any sort of water treatment—it would constitute a “catastrophic loss of water supply”* (Rob Hunt, personal communication 17th April 2008).
8) No major impact on useability of water for irrigation purposes expected; no further precautionary fish barriers expected
9) Assumes that the recreational wild barramundi fishery in north Queensland is obliterated by tilapia, but that pond and dam-based fishing are unaffected→20% reduction of current value of $15 million
10) Based on Possingham et al. (2002): Australian Households are willing to pay $260,000 (year 2001) for restoration of every 10 kilometres of degraded waterway (for fishing and swimming); assumption is that 100 km of waterway restored every year, $ in 2006/07 values
11) People are disturbed by e.g. seeing male display sites in waterways or seeing dead fish floating about; probably small cost.
12) Tilapia have no impact on commercial catch. Refer to 6)
13) There is no loss of non-use values due to tilapia. Existence, bequest, philanthropic values of infested waterways are unchanged.
14) Total value of ecosystem goods and services per hectare of river in Wet Tropics World Heritage Area Curtis, 2004). Adjusted for 2006/07. Extrapolated to whole of N Qld. Loss of value due to tilapia assumed to be 10%. Rounded to nearest $100,000. Studies in the USA show that non-use values alone could be much higher (Loomis, 2004).

This study provides qualitative evidence that tilapia do reduce some direct use values of waterways. While activities do not necessarily change in terms of what people do and where they do it, some qualitative aspects of the experience are negatively affected. Currently affected are:

- Irrigators—through a higher price for irrigation water due to the water price needing to fund measures to prevent the spread of tilapia.
- Recreational fishers—bait collection activities are affected; tilapia disposal requirements; stench of rotting tilapia carcasses alongside waterways.
- Recreational users of waterways at large—through an element of reduction of use values, e.g. associated with the stench of rotting tilapia carcasses alongside waterways.

If tilapia could be controlled to a high degree, these costs could be kept small, but ongoing geographical spread and catastrophic events such as a tilapia-induced fish kill in a drinking water reservoir could generate very high costs indeed if it rendered the water unfit for drinking. For example, for the 160,000 residents of Townsville to purchase bottled drinking water at a cost of $0.70/litre for a period of 20 days only and for drinking purposes only (3 litres/day) would equate to a cost of approximately $7 million. There would be additional, substantial costs incurred from activities such as cleaning up the affected reservoir and water supply infrastructure as well as the cost of health impacts on people who continue to drink water from the water supply. No inclusive quantification is attempted because there is no precedent for such an event, but $10 million would appear to be a conservative estimate.

Costs associated with the loss of non-use values caused by tilapia are also impossible to quantify. While non-use values of waterways may be higher than use values (e.g. Loomis, 2004), the tilapia-related effect needs to be reviewed in the context that in many waterways, tilapia is only one of several introduced fish species and so ecological impacts may be compounded (Canonico *et al*., 2005).

Thus, as McLeod (2004) found for carp, the indirect costs of tilapia, flowing from their ecological characteristics, may well outweigh direct/management costs in the future, if and when it becomes more widely established in north Queensland (and north Australia). The resulting losses to industries—commercial fisheries in particular—could be further outweighed by the loss of values that the Australian people hold for waterways in northern Queensland/Australia.

Overall, the long-term annual cost of tilapia could well be as large as that of carp, which currently amounts to approximately $16 million per annum, but tilapia may prove to have even larger financial impacts.

6 Conclusions

While much is known about the biology of tilapia—it is used in aquaculture in many countries around the world and is a prized eating fish—scientific information on its ecology and the impact of introductions to natural ecosystems, such as those in northern Australia, is scant at best.

This report provides a 'first stab' at the potential economic impact of tilapia in its north Queensland range. This proved methodologically challenging because of the indirect and dispersed nature of (potential) impacts and lack of demonstrated causal relationships between the presence of tilapia in this environment and its direct and indirect impacts. The scale of the project also meant that it was limited in methodology to literature review and the gathering of information from key stakeholders, as a non-market valuation approach could not be pursued.

The research found that current impact is largely restricted to direct costs, which are mainly borne by Queensland tax payers and, to a lesser extent, by NQ Water customers. The direct/management costs associated with tilapia in (north) Queensland are of the magnitude of roughly $1 million per annum, which are mostly directed at prevention, through public education about tilapia and the use of physical barriers to minimise the risk of translocation between catchments via interlinking irrigation channels.

However, this research also identified the potential for much larger costs in the future, provided that the potential which tilapia has to inflict ecological damage will manifest. Current direct costs appear minor when compared to potential impacts on use and non-use values of waterways. In particular, a single event of tilapia-generated fouling of already infested freshwater reservoirs could conceivably cost ten(s) of millions of dollars. Likewise, it tilapia were to become more extensively established, particularly across the Gulf of Carpentaria, and the worst fears about their impact on key commercial native species were realised, losses in commercial fish production of tens of millions of dollars could eventuate

Recreational fishers have been found to take a pragmatic attitude to tilapia and not let the fish impact on their use values too much. However, greater spread of tilapia, greater abundance in waterways and greater ecological impact could see these values more heavily affected.

The results from this study thus support a precautionary approach towards tilapia, which is pursued by the Queensland government (and other states), with tilapia having been declared pest fish and a significant effort going towards public education. Unfortunately, it would appear that this strategy is not entirely effective in preventing the spread of tilapia. It is evident from the dispersal patterns in recent years that human translocations (inadvertent or not) are responsible for the continuing spread of infestation. Recent events suggest that infestation of the Gulf of Carpentaria catchment is already in train or at best imminent.

The value of this economic impact assessment lies in the conceptual insights it developes by scoping the current and potential impacts and costs of tilapia, and by reassessing the risks which tilapia pose to a range of direct and indirect use values, and non-use values of (north) Queensland waterways.

The study exposes the lack of scientific information on tilapia in an Australian context. Systematic and targeted research is required to attain a more accurate understanding of potential risks. Improved scientific information would be most helpful in tailoring policy and management responses. It needs to be considered, particularly in the light of the high degree of difficulty to control tilapia, that the precautionary approach currently employed is not without costs to recreational users of waterways. It would further appear to be particularly helpful to investigate the effects of tilapia in the context of health of waterways and the presence of other introduced (pest) fish for integrated management responses (Linde *et al.*, 2008).

The study also exposes a lack of understanding of the range and magnitude of use and non-use values that people hold for (north) Queensland waterways. A suite of relevant economic valuation techniques is available and could be readily employed. Clearly, tilapia is affecting a number of values. However, these values are also affected by other new, potentially pest fish (e.g. climbing perch; East and Micke, 2008) and other ecological parameters of waterways. Such information would be instrumental in the design of economically efficient policy and management responses in the area of natural resource management in general and the treatment of invasive fish in particular, by providing key parameters for benefit-cost analysis.

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Appendix 1: Covering letter explaining the research

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10th March 2008

NAME
ADDRESS

Dear NAME,

Re: Economic Impact and Risk Assessment of Tilapia in North Queensland

River Consulting, in collaboration with the Australian Centre for Tropical Freshwater Research, is conducting a study into the impact of Tilapia, a declared pest species, in North Queensland.

Tilapia refers to several species of fish coming under the family Cichlidae of which two *Oreochromis mossambicus* (Mozambique mouth brooder) and *Tilapia mariae* (Spotted Tilapia) are present and may be impacting significantly on environmental, social and economic institutions in the region. Both of these fish are present in at least some sections of the Ross, Barron, Burdekin, Star, Fanning, Mulgrave and Herbert Rivers, their tributaries and several other creeks and waterholes. Recently, Tilapia has also been discovered to be present in the Walsh River catchment but may not have established here yet.

An important part of the research is to compile the cost of Tilapia to organisations, including local government, agencies, corporations and other management bodies. Costs may be incurred through monitoring & research, management & control and prevention & education efforts. There may also be additional ways in which Tilapia impacts on your organisation's stakeholders and the community.

We request that you kindly participate in the study by completing the attached questionnaire.

Please return the completed questionnaire by email, fax or mail.

If you have any questions or reservations about any of the questions or how the information will be used please contact me on the details given above.

We thank you for your collaboration.

Yours sincerely,

Daniel Gregg

Appendix 2: Questionnaire to elicit tilapia management costs

Helpful information for completing the questionnaire

Question 1 asks you to detail the financial costs that Tilapia causes your organisation.

It is structured as a table, which is organised by types of actions (rows) and cost components (columns).

Please note that we are seeking costs incurred during the 2006/07 financial year.
If you note costs that were incurred outside that year, please indicate when they were incurred.

We distinguish between monitoring, management and prevention activities.

- "Monitoring" includes anything that you undertake to observe/measure the spread and/or impact of tilapia.
- "Management" includes activities that are aimed at reducing/eradicating tilapia and/or its impact.
- "Prevention" includes activities, which are aimed at preventing the spread of tilapia. It includes education and research activities, and infrastructure projects.

Examples of actions are given to aid in your understanding of our separations of the types of actions. They are meant as a guide and are not exclusive—please detail any items associated with direct and indirect costs that you feel are relevant.

Please place 'N/A' or 'X' into all cells in the table where your organisation is currently not active.

Question 2 asks for a description of the impacts that tilapia has on your stakeholder, e.g. the community or parts of the community. This forms the rationale for your organisation undertaking the actions that you have outlined in Question 1 and also shows issues that may not currently be monitored or managed.

Question 3 asks you to describe how you see the situation developing into the future.

Again, please do not hesitate to contact Daniel Gregg on 07 4775 2448 if you have any questions.

Please add additional pages if the room provided in the questionnaire is insufficient.

Fax (07) 4779 8972; Email daniel.gregg@riverconsulting.com.au; Address - 68 Wellington St, Townsville, Q 4812; Ph (07) 4775 2448

Question 1

What actions, if any, has your organisation undertaken in response to Tilapa?

Please provide details in the relevant cells in the table below with regards to your organisations **costs for financial year 2006/7**.

	What actions were undertaken? How? Where? When/how frequently?	*What was the associated total staff time and approximate salary cost, or the cost of contracting external service providers?*	*What other costs (equipment, operating etc) were incurred? If there were significant capital costs falling outside the financial year 2006/07 please include these and their date of accrual*
1. MONITORING e.g. conducting surveys on the extent of Tilapia presence/establish-ment.			
2. MANAGEMENT e.g. electro-fishing, use of explosives, any other actions to eradicate or maintain populations of Tilapia. NB- prevention actions are considered in the next section.			

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3. PREVENTION	*What actions were undertaken? How? Where? When/how frequently?*	*What was the associated total staff time and approximate salary cost, or the cost of contracting external service providers?*	*What other costs (equipment, operating etc) were incurred?* *If there were significant capital costs falling outside the financial year 2006/07 please include these and their date of accrual*
3.1 Education *e.g. Tilapia terminators, signage, brochures etc.*			
3.2 Research *e.g. research commissioned by your organisation through an external institution*			
3.3 Infrastructure *e.g. Screens on river/irrigation channels*			

Fax (07) 4779 8972; Email daniel.gregg@riverconsulting.com.au;
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Question 4

Are there any other comments or statements that you would like to make with regards to Tilapia in your area?

Declaration

I ________________________ hereby authorise the following information to be used by River Consulting Pty Ltd and the Australian Centre for Tropical Freshwater Research (ACTFR) as material for analysis and possible referencing within a report and/or other publications on the impacts of Oreochromis mossambicus (Mozambique Mouth-brooder) and Tilapia mariae (Spotted Tilapia) in North Queensland.

Signed:

Name, Position:

Telephone number

Appendix 3: Recreational fishing clubs scoping questions.

Impact of Tilapia (*Tilapia mariae* and *Oreochromis mossambicus*) on recreational anglers: focus group discussions

1. How often did you go fishing during 2007? (number of trips)
   i. rivers/creeks
   ii. lakes
   iii. estuaries
   iv. off-shore
   v. inshore

The following questions refer to fishing activities undertaken in the first three categories of question one (above) only.

2. What proportion of your fishing effort last year was from….?
   a. boat
   b. land-based platform

3. Who did you fish with? (e.g. family/friends/etc, give average group size)

4. Please indicate how often last year you travelled the following distances for a fishing activity and the average duration of the trip

	how many times per annum?	What is the average duration?	Predominant location (based on Q1)
< 20 km			
20 - 100km			
100 - 300km			
>300 km			

5. Last year, how often do you recall catching at least one specimen of Tilapia?
   Percentage of fishing trips__________________
   specifically in:_______________________
   (name of river, creek, dam etc)
   an average of _______ specimens of tilapia

6. Did you notice any influence of fishing gear/methods on Tilapia capture (e.g. lures/hooks/etc)?

7. What did you do with the Tilapia you caught?

8. Have you noticed a change in the occurrence of Tilapia / frequency caught?

9. Based on your personal experience, is the catch of Tilapia replacing your normal target species catch or is it additional to this?

Impact of Tilapia (*Tilapia mariae* and *Oreochromis mossambicus*)
on recreational anglers: focus group discussions

10. Have you noticed any (other) changes to the ecosystem that you put down to the presence of Tilapia?

11. Has the presence of Tilapia changed your fishing activity in any way? (e.g. how often you fish, where you fish, etc)

HYPOTHETICAL SITUATION:

12. Imagine there was a Tilapia eradication program, which could effectively remove Tilapia from NQ freshwater systems.
    The program would be paid for by charging freshwater anglers an annual fishing permit.

    What is the maximum amount you would be willing to pay for the annual individual permit?
    $_ _ _ _ _

13. Imagine you would catch Tilapia on every freshwater/estuarine fishing trip you undertake in North Queensland.

    Would that lead you to change your fishing effort?
    (please indicate one of the following)

    NO____ ☐

    YES a) would go fishing in same places but less frequently ________ ☐

    b) would go fishing in same places by more frequently________ ☐

    c) would go fishing as frequently but seek out freshwater______ ☐
    systems that have no Tilapia, e.g_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

    d) would go saltwater fishing instead______________________ ☐

    e) other, please explain:_________________________________ ☐

14. What attracts you to fishing, what do you enjoy about fishing?

Your gender: M / F
Your age: ______ years
Your fishing experience: _______ years, with ______ years in North Queensland