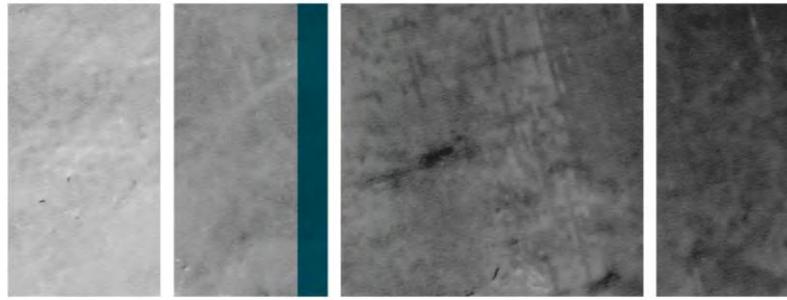


Forum Proceedings: Tilapia in Australia - state of knowledge

Brisbane, 15-16 May 2012

Edited by Wayne Fulton and Kylie Hall





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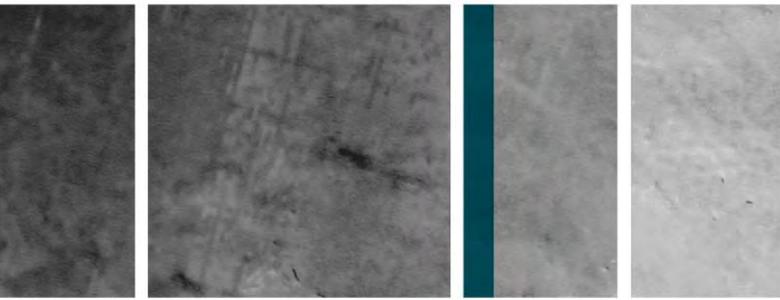
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Hosted by the Invasive Animals Cooperative Research Centre
and the Murray-Darling Basin Authority

An IA CRC Project





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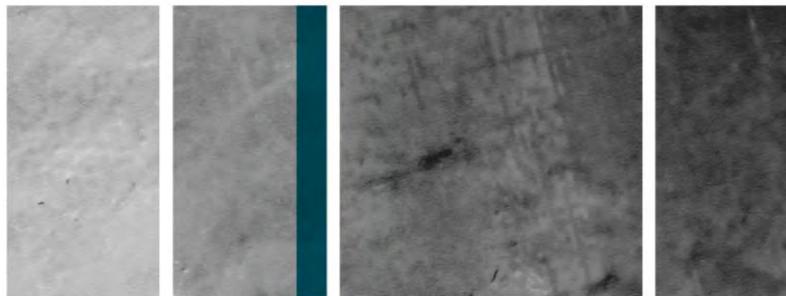
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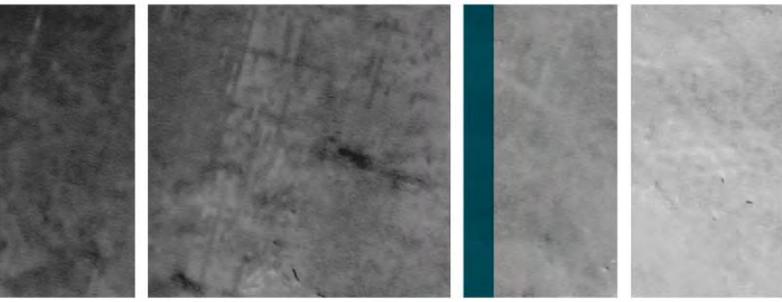
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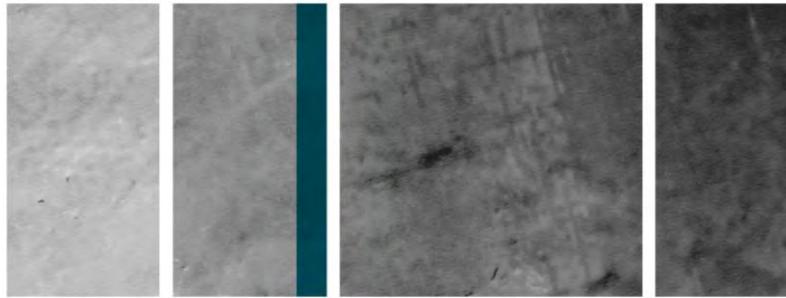
Front cover photo: Tilapia signage. Image: John Koehn



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Tilapia in Australia

The black mangrove cichlid or ‘spotted tilapia’ (*Tilapia mariae*) and the Mozambique tilapia (*Oreochromis mossambicus*) were illegally introduced into Australian waterways during the 1970s. Both species have become well established in the relatively short time since their introduction. At first they were probably released as unwanted aquarium fish, and Mozambique tilapia are now established in catchments in tropical and sub-tropical Australia while black mangrove cichlids are mostly restricted to northeast Queensland. Both tilapia species are declared invasive pests in most Australian states. The rapid rate at which both species are spreading, together with evidence from overseas studies, suggests that they will have harmful impacts in Australia.



Mozambique tilapia (*Oreochromis mossambicus*)

Image: Department of Employment, Economic Development and Innovation (DEEDI), Queensland



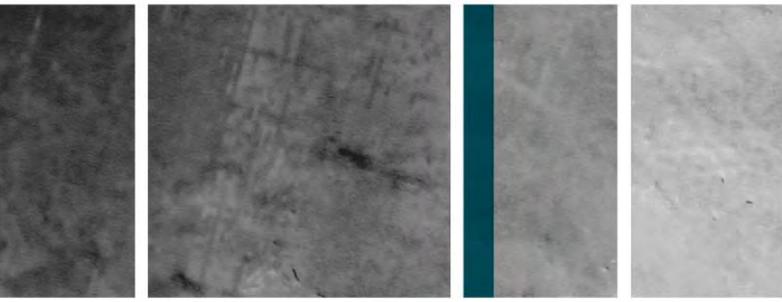
Black mangrove cichlid (*Tilapia mariae*)

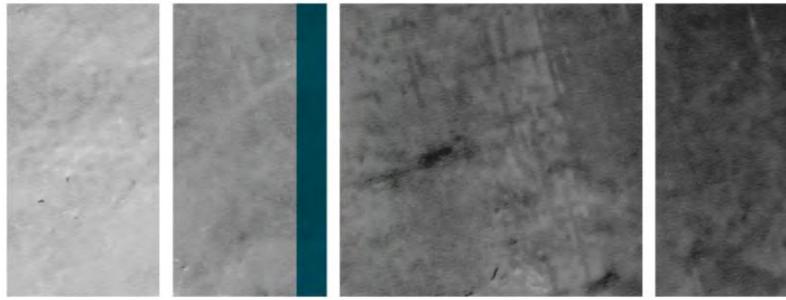
Image: Department of Employment, Economic Development and Innovation (DEEDI), Queensland

Information above from Invasive Animals Cooperative Research Centre **PestSmart: Tilapia** (www.feral.org.au/pestsmart/tilapia/). See this website for additional Fact Sheets and Case Studies on tilapia in Australia.

Ed note: The two species referred to above are the two species currently known to have extensive established populations in the wild in Australia. However a number of other species of the tilapiine group of fishes are present in aquaria in Australia and some may also have smaller established populations in the wild. Throughout this document the term ‘tilapia’ may be used to refer to the group in general or to a particular species. Please note the context in which it is used by the various authors in their papers.

Also note that the title of the article in the Program at pps 7-8 may differ from the final written title as received from the author/s. The presenter at the Forum was the person listed in the Program.





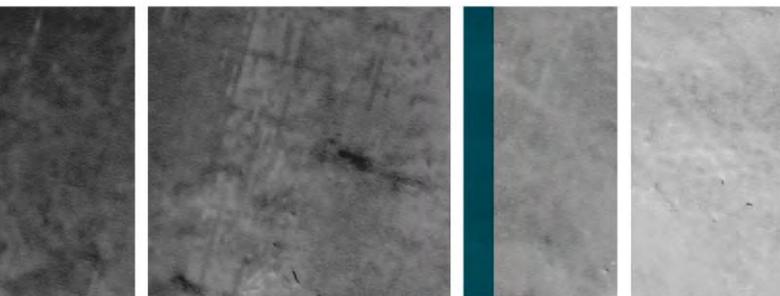
Introduction

Heleena Bamford,
Murray Darling Basin Authority

The Murray Darling Basin Authority welcomes you to the Tilapia Forum here in Brisbane. The Authority has maintained an active interest in managing this species as we recognise tilapia as a major potential threat to the aquatic environment of the Murray-Darling Basin. Although it has not yet been recorded in Basin waters, it is a high risk due to its close proximity being present in at least three Queensland catchments that are adjacent to the Basin. We are also very concerned about the potential impacts this species might have on our environment, particularly native fish communities. So we have a number of actions underway through our Native Fish Strategy Program, actively trying to keep tilapia out of our territory. In particular, we have had a large collaborative project operating with fisheries agencies in Queensland and New South Wales and supported by SEQwater. We have also been supporting the Invasive Animals Cooperative Research Centre and the work it does on tilapia. You will hear more about that work during the course of this Forum.

The Murray-Darling Basin Authority (and its predecessor, the Murray-Darling Basin Commission) have been active in pest fish management for a number of years. One aspect that we have found fundamental to improving outcomes of pest fish management is sharing knowledge. As such, we initiated a similar forum on gambusia last year that was quite successful. So we definitely support events like this Tilapia Forum and the upcoming Carp Forum. Hopefully these events will increase our ability to deal more effectively with pest fish.

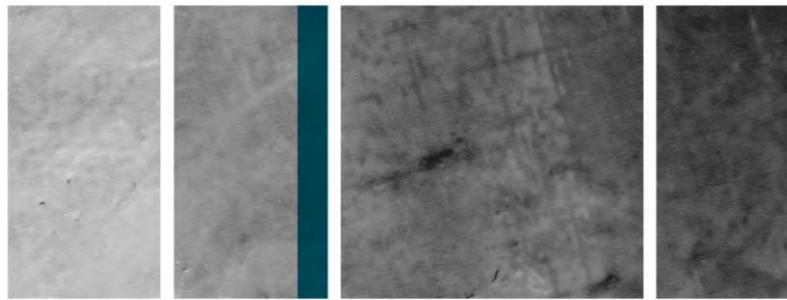
So I would like to formally welcome you to this Forum. Thank you very much to all who are attending these events. I would particularly thank our overseas speakers who have made the effort to attend and also to the interstate people who have travelled to be here as well. We hope you get a lot out of the next two days.



Forum program

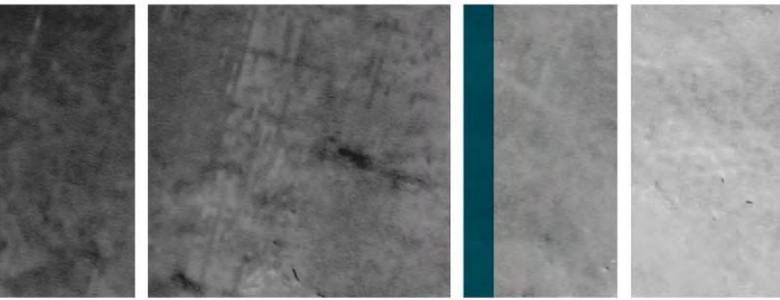
DAY 1

<i>Time</i>	<i>Speaker</i>	<i>Organisation</i>	<i>Talk title</i>
9.00-9.30	Fulton, Wayne/ Bamford, Heleena	IA CRC/ MDBA	Welcome, Introduction and Summary
Biology and impacts			
9.30-10.00	van der Waal, Ben	University of Venda, South Africa	Invasive <i>Tilapia mariae</i> and <i>Oreochromis mossambicus</i> in their native range in Africa and impacts of <i>O. niloticus</i>
10.00-10.30	Bradford, Matt	CSIRO	The biology and management of <i>Tilapia mariae</i> as a native and invasive species: a review
10.30-11.00	Morning tea		
11.00-11.30	Russell, John	Fisheries Queensland	The biology, management and control of invasive tilapia populations in northern Australia
11.30-12.00	Ovenden, Jenny	Fisheries Queensland	Invasion genetics of a noxious freshwater fish; baseline data for tracing the passage and source of tilapia (<i>Oreochromis mossambicus</i>)
12.00-12.30	Stewart, Danielle	Fisheries Queensland	Tilapia in Queensland: where are they and where do they threaten?
12.30-1.00	Small, Fiona	Fisheries Queensland	Understanding tilapia dispersal, diurnal movements and habitat usage in northern Australia
1.00-2.00	Lunch		
2.00-2.30	Norris, Andrew	Fisheries Queensland	Recent tilapia research and monitoring in south-eastern Queensland
2.30-3.00	Morgan, David	Murdoch Uni	Tilapia research in Western Australia
Detection and decision making			
3.00-3.30	Ezaz, Tariq	University Canberra	of New eDNA surveillance for multiple high risk invasive fish techniques
3.30-4.00	Kroon, Frederieke	CSIRO	Predicting presence and absence of <i>Tilapia mariae</i> using environmental variables in the Wet Tropics region
4.00-4.30	Afternoon tea		
4.30-5.00	Clunie, Pam	DSE, Victoria	Towards national emergency response arrangements for freshwater fish incursions in Australia
5.00-5.30	Acevedo, Silvana	DSE, Victoria	Decision support tool for the management of freshwater fish incursions in Australia
5.30-6.00	Hutchison, Michael	Fisheries Queensland	Using warm water to detect and attract tilapia



DAY 2

<i>Time</i>	<i>Speaker</i>	<i>Organisation</i>	<i>Talk title</i>
Problems and solutions worldwide			
9.00-9.30	Brooks, Wesley	Rutgers University, New Jersey, USA	Spotted tilapia (<i>Tilapia mariae</i>) and Mozambique tilapia (<i>Oreochromis mossambicus</i>) in the United States: invasive status, impacts and control
9.30-10.00	Nandlal, Satya	Queensland University of Technology	Tilapia in the western Pacific: impacts of an exotic freshwater fish
10.00-10.30	Morning tea		
Containment and control - options and case studies			
10-10.30	Martens, Charlie	SunWater	SunWater's screening of the Mareeba Dimbulah Water Supply Scheme
11.00-11.30	Pearce, Malcolm	Fisheries Queensland	Case study: Eureka Creek tilapia management
11.30-12.00	Hunt, Rob	Townsville City Council	Tilapia in a potable water supply – an overview of potential water quality and operational risks
12.00-12.30	Thuesen, Paul	Fisheries Queensland	Electrofishing control of an invasive tilapia (<i>Oreochromis mossambicus</i>) population in northern Australia
12.30-1.00	Thresher, Ron	CSIRO	Can sterile males be used to stop the spread of tilapia into the Murray-Darling Basin? Testing the options
1.00-2.00	Lunch		
2.00-2.30	Pearce, Malcolm	Fisheries Queensland	Case study: Lake Barrine tilapia management
Education and extension			
2.30-3.00	Hall, Kylie	IA CRC	Overview of the Invasive Animals Cooperative Research Centre Freshwater Program pest fish research extension activities
3.00-3.30	Stewart, Danielle	Fisheries Queensland	Helping the community help us stop pest fish...?
3.30-4.00	Doolan, Debra	NSW DPI	Social research to understand knowledge of and attitude towards tilapia in communities within or nearby to the Murray-Darling Basin
4.00-4.30	Afternoon tea		
Discussion			
4.30-5.00	Fulton, Wayne	IA CRC	Future research requirements



Invasive Animals CRC: Freshwater program - Tilapia

Wayne Fulton¹

¹Invasive Animals Cooperative Research Centre, University of Canberra, Australian Capital Territory, Australia. (wayne.fulton@invasiveanimals.com)

Focus of the Program

Initially, the major focus for the Invasive Animals Cooperative Research Centre's (IA CRC) Freshwater Program was to develop an Integrated Pest Fish Management Plan for the Murray Darling Basin.

The IA CRC first Operational Plan for July 2005 stated;

"The main focus of the Freshwater Program is the control of high profile invasive fish in the MDB ... the overarching goal of the Program is an integrated pest fish management strategy for the MDB. This will involve developing and testing of applied technologies aimed at sustainable control of priority pest fish species, layered within an integrated strategic plan specifically for the Murray-Darling Basin."

To address these requirements it was decided to look at the requirements of such a plan and try and address some of the knowledge gaps. There are a number of elements that need to be considered in developing such a plan. In no particular order these would include the following;

- Prevention/Detection
- Control options/techniques
- Target species information
- Support framework
- Education/Community engagement

The initial emphasis of projects was on carp although some projects were generic in nature. The overall program included the following projects, some of which had a number of elements within them and some of which took a different direction to that originally envisaged at the outset;

Prevention/Detection

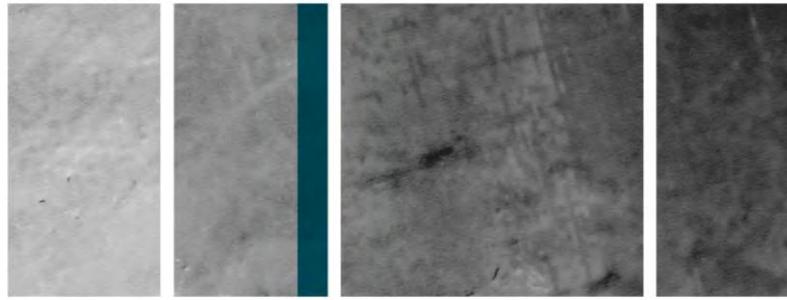
- Generic rapid response plan for new pest fish invasions.

Support framework

- Mapping of pathways for implementation of control options.
- Decision support framework for pest fish incursions

Control options/techniques

- Development of 'daughterless' technology for carp control.
- Koi Herpes Virus assessment.
- Biocide evaluation.
- Development of sensory attractants for pest fish control.
- Carp trapping technologies - Lake Bonney evaluation trial
- Acoustic attractants for carp



Target species information

- Carp reproduction hotspots in the Murray-Darling Basin.
- Carp movement and migration within the Murray-Darling Basin.
- Carp population dynamics - population modelling.
- Carp vulnerability synthesis report
- Tilapia population status and population dynamics.
- Development of genetic detection method for Tilapia (eDNA)

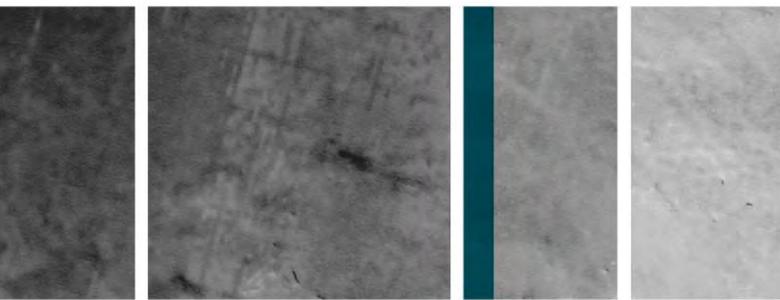
Education/Community engagement

- Community education and engagement.
- Pest fish education and management package

Whilst the Program was mainly targeting carp, tilapia were also regarded as a significant emerging problem about which very little was known. The small initial project on tilapia was expanded later in the Program and the overall work included the following elements;

- Literature review on the biology of Tilapia (2 Qld spp)
- Examination of the biology of both species of Tilapia in Queensland
- Effectiveness of fish down of a Tilapia population as a control technique (Herbeton Weir)
- Use of a predators to assist control of Tilapia
- Habitat preferences of Tilapia
- eDNA detection for Tilapia species
- Preparation of a 'Toolkit' for Tilapia

This Forum has been arranged not only to report on the findings of these projects, but to also bring together information on tilapia from other sources as well.



Invasive *Tilapia mariae* and *Oreochromis mossambicus* in their native ranges in Africa and impacts of *O. niloticus*

Ben CW van der Waal¹

¹University of Venda, Private Bag X5050, Thohoyandou 0950, Limpopo Province, South Africa
bcwvis@gmail.com

Background

Of the 32 300 known fish species globally 13 000+ are primary freshwater species - a high 40%. Of these, 57 species are listed as invasive by the Invasive Species Specialist Group (ISSG) (under the auspices of the Species Survival Commission (SSC) of the International Union for Conservation of Nature (IUCN)). Several tilapia species are among these invasives and furthermore *O. mossambicus* is listed amongst the 100 worst invasive organisms by Lowe et al (2000).

Southern Africa has 280+ freshwater fishes of which the Cichlids represent 36 species, including 6 *Oreochromis* and 4 *Tilapia* species. But all is not well in southern Africa: 21 fish species are listed in Red Data categories and already 24 alien invasive species occur in Southern Africa (increasing to 52 if translocations out of natural range are added). These figures are comparable to those of Australia with 200+ freshwater fish species and 44 invasives (Koehn & MacKenzie 2004).

One question that may be asked is what makes some regions more susceptible to invasion? Major aspects are the available ranges of habitat diversity, and then its historical isolation as reflected in the community structures and niche occupation. According to Morrongiello et al (2011) the following regions have a high risk of invasion by freshwater fishes: southern South America, western North America, Central Europe, southern Africa, southern East Asia and eastern Australia.

But a third factor for successful invasion is human disturbance, and in the case of fish this implies:

- Habitat disturbance - dams and inter-basin transfers create new habitat and migration routes
- Economic fluxes - angling, aquarium trade and aquaculture increase chances for introductions
- Economic development - import and export create opportunities for unintentional introductions.

The tilapia group

The tilapiines are a subfamily of the 2000 species strong family Cichlidae. The original genus *Tilapia* was split by Trewavas in 1982 into three genera, based on breeding behaviour which was found to be a better distinguishing factor than meristic characters. The genus *Tilapia* with 21 species is considered as the more basic group. They are substrate spawners, where female and male participate in brooding. A second group, *Sarotherodon* is characterised by mouth brooding by the male and consists of 10 species, and in the largest genus, *Oreochromis*, with 33 recognised species, mouth brooding is done by female fish (Trewavas 1983).

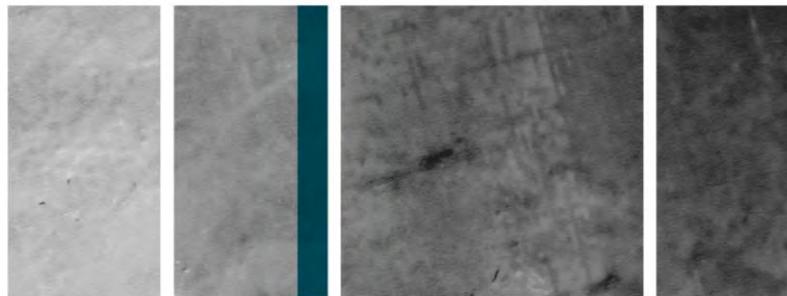


Table 1: Major differences between *Tilapia* and *Oreochromis* spawning (modified from Trewavas 1983)

<i>Tilapia</i>	<i>Oreochromis</i>
Males usually do not compete for nest sites	Males compete in breeding arena for best sites for nest building. The most dominant male constructs the largest saucer shaped nest in the most favourable site
Substrate brooders, eggs and early young adhesive	Mouth brooders, eggs non-adhesive
Eggs small but numerous	Eggs larger but fewer
Minimal sexual dimorphism, sexes look alike	Sexual dimorphism - males bigger, larger mouth and bold coloration
Monogamous, pair bonding	Polygamous, no pair bonding
No arena spawning	Arena spawning
No separate brooding area	Separate brooding area
Both parents care for eggs and young	Only female mouth broods eggs and young

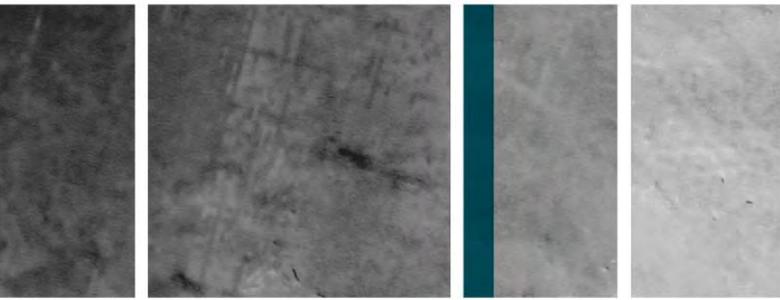
Table 2: Difference between *Tilapia* and *Oreochromis* - feeding biology (modified from Trewavas 1983).

<i>Tilapia</i>	<i>Oreochromis</i>
Trend towards aquatic plant and periphyton feeding as adult	Trend towards phytoplankton feeding as adults
Coarser pharyngeal teeth enable sorting of coarser food particle	Pharyngeal teeth fine for sorting fine food particles
Lower number of gill rakers 6-17 - limits filtering abilities	High number of gill rakers - 16-27 - facilitates filter feeding algae from water column

Summary of the biology of two African cichlids that have become invasive alien species in Australia

1. *Tilapia mariae* - spotted tilapia or black mangrove cichlid (declared noxious in Queensland)

- Natural distribution: coastal areas of West Africa (Figure 1).
- Adults prefer standing or running water and young shallow vegetated standing water in tropical coastal regions. A tropical species that cannot survive low water temperatures: Lowest temperature survived 11.5°C
- Grows to 30cm long and 9 years old.
- Population length frequency peaks at 10 and 14 cm, max length at 19-22cm - but in Florida, USA up to 35cm and 1.35kg.
- Can tolerate up to 8ppm salinity - lives in estuaries.
- Eats periphyton, diatoms, filamentous algae, detritus - typical tilapia diet.
- Food items found in stomachs: filamentous algae, diatoms, desmids, detritus, terrestrial and aquatic invertebrates, but seems not to feed on zooplankton. There is



a change from more single celled algae and aquatic insects in young to more filamentous algae and terrestrial insects in adults.

- Spawn when rivers flood [summer], multiple spawner with two breeding peaks in July and December, but breed through the year. Spawning seems to be synchronised with full moon - advantage to avoid predation.
- Can become fecund [female] at 7cm and one year of age.
- Lay 200 - 1000+ eggs on substrate, male fertilises, female protects and fans eggs.
- Fecundity increases with weight up to 580 eggs per female for 15cm fish. Other data indicate up to 3200 egg count.
- Male guards female and nest against intruders.
- Incubation 4-7 days, eggs transferred to cleaned pit dug by parents.
- Parental care extremely long - up to 60 days until larvae are 20-40 mm.
- Regarded as K-selected species - based on extended parental care, low fecundity, large eggs
- But it also has a high reproductive potential, making it a candidate invasive species.

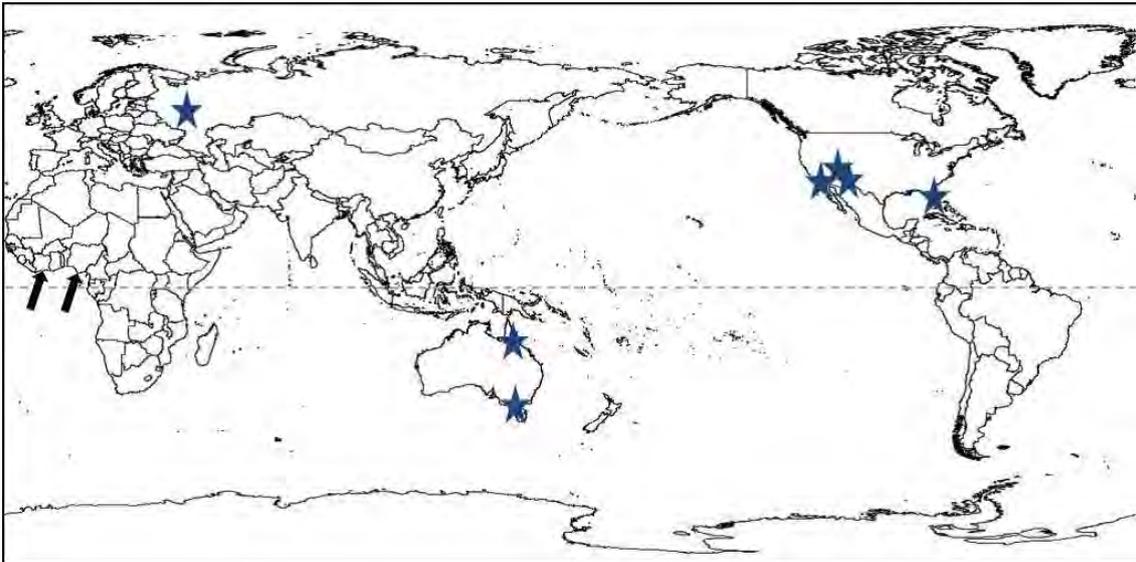
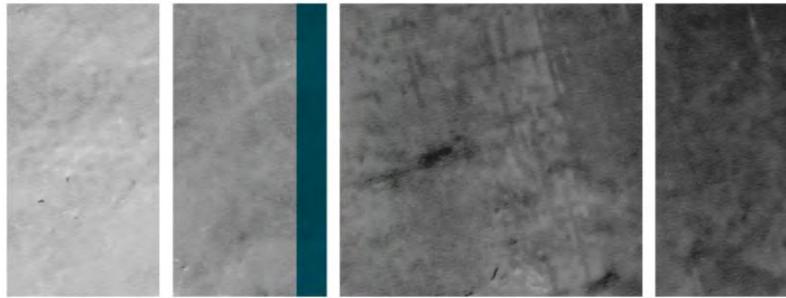


Figure 1: World map showing the natural distribution of *Tilapia mariae* in West Africa from Cote d'Ivoire to Cameroon (bold arrows) and reported introductions (stars). (From Bradford et al 2011).



Other potential invasive *Tilapia* species

Some related *Tilapia* species in southern Africa that represent further potential invasive threats:

Tilapia sparrmanii, banded tilapia

T. mariae is similar to *T. sparrmanii*: an ubiquitous small tilapia from Congo southwards to the Orange River in South Africa.



Figure 2: *Tilapia mariae*.
(Photo: <http://www.kidsfishing.org>.)



Figure 3: *Tilapia sparrmanii*, Zambezi River.
Photo: BCW van der Waal

T. sparrmanii prefers vegetated areas and is successful in various conditions: streams, wetlands, lakes. It has similar feeding habits - plankton, algae, but also insects. Substrate breeding similar to *T. mariae*: builds small nests in which eggs and larvae are kept and protected.

T. sparrmanii is not a dominant species anywhere and is migratory on floodplains but has great invasive potential and has successfully invaded rivers south of its natural range in South Africa.

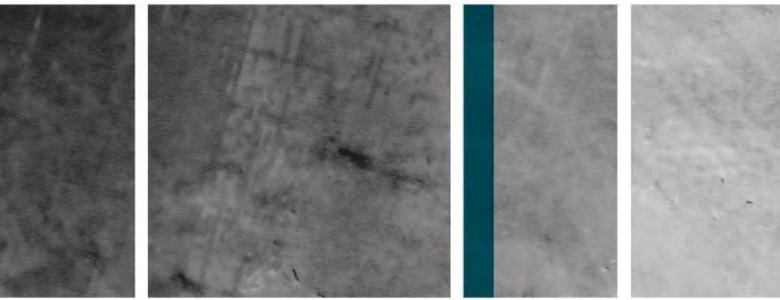
Tilapia rendalli

Tilapia rendalli (redbreast tilapia) and closely related *T. zillii* of Eastern Africa has even more invasive potential:

- It is the largest tilapia species and grows up to 45cm and 2 kg.
- Adults herbivorous, young eat plankton.
- Migrates actively into floodplains, spawns in shallow weeded places.
- Multiple nest spawner, parental care by both parents, high fecundity [up to 8500 eggs].
- Can dominate fish communities, transform habitat by removing all aquatic vegetation. It reportedly transformed manmade ponds in Southern Africa (Wager 1968, Junor 1969).
- Established as alien invasive species in 22 countries.



Figure 4: Nest of *T. rendalli* in 40cm deep water in newly inundated floodplain, Kwando River, Zambezi system. Photo: BCW van der Waal.



2. *Oreochromis mossambicus* Mozambique tilapia

Declared noxious in Australia and listed as one of world's 100 most invasive organisms.

Characteristics:

- Prominent sexual differences between breeding males and females
- Breeding male has dark upper parts, white cheek, enlarged mouth.
- Female olive to silvery with three to five spot or bars on sides. Breeding females have yellowish cheeks.

Feeding biology:

Young up to 50mm eat zooplankton but diet changes to phytoplankton and detritus when adult. Diatoms are a very important diet component. One of the attributes to the success of this species is the fact that stomach pH can drop to 1.0 - enough to lyse bacteria (Moriarty 1973).



Figure 5: Male *Oreochromis mossambicus* demonstrating dark upper sides, whitish cheek and enlarged mouth and lips. Photo: South African Institute for Aquatic Biodiversity.



Figure 6: Female of *O. mossambicus* with general dull grey colour, three spots and six faint lateral bars. Photo: BCW van der Waal.

Breeding biology:

- Breeds communally in leks - strong competition between males for nest sites.
- Strict hierarchical dominance.
- Urination carrying pheromones play a role in interaction between fishes.
- Females take up eggs in their mouths as soon as they are laid, leave the nests and move to shallow weeded brooding area to brood eggs and young for 2-3 weeks
- Aggressive species - chase other species away from arena.



Figure 7: Nests of the closely related *O. andersonii* the Okavango Delta, Botswana. Photo: BCW van der Waal.

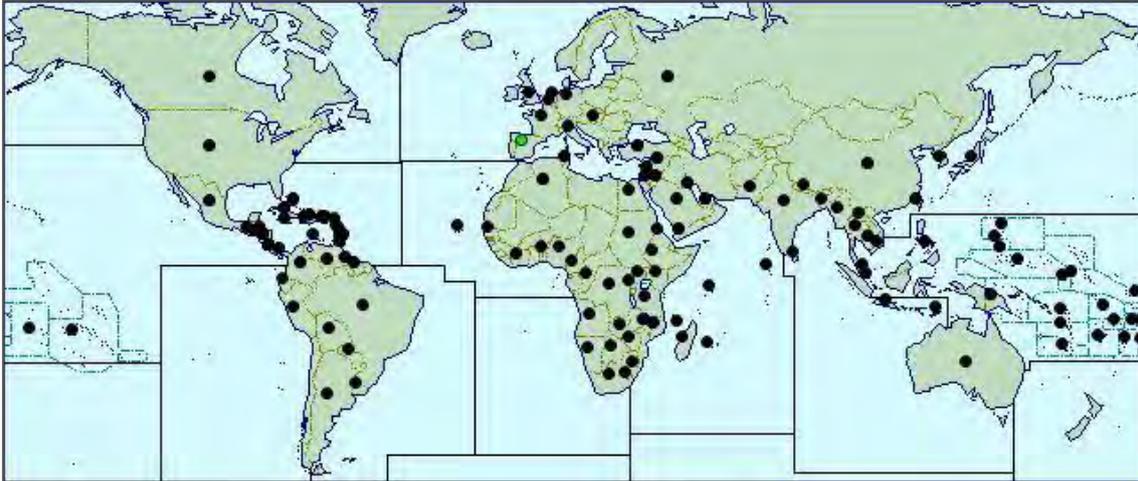
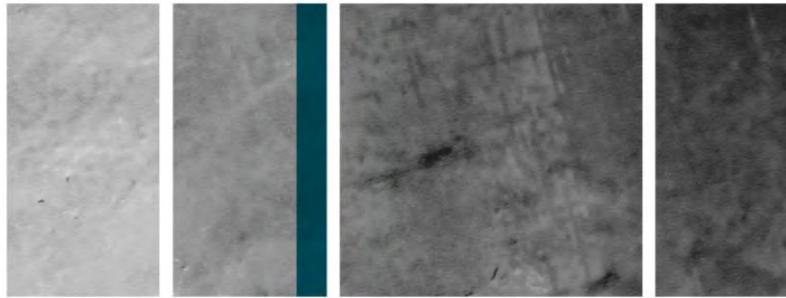


Figure 8: Worldwide distribution of *Mozambique tilapia* [From CABI 2014]

Global spread of Mozambique tilapia

- Mozambique tilapia was spread before the Second World War to control weeds, then later as a preferred aquaculture species to all tropical regions. It is now established in 94 countries, including south eastern Asia and both Americas and Australia.
- It has been in Australia since the 1970's, brought in as aquarium fish.
- Of special concern is a report of a separate hybrid [*O. mossambicus/niloticus/aureus*] population in the Cairns region that poses an extra threat [Arthington and Bluhdorn 1994, Russell et al 2011].



Figure 9: Natural distribution of *O. mossambicus* in southern Africa (From SAIAB).

Although it has been introduced to so many countries for fish farming, little tilapia farming takes place in South Africa itself. Reasons include low winter inland water temperatures, lower growth rate than reported in other species and complicated permit system. But in southern Africa it is regarded as important in recreational angling and subsistence fisheries.

Figure 10: Aquaculture of Mozambique tilapia under plastic tunnels to conserve heat near Johannesburg, South Africa. (Photo: synaptoman.files.wordpress.com/2011/08/dicla1.jpg)



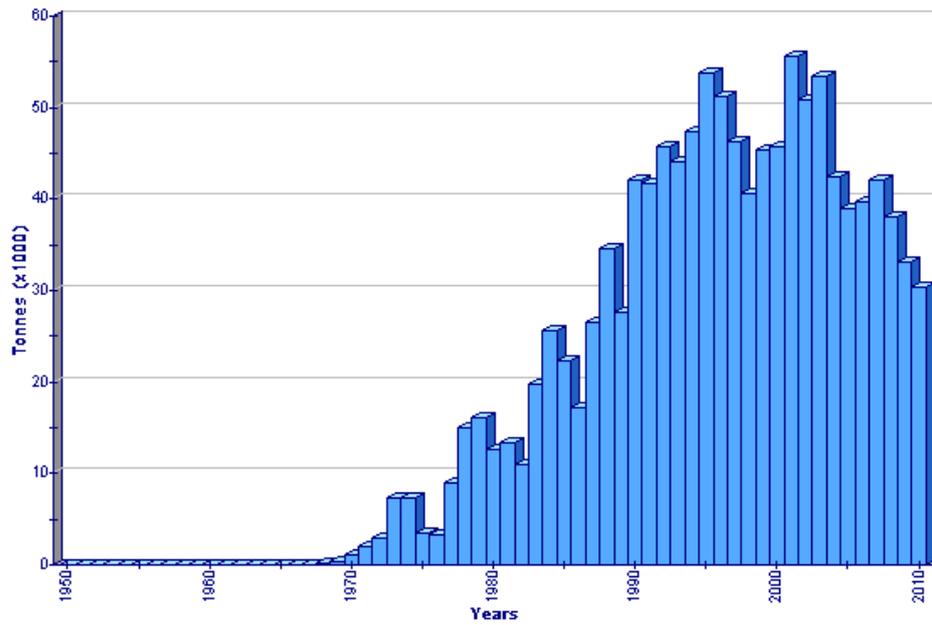
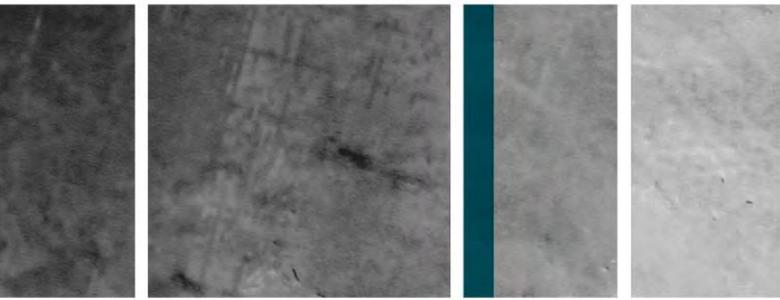
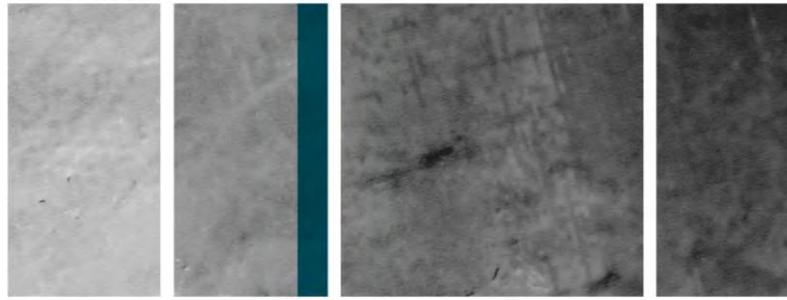


Figure 11: Production of Mozambique tilapia is decreasing globally (FAO 2014).



Figure 12: Prize *O. andersonii*, closely related to the Mozambique tilapia, at an annual international angling competition on the Zambezi River. (Photo: BCW van der Waal).



3. Threats to *Oreochromis* species in Africa?

Of the 30 *Oreochromis* species of Africa listed by IUCN, 21 are Red Data species as follows:

<i>IUCN Status</i>	<i>Number of species listed (IUCN 2013)</i>
Near threatened	1
Vulnerable	6
Endangered	6
Critically endangered	8

This is not the result of habitat deterioration but rather caused by the introduction of predatory Nile perch (*Lates niloticus*) into Lake Victoria and hybridization of local species with introduced species, mainly Nile tilapia (*Oreochromis niloticus*).

In southern Africa the IUCN (IUCN 2013) status of southern African tilapias as a direct result of Nile tilapia introduction and hybridisation is now as follows:

- *O. mossambicus* near threatened
- *O. mortimeri* critically endangered
- *O. andersonii* vulnerable
- *O. macrochir* vulnerable

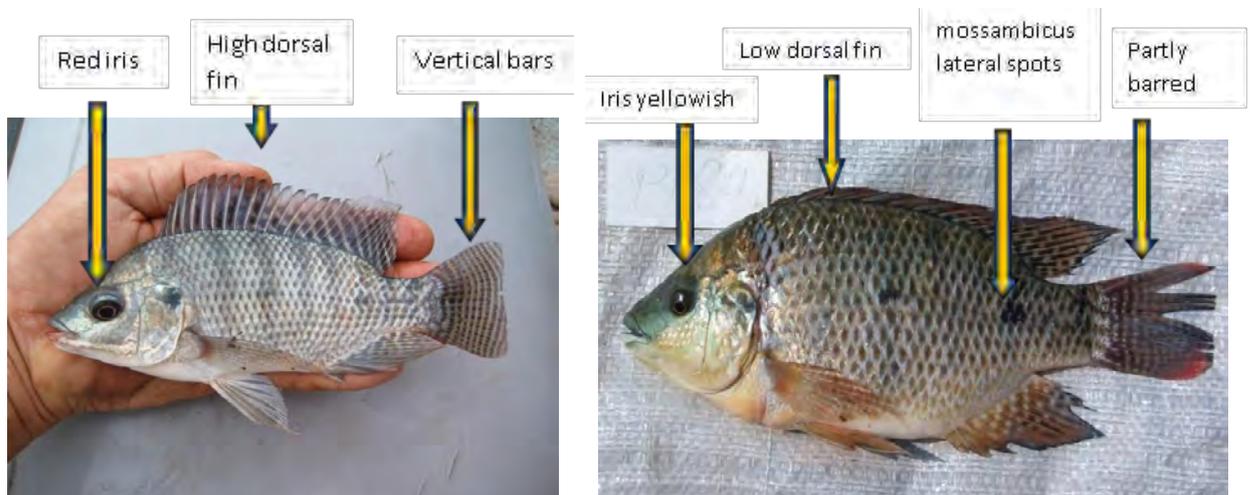
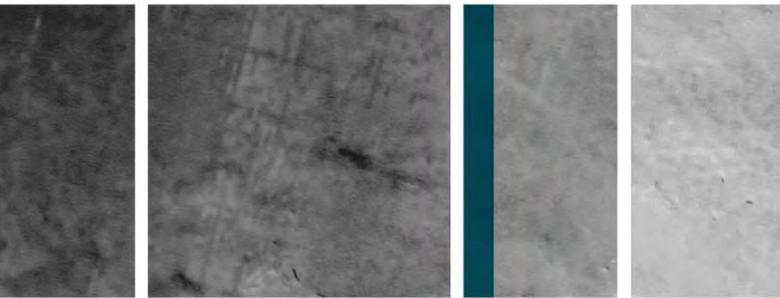


Figure 13: *Oreochromis niloticus* and *O. mossambicus/niloticus* hybrid. Points to recognise Nile tilapia or hybrids are marked with yellow bars. (Photo : BCW van der Waal)



Nile tilapia - an even more invasive tilapia with some 'superior' invasive characteristics:

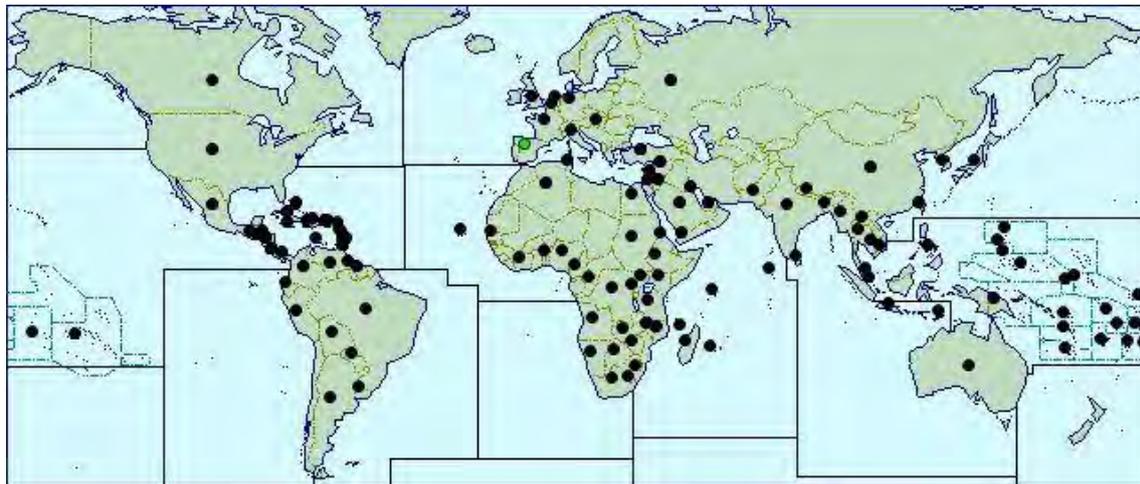


Figure 14: Worldwide distribution of *O. niloticus* (from CABI 2014). Distributed to 102 countries, now the primary fish of tropical aquaculture.

- Grows to a recorded length of 63cm and weight of 6270g compared to the 45cm of *O. mossambicus* and record weight (SA angling record) of 3110g (IGFA 2014).
- Has a higher fecundity than the Mozambique tilapia, both absolute [grows bigger and heavier] and as percentage weight [eggs smaller].
- Growth rate higher - in experiments found to be 1.4 to 2 times that of Mozambique tilapia (personal observation).
- Algal benthic feeder but can switch to a detritivore, filter feeding, omnivore and carnivore feeding habit.
- Aggressive spawning behaviour facilitates male Nile tilapia fertilizing all available females, even of other species.
- Leads to introgression of Nile tilapia genes into an existing tilapia population.
- Result is hybrids leading to disappearance of original species.
- Nile tilapia characteristics dominate in hybrids and only a small portion of original species genetic characteristics remain.

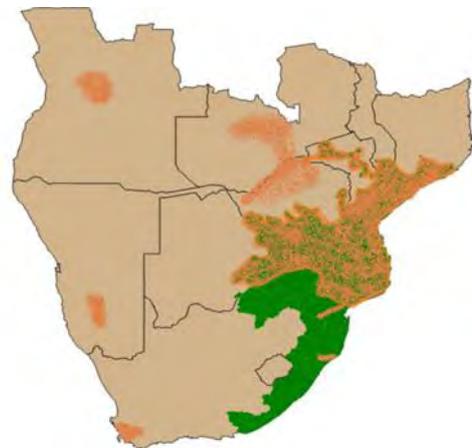
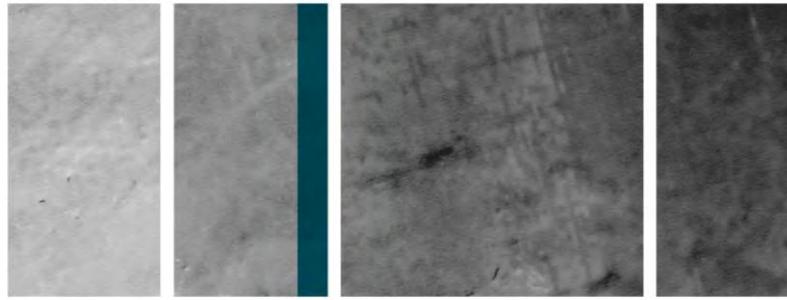


Figure 15: Distribution of Mozambique and Nile tilapia in southern Africa. Green = natural distribution of *O. mossambicus* and pink = reported distribution of *O. niloticus*. Based on data from SAIAB and own information.



Some examples of take-over by Nile tilapia in Africa:

- Two endemic *Oreochromis* species (*Oreochromis esculentus* and *O. variabilis*) were outcompeted to near extinction in Lake Victoria after Nile tilapia were stocked there 30 years earlier (Witte et al. 1992).
- Ten years after escaping into Lake Kariba, the local *O. mortimeri* (Kariba tilapia) was replaced in the 200km long lake. It is now difficult to find. (Weyl 2012).
- In Lake Chicamba in Mozambique it took 2 years for *O. niloticus* to dominate fishery catches (Weyl 2011).
- In the smaller Zhovhe reservoir in southern Zimbabwe, no pure Mozambique tilapia, a few obvious hybrids and rest of a sample of 100 + fish Nile tilapia were collected 8 years after first introduction of a few Nile tilapia (personal observation, Tweddle 2011).

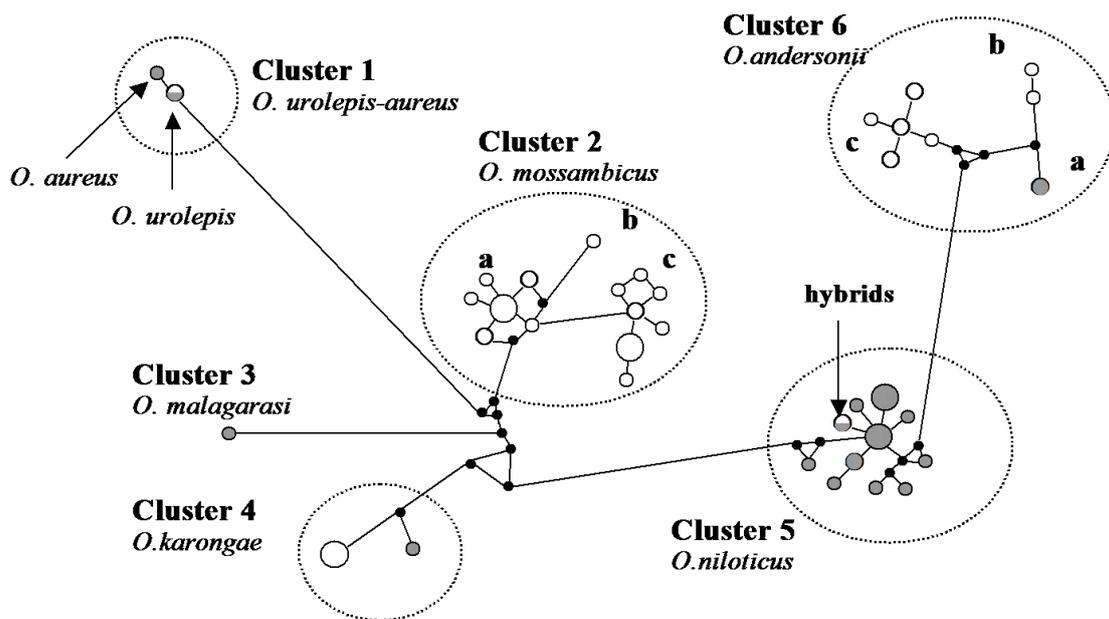


Figure 16: Genetic relationship between *Oreochromis mossambicus*, *O. niloticus* and other southern African species. (D'Amato et al 2007)

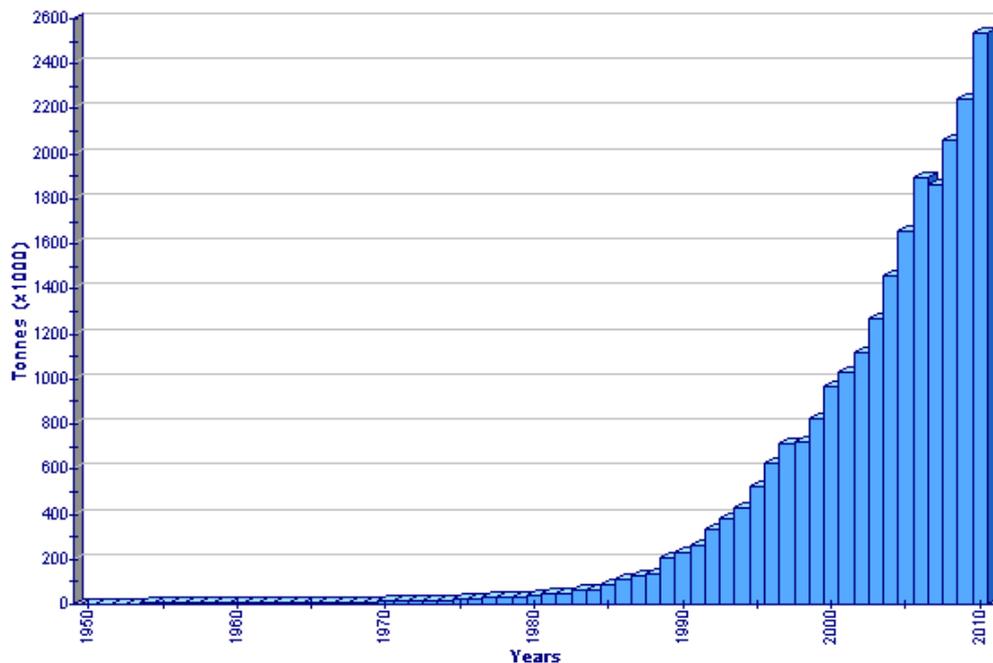
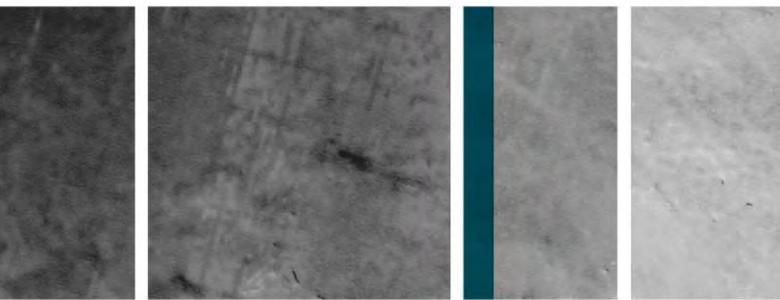
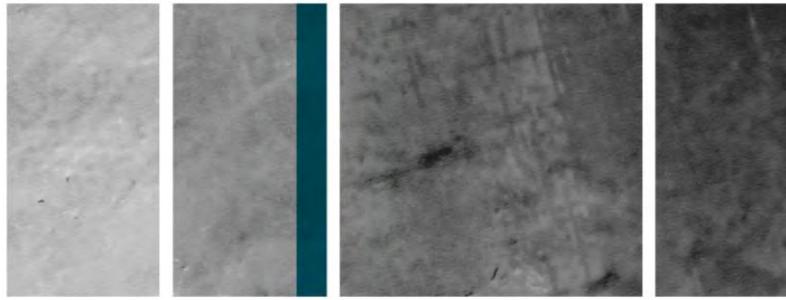


Figure 17: Trends in global Nile tilapia production. There is an exponential increase in production. (FAO 2005-2014).

Effect of hybridization on Mozambique tilapia populations in South Africa.

- No negative inbreeding genetic effects have been reported thus far.
- Fish from the Lower Zambezi, rivers in Zimbabwe, Limpopo River and even some rivers further south, are potentially hybrids and should not be used to breed *O. mossambicus* for stocking waters.
- High dams of reservoirs and weirs act as effective barriers for upstream migration of Nile tilapia. Many reservoirs in tributaries still contain pure (but not genetically tested) populations.
- Tilapia populations in upper reaches of rivers above dams can stay pure unless stocked with Nile tilapia or hybrids by anglers, farmers etc.
- IUCN status of Mozambique tilapia was changed in 2010 from LEAST CONCERN to NEAR THREATENED as result of this threat.
- No active steps have (yet) been taken by authorities in either Zimbabwe or South Africa to protect genetically unpolluted populations of the indigenous Mozambique tilapia in reservoirs or isolated smaller river systems that can effectively be kept pure.
- No programmes to control established hybrid populations have been considered.



- A controversial zoning system was proposed in South Africa to allow Nile tilapia farming in a few regions where it is already present but not in regions where it is not present. This zoning system has however not been implemented as yet.

Conclusions

- Both invasive Australian tilapia are part of fish assemblages in their home range where they play a non-dominant role. In manmade lakes, *O. mossambicus* often is one of the dominant species but never over-populated and stunted. In smaller waterbodies some stunting may occur.
- There are other *Tilapia* and *Oreochromis* species in Africa with worse invasiveness characteristics.
- No conservation action has as yet been taken to protect species in Africa threatened by hybridisation by Nile tilapia.
- Australia should take preventive action to allowing introduction of Nile tilapia.

Some suggestions on the way forward

What to do with invasives that have already established themselves?

Global changes are driven by atmospheric and oceanic changes, but invasives and biodiversity changes are a third driving force that has to be considered. Global warming and weather pattern change may assist in the further establishment of tilapia populations in Australia.

Tilapia are considered a serious threat to biodiversity in Australia (Canonico et al 2005). There is also a great risk the present range will be expanded through natural and man-assisted spread. Preventive action is thus imperative and the present emphasis on preventing further distribution is justified.

Special attention should be given to control the aquarium trade - restrict import, breed own supply.

Another priority is to completely prohibit Nile tilapia access or Nile tilapia fish farming in Australia.

Tilapia cannot effectively be removed by current methods where it has already become established and we may have to learn to live with it. In those areas tilapia could actually be utilised. Why not harvest tilapia as food? If you cannot beat them, eat them! Selective tilapia-based fisheries can be established in reservoirs. This will decrease population numbers and simultaneously provide food or income opportunities.

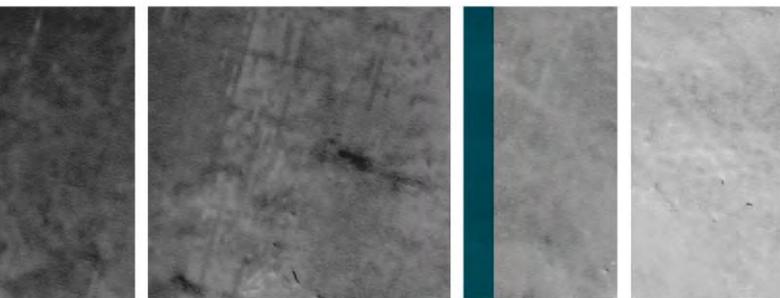
What have we learnt?

New trends and suggestions

Is 'nativeness' becoming an oxymoron? 'Nativeness may now be as meaningless as the idea of wilderness' (Walsh 2011).

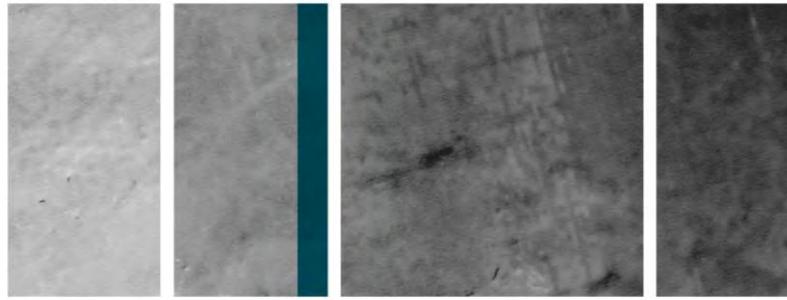
Homogenization is part [and the price] of globalization (Davis et al 2011).

In the light of the above we may have to reconsider each non-native species before declaring it as an invasive species and rather learn to use the new components of an ecosystem where it proves impractical to remove it.



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Questions

Q: Effectiveness of most pest fish control programs depends on the stock recruitment relationship that the fish has, are there any data from Africa or South Africa on the native stock recruitment relationship for *O. mossambicus*?

Ben: I don't think that there are data available although we do have some of it in terms of fisheries.

Q: I understand that the type location of *O. mossambicus* is under threat. Are any measures being taken to protect it?

Ben: There are few *O. mossambicus* left. Most people do not even know about it. One lady working in the lower part of Mozambique has found *O. aureus*, *O. niloticus* and *O. mossambicus* and hybrids. I have looked at some photographs of the fish and you could only guess what species it was.

Q: I would like to comment on your suggestion that a way to beat tilapia may be to eat them. This is contrary to current Australian thinking as most of the tilapia that have moved have been moved by humans and once they get into a river system they are able to invade the rest of that river system; but movement between river systems is done by people. If you start giving them a value such as a commercial fishery you encourage people to move them and we are against giving them a value.

Ben: In the end I think you have to be realistic. What do you do with them ...catch them and let them rot?

Q: How common is stunting in *O. mossambicus* in South Africa? One of our concerns in Australia is the stunted populations that would affect any commercial value that a fishery might have.

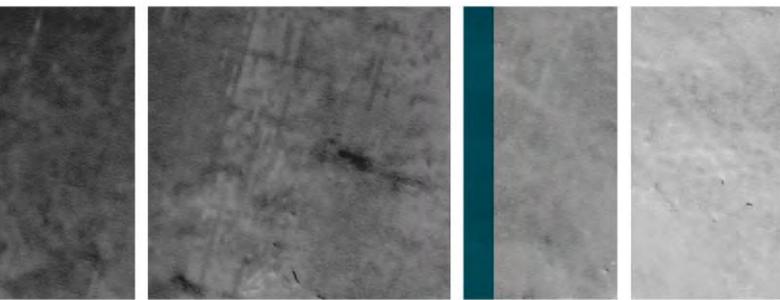
Ben: An interesting question. There are some hot-springs in South Africa and all have stunted populations. Lake Sibaya, which is a deep coastal lake - fish do not grow more than 30 cm - shortage of quality food. Farm ponds also become over-populated and if you farm tilapia in these, you need to add a predator. For this reason fish farming has moved away from *O. mossambicus*. In natural systems like floodplains or bigger rivers with predators they tend to grow to an optimum size and they tend to breed at a larger size.

Q: Nile tilapia ...worst invader in about 152 countries what is your opinion about the GIFT strain of Nile tilapia and other strains?

Ben: GIFT strain is not present in southern Africa. As far as I know the strain we have is more or less pure. Someone is trying to bring them into South Africa at the moment...not sure of hybrids presence further north in Africa,

Q: With niloticus, is the main method of impact through hybridisation and also is there any research on the impact of niloticus on other species

Ben: Unfortunately we have no idea at this stage as there is little work so far.



The biology and management of *Tilapia mariae* as a native and invasive species: a review

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Objectives / Background

Tilapia mariae Boulenger 1899 (Cichlidae) is a tropical teleost native to West African coastal drainages in the Gulf of Guinea. Within its natural range, *T. mariae* is abundant and contributes to the local subsistence and artisanal fisheries, however it is not extensively utilised for aquaculture. Outside its native range, *T. mariae* has proliferated in the USA and Australia. While tilapiine species are considered to be amongst the world's most destructive invasive alien species, surprisingly little information is available on the biology of *T. mariae* and the potential impacts on species and aquatic ecosystems outside of its native range.

The authors undertook a review of published information on *Tilapia mariae* from its native and introduced range, that was published in *Marine and Freshwater Research* (Bradford et al 2011). The review aims to improve effective management of fisheries in the natural range of *T. mariae* as well as manage current infestations, reduce further spread, and promote research on control measures.

Summary of findings

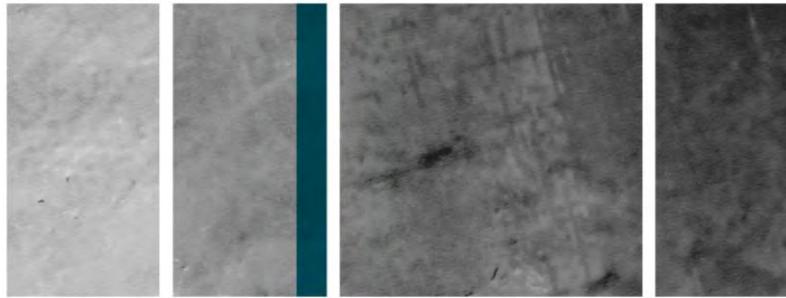
The biology of *T. mariae*, unlike other tilapiine species, has not been extensively studied, with a total of 101 works identified and included in our review. Of these, approximately 50% are field studies conducted in its native environment, and 17% are studies and reports from its introduced range.

Much of the information on *T. mariae* from its native range can be found in a small number of key papers, most originating in Nigeria (Whitehead 1962; Schwank 1987; Anene 1999, 2004a,b; Ikoma and Jessa 2003; King and Etim 2004; Anene and Okerie 2008). In its native range, the distribution, abundance, habitat, reproduction and diet have been well studied. Other aspects of biology including growth and development, tolerances and toxicities, threats, and physiology have been inadequately or poorly studied.

Although *T. mariae* has been present in the USA for at least 40 years, little information is available on the biology of the species in that context. Only nine published works relating to the biology of the species were located and these addressed the subjects of distribution (3 papers), management (2), impacts (2), reproduction (1) and potential control (1).

In Australia, *T. mariae* is currently restricted to eastern flowing rivers near Cairns, North Queensland and an isolated population in an artificially heated pond in Victoria. Only four studies specifically addressing the biology of the species in Australia could be found and these addressed the subjects of its biology in Victoria (2 papers), genetics (1) and control (1).

Even fewer of these studies have addressed impacts on ichthyofauna and habitats in the species' introduced range. These are limited to a summary of impacts on native species and sport-fisheries in the USA (Courtney and Deacon 1983), competition and displacement of a native species with similar reproductive and habitat requirements (Brooks and Jordon 2010), and the use of environmental variables to predict distribution and impact (Kroon et al 2011).



Moreover, there is a paucity of research into management options for *T. mariae*. Papers from the USA report on the use of a native fish species (Annett 1998), and an introduced cichlid (Shafland 1995), while there is one report on a successful eradication attempt in North Queensland (Pearce et al 2009).

Key messages

The studies included in our review highlight a number of characteristics of the species' biology.

- *T. mariae* shows great variation in morphological attributes, including condition factor, size distributions, and length-weight relationships, in response to the hugely varied habitats that the species is found in.
- These studies appear to show some plasticity in reproductive behaviour, particularly in the manner in which parental care is exhibited. Specifically, while *T. mariae* is generally described as a monogamous breeding species, both laboratory and field studies have demonstrated that both bigamy and polygamy occur.
- *T. mariae* demonstrates a variety of feeding behaviours and dietary components, which are reflected in the species' dental anatomy and gill morphology. We propose that, relative to species with specialized reproductive and feeding behaviours, such plasticity may contribute to *T. mariae*'s competitive advantage in both native and introduced regions.
- The species' documented tolerance of a wide range of temperatures, salinity and dissolved oxygen concentrations, and its aggressive behaviour to other piscine species, is likely to further consolidate this advantage.
- The inferred high fecundity of *T. mariae* does not appear to be supported by the relatively low number of eggs produced per female, the high brood mortality, and the high predation pressure suffered by embryonic, larval and juvenile stages.

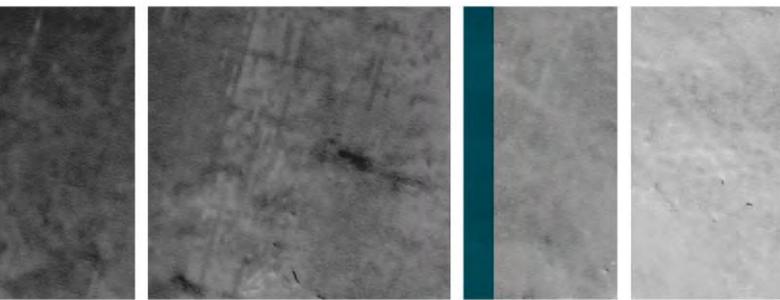
Knowledge gaps

Numerous aspects of *T. mariae*'s biology are not adequately covered by currently available scientific literature. These include:

- growth and development, including condition factor, growth rate and stunting (due to variability in habitat, diet and morphology)
- the physiology of the species including determining hormone levels during critical phases of reproduction
- environmental tolerances and toxicities to understand range expansion, rate of spread and population persistence
- threats and predators that may limit range expansions and give insights into novel control and management techniques.

Our review also highlights the lack of research effort that has been directed to *T. mariae* in its introduced range, specifically:

- the management, control or eradication of the species
- the impacts on native ichthyofauna and habitat.



Moreover, there are aspects where the biology is well studied in the species' native range but due to its behavioural plasticity *T. mariae* will likely behave differently in its introduced range. For example, Annett et al (1999) describes reproduction, courtship and parental care in a Florida canal system that differs significantly from behaviour in its native range. Since the publication of our review a number of these reproductive, growth and development, and physiological knowledge gaps in the Australian setting have been addressed by Russell et al (2012).

Management / Research recommendations

There are a number of knowledge gaps in the biology of *T. mariae* that should be addressed as a priority:

- environmental tolerances in the Australian setting
- impacts on Australian ichthyofauna and habitat
- variation in reproduction, growth and diet in the Australian setting
- Australian predators and threats.

These findings along with our current knowledge of the species should be used to model invasion patterns and processes which will allow us to target control and management effort. In addition, quantifying *T. mariae*'s role in the aquatic food web may elucidate novel control and management strategies, and ultimately inform the rehabilitation and protection of Australian aquatic ecosystems.

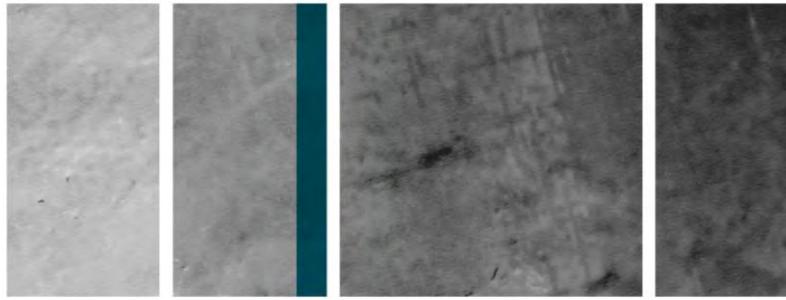
Consideration should also be given to control and management methods that target those aspects of biology that give *T. mariae* a competitive advantage over Australian native species. While many native species have specialised reproductive and feeding behaviours, *T. mariae* shows plasticity in reproductive behaviour and dietary components and can tolerate a wide range of temperatures, salinity and dissolved oxygen concentrations. We hypothesise that limiting large fluctuations in environmental parameters by maintaining and rehabilitating riparian vegetation and maintaining natural stream flows will assist native species to compete.

Acknowledgments

The authors acknowledge funding from the Marine and Tropical Science and Research Facility and the Invasive Animals Cooperative Research Centre.

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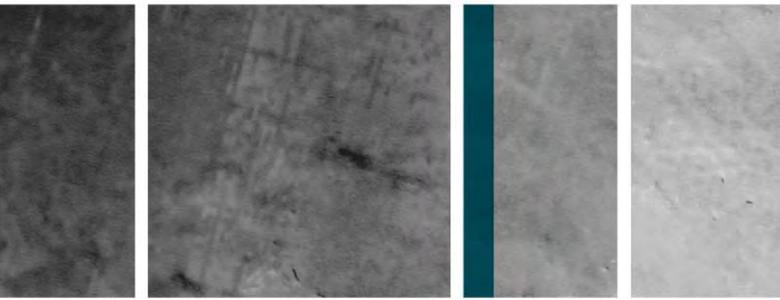


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Questions

Q: Had a very unusual kill of tilapia in summer (no other species) any occurrence in aquaculture of related species of susceptibility to disease?

Matt: Didn't find any.



The biology, management and control of invasive tilapia populations in northern Australia – an overview of Invasive Animals Cooperative Research Centre (IA CRC) research

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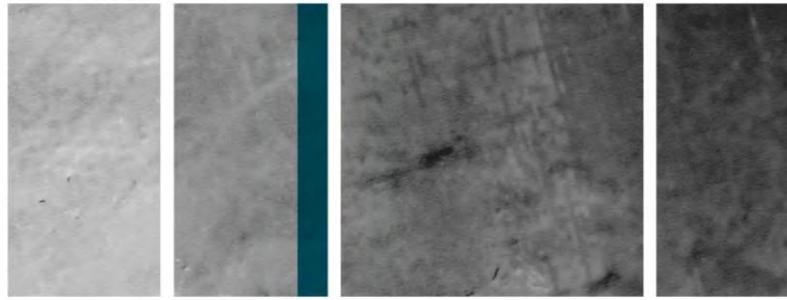
Background / Objectives

Two species of tilapia, *Tilapia mariae* and *Oreochromis cf. mossambicus*, have been progressively colonising watercourses in eastern Queensland and Western Australia since the early 1970s and there is potential for at least one of these pest species to move into the Murray-Darling Basin and into the Gulf of Carpentaria drainage (Russell et al 2012b). Current control measures are mostly restricted to public education, limited spot eradications using chemicals and the installation of expensive fish exclusion screens (Mackenzie and Bryant 2001; Mackenzie et al 2001; Russell et al 2012b). Initially the work funded by the Invasive Animals Cooperative Research Centre (IACRC) on tilapia control and management (2006-2009), concentrated on three areas:

- investigating the biology and ecology of Australian populations of *T. mariae* and *O. cf. mossambicus* to identify potential vulnerabilities in their life histories that may be exploited to control infestations;
- determining the efficacy of various potential control strategies through simulation modelling; and
- trialling the effectiveness of mechanical removal using electrofishing as a control measure in a small weir.

In the second phase of the IACRC (2010-2012), this work was expanded into new areas including:

- Tracking the movements and dispersal of tilapia in a small weir using acoustic tagging technologies;
- Extending the abovementioned ongoing trial control program using electrofishing by concurrently introducing a predator (barramundi, *Lates calcarifer*) into the weir to further reduce the remaining numbers of *O. cf. mossambicus* (particularly the juveniles);
- Developing and publishing a ‘toolkit’ of relevant information on invasive populations of tilapia, including their biology, ecology, impacts and management, for use by a wide cross-section of interested stakeholders.
- Collaborating with the University of Notre Dame in the United States to determine the feasibility of using the presence of environmental DNA (eDNA) as a surveillance tool for the early detection of tilapia.



Summary of findings

The initial IACRC study of invasive tilapia populations in north Queensland was directed mainly towards identifying vulnerabilities in their life histories that could potentially be exploited to manage new and existing infestations. This involved an intensive sampling program which yielded over 8000 fish from both species from five geographically close locations in north-eastern Queensland. The samples were used to determine reproductive seasonality, movements, fecundity, age structure, size- and age-at-first maturity and the prevalence of 'stunting'.

These tilapia populations, particularly those containing *O. cf. mossambicus*, showed considerable plasticity in their reproductive and growth parameters. This inherent variability is partly responsible for the capacity of these species to quickly and efficiently invade new and sometimes marginal areas. A high level of parental care ensuring that the majority of their eggs and larvae are recruited as juveniles and the ability to spawn multiple broods throughout a year-round reproductive season also gives these tilapia species a significant competitive advantage over native fishes (Russell et al 2012a).

Invasion of Queensland waterways is continuing (Russell et al 2012b) and aging studies of the two largest populations of *T. mariae* in north Queensland suggest that they have only recently become established (Russell et al 2010). These data were also used in the successful adaption of the CARPSIM model (Brown and Walker 2004) to demonstrate the effectiveness of various management scenarios on both *T. mariae* and *O. cf. mossambicus* populations. Some of the simulations that were done suggest that it would be possible to drive tilapia populations down to pseudo-extinction using very high levels of fishing pressure or a combination of fishing effort and recruitment failure. However, simulations that used more realistic and sustainable estimates of fishing effort, levels of spawning disruption and other interventions suggested that, while it was possible to drive tilapia abundance down to relatively low levels, populations would not become pseudo-extinct and would quickly recover to previous levels once the interventions ceased (Russell et al 2010).

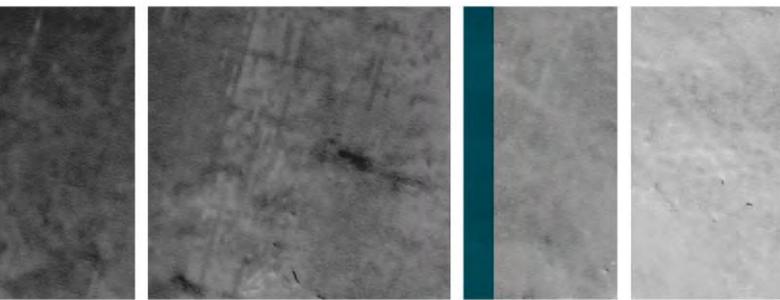
A field trial that investigated the potential of both mechanical removal of fish and predator introduction as population control measures in a small impoundment was also undertaken. It was demonstrated that electrofishing (Error! Reference source not found.) could successfully and cost-effectively be used to reduce the abundance of mature *O. cf. mossambicus* in the small weir (Thuesen *et al.*, 2011).

While the results of the tracking study of *O. cf. mossambicus* in the same weir are yet to be fully analysed, initial results suggests that there are 'hotspots' for this species in the impoundment (see Thomson et al 2014 in this document).

The results of the predator control study were inconclusive as only a small number of *L. calcarifer* were eventually recaptured, possibly because particularly cool water temperatures in winter adversely affected their survival. Of those *L. calcarifer* that were stomach-flushed, there was no evidence that juvenile *O. cf. mossambicus* were being consumed



Figure 18: Mechanical removal techniques such as electrofishing can be effective in reducing the numbers of mature tilapia in small impoundments.



A 'toolkit' that contains relevant management and biological information in a variety of tilapia case studies and factsheets was developed for use by a wide cross-section of stakeholders (see www.feral.org.au/pestsmart/tilapia).

The future development of an innovative surveillance technique using environmental DNA (eDNA) that can potentially detect the presence of small numbers of tilapia, thereby reducing the need for costly surveys, was investigated. The early results were presented to a specially convened eDNA stakeholder workshop in Brisbane on the 22 June 2012 by Dr Lindsay Chadderton of the US Nature Conservancy. While needing further development, the information presented suggests that this technology can be applied to successfully detect the presence of both *O. cf. mossambicus* and *T. mariae* in a range of different habitats.

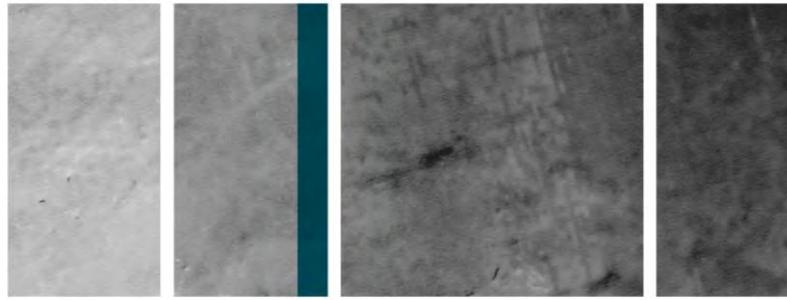
Key messages

- Reproductive specializations such as parental care and plasticity in life history characteristics help to make tilapia a 'model' invader capable of occupying a wide variety of habitat types, enabling them to successfully compete with native species.
- Currently, there is no 'silver bullet' to control tilapia populations at a landscape level and they will probably continue to expand their range in the future.
- The availability of sensitive early warning methodologies such as eDNA technology may increase the chances of some eradications using traditional techniques such as the application of piscicides.
- The use of mechanical removal techniques may be suitable for controlling tilapia populations in small areas where traditional techniques, such as the use of piscicides, cannot be used (e.g. in urban water supplies).
- Where the use of piscicides is not a viable option (i.e. other than in small, discrete populations), modelling suggests that it would be extremely difficult to eradicate established populations of either tilapia species.

Management / Research Recommendations / Knowledge gaps

Current management options are limited to:

- Spot eradications of new incursions where the population is limited to a discrete area and where there is little or no prospect of recolonisation from adjacent areas. Historically, these types of eradication attempts have had only patchy success and have largely been limited to small lagoons or ponds. However, in 2008 a tilapia population in a creek system in the upper Gulf of Carpentaria drainage was successfully destroyed using rotenone. This population was the first to be recorded in that drainage and, as such, was given priority for eradication to prevent downstream colonisation.
- In Queensland, much effort has been put into the development of education and extension packages for pest fish, including tilapia. A curriculum has been written for use in schools and some packages, including a 'train the trainer kit' sponsored by the Murray Darling Basin Authority are available. The IACRC is developing a comprehensive range of case studies and factsheets on tilapia and other pest species which are being progressively published in both hard copy and on the web site www.feral.org.au/tilapia-in-australia/.



- Raising community awareness through the development of a model to demonstrate to stakeholder groups (and fisheries managers) the efficacy of various management scenarios on tilapia populations.
- Screens on pipelines and irrigation channels to prevent inter-basin translocation; whilst expensive, they are an effective means of preventing natural dispersal.

Research recommendations:

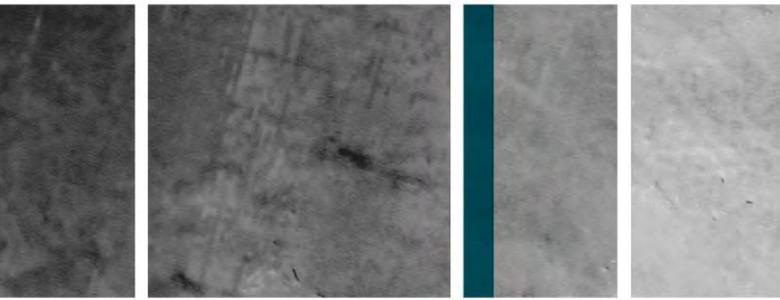
- Effective early detection techniques are the key to eradicating new tilapia incursions in previously unaffected areas and the potential for using environmental DNA technology should continue to be investigated.
- The use of predator introduction as a viable control option, whilst unsuccessful in this current study to control *O. cf. mossambicus*, should continue to be investigated. An introduced predator has apparently been successfully used to control *T. mariae* in the United States (Shafland, 1995) and a similar strategy using an Australian native predator species should be trialled for *T. mariae* control in Australia.
- Further investigate apparent specific habitat preferences of *O. cf. mossambicus* in impoundments and determine if this is a potential vulnerability that could be exploited as part of future management programs.
- The future development of novel methodologies, for example ‘daughterless technology’, offer hope for the widespread removal of tilapia from Australian watercourses.

Acknowledgements

This work was funded by the Invasive Animals Cooperative Research Centre in conjunction with the Queensland Department of Agriculture, Fisheries and Forestry. We are grateful for the invaluable technical assistance given by T. Adams, J. Fitzsimmons, M. Pearce and J. Sariman and other staff at the Northern Fisheries Centre. Alf Hogan and Terry Vallance provided valuable field support and access to field data they collected before the commencement of this project.

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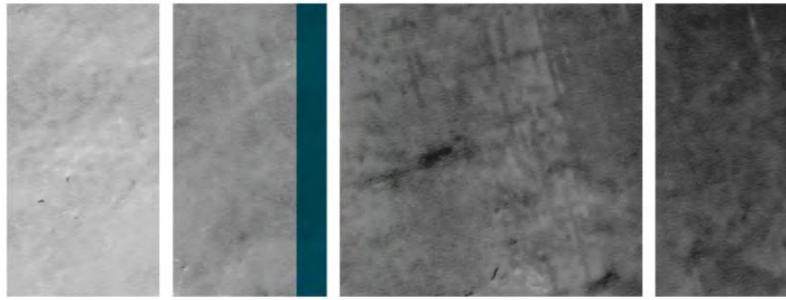
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Questions

Q: What is the survival rate of these fish

John: Generally high because of the parental care. Even though the number of eggs might be quite small compared to something like a barramundi which produces very large numbers of very small eggs which are released into the environment but have a very low survival, because of this parental care, tilapia are looking after the young at a stage when they are most vulnerable and the survival is therefore very high.



Invasion genetics of tilapia (*Oreochromis spp*) in Queensland, Australia

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Objectives and background

Tilapiine species are the archetypal invasive species. They are renowned for survival in harsh environments and can adapt reproduction and diet to local conditions.

Oreochromis spp were first reported from Queensland in the 1970s and have rapidly spread to the majority of coastal catchments. They are on the verge of the largest inland freshwater system in Australia, the Murray-Darling Basin.

An earlier genetic study (late 1980s) suggested that several Queensland populations of *Oreochromis mossambicus* were derived from introductions from the same aquarium stock, and there was evidence of additional hybrid populations in the Cairns region.

The objective of this study was to determine the number of separate genetic strains of *Oreochromis* in Queensland. This would allow the detection of new introductions into Queensland and to decide if genetic assignment tests could be used to determine the source populations of future incursions.

Summary of findings

Four strains of *Oreochromis* were found (Ovenden et al In preparation); three more than identified by a previous genetic study (Mather and Arthington 1991). One strain was *O. mossambicus*, but the other strains represented new species; *O. spirulus*, *O. urolepis* and *O. aureus*.

The strain found in Tingalpa Weir was unlikely to have been present in the 1980s when sampled by Mather and Arthington (1991). Some Tingalpa Weir fish may be hybrids between the original strain and the new strain, but the majority of fish are likely to represent the new strain.

Five pairs of locations sampled in this study had the same genetic strain. These were assumed to be examples of human-mediated translocations as, 1) they were in different catchments (ie could not have occurred due to natural dispersal), and 2) for each pair of collection locations, tilapia were reported from one location about ten years before the second location (Figure 1).

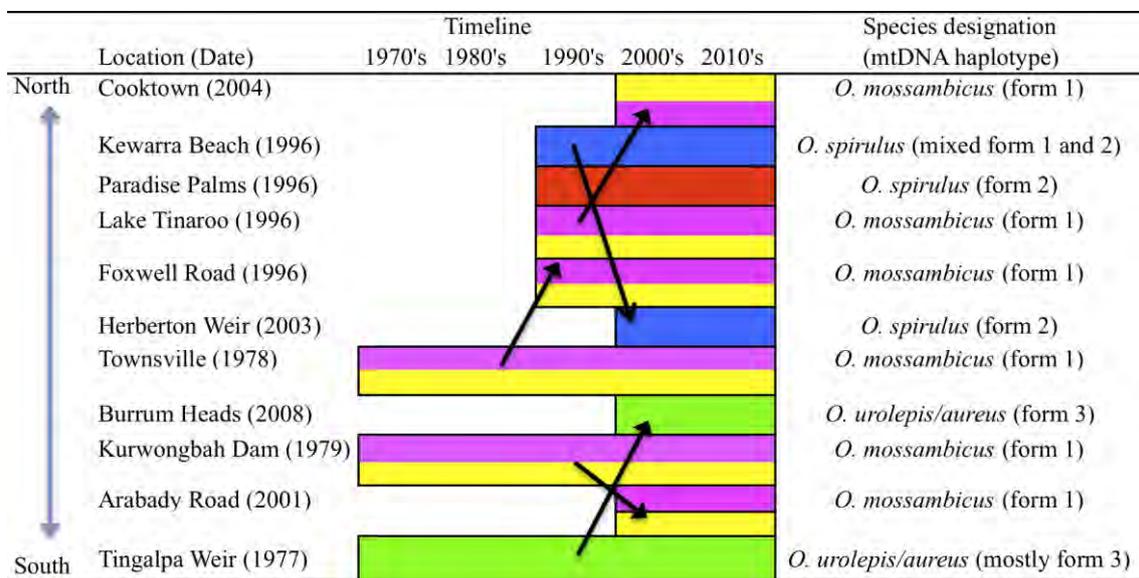
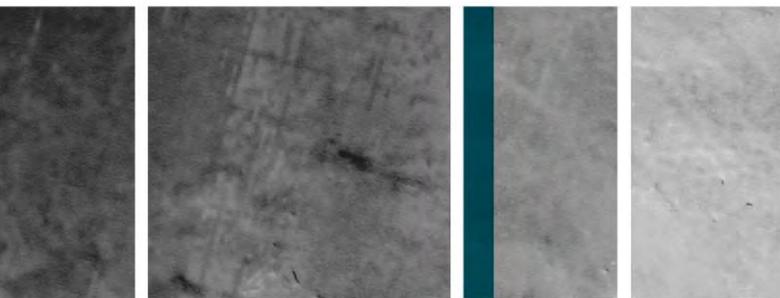


Figure 19: Occurrence of four genetic strains (pink/yellow, blue, red and green) and their likely species designations in northern to southern Queensland collection locations plotted against the date when they were first recorded in that location to the present decade. Arrows indicate possible between catchment (ie human-mediated translocation) dispersal (Ovenden et al submitted).

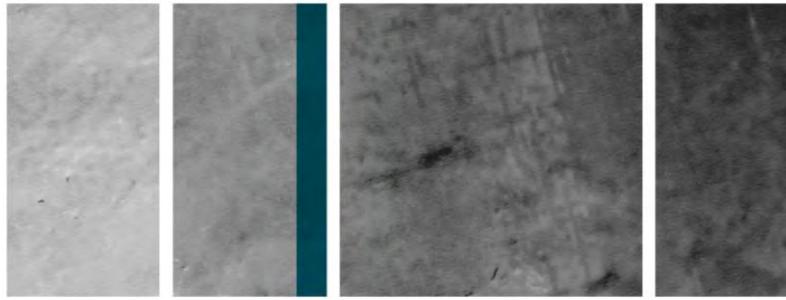
One human-mediated translocation was particularly interesting. It gave rise to three separate homozygous populations, suggesting the following events, 1) at least one female and one male (or one female brooding fertilized eggs or larvae) were taken into captivity from the Townsville population, 2) a considerable amount of inbreeding occurred in captivity during which heterozygosity was reduced to zero, 3) inbred offspring were released into virgin habitat, and 4) despite lack of genetic diversity, three viable populations of tilapia were established.

Key messages

Tilapia species occurring in the wild in Queensland consist of *Oreochromis spirulus*, *O. urolepis* and *O. aureus* in addition to known species *O. mossambicus* and *Tilapia mariae*. However, it is likely that the majority of *Oreochromis* individuals are inter-species hybrids, given their known ability to hybridise and their assumed origin from the aquarium industry where hybridisation is common. Further genetic analyses would be needed to test the hybrid status of Tilapia in Queensland.

Despite regulations against their possession and import, new strains of *Oreochromis* have been introduced into Queensland since the late 1980s. At least one of these new strains has displaced an existing strain, suggesting superior ecological fitness. Displacement appeared to involve hybridisation confirming the ability of the stains to interbreed.

Genetic data supported human-mediated translocation of tilapia between catchments. There was evidence of two types of translocation events; direct and indirect. Direct translocation presumably occurred when fish were moved between catchments, possibly as live bait for angling. Indirect translocation occurred when tilapia were assumed to be taken into captivity for breeding, during which time they lost the majority of their genetic diversity before being



re-introduced to habitats in Queensland. Genetic diversity does not appear to be essential for viable, invasive populations.

Despite the occurrence of translocation, it has been rare enough to maintain separate genetic strains in most locations. Genetic differences between populations are sufficient to trace the source of future incursions, monitor the success of eradication programs and to test for the introductions of new strains or species in the future.

Management / Research recommendations

We recommend:

- Tilapia from catchments adjoining the Murray-Darling Basin are genetically characterised, so this information can be used to pinpoint the source of possible future incursions.
- Tilapia from Queensland catchments are assayed to provide genetic reference data for monitoring introductions, translocations and eradications across the entire state.

Knowledge gaps

It is not known if:

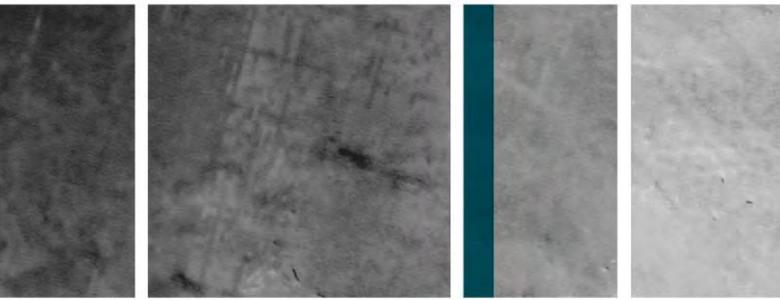
- the four strains in Queensland can be identified morphologically
- fish from the three populations that have been shown to lack genetic diversity have lower fitness
- hybridization between strains leads to higher fitness
- other habitats in Queensland support tilapia of other strains or species.

Acknowledgments

We thank the Invasive Animals Cooperative Research Centre for convening the workshop and publishing these proceedings. We also thank the Murray-Darling Basin Authority for supporting the genetic studies.

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Questions

Q: Do you have any information from Western Australia?

Jenny: No samples from WA

Q: Should we care that we have got more strains being introduced given that the first strain of tilapia introduced was so plastic?

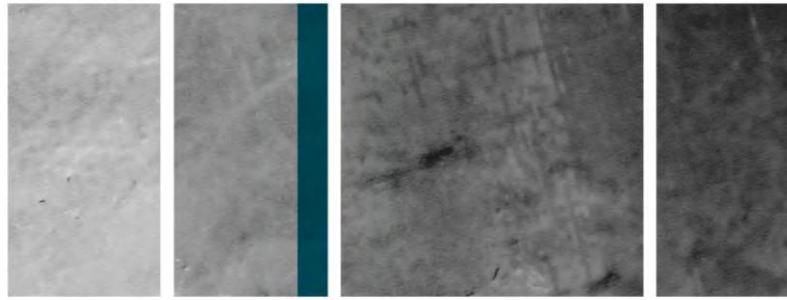
Jenny: I would suggest that we do need to be concerned because introductions from foreign sources are ongoing and they might actually include other species as well and we really do not want that. For example, some of the other tilapias are slightly more cold tolerant which might make them more adaptable to more southern areas

Q: is there any evidence that the more diverse populations are more plastic than the clonal ones or is there any evidence that the more diverse populations are more invasive?

Jenny: That would make a very good research topic. Only just discovered this last week. Looked at the data very closely and all of the fish that we examined from one site had identical genotypes I do not know of any other situation in the wild where you have introduced fish that are genetically identical.

Q: If the populations are not genetically diverse does that present opportunity for genetic manipulation and control measures?

Jenny: Possibly, I need to think about that further. What we have is a mixture of genetically clonal populations and a contrast in that all the other populations have a high degree of diversity so to compare phenotypic plasticity between these populations might give you some ideas for control



Tilapia in Queensland: where are they and where do they threaten?

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Objectives / background

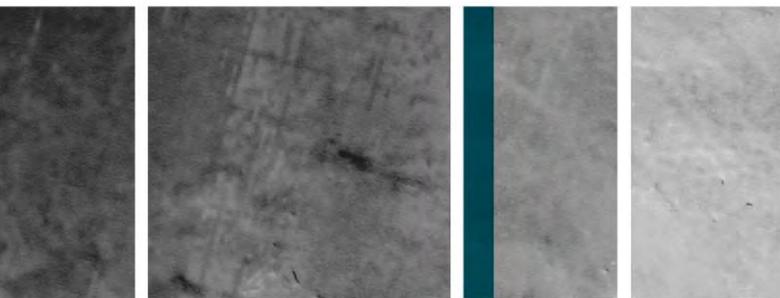
Oreochromis mossambicus have become established in 17 of Queensland's 76 catchments, and recently the public have reported tilapia in 2 additional catchments. Tilapia have not yet been found within the Murray-Darling Basin (MDB), however the MDB is considered at high risk of infestation via human assisted translocation of these cichlids.

Review of the literature shows that tilapia have the temperature tolerance to survive over winter and reproduce in the warmer months in the MDB. Their rate of spread in other parts of Australia and internationally suggests that a single incursion has the potential to invade the entire basin. Due to the establishment of this species in southern Queensland, the possibility of invasion in the MDB is high. Once any pest fish becomes established in an open waterway they are almost impossible to eradicate. Urgent measures are needed to prevent this occurrence, such as an increase in community capacity to identify and report tilapia.

Most new pest fish incursions are the result of people translocating them between waterways, or stocking private dams. People move and stock pest fish for a variety of reasons, some of which are not well understood. However, of particular concern with tilapia is their value as an eating fish overseas and their attraction as a convenient live bait.

The MDBA funded a collaborative, multifaceted project to develop strategies to help stop tilapia becoming established in the MDB. One component of the project was aimed at increasing the capacity of communities in and around the Basin to help achieve this goal. A variety of communication products were developed, driven by the outcomes of social research and people's attitudes towards pest fish and specifically tilapia in the region. This material was delivered to vulnerable areas in Qld and NSW via a communications campaign. A train the trainer package and pest fish field guide was also developed and delivered via workshops within these communities to key stakeholders.

[Abstract only provided]



Understanding tilapia dispersal, diurnal movements, and habitat usage in northern Australia

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Objectives / Background

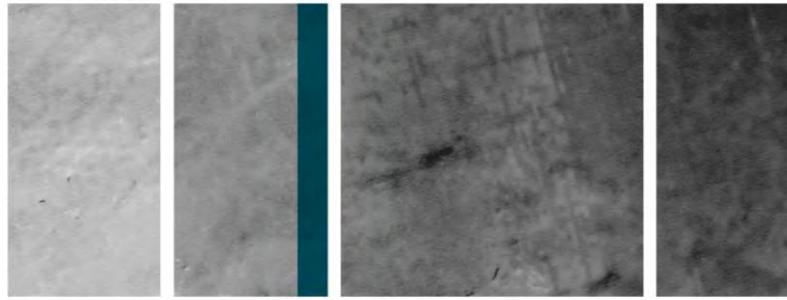
Mozambique tilapia (*Oreochromis mossambicus*) is a deep-bodied cichlid native to the south-east coast of Africa. The species has a plastic life history and is capable of surviving in a wide range of different habitat types and environmental conditions (Russell et al. 2012a). Where conditions are sub-optimal, the species is able to defer growth in favour of early maturation with individuals in Australia as small as 7 cm found to be reproductively active (Russell et al. 2012b). This trait coupled with high levels of parental care, destructive nest building activities and their overall aggressive nature has earned Mozambique tilapia a place on the world's top 100 most invasive species list (IUCN Global Invasive Species Database, 2006). Currently we are using acoustic telemetry to characterise intra-water body movements and habitat usage of a population in a small weir in northern Australia. The results of this study will increase our understanding of the diurnal movements, dispersal and habitat usage of *O. mossambicus* in tropical Australian impoundments and will assist in the design of more effective management and control programs.

Summary of findings

To assess the suitability of *O. mossambicus* for tracking studies, a three month tank trial experiment was conducted at the Northern Fisheries Centre, Cairns. This experiment involved determining the appropriate tag type to use in a subsequent field tracking experiment. The retention rates of three different types of 7 mm diameter replica transmitters (externally attached, internally implanted, and internally implanted with an external whip antenna) were evaluated. All externally attached tags were shed before the completion of the experiment and 80% of fish with internally implanted tags with external antenna died during the experiment (Table 1). Fish with internally implanted tags were found to have the highest tag retention and survival rates. Following this trial, ten mature fish (five males and five females) from the source population (Herberton Weir) were surgically implanted with acoustic telemetry tags (Vemco type VP9 tags, Vemco Corporation, Halifax, Nova Scotia; www.vemco.com). These tags are similar in dimension to the replica tags initially trialled. These tags also include an internal pressure sensor to gauge fish depth. Tagged fish, once fully recovered from surgery, were released back into the weir and are currently being tracked using fixed receiver stations (Vemco type VR2W).

Table 1: Replica transmitter retention experiment results. Different letters in the same vertical column indicate a significant difference ($p < 0.05$)

Tag type	Number tagged	Percentage tags shed and/or died
Internal	5	20a*
External	5	100b
Internal with external whip	5	100b



Preliminary analyses of movement data were undertaken using kernel density estimation (KDE) techniques in conjunction with the Home Range Tools extension (Rodgers et al. 2007) of ArcGIS software (Ersi, Redlands California; www.esri.com). KDE is a statistical method that describes the probability of finding an animal in any one place. This style of analysis is typically used to define the home range of an individual animal or of a population. This style of analysis allows delineation of areas of the weir where *O. mossambicus* congregate.

Preliminary analyses showed that fish were congregating in a number of distinct areas, mostly around the perimeter of the weir rather than in the open water areas (Figure 1). Additionally, examination of depth profile data (Figure 2) show that fish may be occupying slightly deeper water during the night. Once all data collections are complete, further analyses will be undertaken to explore potential correlations with other physical and environmental variables including water temperature, rainfall and season.

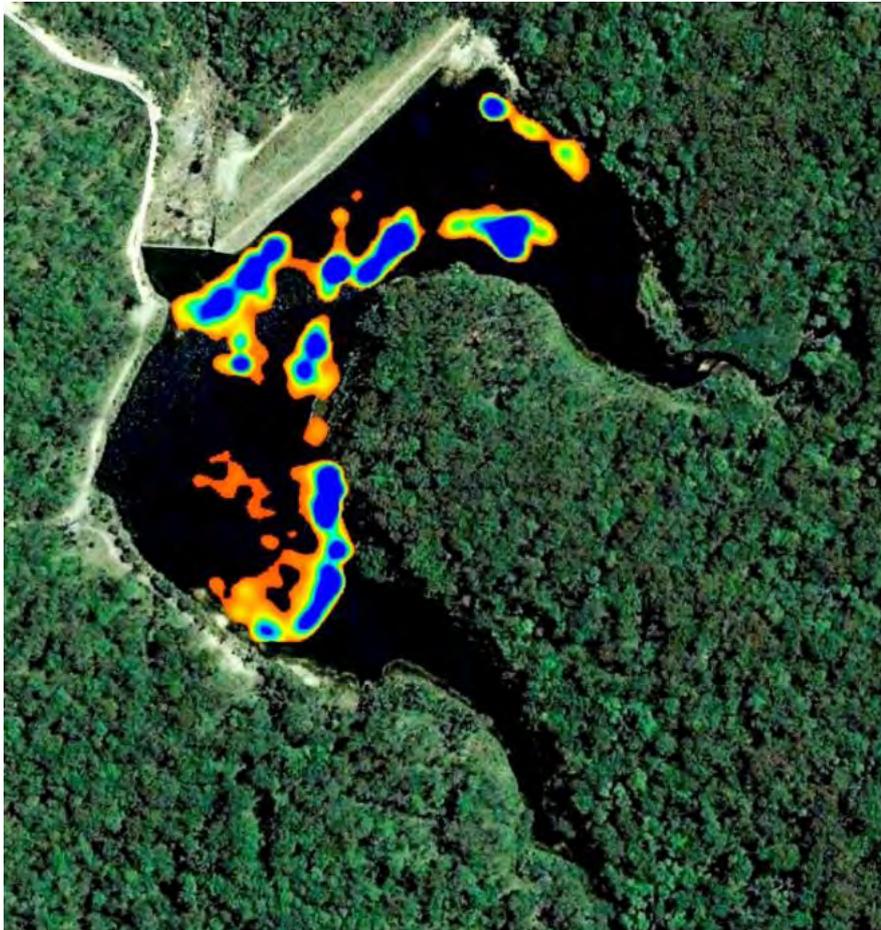


Figure 1: Example of kernel density estimation (KDE) showing the habitat usage of a single fish (T05) over a one week period during autumn 2011. Blue areas represent 95% of tag detections, green 90% and orange 50%. Smoothing was done using least squares cross validation, raster grid size 50 metres.

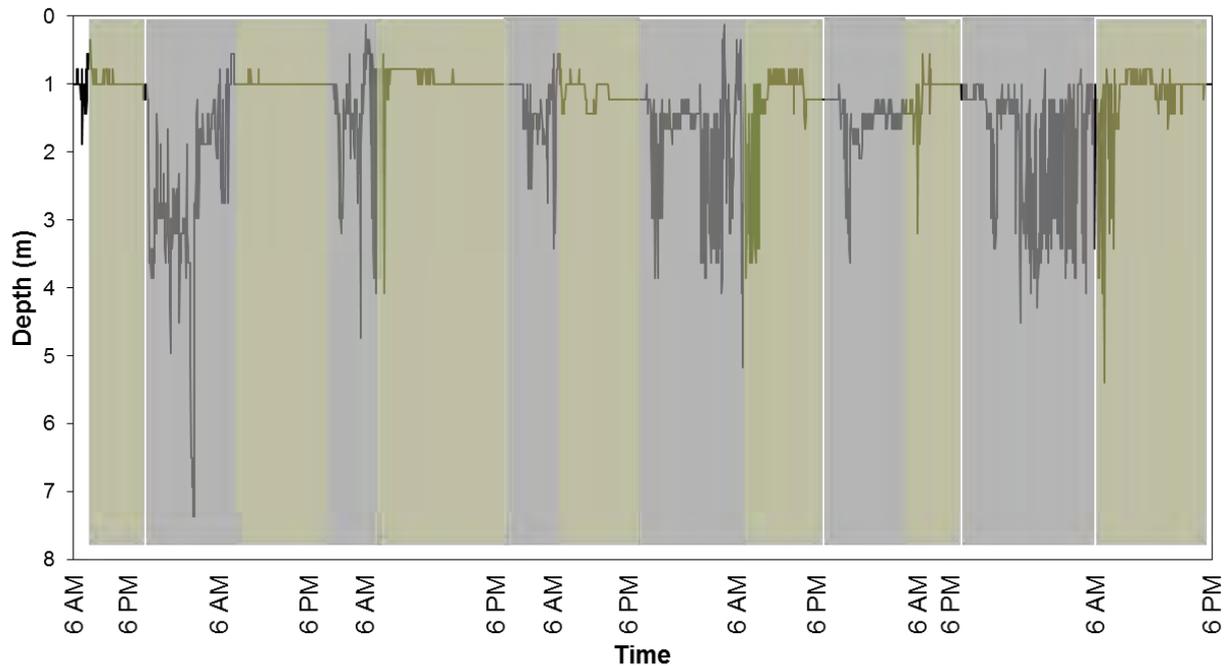
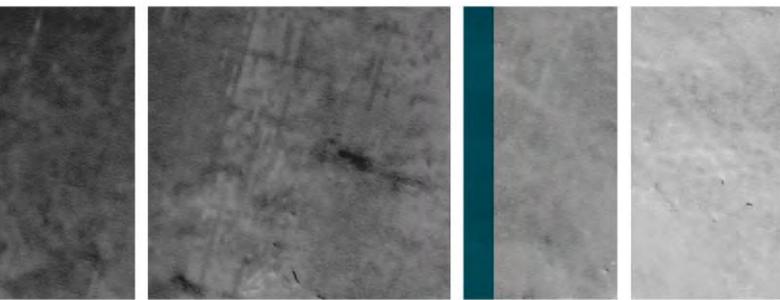


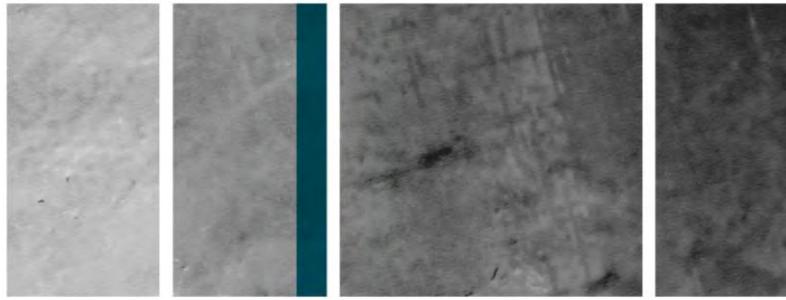
Figure 2: Diurnal depth profile showing the activity of a single fish (T05) over a seven day period during autumn 2011. Night is represented by grey background and day time by yellow. Night and day appear to be different lengths due to different numbers of detections recorded during each period.

Key messages

- *Oreochromis mossambicus* do appear to prefer specific areas of the study impoundment and this behavioural trait may be used in future control programs. Further work to define the nature, seasonality and predictability of these ‘hot spots’ needs to be undertaken to enable these strategies to be developed.
- Future management programs for *O. mossambicus* can be greatly enhanced through a better understanding of behavioural traits such as diurnal activity, specific habitat utilisation and environmental parameters such as water temperature and flow.

Management / Research Recommendations

The results of this study strongly suggest that *O. mossambicus* tend to congregate in specific areas of the weir. This may be a vulnerability that can be exploited as part of future management programs and could include fine tuning existing control measures that have already proven successful in reducing the adult population (Thuesen *et al*, 2011). However, before this is done further targeted research needs to be undertaken examining the movements of this species (and others) in this impoundment in relation to other variables. For example, the relationship between the fishes physical location and variables such as substrate type, water level, water temperature, lunar cycles and rainfall events. Furthermore, given that this species has not only been introduced into impoundments but also into creeks and rivers, future tracking studies need to thoroughly document the species movements in a riverine environment as well.



Knowledge gaps

What are the movement patterns of *O. mossambicus* in a riverine environment and could this information be used to design control programs?

How do other invasive tilapia species resident in Australian waters (e.g. the black mangrove cichlid *Tilapia mariae*), utilise habitat in both open and closed water bodies?

Are there vulnerabilities in the life cycles of tilapiines, such as spawning aggregations that could be exploited in control programs?

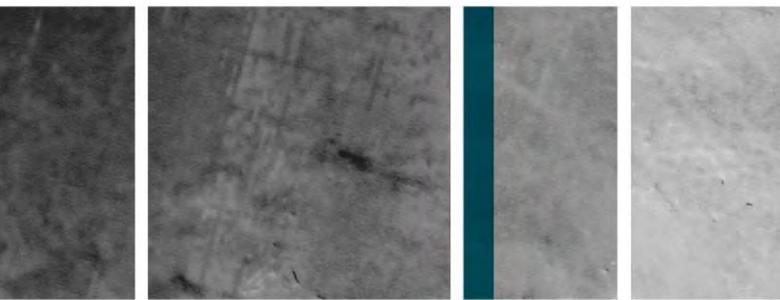
What are the dispersal rates of newly established invasive populations of tilapia?

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Recent tilapia research and monitoring in south-eastern Queensland

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Background

Three areas of research and monitoring have been carried out recently in south-eastern Queensland. Comparison of capture techniques, surveys for new incursions and identification of tilapia habitat preferences. Habitat preferences also incorporated work on water temperature but that component is reported in more depth by Hutchison et al.

Summary of findings

Comparisons of capture techniques

Four capture techniques (boat electrofishing, fyke netting, bait traps and opera house traps) were compared simultaneously in both winter and summer months at sites in south-eastern Queensland infested with tilapia. Electrofishing and fyke netting gave the best results. Bait traps and opera house traps have low capture rates. Electrofishing was more efficient by gear application effort, but fyke netting was more efficient when measured by staff effort. Electrofishing captured the largest size range of fish, but fyke netting captured more small fish. Fyke nets targeted shallower areas than electrofishing.

Surveys for new incursions of tilapia and other pest species

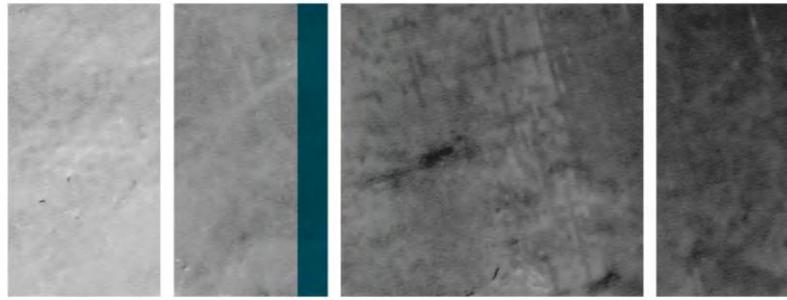
The northern Murray Darling-Basin (M-DB) is under threat from invasion by tilapia. High threat areas were identified based on the following parameters;

- Proximity to catchments with known populations of tilapia
- Proximity to large population centres or popular fishing areas, where deliberate or accidental translocation risk is likely to be increased
- Sites known to have temperatures high enough for tilapia to overwinter near these areas.

Eleven high risk sites were surveyed by electrofishing and fyke netting in winter 2010. Sites adjacent to the basin were also surveyed to determine spread of tilapia to the margins of the Basin.

Following major flooding in the northern M-DB and south-eastern Queensland in late 2010 and early 2011, surveys were expanded to include areas that could have been at risk from tilapia and other non-indigenous species through flood assisted incursion. Flooding inundated fish ponds, farm dams and even pet shops. It was also thought that the upper Burnett (coastal) and upper Nudleys Creek (M-DB) catchments may have connected during major flooding.

No tilapia were located in the Murray-Darling Basin. The only non-native species recorded (mosquitofish *Gambusia holbrooki*, carp *Cyprinus carpio* and goldfish *Carrasius auratus*) were already known from the M-DB. Tilapia were detected just 10 km away from the M-DB in the upper Burnett system.



Habitat preferences of tilapia

Habitat parameters such as water temperature, riparian condition, bottom substrate, aquatic vegetation, depth, woody debris were recorded during gear comparison surveys in Wivenhoe dam, Lake Kurwongbah and the Caboolture River. Surveys were repeated in winter and summer. Tilapia catch rates from multiple locations were correlated with habitat parameters.

Acoustic telemetry was used to monitor winter habitat use by 32 tilapia (> 300 g) in an arm of Lake Kurwongbah. The habitat type occupied by each fish was recorded on the hour for the duration of the study by overlaying fish movements on a habitat distribution map. Catch rates were significantly higher in areas with Red-leg (*Polygonum spp*), Para grass (*Urochloa mutica*), water lilies (*Nymphaea sp*) and cabomba (*Cambomba caroliniana*). Tilapia were typically more abundant in shallow waters (< 1.0 m). Conversely significantly less tilapia were found when timber and woody debris were present in the water.

In winter acoustic telemetry detected tilapia most frequently in open-waters, especially adjacent to aquatic vegetation. The majority of detections (> 85%) occurred towards the end of a dam arm away from the entrance to the main body of the dam. This area consisted primarily of open water and broken lily and cabomba in 1.5-2 m depth. Use of dense aquatic macrophyte and emergent vegetation areas was probably underestimated, as acoustic signals were lost in this habitat. Electrofishing indicated use of these habitats. Open water use was more frequent late evening to mid-morning. Afternoon and early evening had increased use of broken lily and cabomba and thick lily and cabomba habitats. Habitat use changed with progression from winter to spring as water temperatures warmed.

Recommendations

- Fyke nets could be easily deployed by community groups. If used in conjunction with electrofishing, fykes could be an effective means of detecting tilapia.
- Further surveys are recommended in the upper Nudleys Creek catchment as this is the closest known part of the M-DB to a tilapia population and major flooding is believed to have connected Nudleys Creek catchment to the catchment containing tilapia.
- There should be potential to make riverine habitat less favourable for tilapia through re-snagging and riparian zone restoration to increase shading. Shade may help keep water temperatures down and reduce growth of macrophytes and emergents.
- Habitat usage should be incorporated into removal and early detection strategies. In winter effort should focus on deep water adjacent to vegetation, or amongst broken vegetation in 1.5-2 m depth and make use of diurnal movement between deeper and shallower areas.
- In summer tilapia should be targeted in shallow areas amongst dispersed vegetation or adjacent to dense vegetation where the substrate is sandy.

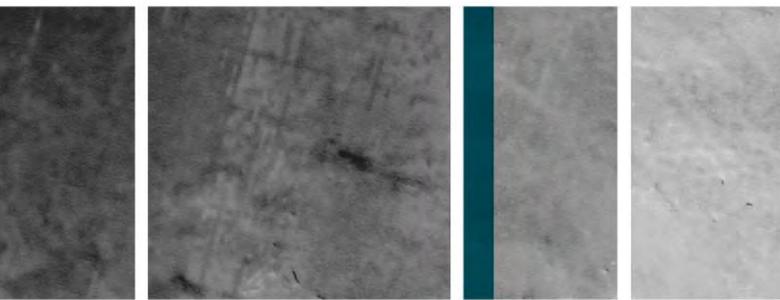
Questions

Q: Have you ever done any work on whether tilapia are attracted to light or to other organisms that are attracted to light as we have observed them aggregating at night under structures such as bridges that have light sources?

Andrew: No, we have not done any work on that.

Q: Did you use any attractants such as baits when you were trialling fyke nets and opera house traps?

Andrew: No we didn't but we have identified some potential attractants that could be added into a lure or a bait.



History of cichlids in Western Australian aquatic ecosystems

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Summary

Three species of the family Cichlidae have been reported from Western Australian waterways, including *Tilapia zillii*, *Oreochromis mossambicus* and *Geophagus brasiliensis*. While *T. zillii* was first found in 1975 and was successfully eradicated, *O. mossambicus* was first recorded in natural waterways of Western Australia in 1981, and has since spread to a further three river systems through either human-assisted dispersal or from flooding events.

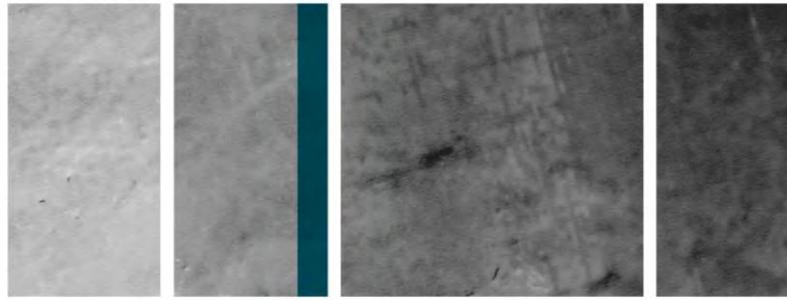
Recent research assessing the distribution and impact of the species in Western Australia suggests that *O. mossambicus* poses a serious threat to the unique aquatic fauna of Western Australian inland waters, including estuaries. The entry of other cichlids into the State's waterways, including *G. brasiliensis*, which was first discovered in 2006, has the potential to impact Western Australia's unique aquatic fauna in both inland freshwaters and estuaries.

First records of cichlids in WA

Western Australian rivers are divided into three main drainage divisions; the Southwest Coastal, the Indian Ocean (or Pilbara) and the Timor Sea (Kimberley) Drainage Divisions. The first published record of cichlids in Western Australia was in Chubb *et al.* (1979) for *Tilapia zillii* in the Swan River catchment. Allen (1989) reported both *Tilapia zillii* and *Sarotherodon mossambica* (*Oreochromis mossambicus*) from Western Australia. *Tilapia zillii* was discovered in small ponds and drains running into the Swan River estuary, in the Perth metropolitan area (Bayswater) in 1975, which lies within the Southwest Coastal Drainage Division (Chubb *et al.* 1979). These specimens were identified by Ethelwyn Trevawas at the British Museum of Natural History (G. Allen pers. comm.). Allen (1989) reported *O. mossambicus* from the Gascoyne River and in farm dams near Geraldton in the southern Indian Ocean (or Pilbara) Drainage Division. Within the Western Australian Museum database, the Gascoyne record is dated 1981, while the record for the Geraldton farm dam population is dated 1978; specimens from each location were also identified by E. Trevawas at the British Museum of Natural History.

It is noteworthy that two of the most important earlier contributions to freshwater ichthyology in Western Australia, Allen (1982) and Coy (1979), did not mention any members of the Cichlidae in the State. Therefore, the introduction of cichlids into Western Australia is relatively recent, and since those earlier records in the late 1970s and early 1980s, a further species has been discovered (Pearl Cichlid *Geophagus brasiliensis*) in the Perth area in 2006 (Beatty *et al.* 2010).

No species of Cichlidae has ever been reported from the Kimberley (Morgan *et al.* 2011) or northern Pilbara (Morgan and Gill 2004).



Expansion of cichlids in WA

Since the early introductions of cichlids in Western Australia, a number of valuable published contributions documenting their recent spread include: Morgan et al (2004) in a review of introduced freshwater fishes in Western Australia, and that of Morgan and Gill (2004) on the fishes in inland waters of the Indian Ocean Drainage Division. These publications included the presence of *O. mossambicus* in the Chapman River near Geraldton, where the species is effectively contained to the estuary of that river by a weir. They also document the spread of *O. mossambicus* further north of the Gascoyne River into the Minilya and Lyndon Rivers. While contained to the southern Pilbara, it was the sixth most abundant species recorded by Morgan and Gill (2004), and was found in a considerable range of salinities, from 0.9 to 95 ppt, highlighting the environmental tolerance of the species. The mechanism of spread of *O. mossambicus* to the Minilya and Lyndon Rivers is not clear, but is likely to have occurred during flooding of the Gascoyne River or via human-assisted dispersal. The species has also recently (2010) been recorded in Lake MacLeod, of which the Minilya and Lyndon Rivers are the major tributaries.

The Western Australian Museum record for the Chapman River region is from a series of compensating ponds in Geraldton building yards. It is likely that they entered the Chapman River via either deliberate introduction or through a flood event (Morgan et al 2004).

New records for *G. brasiliensis* occurred during 2011 and 2012 in the Swan River catchment, including the estuary and a major tributary (Department of Fisheries unpublished data, Swan River Trust unpublished data). See Fig 1 for current distribution of cichlids in Western Australia.

Impact assessments

Morgan and Gill (2004) noted that the relative abundance of two endemic freshwater teleosts of the Pilbara Drainage Division, *Craterocephalus cuneiceps* and *Hypseleotris aurea* in the Gascoyne River, where *O. mossambicus* was often the most numerically dominant species, was considerably lower in the presence of *O. mossambicus* compared to the Murchison River which contained no feral fishes. They suggested that this reduced abundance may be a direct impact of the agonistic territorial behaviour of male *O. mossambicus* (Turner 1986) and the high degree of dietary overlap (see also Maddern et al 2007). They conceded that in light of the absence of historical abundance data for *C. cuneiceps* and *H. aurea* in the Gascoyne River prior to the introduction of *O. mossambicus* the relationship could not be confirmed.

Apart from distributional data and habitat associations in Morgan and Gill (2004) and Morgan et al (2004), the most important contribution to the impact of *O. mossambicus* in Western Australian river systems was that undertaken by Maddern et al (2007). This study documented the seasonal and ontogenetic changes in diet of ~200 individual *O. mossambicus* and sympatric species in both the Gascoyne and Chapman Rivers and thus included comparisons in fresh inland waters in the Gascoyne River and estuarine waters in the Chapman River.

Maddern et al (2007) concluded that although the diets of all species captured in the Chapman and Gascoyne rivers were significantly different, the diets of *O. mossambicus* and the native species *C. cuneiceps* and *H. aurea* were very similar, with all species consuming the same detritus. They also concluded that competition for resources and habitat would increase in these north-western Australian intermittent (desert) systems such as the Gascoyne River. This, combined with the nest-guarding aggression of the feral species, is of concern and the spread of the species north and south is probably inevitable (Maddern et al 2007).

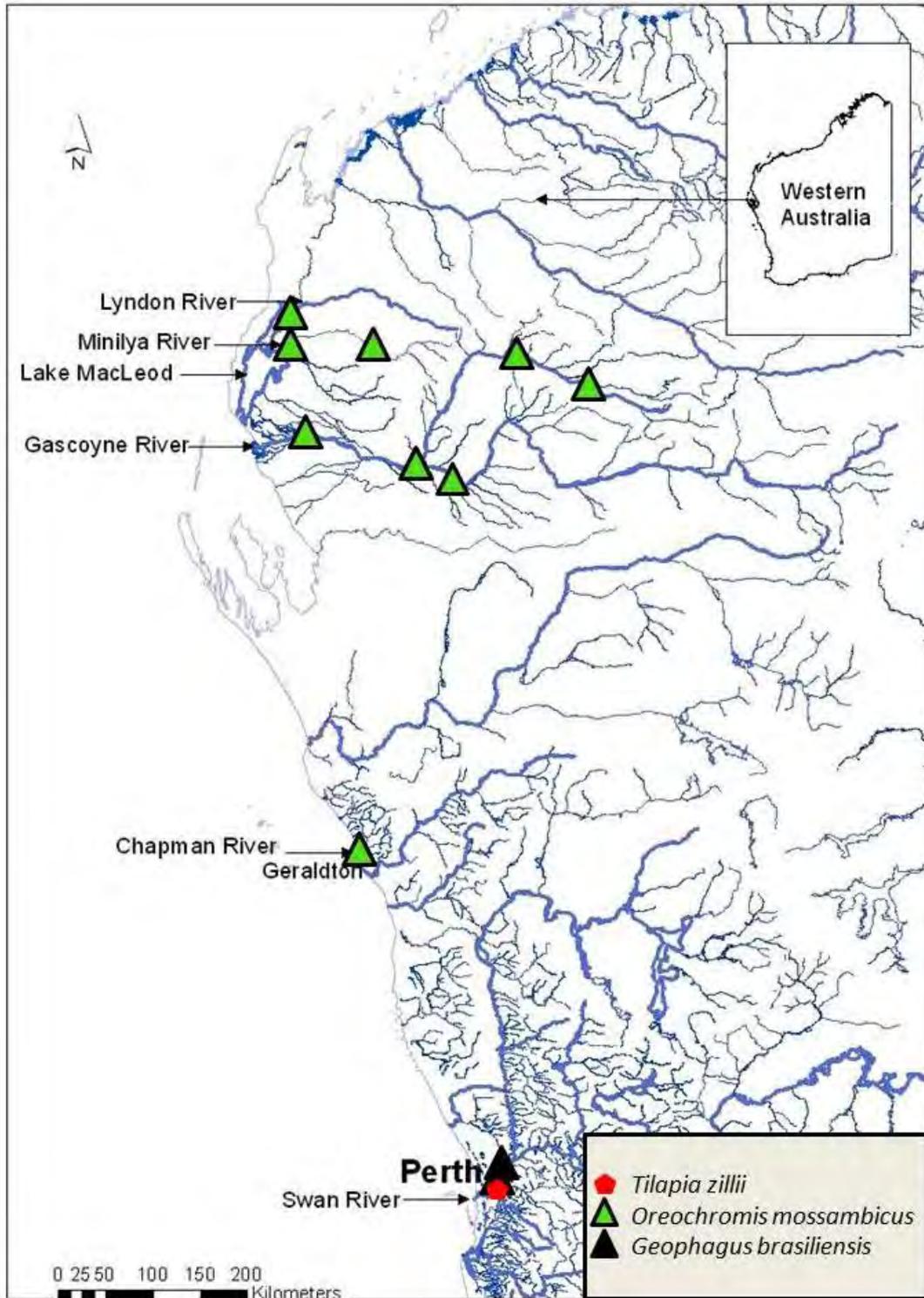
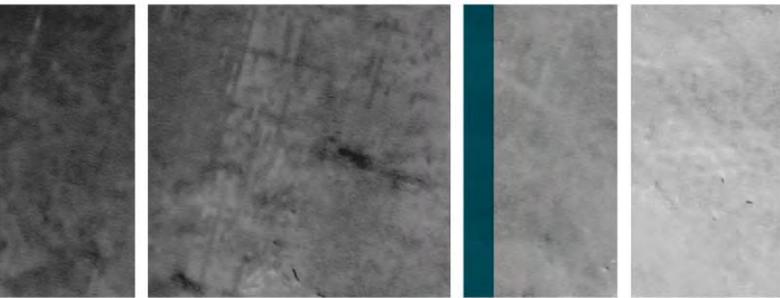
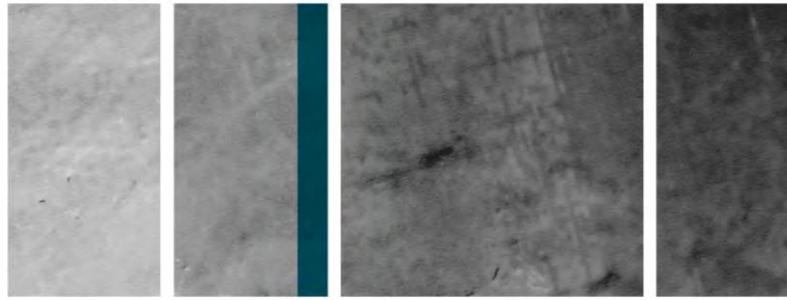


Figure 120: Current known distribution of cichlids in Western Australia



Management / Research Recommendations

Historical control measures

Importantly, attempts have been made to control the spread of all three incursions of cichlid species in Western Australia. Historical internal documents from the Department of Fisheries and Wildlife (now superseded by the Department of Fisheries and the Department of Environment and Conservation), provide a good account of the eradication of *T. zillii* from the Bayswater area near John Forrest High School (Perth) in 1975, summarised in Chubb et al (1979). A total of 133 were removed by seine netting and ultimately the deployment of rotenone by staff from the Department and the Western Australian Museum, and the report concluded that they had been eliminated. The document noted that many had also previously been removed by aquarium dealers. The document also made some valid recommendations, including for example, that *Tilapia* be banned from sale in Western Australia and that the aquarium trade be obliged to display signage provided by the Department informing members of the general public of the dangers of releasing introduced fishes.

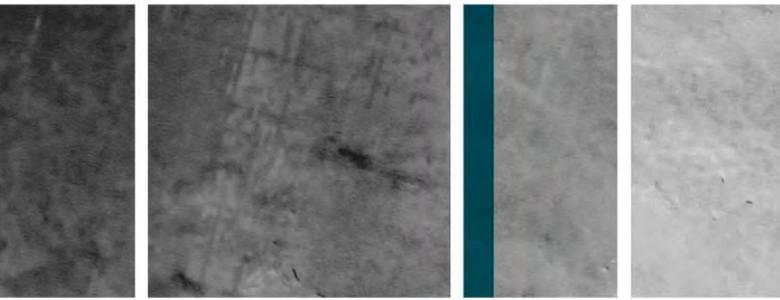
In 1978, five ponds in the Geraldton Building Company yards (near the Chapman River) were poisoned with rotenone by Department of Fisheries and Wildlife staff, which resulted in 5449 *O. mossambicus* being retrieved (Department of Fisheries and Wildlife internal document). The eradication was well documented and it was believed all were killed. It is possible that the species entered the Chapman River system prior to the rotenone event.

Since 2006, an ongoing control program for *G. brasiliensis* has been conducted by the Department of Fisheries, Murdoch University's Freshwater Fish Group & Fish Health Unit and the Swan River Trust. A Pearl Cichlid Taskforce Committee has been coordinating control attempts from 2006 to the present in Bennett Brook, a tributary of the Swan River. Unfortunately the species has now entered the Swan River estuary and a new population has been found in another tributary (Ellen Brook). Control measures continue.

With the exception of the eradication of *O. mossambicus* in the Geraldton Building Company ponds, we are not aware of any measures to control the species in the Chapman, Gascoyne, Minilya or Lyndon rivers. The impact of the species in these systems warrants further investigation. There is also likely to be many future releases of cichlids into Western Australian waters, and those already here are likely to spread, ultimately threatening the State's unique aquatic fauna. Much has changed since Allen (1982) wrote "The only good thing about introduced fishes in Western Australia is that there are very few of them".

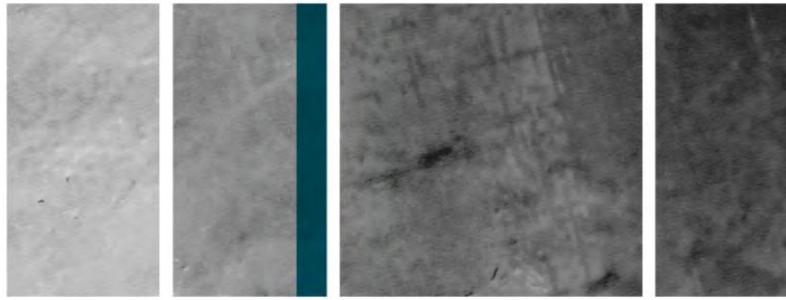
Acknowledgments

We would like to acknowledge staff at the Western Australian Museum, including Sue Morrison and the two former Curator of Fishes, Barry Hutchins and Gerry Allen for providing historical information. We would also like to thank members of the Department of Fisheries' Research Division and Murdoch University's Freshwater Fish Group & Fish Health Unit.



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eDNA surveillance for high risk invasive fish

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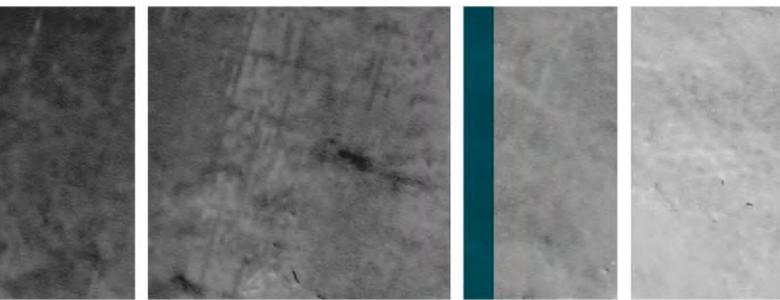
Introduction

The early ‘acclimatisation phase’ of human introduction of sport fish (such as trout, tench and redfin perch) has passed (Clements 1988) and ornamental fish now are the main source of new introductions of exotic fish to Australia. The ornamental fish industry in Australia is estimated to be worth \$350 million a year. There are around 2,000 species in the ornamental fish trade nationally, and many of the species favoured by aquarists are exotic. The volumes are huge – Australian Quarantine and Inspection Service (AQIS) data show that approximately 19 million ornamental fish were imported into Australia in 2008 alone (Biosecurity Australia 2009).

Of the estimated 12.5 million freshwater ornamental fish imported into Australia in 2003-2004 by one major importer, approximately 57% were poeciliids, 25% goldfish, 8% catfish, 8% gouramis and 2% cichlids (Biosecurity Australia 2009). Approximately 569 fish species are on the national noxious list. A further 778 species which are potentially noxious are on a gray list on a grey and require further investigation and risk assessment (NRMMC 2006). Some 130 of these are considered high risk. Australia has established populations of at least 37 alien fish species, and the number continues to grow (Lintermans 2004, Corfield et al 2008). Many of these species have been shown to, or are suspected of, having a significant impact on native biodiversity through predation, aggression, competition for resources, habitat change, spreading disease and parasites or through hybridization and gene introgression (Lintermans 2004, Corfield et al 2008).

Many fish species in the ornamental fish trade are not on the current national permitted species lists of the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* or covered by quarantine regulations. It may be that such species have been permitted under previous statutory arrangements, some have been and will continue to be smuggled in, but many are also likely to have been imported undetected as part of legitimate shipments. As prevention is better than cure, one obvious point of control is at our borders. Distinguishing fish species is a matter for experts, especially if they are juveniles. Reliable identification is difficult or impossible for those charged with border inspections, and so there is a need for a rapid and reliable method of screening imported fish. A second key area for control is early detection and intervention before a new invasive species is able to establish and spread. Once established, exotic fish can be very difficult and expensive, if not impossible to eradicate (Simberloff 2003).

Fish surveillance approaches such as nets or electrofishing have low capture probabilities and are only reliable indicators of occurrence for species present at moderate to high abundance (Magnuson et al 1994). These methods are also resource intensive meaning that widespread and effective programs cannot be supported. As a consequence, the low detection probability for rare species, such as those likely following a recent incursion event, may lead a species to be considered absent when it is actually present (Gu and Swihart 2004). The cost of a false negative for highly invasive species may be catastrophic if, as a result, eradication measures



are not implemented when eradication is possible. Reducing the risk of a false negative for rare species requires increased sampling effort or improvement of the detection technique (McDonald 2004). DNA technologies promise a rapid and reliable method for early detection of invasive species to complement traditional approaches.

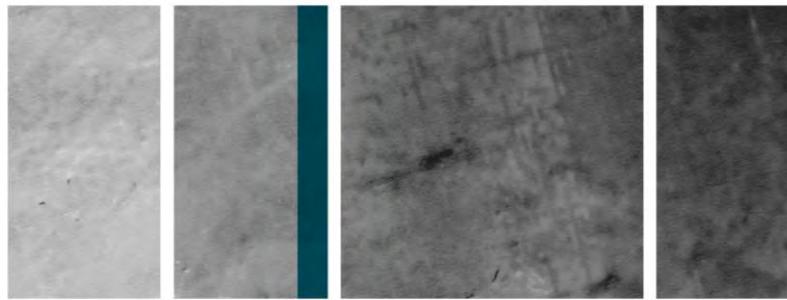
These technologies rely upon the observation that aquatic organisms, including fish, discharge cells containing DNA with faeces or urine, as skin sloughs or in mucoidal secretions. These cells and extracellular DNA become adsorbed to particles and persist and accumulate in water (Poté et al 2009, Dejean et al 2011) to the point where individualised sequences are detectable using PCR amplification of species-specific DNA markers. This approach, together with the new wave of DNA technologies (Glenn 2011), promises to provide tools for detecting illegal shipments at the time they cross our borders and for early detection of invasions in our rivers and wetlands. These technologies are being used in the detection of biota in ballast water (Deagle et al 2003), in benthic community composition in estuaries (Purdy et al 2002), estimating fish composition (Minamoto et al 2011), in early detection of fish invasions in freshwaters (Jerde et al 2011), estimation of fish biomass (Takahara et al 2012), and to determine the presence of species of interest that are rare or in low abundance (Ficetola et al 2008, Goldberg et al 2011, Jerde et al 2011, Thomsen et al 2012).

Our project, funded by the Invasive Animals Cooperative Research Centre, will develop a generalised system of detection for fish of high risk of establishment and invasion, using environmental (water-borne) DNA (eDNA). Our approach will deliver both quality diagnostic tests for species of high invasive risk and a framework for developing tests for additional species. This general approach has been used successfully to detect Asian carp in the Great Lakes of North America (Jerde et al 2011, Mahon et al 2011), will be trialled for the detection of Tilapia in Australia, and expanded to include a range of high profile invasive species. Our project includes a method for producing multiple diagnostic markers simultaneously for non-model species and potential approaches for the rapid processing of water samples. Success in this project will pave the way for broadscale eDNA surveillance of invasive fish with complementary applications in the survey of rare and endangered species.

The changing landscape of environmental genomics

The field of genomics is moving with astonishing rapidity. Tasks that were challenging or prohibitively expensive only a few years ago are becoming routine. The most commonly cited example of this progress is that of generating a full genome sequence, which cost approximately \$95 million a little over a decade ago, only to decrease in cost for comparable sequencing progressively and precipitously to around \$7,000 at last estimate (2011 data from the NHGRI Large-Scale Genome Sequencing Program presented by the National Human Genome Research Institute), and likely to drop to around \$1,000 within the next five years. A de novo sequence from an organism with little or no prior genomic information now costs only \$220,000 in sequencing and bioinformatics costs of assembly and gene annotation (as of June 2012, Guojie Zhang, BGI-Shenzhen, personal communication).

Next generation (NextGen) sequencing (Glenn 2011) has opened the door to genomic analysis of non-model organisms – those without the prior and solid foundation of genomic sequence information available for model species such as mouse, human, chicken and zebrafish. The value of NextGen sequencing in the study of human genetics and disease are unquestioned (Mardis 2008), and it promises to revolutionize agriculture (Varshney et al 2009). However, NextGen sequencing also promises to accelerate the rate of discoveries in population genetics, ecology, evolution and environmental genomics of non-model organisms, as well as presenting opportunities to answer questions that were intractable using earlier technologies.



Without trying to be comprehensive regarding the value of these technologies, specific attention is drawn to the dramatically improved capacity to identify microsatellite markers for use in population genetics of non-model organisms (Malausa et al 2011) – this is now becoming routine, where previously the availability and quantity of microsatellite markers was a serious constraint. It required a painstaking process of enrichment of sequence containing microsatellites, cloning and Sanger sequencing. There are new avenues for genome-wide identification, characterization and screening of SNP markers (single nucleotide variants that, in combination, can be diagnostic at almost any taxonomic level, in demonstrating introgression (Hohenlohe et al 2011), or establishing familial relationships). They have proven extremely valuable in studies of human genetics and disease. Even in the absence of a reference genome, by appropriate filtering and definition of allelic sequences, techniques such as Restriction site Associated DNA sequencing (RADSeq) can deliver huge numbers of SNPs for analysis (Baird et al 2008, Davey and Blaxter 2011). The information generated by several hundred diagnostic SNPs will be superior to that generated by the current standard of about a dozen microsatellites for most applications in population genetics (Seeb et al 2011). NextGen technology will soon be sufficiently inexpensive for feasible large scale screening of samples in addition to marker generation.

NextGen sequencing is clearly a transformative technology, which brings a much wider range of species, disciplinary areas, and problems within reach of genomics. It is changing the face of the field, where the physical infrastructure and technology is not the limiting factor in data generation, and greater emphasis is placed on having the necessary samples to address novel questions of substance or novel applications. Of direct interest to us is the potential of NextGen technologies in environmental genomics, where one can screen for diversity and compositional change across sites in taxa that are indicators of pollution, such as chironomids and mayflies, or screen for ‘ring-ins’ in importation of ornamental fish, for early detection of invasive species in our waterways or for detection of endangered species which may be present in very low abundances.

Approach

Target species

The large number of exotic fish species with the potential to invade Australian inland waters demands a targeted approach to marker development. Priority invasive species will be selected for marker development through consultation with federal and state biosecurity agencies – species on the surveillance alert or national noxious fish lists; those identified as having a high risk of establishment or spread through risk assessment (Bomford 2008); and species already well established, but which pose significant risks to threatened native species in catchments where the exotic species is currently absent (Table 1).

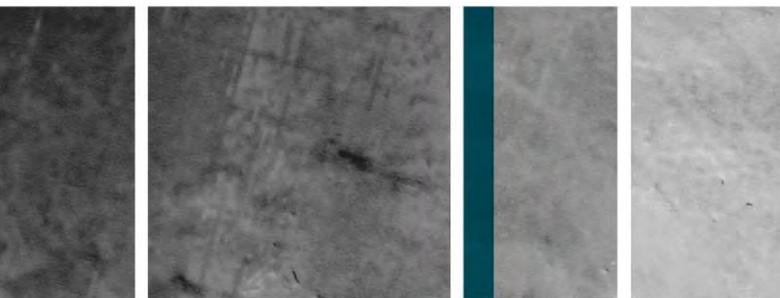


Table 1: Preliminary list of target species for which the diagnostic test will be developed for eDNA detection.

<i>Species common name</i>	<i>Scientific name</i>	<i>eDNA sample source</i>	<i>Invasion status</i>
Oriental weatherloach	<i>Misgurnus anguillicaudatus</i>	Molonglo, Murrumbidgee, Lower Cotter catchment	Established
Redfin perch	<i>Perca fluviatilis</i>	Murrumbidgee, Molonglo, Paddys	Established
Brown trout	<i>Salmo trutta</i>	Lower Cotter catchment, Queanbeyan, Goodradigbee	Established
Pearl eartheater	<i>Geophagus brasiliensis</i>	Perth (WA) including Swan River and Bennett Brook	Established
Speckled mosquitofish	<i>Phalloceros caudimaculatus</i>	Perth (WA) including Canning River, Bull Creek, Churchmans Brook	Established
Walking catfish	<i>Clarias batrachus</i>	From frozen food trade	Established in PNG
Snakehead	<i>Channa spp.</i>	From frozen food trade	Established in PNG
Climbing perch	<i>Anabas testudineus</i>	From frozen food trade	Established in PNG

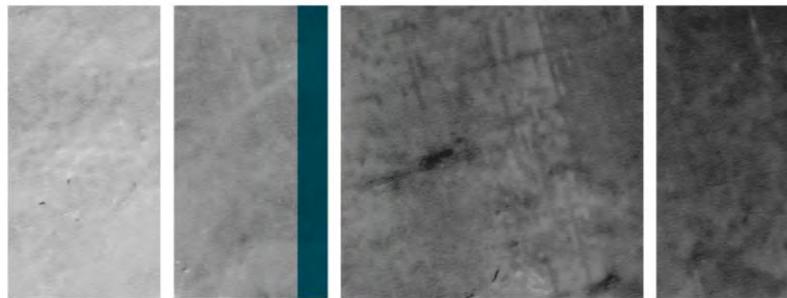
Selection of markers

Specific genes or genomic regions that are diagnostic at the level of species, such as 18S rRNA, 12S rRNA and mitochondrial DNA (Hardy et al 2011), will yield a suite of markers of considerable utility for species identification from water samples. In a second approach, drawing upon new generation sequencing technologies, we will use RADSeq tags (Baird et al 2008) to develop a series of diagnostic single nucleotide markers (SNPs) for our target species. The SNP approach will be more sensitive at the population level than will be markers obtained from 18S rRNA, 12S rRNA and mtDNA, and so may be useful in establishing provenance of source populations, and will be more amenable to automation.

Protocols for water sampling

A key ingredient in the success of this project will be the development of protocols for water sampling and DNA extraction. Using Tilapia as a trial species, water samples will be collected from replicate tanks containing low fish densities and DNA extracted using published protocols developed for eDNA extraction (Ficetola et al 2008). The fish will be removed once DNA concentrations have reached equilibrium, and DNA monitoring will continue until DNA can no longer be detected. These data will provide baseline information on the persistence of our target DNA over time in a simple aquatic system and will form the base-line for detection trials in natural waterways.

To determine the effectiveness of our markers in natural systems, we will take replicate water samples across a range of Australian sites known to contain populations of Tilapia. We will focus particularly on sites where the species is known to occur and will use site occupancy models to evaluate the covariates that lead to increased detection (Jerde and Lewis 2007, Jerde and Bossenbroek 2009). Standard environment covariates (eg flow, pH, turbidity, conductivity, temperature, habitat, substrate, depth and width) will be measured at each site. Turbidity can present a formidable challenge to eDNA detection.



Genotyping samples

Under our current proposal, a custom microarray using species-specific short sequence identified in rRNA and mtDNA genes will be generated to include all fish species of interest, not just invasive species. A custom Fluidigm Dynamic Array (Wang et al 2009) will be developed for SNPs that are collectively diagnostic at and below the species level. Fluidigm Dynamic Array Integrated Fluidic Circuits are designed for high sample throughput and low to mid-multiplex SNP genotyping (for up to 96 SNPs) which enables fast and accurate low-cost genotyping in plants and animals compared to the traditional microarray approach (Wang et al 2009).

However, options available for high-throughput genotyping of gene makers and SNPs are rapidly changing, both in availability and cost (Table 2). The sequencing technologies announced by Oxford Nanopore (Eisenstein 2012) promise to generate up to 1Gb of genomic data on the desktop with a device little larger than a thumb drive and permits real time analysis of sequences as they are generated. This, at a cost of \$900 per run, promises to meet the primary challenge faced in monitoring the passage of unwanted fish across our borders, that of real time detection by customs authorities. For larger scale screening projects, direct sequencing of samples, enriched for markers of interest, is available through the Illumina sequencing platforms, and likely soon to become sufficiently affordable to challenge existing approaches using custom microarray chips or Fluidigm dynamic arrays. The rapid development of the technologies demands a flexible and adaptive approach to generating solutions to the problems of invasive fish detection.

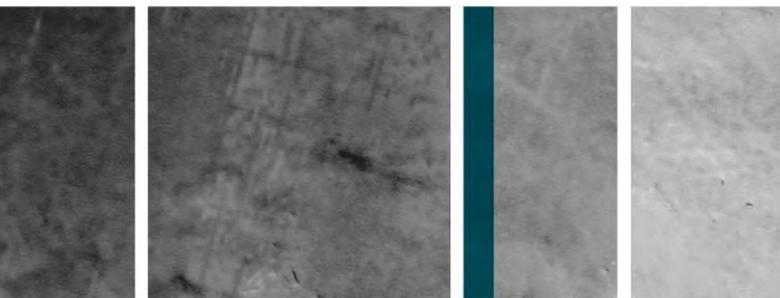
Table 2: Comparison of chemistry and detection of various currently popular SNP genotyping (Peatman 2011).

<i>Platform</i>	<i>Company</i>	<i>Chemistry</i>	<i>Detection</i>
iSelect HD Custom	Illumina	Single-base extension	Fluorescence
GoldenGate	Illumina	Allele-specific primer extension	Fluorescence
MyGeneChip Custom Array	Affymetrix	Differential hybridization	Fluorescence
MassArray	Sequenom	Single-base extension	Mass Spectrometry
SNPstream	Beckman Coulter	Single-base extension	Fluorescence
Taqman Open Array	Applied Biosystems	TaqMan-5' nuclease	Fluorescence
Dynamic Array	Fluidigm	TaqMan-5' nuclease	Fluorescence

Conclusions and future directions

Completion of this work will see the development and testing of a low cost and robust high throughput technology for the detection of specific invasive fish species. We will have estimates of the sensitivity of these approaches in relation to fish presence and abundance and therefore estimates of the detectability provided by the technology. In addition, we will have a clear methodology for producing markers for additional species of concern. Given that it is likely that there are more than 1,100 potentially invasive fish species in the Australian aquarium trade, the ability to rapidly develop diagnostic markers for new species will be of paramount importance.

By targeting the detection of minute amounts of DNA from complex eDNA samples, these technologies will provide the ability to detect multiple invasive species simultaneously from the same water samples. This in turn, will provide the ability to detect introductions of key invasive species threatening range extension earlier. These same technologies, including the

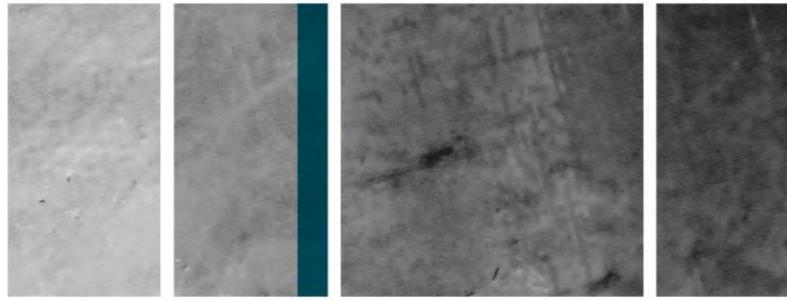


promise of technologies from Oxford Nanopore (the Minlon; Eisenstein 2012), will provide the ability to screen effectively live aquarium fish at the point of importation and before their dissemination into the wider Australian community. Interception at the border will greatly slow down the rate at which new invasive species will be added to Australian waterways with the commensurate reduction in the cost of eradication or control and in the damage done to Australian aquatic ecosystems.

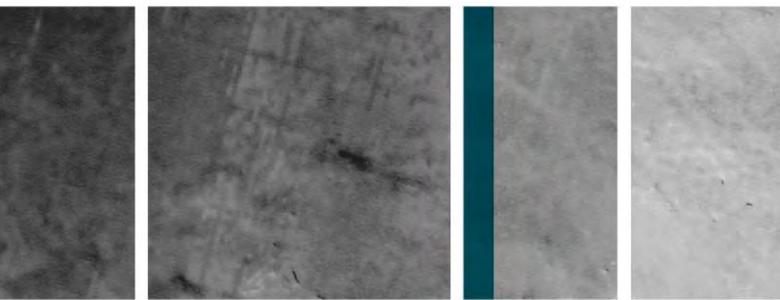
When combined with a coordinated approach to the systematic collection of water samples across states and territories, these technologies will provide the means to provide early warnings of introductions. They also enable the establishment of early management strategies such as intervention to eradicate or contain the spread, and thereby facilitate more cost effective management of nationally or regionally listed threatened species.

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Questions

Q: A lot of the threats are going to come from Northern Australia, can you tell me about the longevity of eDNA in warm water?

Tariq: Depends on how the DNA is in the water. If it is a free DNA it degrades very quickly at 18-20 degrees C. If it is deposited in the sludge then it can stay non-degraded for quite a while. It will degrade, but more slowly, so it can be used for this sort of detection. These markers are really small so you do not need a large chunk of DNA for this method.

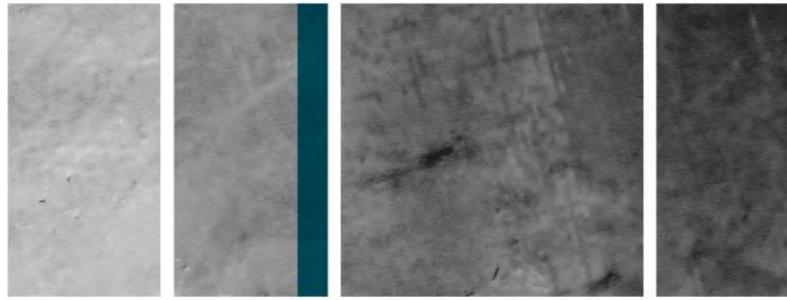
Q: At 30 degree water you wouldn't expect it to last very long at all?

Tariq: If it is free DNA it will be broken down but if it is deposited in the sludge then it will be protected to some degree for a lot longer

Q: Are waters with high levels of organics or high turbidity an issue?

Tariq: No, because when you isolate the DNA you can optimise that option

Q: At CSIRO in Hobart we do a lot of work with ballast water but we have to filter 1000's of litres to get a detection event and we are still concerned about false negatives. There is a concern about how far you can push the limits...are you going to have to filter 1000's of litres of sludge to get a detection event and do you have any feel from the literature as to what the real sensitivity is?



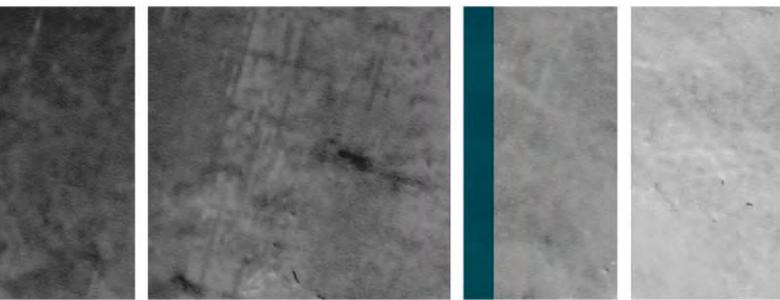
Tariq: For the ballast water technique they needed quite a bit of DNA for that. Recent papers have looked at this problem and we will use a different method where we can amplify the amount of DNA using a bacterial replication method.

Q. A question about the accuracy of your system, if some person wants to bring in a fish species?

Tariq: The technique will be very powerful because the markers that we will use are very specific

Q. Is there potential for cyptic species to come into Australia if they are not already on your target list?

Tariq: Yes there will be if they are not on the list.



Research to support management of non-native fish species

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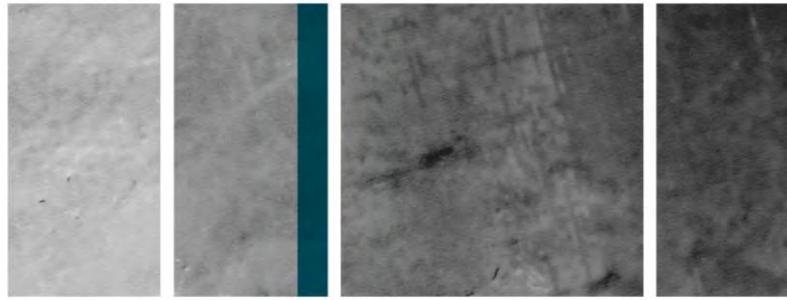
1. Predicting presence and absence of *Tilapia mariae* using environmental variables in the Wet Tropics region

The Wet Tropics World Heritage Area of Far North Queensland contains 78 (40%) of Australia's 190 freshwater fish species (Pusey and Kennard 1996). These species, however, are threatened by the presence of at least six non-native fish species, including two species of Cichlidae, namely *Tilapia mariae* Boulenger, 1899 (Spotted tilapia) (Bradford et al 2011) and *Oreochromis mossambicus* (Peters 1852) (Mozambique mouthbrooder) (Russell et al 2012), and four species of Poeciliidae, namely *Poecilia reticulata* Peters, 1859 (Guppy), *Gambusia holbrooki* (Girard, 1859) (Mosquitofish), *Xiphophorus helleri* Heckel, 1848 (Swordtail), and *X. maculatus* (Günther, 1866) (Platy) (Allen et al 2003; Webb 2007). In addition to these introduced species, more than 13 non-native fish species have also been recorded from adjacent areas (Webb 2007). Eradication of non-native populations has rarely been achieved within the Wet Tropics region and control options vary in their effectiveness (but see Thuesen et al 2011) and control options vary in their effectiveness. Understanding the distribution and abundance of non-native fish species in the Wet Tropics landscapes may enable the prediction of those landscape features that may drive invasion.

In this study, we examined whether environmental variables could be used to predict the presence and abundance of non-native fish at the stream, catchment and regional scale in the Wet Tropics region (Kroon et al 2011). First, we conducted a proof-of-concept using existing fish and environmental data from previous projects at the stream scale. To determine whether non-native fish abundance varied with environmental variables at the stream scale, we used correlation analysis to relate Spotted tilapia (*Tilapia mariae*) relative abundance (Freshwater Creek) or guppy abundance (*Poecilia reticulata*) (Mossman River) with water quality, habitat, and catchment (guppy only) variables. Relative abundance of *T. mariae* increased significantly with maximum pool width, average pool width, and snags in pools. Relative abundance of *P. reticulata* decreased significantly with root masses, and proportion of grazing land use in the area upstream of the sampling location.

Second, we conducted a field study at a catchment scale to assess whether the correlations established at stream scale would hold up at larger scales. To determine whether non-native fish abundance varied with environmental variables at the catchment scale, we conducted backpack electrofishing surveys at 26 freshwater sites in the Mulgrave Catchment from December 2008 to March 2009. We found three non-native fish species (*T. mariae* 11 sites, *P. reticulata* 5 sites, and *Xiphophorus maculatus* 3 sites). The relative abundance of *T. mariae* was not significantly related with any of the environmental variables examined. In contrast, the relative abundances of *P. reticulata* and *X. maculatus* were significantly related with 18 and 15 out of the 64 environmental variables examined (see Kroon et al 2011 for detail).

Results from non-metric multidimensional scaling indicate that species abundance assemblages from sites with non-native species were consistently more similar to each other than to those from sites without non-native species, and vice versa. In particular, native (*Tandanus tandanus*, *Hephaestus fuliginosus*, *Glossamia aprion*) and endemic (*Glossogobius bellendenensis*, *Cairnsichthys rhombosomoides*) fish species were more abundant at sites without non-native species.



Finally, we aimed to examine whether we could identify potential hot-spots for non-native fish at the catchment and regional scale, using predictor environmental variables identified at stream and catchment scale. To document locations of non-native fish, we

- i. extracted presence records from the Fish Atlas of Northern Australia and,
- ii. obtained presence and absence records from seventeen local and regional fish experts during a one-day workshop.

A total of 1,106 records were identified comprising 347 presence and three uncertain records for a total of seven species, and 756 absence records, and submitted to the relevant Queensland Government agency through the North Qld Pest Fish Advisory Group for inclusion in State-wide pest fish maps (Kroon et al in review). These records were intersected with nine spatial layers containing environmental information, and locations where combined environmental variables are suitable (presence) or non-suitable (absence) for non-native fish were identified in the Wet Tropics region (see Kroon et al 2011 for detail).

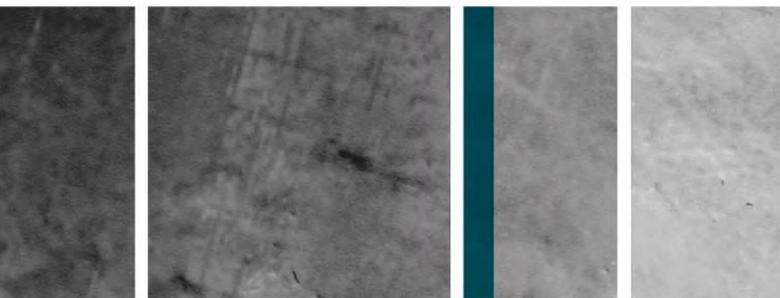
Combined, this information will contribute to improved management of the fish fauna of the Wet Tropics region, including minimisation and reduction of spread of non-native fish species.

2. Detection and analysis of sound production

Bio-acoustic monitoring is often used in ecology as a passive and non-invasive method to quantify the presence and abundance of a species of interest. For example, bio-acoustics has been used to monitor whales (Mellinger 2004; Baumgartner and Mussoline 2011), birds (Brandes 2008), bats (Parsons and Jones 2000), toads (Hu et al 2009), and frogs (Taylor et al 1996). Machine learning and artificial intelligence techniques have been successfully used for sound detection and classification based on the narrowband sound emitted by these species. Few recent studies have characterised the broadband sound features of fish species in the marine (Boyle and Tricas 2010) and freshwater (Longrie et al 2009; Maruska et al 2012) environments.

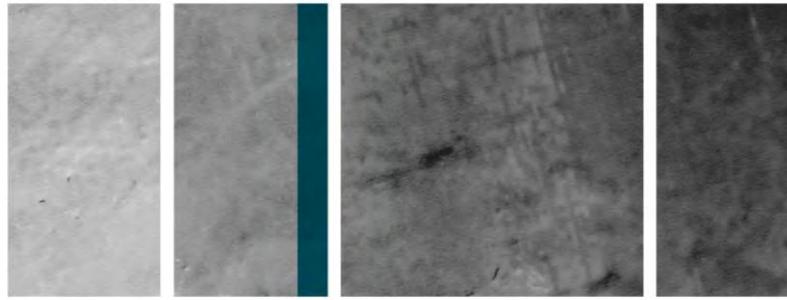
This study is the first to record broadband sound emitted by female *T. mariae* (Kottege et al in review). The click sound was approximately 10 ms in duration with most of the spectral energy in the 3-8 kHz region with higher harmonics. Females of 17 cichlid species have been found to produce sounds, but not in *T. mariae* (Lobel 1998; Longrie et al 2013). We confirmed the sex of the fish emitting the sound by synchronised audio/video and autopsy.

To explore the potential of automated detection of *T. mariae* invasion fronts in the field using a large-scale wireless sensor network, we developed a small set of spectral and temporal features to aid in the automatic detection and classification of this sound (Kottege et al in review). The detection and segmentation algorithm found a total of 821 sounds in our recordings which included all of the total 48 click sounds by the female *T. mariae*. Moreover, results show a high degree of classification accuracy after evaluating the detection method for *T. mariae* sounds and comparing its performance against other methods. These results demonstrate that our developed algorithms are well-suited for classification on embedded devices, which can be deployed to implement a large scale wireless sensor network for automated species detection.



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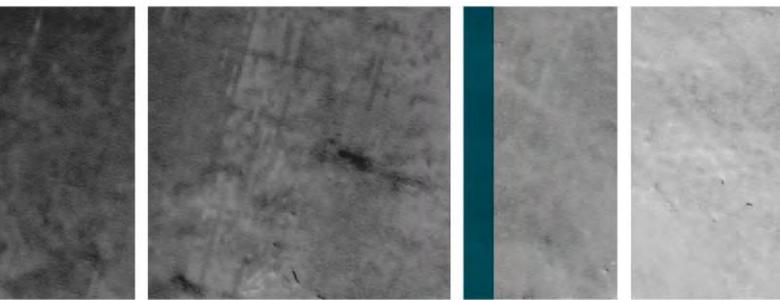
Questions

Q: Did you actually play the sound back to the fish in the tank to see what their reaction was?

Frederieke: No not yet. After recording, it took quite a while to isolate the sound and link it with the video. In the meantime the fish have bred so we need to wait till the fish are ready to breed again.

Q: Have you tested more than one individual and can you actually identify the number of fish or are there are different individuals making the noises?

Frederieke: No, we only worked with the one pair at this stage.



Towards a national emergency response system for freshwater fish incursions in Australia

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Objectives / Background

Freshwater fish incursions are a significant issue in Australia and a major biosecurity risk to freshwater ecosystems. The introduction of freshwater fish to areas outside their natural range can result in numerous environmental, social and economic impacts. Currently 44 alien freshwater fish species have been recorded in Australian freshwaters, with a further 76 native freshwater fish found outside their natural range.

Preventing alien freshwater fish incursions into the natural environment, through quarantine, legislation and education, is the most cost effective management approach. Once an incursion has occurred, appropriate national emergency response arrangements are required to facilitate coordinated, cooperative and timely response actions to provide the best opportunity for containment and eradication.

Effective response to freshwater fish incursions in Australia has been inhibited by a lack of national emergency response arrangements. This project aimed to progress the development of such arrangements. The Steering Committee incorporated members from all state and territory jurisdictions responsible for invasive species management. Extensive consultation was also undertaken with national sectoral committee members and those involved within other sectors where comprehensive biosecurity arrangements are in place.

Summary of findings

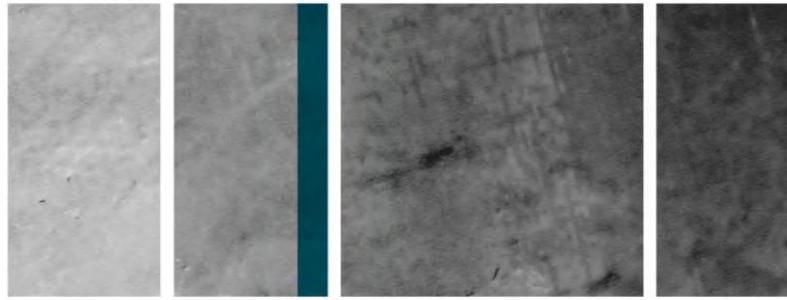
Learning from the experiences of other biosecurity sectors

This project identified the clear need for freshwater fish incursion management to learn from the experiences of those within other sectors where comprehensive biosecurity arrangements are in place (i.e. AUSVETPLAN, AQUAVETPLAN, PLANTPLAN, National System for the Prevention and Management of Marine Pest Incursions). Emergency management includes a range of measures to manage risks to the environment, economy and society. A general framework commonly applied when managing pest and disease incursions in Australia incorporates governance and infrastructure, measures for prevention, emergency preparedness and response, ongoing management and control and supporting arrangements. Developing national arrangements for alien freshwater fish incursions in accordance with such a framework will facilitate coordinated, cooperative and efficient management of this risk.

Linking to relevant national processes

During the course of this project, a National Environmental Biosecurity Response Agreement (NEBRA) was in the process of development, as a component of the Intergovernmental Agreement on Biosecurity (IGAB). This intergovernmental agreement will provide national arrangements for response to nationally significant biosecurity incidents where there are predominately public benefits and will apply to freshwater fish incursions. The development of emergency response resources for freshwater fish incursions will need to be consistent with the conditions stipulated in this agreement.

The project also recognised the importance of linking with another national project relating to biosecurity arrangements - 'Harmonising Australia's Biosecurity Emergency Response



Arrangements'. The National Biosecurity Committee formed the Biosecurity Emergency Preparedness Working Group (BEPWG) which is implementing an action plan to reduce duplication, increase alignment with the broader emergency management community, and align with existing nationally recognised standards.

Review findings

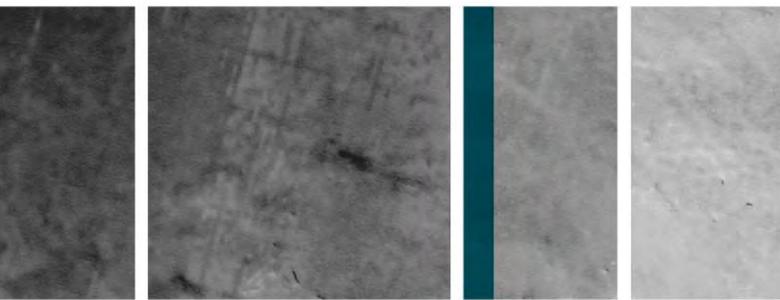
This project undertook a review of:

- international and national approaches to new alien freshwater fish incursions
- surveillance, eradication and control programs in Australia, and
- short-term barrier and containment methods.

The review of international and national approaches to new alien freshwater fish incursions highlighted the importance of understanding the issues, challenges and approaches to alien fish management. This enables learning from incursion experiences in countries which have advanced approaches, such as New Zealand and the USA, as well as understanding the potential risks of entry of alien species from other countries. Australian agencies should actively participate in key international forums such as the International Conference on Aquatic Invasive Species and international agency exchange programs to build relationships and learn about the latest scientific knowledge, research, technological developments, education and outreach programs, as well as legislative, policy and management approaches to aquatic invasive species.

The review of surveillance, eradication and control programs in Australia found that historically, response activities to alien freshwater fish incursions across Australia have been generally ad hoc, inconsistent and uncoordinated. Management of such incursions among jurisdictions in Australia is variable. Jurisdictions largely rely on passive surveillance to detect new incursions - a process hindered by limited community awareness of alien fish issues, as well as poor understanding of the vectors and pathways of introduction. Very few active surveillance programs exist and the majority of new incursions are detected through general fish survey and monitoring programs. The varying roles and responsibilities of agencies and staff are sometimes not clearly defined or embraced. In some jurisdictions, fisheries staff lack basic emergency response training and there are limited resources and staff with skills to manage incursions. Legislation and terminology relating to alien freshwater fish management is inconsistent across the country, although the process of incorporation of the National Noxious Fish Species List into fisheries regulations is an important step in addressing this inconsistency. There is no national community education program targeting alien fish species. Most jurisdictions have specific online information regarding particular pest fish issues, such as prevention of dumping of ornamental fish. There is no national reporting system for alien fish incursions. Most jurisdictions have specific arrangements such as phone hotline services. There is no universal national risk assessment procedure for determining whether to respond to an alien freshwater fish incursion and priority of response.

Previous management approaches for eradication and control of alien freshwater fish in Australia include physical removal, chemical methods, habitat manipulations and biological control. Well known and widespread species and those of greatest concern have received the greatest attention. There are limited examples of successful eradication and the majority of eradication exercises have involved application of rotenone. Control programs have included a combination of electrofishing, netting, screening and water manipulation. Documentation of the purpose, procedures and results of eradication and control programs is improving. Incorporation of monitoring within such programs is an essential component.



The review of short-term barrier and containment methods indicated that research, development and application of fish barriers have largely occurred in the USA, UK, Europe and New Zealand, with limited application in Australia. Fish barriers can be categorised as physical or behavioural. Effective physical barriers provide complete exclusion of fish, whereas behavioural barriers involve the application of an external stimulus to evoke a fish response. Fish barriers vary in design and thus also effectiveness, cost, construction and installation difficulty, operational and maintenance requirements, flow applicability and requirements, power supply needs and safety. Fish barriers to contain new fish incursions must be easy and quick to deploy and are often temporary.

Management Recommendations

The final report provided direction on how to advance the development of national emergency response arrangements. A suite of recommendations were identified; some recommendations are entirely new, while others link to existing processes that may require revision or expansion. The recommendations which were identified encompass the importance of learning from, and aligning with, existing processes within other biosecurity sectors. Recommendations also addressed gaps identified within the review regarding surveillance, eradication and control programs, and short-term barrier and containment methods.

Recommendations were grouped broadly within the following themes:

- raising national awareness and process initiation
- emergency response arrangements
- supporting arrangements.

Raising national awareness and process initiation

A key first step requires raising national awareness through national biosecurity forums to the relevant Ministerial Councils and ensuring a national sectoral committee is responsible for developing national emergency response arrangements.

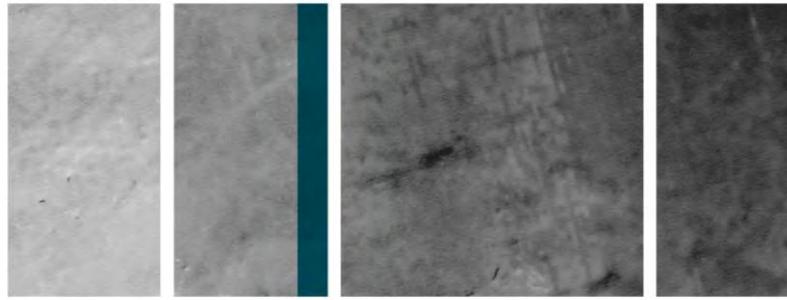
Emergency response arrangements

These recommendations incorporate a variety of documents, programs and resources which are required specifically for freshwater fish incursions. These include creating risk assessment procedures and priority lists and species specific management/response plans. National operational manuals including for animal destruction, disposal and decontamination, and technical manuals for rotenone and electrofishing are also needed.

Supporting arrangements

These encompassed management support products such as decision support tools, a national freshwater fish incursion register and a national control program database. Many communication resources and training tools are also required including a taxonomic experts register, educational products and national training programs for freshwater fish incursion response.

Targeted research and development programs are required to address gaps identified within the review. These include physical and behavioural barriers, chemical treatment, pathway analysis, social analysis, detection capacity of survey techniques, molecular probes for species detection. A greater understanding of the biology, ecology and impact of alien freshwater fish would also assist more effective management.



Progress in National Freshwater Fish Biosecurity Arrangements

Since the completion of the project in 2010, there has been some progress in the management of national freshwater fish biosecurity risks. NEBRA now provides national arrangements for response to nationally significant biosecurity incidents where there are predominately public benefits. The BEPWG process is continuing to develop resources to reduce duplication across biosecurity sectors, increase alignment with the broader emergency management community, and align with existing nationally recognised standards. There have been changes to national committees, including the disbanding of the Environmental Biosecurity Committee.

A National Strategy for Management of Freshwater Pest Fish is currently being prepared by the Vertebrate Pest Committee - Freshwater Fish Working Group (VPC FFWG), and this project has contributed to its development. The Murray Darling Basin Authority has prepared an advanced draft of an Alien Fish Plan for the Murray Darling Basin. The Ornamental Fish Management Implementation Group (OFMIG) was established in 2007 to implement the national strategy for the management of the aquarium trade. In 2011, OFMIG merged with the VPC FFWG. It continues to review ornamental fish species for inclusion on the National Noxious Species List. The Invasive Animal Cooperative Research Centre has also funded the development of a decision-support tool for the management of freshwater fish incursions.

Acknowledgments

We thank members of the project team, the steering committee and other biosecurity sectoral committee members for their guidance and contribution towards advancing this project.

Further Reading

Ayres R and Clunie P (2010). Management of freshwater fish incursions: a review. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra, Australia.

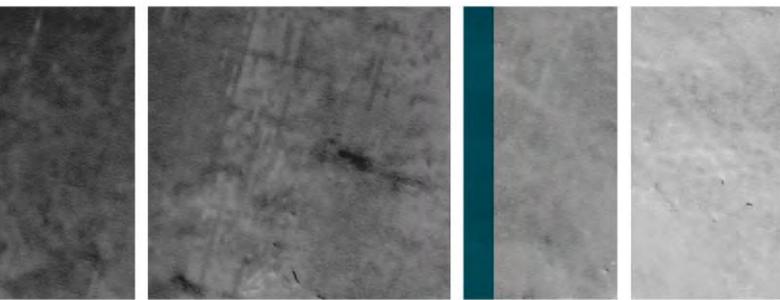
Ayres R and Clunie P (2010). Towards a national emergency response system for freshwater fish incursions. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra, Australia.

Questions

Comment: When the Marine Pest rapid response plan was developed the biggest single stumbling block was getting the funding arrangements between the states and the commonwealth in place. The fact that there is now a generic funding process in place will facilitate this process greatly

Q: You have written a report and made recommendations, has the report been distributed to all the jurisdictions that need to get it?

Pam: There is a lot of overlap between our steering group and the key people that need to get the report. The people that are developing a national strategy for pest fish are also aware of the work.



Decision support tool for the management of freshwater fish incursions in Australia

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Background

There are no national emergency response arrangements for freshwater fish incursions in Australia. Individual states and territories vary widely in their current response arrangements to freshwater fish incursions, with many being dealt with on an ad-hoc basis and with varying degrees of efficacy. Actions to advance developing a national emergency response system for freshwater fish incursions in Australia were recommended in a recent review conducted by Ayres and Clunie (2010), including creating a web-based decision support tool (DST) to provide direction and assistance in managing freshwater fish incursions.

The development of the DST involved consultation with end-users from all Australian states and territories responsible for managing new freshwater fish incursions (eg natural resource managers and government agencies) as well as a Technical Pest Fish Advisory Group comprising field-based staff with expertise on capturing a wide range of fish species from a variety of habitats. Such consultation ensured that the DST's development included input from all jurisdictions and perspectives, and catered for the needs of end-users.

Aims

The aims of the DST for managing freshwater fish incursions in Australia were to:

- Maximize the speed and quality of reporting and response which are critical in the early stages of an incursion.
- Provide a logical and structured decision making process.
- Provide comprehensive planning documentation.
- Provide advice on the most appropriate management option considering circumstances of the incursion.
- Facilitate communication and consistency of approaches between agencies.

Users

The tool is targeted at scientific researchers and natural resource managers conducting surveys or monitoring programs, or those with background in ecological management.

Framework

The DST follows a question/answer format and the user is led through a series of questions relating to the species sighting, details of the fish and its capture, and site information. These questions address issues that managers consider when deciding on appropriate eradication or control techniques to apply (Figure 1). Two sections of the DST (fish details and site details) directly influence the decision making process and ultimately, the suggested eradication or control method to manage a freshwater fish incursion at a particular location.

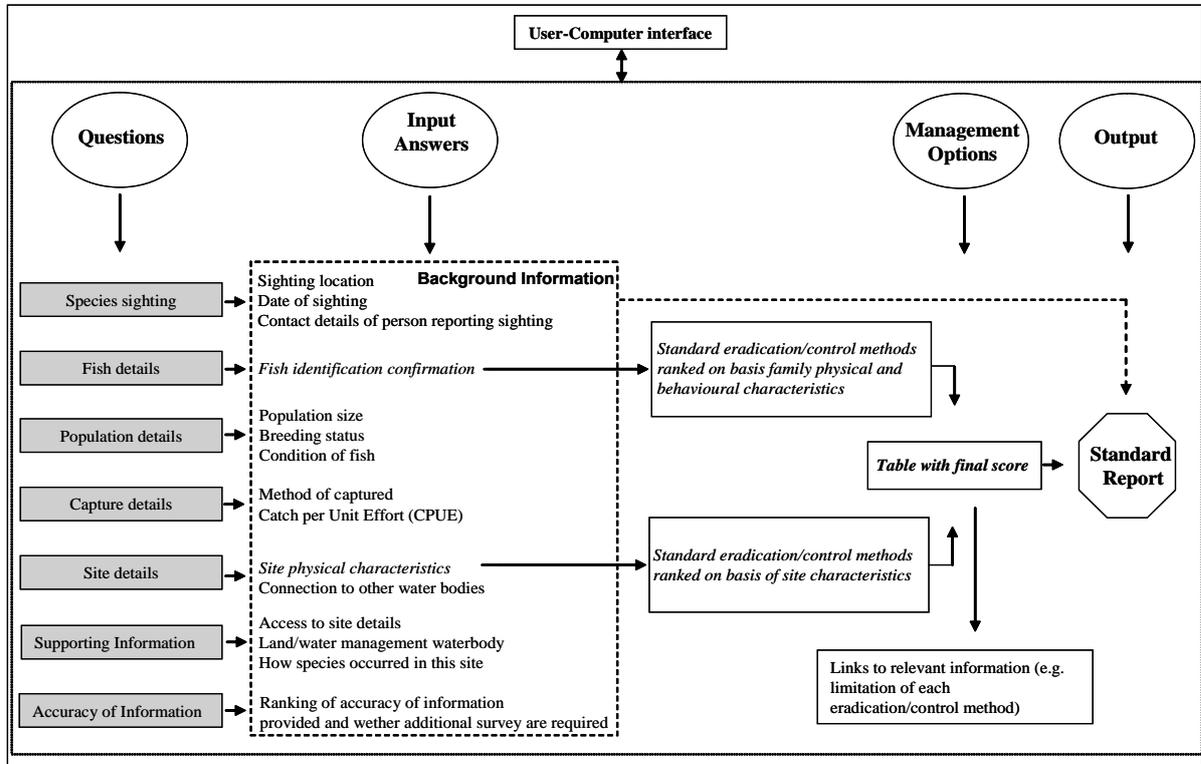
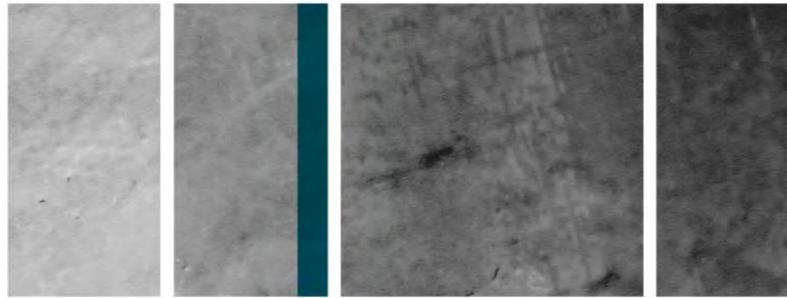


Figure 121: Framework of decision support tool for the management of freshwater fish incursions in Australia.

Final Product

A standard online summary report and management options report is produced once all sections have been answered by the user. The summary report with the management options is then submitted to and assessed by the relevant state government authority responsible for the management of freshwater fish incursion. Managers are then able to consider their options, taking into consideration current permits, resources and capability.

Future work

Stage two of the DST:

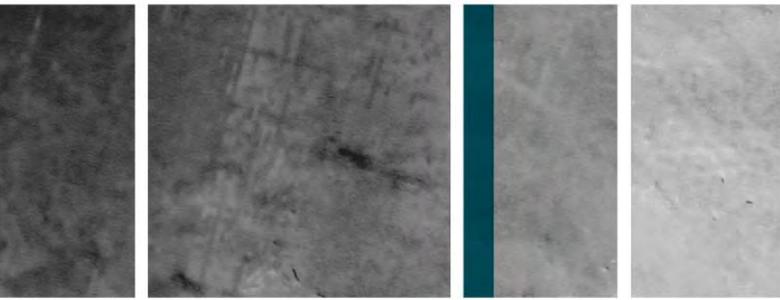
There is a need to continue to engage with key jurisdictional representatives to determine how this tool can best meet the needs of these managers and how it can be compliant existing processes efficiently.

Stage two includes:

- Compilation of feedback from practitioners and refinement of the tool to include specific state and territory requirements.

Stage three of the DST:

There is the potential for this tool to incorporate additional components in the future (subject to funding), such as:



- A national fish incursion register, providing information such as species incursion histories, incursion details for specific locations and incursion maps.
- A national control program database.

The DST could potentially also have applicability for the management of other terrestrial and aquatic invasive species.

Key messages

- The DST maximizes the speed and quality of incursion reporting and helps the responsible government agency decide on the most appropriate management action.
- The DST also provides government agency staff access to other relevant information and facilitates consistency in the decision making approach by government agencies throughout Australia.

The DST for managing freshwater fish incursions is free and can be accessed through the IA CRC PestSmart Toolkit website: <http://www.feral.org.au/dss/> The on-going support and maintenance of the tool is conducted by IA CRC.

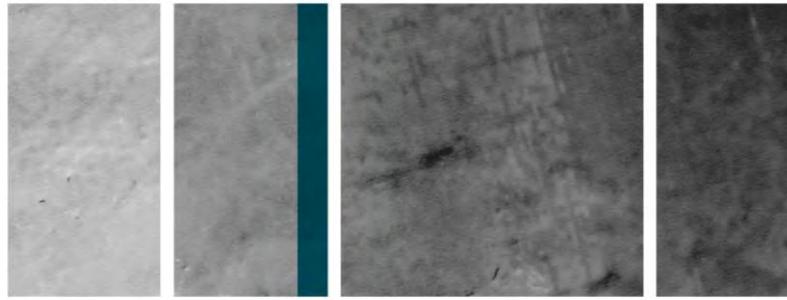
Reference

Ayres R and Clunie P (2010) Management of freshwater fish incursions: a review. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra, Australia.

Questions

Q: In a marine context at least, almost all the reports we get on new incursions are from fishermen, divers and school kids, I can't see a school kid using this tool, so for whom is this tool designed? It needs to be very simple or people won't bother.

Silvana: That is the reason why you have the choice of scientific users and community users, so the process can be very simple for some users. That would then be emailed to a relevant government agency who may contact the person and gather more information.



Using warm water to detect and attract tilapia

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Background

Tilapia, *Oreochromis mossambicus* are of tropical and sub-tropical origin. Lower reported thermal tolerances for this species range between 6°C and 16°C (Hutchison et al 2011 and references cited therein). Winter water temperatures in the southern part of their range in Australia can reach these sub-optimal levels. In sub-optimal temperatures fish are known to behaviourally thermo regulate by seeking out warmer areas in a water body (Wootton 1990).

This behaviour has potential to be exploited in the southern part of the range of tilapia to improve the efficiency of early detection and removal of tilapia. The potential to use this behaviour for development of a thermal trap was also investigated.

Summary of findings

A variety of methods were used to determine the thermal characteristics of three water bodies in south-eastern Queensland during winter. This included recording surface temperatures at regular spatial intervals from a boat, analysing Landsat7 Thematic Mapper Plus (TMP+) images (Figure 1) and setting an array of data loggers to record water temperatures continuously at different depths below the surface and at 30 cm below the surface in different depths of water in different habitats.

All methods revealed variability in temperatures across a water body. Some areas were consistently warmer or cooler. Riparian shading seemed to contribute to cooling in riverine habitats. Single boat surveys of temperatures were best restricted to smaller areas (eg an arm of a lake or short reach of river), to minimise confounding effects of time of day. However use of multiple boats simultaneously with calibrated temperature probes can permit rapid assessment of large areas of a water-body.

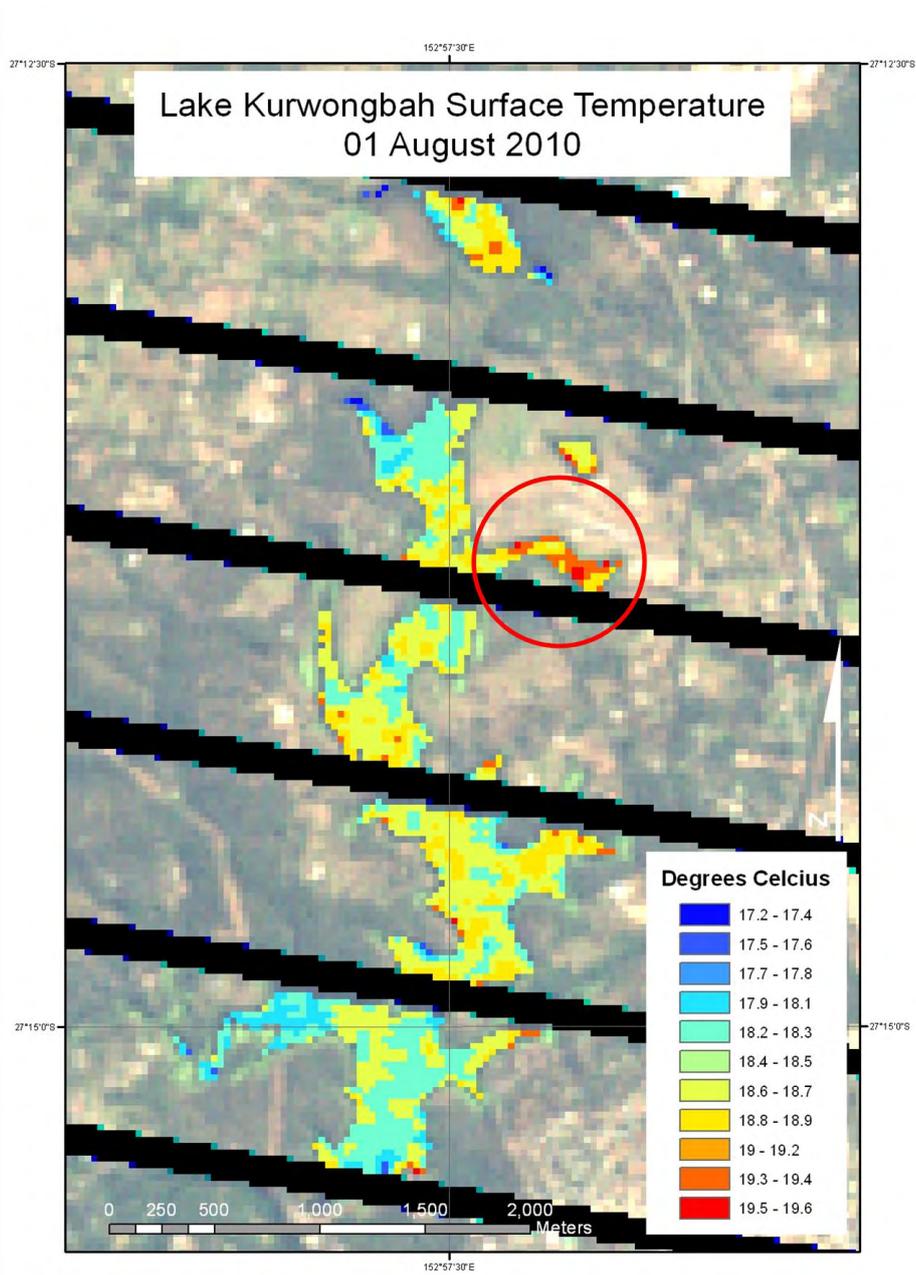
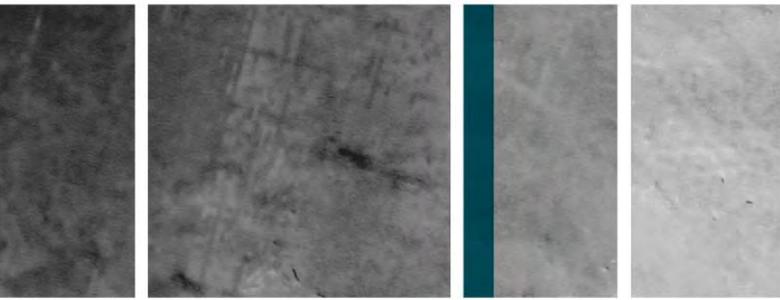


Figure 1: Landsat7 TMP+ thermal image of Lake Kurwongbah, 01 August (winter) 2010. Note the relatively warm arm inside the red circle. Tilapia were found to aggregate in this arm. Due to a malfunctioning scan line corrector, stripes of ‘no data’ occur throughout all ETM+ images since 2003.

Shallow exposed areas showed the greatest daily variation, being warmer than deeper waters for a short part of the afternoon, but substantially colder at night and in the early morning (Figure 2).

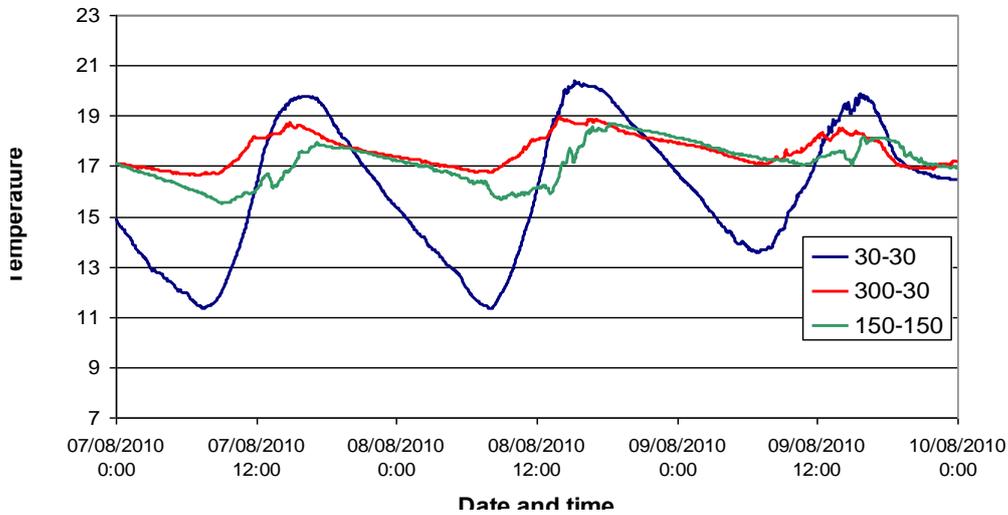
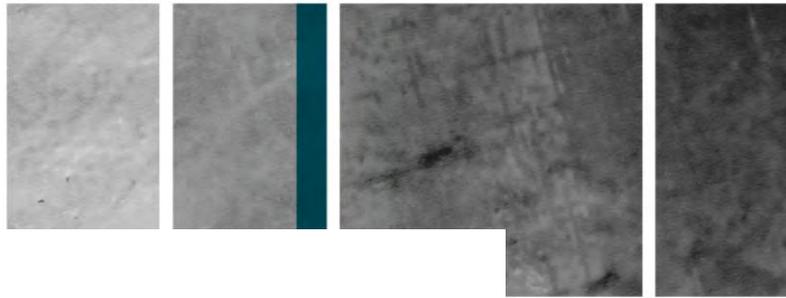


Figure 2: Daily water temperature profiles 7-10 August 2010 on the southern shores of Apel Inlet, Lake Wivenhoe. Three locations within the water column are profiled: shallow (0.3m depth in 0.3m water = 30-30), deep (0.3m depth in 3.0m water = 300-30) and bottom (1.5m depth in 1.5m water = 150-150). There was limited macrophyte cover at this site.

Surface water in deeper areas was far more stable (up to 8 degrees warmer than shallows at night) and bottom water at a depth of 1.5 m was also stable. Emergent macrophytes appear to trap and retain heat and permit shallow waters to remain heated for much longer periods than exposed areas (Figure 3). Areas with macrophytes were only cooler than deeper areas for a relatively short period in the morning. Water at 1.5 metres depth also retained heat better in the vicinity of macrophytes. Electrofishing surveys suggested tilapia were aggregating in this habitat type over winter. Acoustic tracking of tilapia confirmed that they were aggregating in the same habitat.

Kurwongbah Raceway Arm South bank

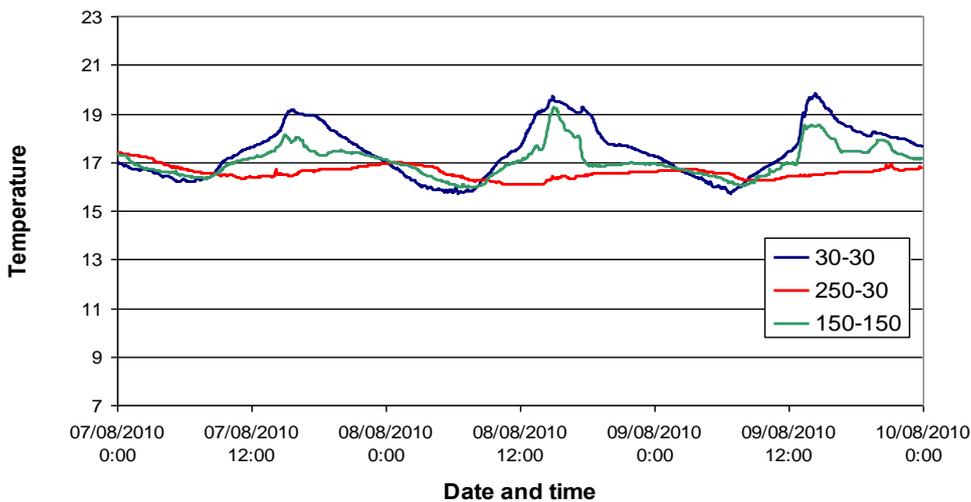
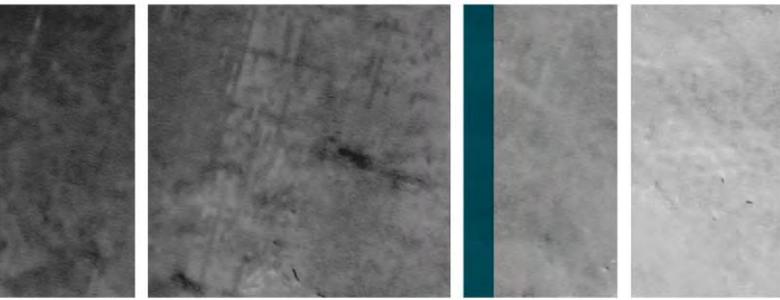


Figure 3: Daily water temperature profiles 7-10 August 2010 for the southern shore of the arm of Lake Kurwongbah Dam adjacent to Lakeside Raceway. Three locations within the water column are profiled: shallow (0.3 m depth in 0.3 m water = 30-30), deep (0.3 m depth in 2.5 m water = 250-30) and bottom (1.5 m depth in 1.5 m water = 150-150). This area had extensive macrophyte cover which appeared to insulate the shallow waters in contrast to Apel Inlet in Figure 2.



Tilapia catch rates were positively correlated with temperature. Aggregations of tilapia were observed in an area with consistently warmer temperatures through winter (Figure 2). Under laboratory conditions tilapia were also demonstrated to move along a 2°C thermal gradient (Figure 4) and preliminary testing of a thermal trap concept in a large tank (Figure 5) suggests the idea has merit as a removal or early detection tool.

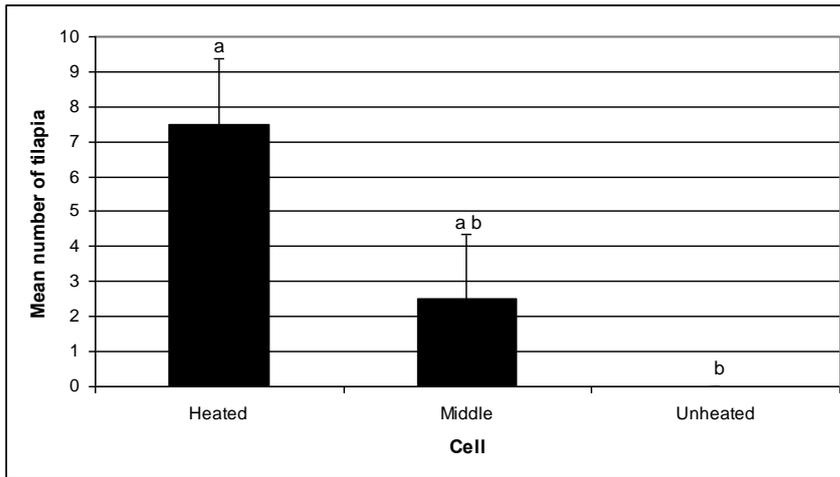


Figure 4: Use of simulated thermal trap (heated cell) by tilapia in comparison to open water (middle of tank) and an unheated simulated trap. Difference in temperature between the unheated area and heated area was approximately 2°C. The middle cell had intermediate temperatures. Cells that do not share a letter in common are significantly different ($p < 0.05$). Values are means and error bars are one standard error of the mean. Number of replicates = 6.

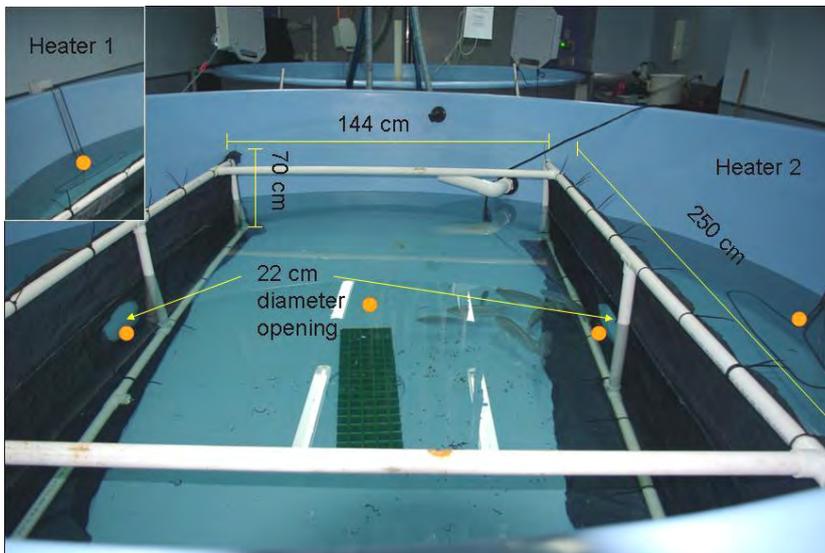
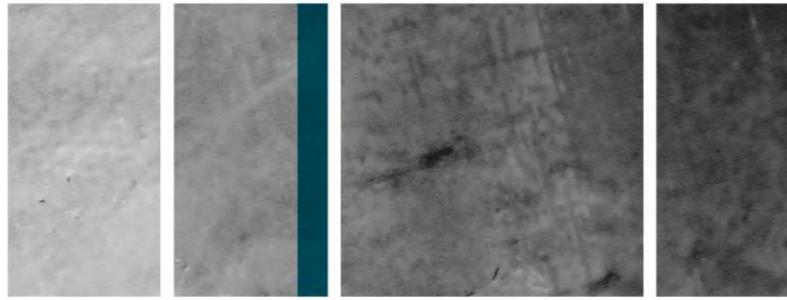


Figure 5: Simulated thermal trap tank. A school of tilapia have just been introduced to the middle chamber of the tank. The tank diameter is 3 metres. Frames on the edges of pseudo traps are covered in shade cloth and a layer of transparent plastic to retain heat. Frame dimensions are shown in the figure. Water is filled to a depth 50 cm. There are two heaters in the tank. The inset shows the heater on the left side of the tank. Only one heater was switched on. The heater switched on was altered between replicates. This was to eliminate side bias. Orange dots show points where temperatures were recorded.



Key messages

Water temperatures vary in three dimensional space in water-bodies. Some sites are consistently warmer during winter than other parts of the same water-body.

Deeper waters are generally more thermally stable than shallow waters. However macrophyte beds in shallow waters can trap heat during the day and can provide thermal refugia well into the evening.

During winter months, areas that are warmer than surrounding waters, especially if also associated with floating and emergent macrophytes are expected to be aggregation sites for tilapia. Such sites could be targeted for removal or early detection of tilapia during winter. Additional heat applied in these areas in a thermal trap could be one potential method for efficient detection and removal of tilapia.

Recommendations

Until more temperature data is available, early detection of tilapia in winter in the Murray-Darling Basin should focus on larger water bodies in 1.5-2.0 metre depth range, especially in the vicinity of floating or emergent macrophyte beds. These are the areas most likely to offer thermal refugia. Community groups (such as fishing clubs) may be able to rapidly assess water temperatures in rivers and large lakes and lagoons using multiple boats simultaneously to determine potential tilapia aggregation areas.

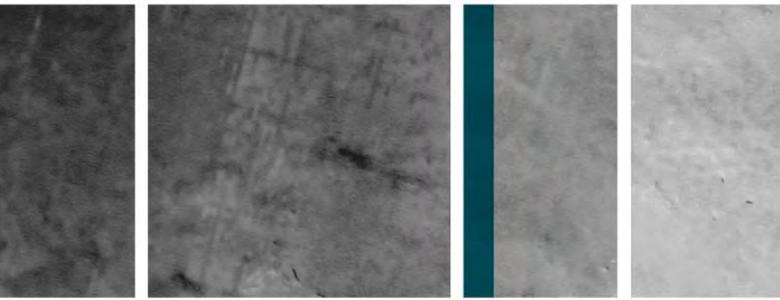
Remote sensing using Landsat 7 ETM+ will be suitable for assessing winter temperature patterns in larger water bodies in the Murray-Darling Basin to determine possible sites to search for tilapia. However the resolution is not fine enough for most riverine habitats. Fine resolution remote sensing systems are available (both aircraft and satellite mounted) but they are much more expensive to use for obtaining data.

There is already a network of water temperature loggers in the Murray-Darling Basin owned by various water management agencies. If these loggers are set in shallow waters they could produce misleading results in terms of the potential for tilapia to over-winter. It is possible that much warmer temperatures could be in deeper waters close by. Information on the position of the loggers is important. A network of loggers set over deeper water in the larger river pools, lagoons, weirs and impoundments will create a more accurate picture of waters where tilapia are likely to survive (or not survive) over winter.

It is recommended that prototype thermal traps be developed and tested in winter in an area with an existing tilapia population. Field testing is essential to determine their potential as a control and detection tool.

Acknowledgements

Analysis of the remote sensing data was graciously conducted by Glen Stichbury, Brendan Hicks, and Mathew Allan from Lake Ecosystem Restoration New Zealand, at the University of Waikato. This work was funded by the Murray-Darling Basin Authority, Native Fish Strategy. Seqwater provided temperature data loggers and acoustic tracking equipment for this work.



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Hutchison M, Sarac Z. and Norris A (2011). *Mozambique Tilapia: The Potential for Mozambique Tilapia *Oreochromis mossambicus* to Invade the Murray-Darling Basin and the Likely Impact: A Review of Existing Information*. Murray-Darling Basin Authority publication 153/11.

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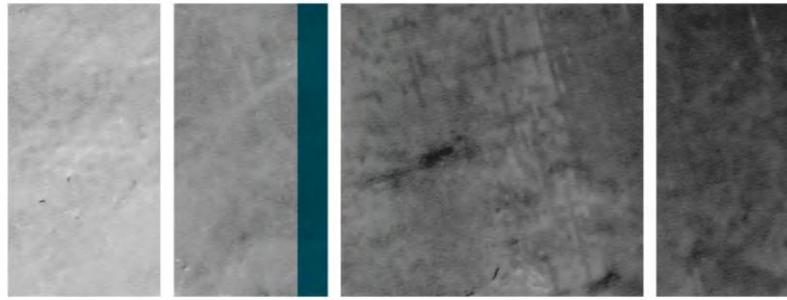
Questions

Q: Any thoughts on cold water as a barrier for tilapia?

Michael: It probably would be, but you could also have problems for native fish. In relation to this you need to be careful in interpreting existing temperature data because there is a lot of capacity for variation on small spatial scales.

Q: Can prevailing winds make any difference to water temperature profiles?

Michael: They possibly could, and so could aspect



Spotted tilapia (*Tilapia mariae*) and Mozambique tilapia (*Oreochromis mossambicus*) in the United States: invasive status, impacts and control

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Objectives / Background

The Mozambique tilapia (*Oreochromis mossambicus*) has been established in the USA since at least the early 1950s mainly through intentional stocking (Nico 2012a), while the spotted tilapia (*Tilapia mariae*) became established in the early 1970s mainly via escape or aquarium release (Nico 2012b). Congruent with their introduction dates and major modes of introduction, *O. mossambicus* (Fig 1) is more widely established than *T. mariae* (Fig 2) throughout the USA.

To date, few studies have gauged the ecological impacts of these invaders on aquatic communities in the USA. *O. mossambicus* has been suspected in the population declines of two native fish species; Desert pupfish, *Cyprinodon macularius*, in California's Salton Sea (Courtenay and Robins 1989, Swift et al 1993) and Striped mullet, *Mugil cephalus*, in Hawaii (Randall 1987, Devick 1991); across its introduced range, but has generally attracted little attention from resource managers. *T. mariae*, meanwhile, has been regarded as a species of special concern because of its propensity to become the most dominant fish (by biomass) where it has established (Courtenay and Hensley 1979; Courtenay and Deacon 1982, 1983).

So far, federal efforts have been limited to the creation and maintenance of a central database for spatially-referenced biogeographical accounts of introduced aquatic species (USGS NAS- accessible at <http://nas.er.usgs.gov>). Additionally, most states have either been unable or unwilling to control or eradicate these populations (P Fuller, personal communication). Only the state of Florida has committed to any consistent control efforts, though these efforts are limited by availability of funds, often forcing managers to select target species and methods of control based primarily on cost-effectiveness rather than by perceived threat. *T. mariae* populations have dropped since 1984 when state managers successfully released Peacock bass (*Cichla ocellaris*) as a biocontrol agent (Shafland 1999); however, the species remains relatively common and has continued to expand its range northward (Trexler et al 2000, Chick et al 2004, Chimney and Jordan 2008).

The two major predators of *T. mariae* in South Florida canals, the introduced *C. ocellaris* and native Largemouth bass (*Micropterus salmoides*) can only consume about 50% of the *T. mariae* forage available (spotted tilapia above 8-10 cm in total length are generally free from predation risk from these predators) (Hill et al 2004).

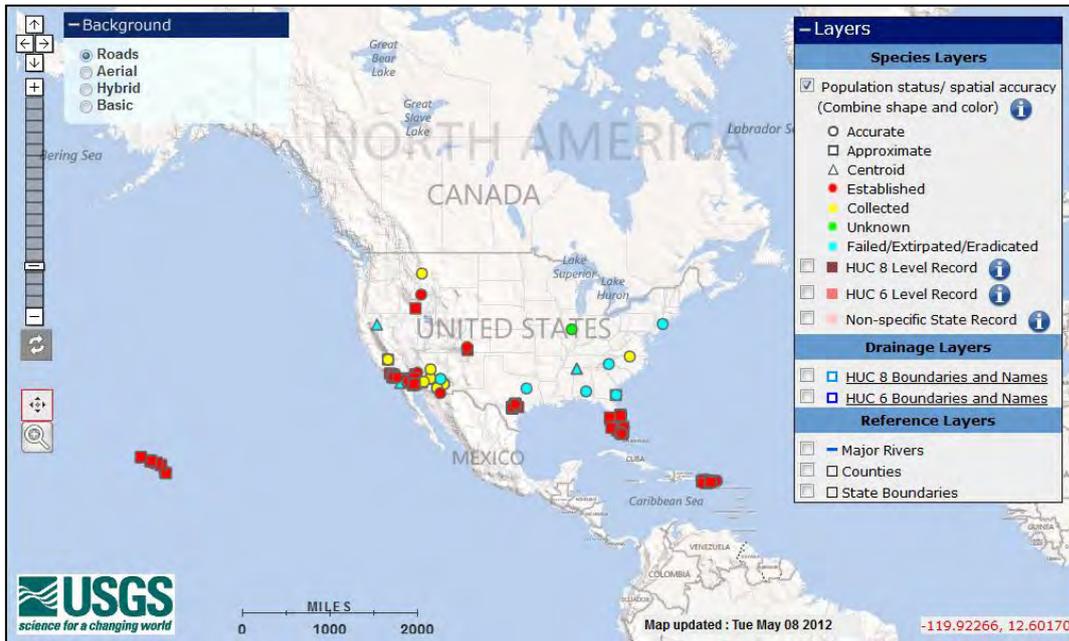
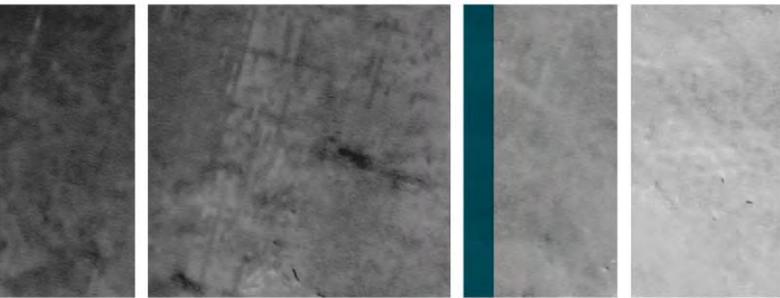


Figure 1: Range of *O. mossambicus* in the United States.

Source: <http://nas2.er.usgs.gov/viewer/omap.aspx?SpeciesID=466>

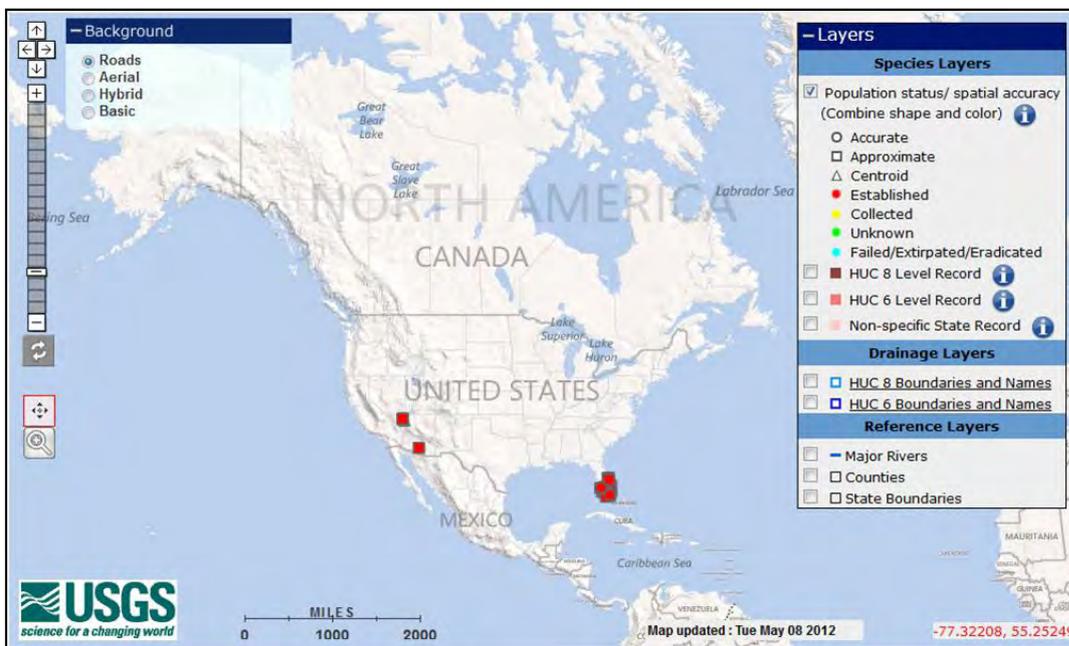
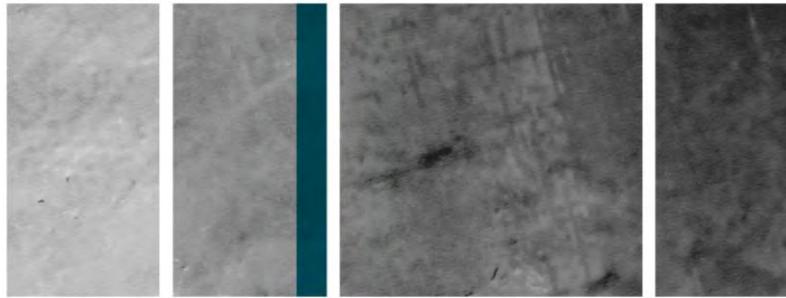


Figure 2: Range of *T. mariae* in the United States.

Source: <http://nas2.er.usgs.gov/viewer/omap.aspx?SpeciesID=482>



In Florida, *T. mariae*'s rapid population growth prompted apprehension over the impact this species might have on populations of native *Lepomis* sunfishes, an economically and ecologically important genus that shares similar territorial and spawning behaviors with *T. mariae* (Courtenay and Hensley 1979). It has been theorised that the aggressive nature of these tilapias could serve to explain their rapid population expansion in South Florida's canals at the expense of *Lepomis* populations (Courtenay and Hensley 1979). We tested the hypothesis that *T. mariae* individuals would be more aggressive towards interspecific competitors than *Lepomis* sunfish, resulting in greater rates of territorial acquisition and defense (Brooks and Jordan 2010). We randomly paired size-matched wild-collected juveniles of each group for interspecific territorial competition trials (Brooks and Jordan 2010). These trials took place for 15 minutes in 18 litre tanks with a bottom surface area of 0.1 m² and a sand bed of 2 cm depth (Brooks and Jordan 2010) (see Fig 3).



Figure 3: *T. mariae* resident attacking *Lepomis gulosus* intruder during territorial competition trials.

Summary of findings

T. mariae were found to be bolder and more aggressive than *Lepomis* sunfishes (Brooks and Jordan 2010). Additionally, *T. mariae* territory residents resisted all *Lepomis* sunfish intruders, whereas 30% of *Lepomis* sunfish residents were ejected from their territories by *T. mariae* intruders (Brooks and Jordan 2010). In scramble trials (where each group representative was introduced simultaneously), *T. mariae* became dominant in 78.9% of trials while the remaining trials saw neither individual become territorially dominant (Brooks and Jordan 2010). These interactions were not affected by different habitat arrangements in the experimental tanks (Brooks and Jordan 2010). It is likely that these enhanced behaviours are an important component of their success throughout their introduced range and have great potential to negatively impact competing native species (Brooks and Jordan 2010). See Figs 4 and 5 for summaries of species interactions).

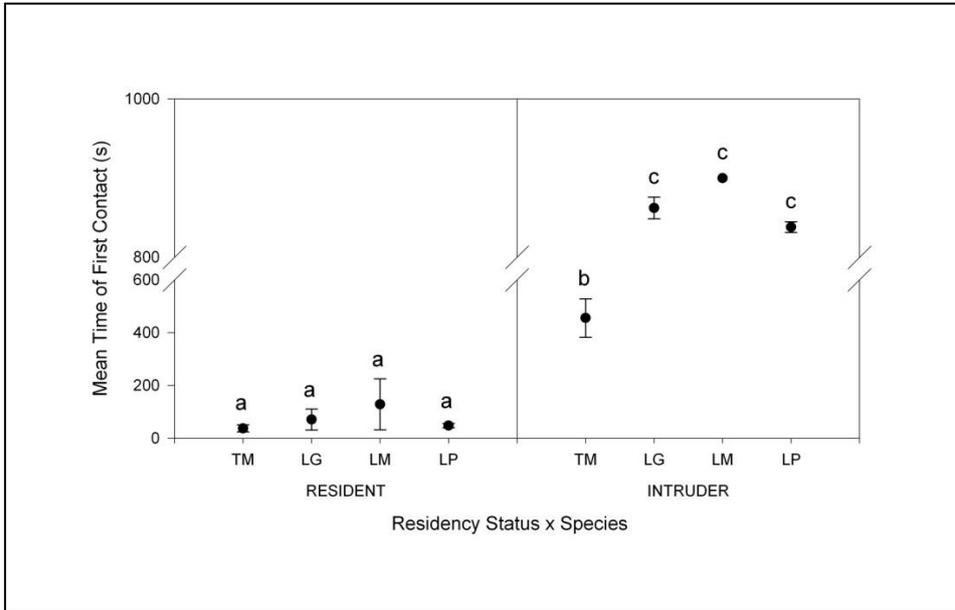
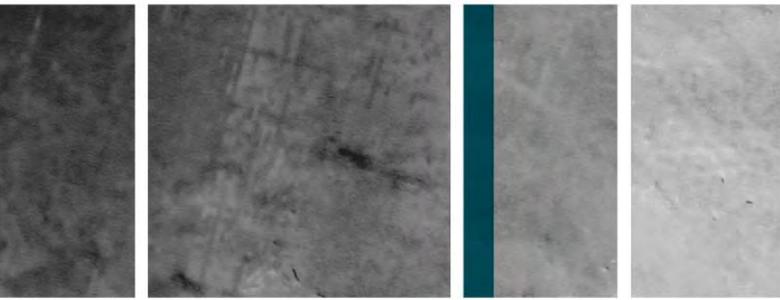


Figure 4: (taken from Brooks and Jordan 2010). Resident and intruder boldness by species as measured in time of first aggressive contact (TM- *Tilapia mariae*, LG- *Lepomis gulosus*, LM- *Lepomis macrochirus mysticalus*, LP- *Lepomis punctatus punctatus*). Letters above bars indicate significant group differences. Residents were allowed to establish territories in experimental tanks for 48 hours before the introduction of an intruder.

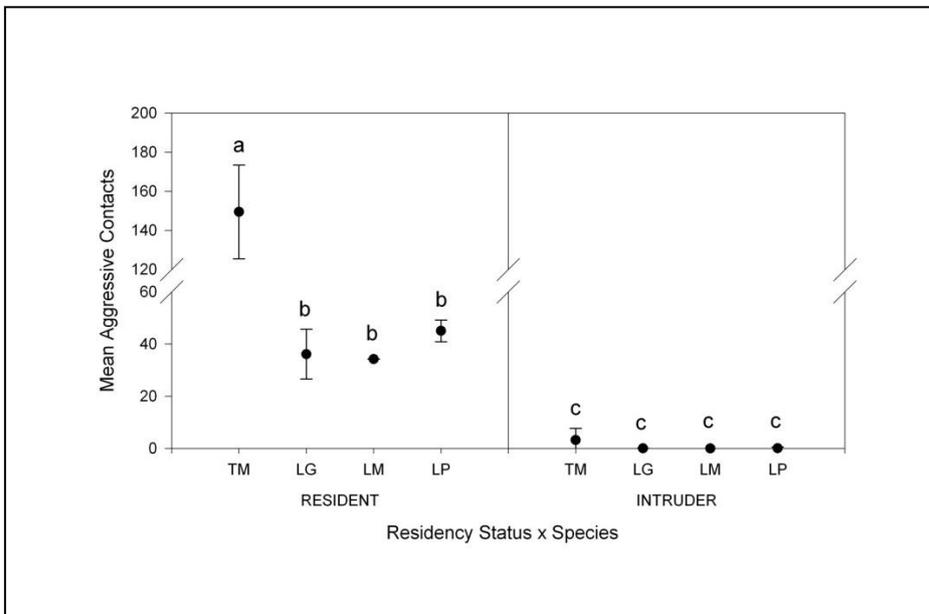
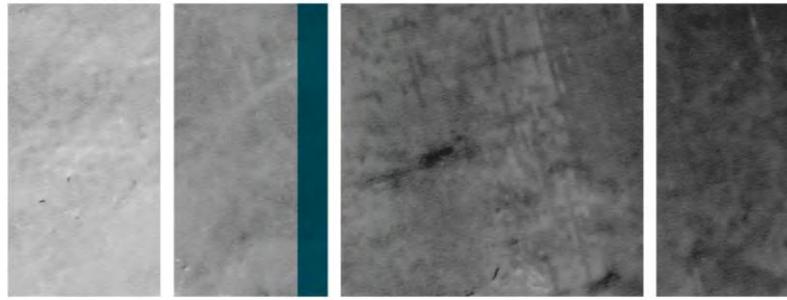


Figure 522: (Taken from Brooks and Jordan 2010): Resident and intruder aggression by species as measured in number of aggressive contacts (TM- *Tilapia mariae*, LG- *Lepomis gulosus*, LM- *Lepomis macrochirus mysticalus*, LP- *Lepomis punctatus punctatus*). Letters above bars indicate significant group differences. Residents were allowed to establish territories in experimental tanks for 48 hours before the introduction of an intruder.



Management / Research recommendations

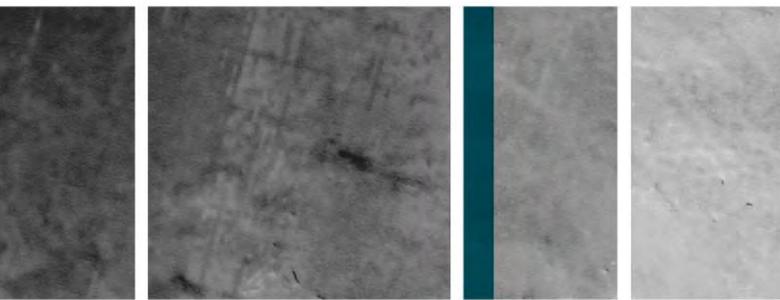
- Special consideration should be given to monitoring native species populations that may share spawning habitat requirements with invasive tilapiines.
- In order to limit the impacts of invasive tilapiines, it is important to understand the factors that allow them to become so successful. In South Florida, *T. mariae* reach greatest densities in the urban canal system where predators and competitors are less plentiful and where they can easily find thermal and oxygenated refuges. In this system, control of *T. mariae* populations would necessitate increasing predator and competitor populations and reducing or eliminating thermal and oxygenated refuges.

Knowledge gaps

- It is unknown whether *T. mariae* and *O. mossambicus* will eventually be as successful in colonising natural wetlands of South Florida to the extent they have been in vastly human-modified areas.
- Many invasive species, including other species of cichlids in South Florida, have increased their population densities and range quickly only to suffer range and population reductions as they become thoroughly incorporated into the ecosystem (or as other species introductions replace them). The extent to which this will apply to *T. mariae*, in particular, is unclear.
- Condition factor analyses of different populations of the same species may give managers additional insights on what abiotic and biotic conditions are optimal/suboptimal for the species across its introduced range.

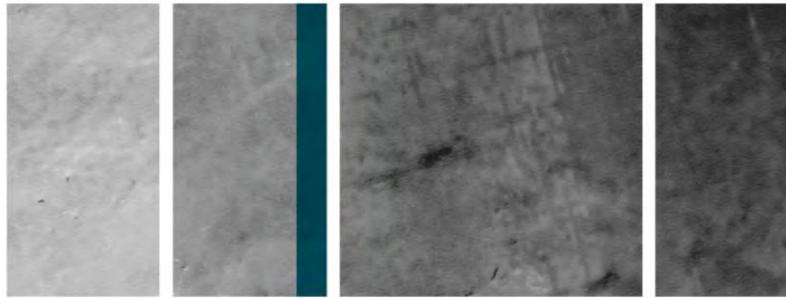
Acknowledgements

I thank R Jordan, J Lockwood, D Howe, A Brooks, L Grubbs, L Brooks, D Mellor, R Burrows, C Kennedy and B Purcell for their time and efforts in support of this research. Permits for this research were acquired from the South Florida Water Management District, Big Cypress National Preserve, and Everglades National Park. All laboratory research was conducted under IACUC #04-037. Funding for this work was provided through the Rutgers University Faculty Research Council. P Fuller provided additional information regarding federal and state management efforts. I also would like to thank the Invasive Animals Cooperative Research Centre for the invitation to share this research and for the opportunity to learn about Australia's own battles with these invaders.



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Questions

Q: You suggest that increasing the amount of spawning habitat available may lead to an increase in the native fish species however you have also shown that tilapia out-compete native species for those spawning habitats, will that not just lead to a boom in tilapia numbers?

Wes: Not too sure, that is possible, but hopefully you provide some space where the competitors can find a foothold as well. Even some of the predators rely on the same habitats for spawning.

Q: You said that some of the populations of tilapia have been extirpated, how was that done?

Wes: Usually they have been small isolated populations and they have removed them with rotenone. Two other species have died out on their own. So many new species coming in that it is difficult to know what is happening.

Q: Interested in what you are proposing as a control option, the social side of things is one of the most difficult things to get across, how receptive do you think the community would be to increasing the habitat for alligators and changing the configuration of the canals for example?

Wes: Always a difficult issue, I would say the community is fairly split in South Florida, there are initiatives underway to convert some of the canals into greenways, that may provide an area in which they can test some of these restoration strategies, at least in small sections to see how the community responds to it. There would be less of a problem doing this in the agricultural areas than in the built up urban areas. Some of the species that you are looking to enhance are the focus of very valuable recreational fisheries and this would help get support for the restorations.

Comment: We have the same experiences with aggression for *T. mariae* kept in tanks both towards other species and to the same species.

Wes: Didn't show that data but they are actually more aggressive towards their own species than they are to other species

Q: You mentioned a number of capture methods such as seine netting and traps, what was the best method and did you try electrofishing?

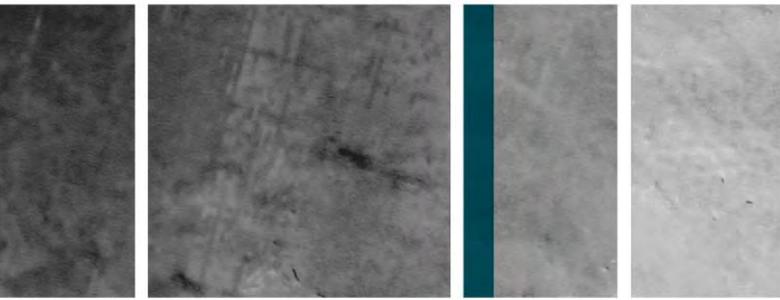
Wes: Did not try electrofishing as I did not have the equipment available. For other methods it depended on the site. Used cast netting where it was suitable; that was easy and provided good catch-per-unit-effort. Minnow traps were really successful for native sunfish; seine netting where we could do it was also fairly successful. Whatever works, I used multiple approaches wherever I was.

Q: Interested and disturbed at the introduction of a non-native predator for control. How did that process play out in relation to for and against and public debate?

Wes: It happened in about 1984 and I am not aware of the processes of debate. However it has been shown to be an economic benefit with no environmental impacts and that has been studied considerably, but it hasn't eradicated any introduced species either.

Q: In relation to the introduction of peacock bass, has there been any evidence of them turning up in other areas due to human translocation as that is a concern in Australia?

Wes: I would be more concerned about that here in Australia as in Florida there is really nowhere they can take them as they can't go further south into the warmer water that they prefer.



Tilapia in the western Pacific: impacts of an exotic freshwater fish

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While aquaculture has been practiced for more than 1000 years, modern aquaculture of freshwater tilapia species is essentially a post-1950 phenomenon. Early perceptions that the Mozambique tilapia (*Oreochromis mossambicus*) could potentially address growing animal protein needs in the Asia-Pacific region have proven to be incorrect. Of the 70 species of tilapia, Nile tilapia (*O. niloticus*) has replaced *O. mossambicus* as the preferred tilapia species for aquaculture across the region. *O. niloticus* has made a significant contribution to animal protein needs in many rural Asian communities and it has also had a major impact on aquaculture development in Pacific Island Nations (PINs) since the 1980s. In parallel feral *O. mossambicus* stocks have become a significant exotic pest and impacted aquaculture and natural ecosystems.

Aquaculture of tilapia provides a classic example of a success story for a species group outside of its natural distribution range. Production of tilapias currently approaches 1000 tonnes in PINs, the great bulk of which comes from Papua New Guinea accounting for nearly 60%, followed by Fiji with around 30% of total production. It is important to note, however, that tilapia culture has also been adopted in other smaller PINs, for example, Vanuatu, Solomon Islands, Samoa, Cook Islands, American Samoa, Guam and Nauru and production is increasing. Farming systems range from rural subsistence to semi-intensive commercial operations. Earthen ponds are the most common culture system and use of culture systems and management strategies will depend on each farmer's resources, site characteristics, environmental conditions, socio-economic factors, technological capacity and local market demand. Production costs and yields vary from 'island' to 'island' depending on the level of management used. Expansion of tilapia farming is constrained however by a number of factors across the region, some of which include; deterioration of the genetic quality of the stocks due to introgression of feral *O. mossambicus* genes into *O. niloticus* culture stocks. While improved breeds of *O. niloticus* have been developed, there is a need to eradicate or control *O. mossambicus* feral stocks from farms and adjacent waterways to ensure sustained production and effective dissemination of improved tilapia culture breeds to farmers.

[Abstract only provided]

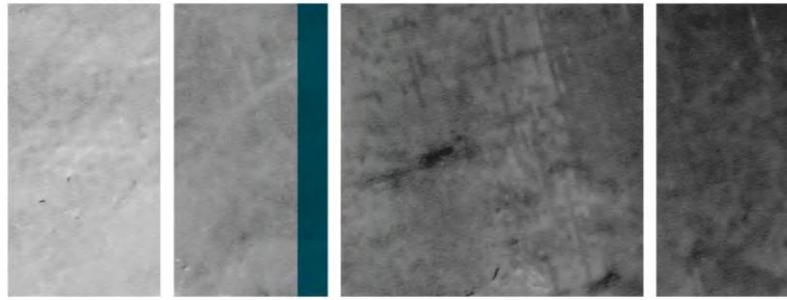
Questions

Q: You mentioned that tilapia are not only in freshwater systems but also estuarine and marine systems. One of the questions that has been raised in Queensland is that *Oreochromis* populations might eventually make their way out to the Barrier Reef, and there have been some unconfirmed reports of them on some near shore islands. What is your experience with that issue and do you know if they can spend their entire lifecycle in marine waters?

Satya: Yes it has gone into some marine environments and I have seen them there but I do not know if they reproduce there. **Comment:** Mozambique tilapia occurs all along the east coast of Africa and it is believed that some of those rivers have been populated by marine movement. I have seen *mossambicus* in marine conditions, that is pure sea-water but I don't know if it can breed there.

Q: Assuming that the legislative processes would change in Australia to allow tilapia to be harvested or produced via aquaculture, do you have any thoughts on that considering that there are issues with it stunting, issues with it competing with Nile tilapia and issues with it competing with imported tilapia?

Satya: I think it could be cultured but not *O. mossambicus*. It could be done safely and I think there is potential for it.



SunWater's screening of the Mareeba Dimbulah Water Supply Scheme

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Objectives / Background

SunWater's Mareeba Dimbulah Water Supply Scheme (MDWSS) in North Queensland includes approximately 400 km of channels and pipelines delivering water from Tinaroo Falls Dam on the Barron River Catchment on the east coast of Far North Queensland to farmlands over The Great Dividing Range in the Mitchell River Catchment feeding into the Gulf of Carpentaria.

Tilapia were first discovered in tributaries of the upper Barron River in the early 1990's. There is evidence to suggest the original infestation came from a back yard, ornamental pond within the upper catchment. However there could have been other concurrent points of entry. Over many years they have spread to the Barron River and Lake Tinaroo. While Tilapia have been in the southern reaches of Lake Tinaroo for many years it was only in 2000 that they were found near the Dam wall. Although they were only initially found in small numbers around the Dam wall, it was only a matter of time before the population density increased around the entire lake. High populations of Tilapia are also present in the Lower Barron (below Barron Falls). While the reach of river between Tinaroo Falls and Barron Falls has relatively few Tilapia, they are now present through the entire length of the Barron system.

In 2012, the Walsh and Mitchell Rivers appeared to be free of Tilapia. As the Mareeba Dimbulah Water Supply Scheme delivers water from Lake Tinaroo, across the Great Dividing Range, to supplement the Walsh and Mitchell rivers, there was concern that the scheme may act as a translocation mechanism. As the Walsh/Mitchell river systems flow across Cape York and into the Gulf of Carpentaria, it is critical that Tilapia do not enter these environmentally sensitive river systems. Prior to the screen being constructed, electrofishing sampling in the channel system was undertaken with no Tilapia found.

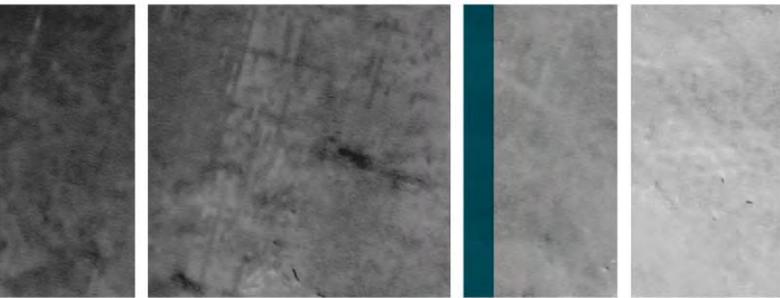
Although it is extremely unlikely that Tilapia could survive passage through the outlet works, it cannot be proven beyond doubt. As providing a mechanism for translocation of noxious fish could represent a breach of the Fisheries Act, SunWater undertook research and designed the 'Fish Exclusion Screens' in the channel system.

Summary of findings

Research into screens

The aims of the research were to develop a screening solution to contain Tilapia to the Barron system with total exclusion from the Mitchell system, to ensure that services to irrigators of the channel system were not adversely affected by the installation and operation of such a screen and to successfully address the issue of cleaning of the fine screens.

SunWater investigated the Coanda effect screens (Figure 1) which consist of an inclined screen structure utilising a tilted-wire screen panel installed in the sloping downstream face of an overflow weir. The use of this tilted wire arrangement allows a significantly larger portion of flow to be forced through the screen than with conventional screens (eg vertical flat-plate screens). This type of screen had not been utilised very much in Australia although it had been commercially available in the United States of America for about ten years.



However, the flow capacity through the Coanda screens planned by SunWater is believed to be much larger than used anywhere in the world.

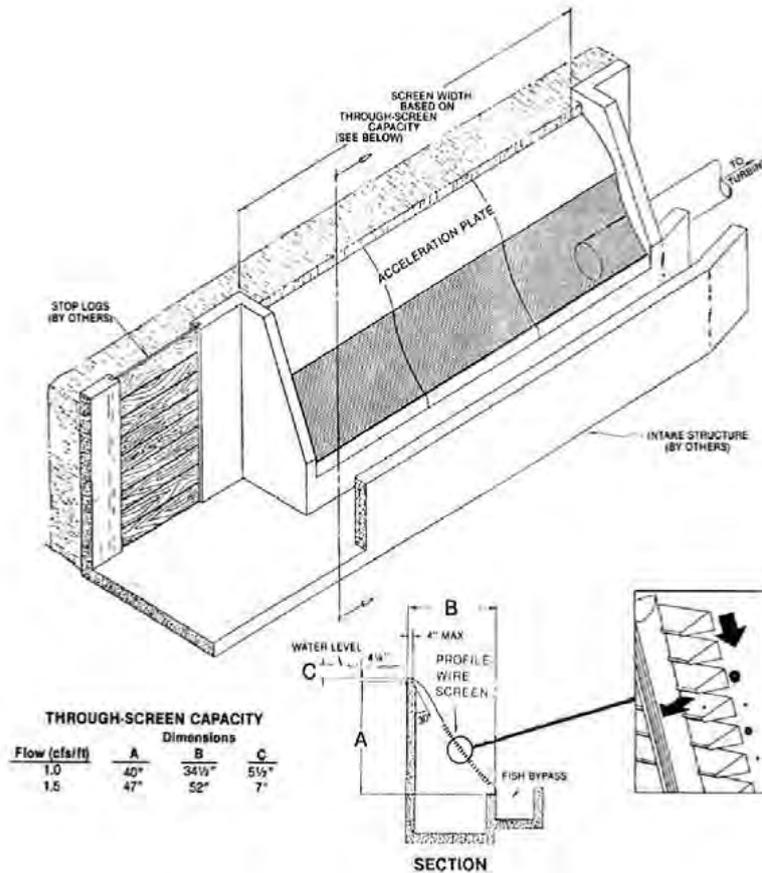


Figure 1: Schematic of Coanda screen.

At the SunWater hydraulics laboratory in Rocklea (Brisbane) the suitability of the Coanda effect screen was researched and trialled using two- and three-dimensional hydraulic models (Figure 2). Coanda screens have high flow-handling capacities for their size, are essentially self-cleaning, and have the ability to exclude very fine debris and small aquatic organisms. The Coanda effect hydro-shear wedge wire screens were manufactured out of stainless steel.

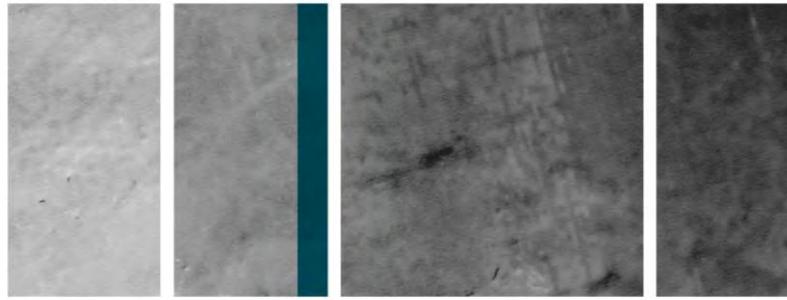


Figure 2: Two dimensional model trial of Coanda screen.

Fish tests

Initially three traditional stainless steel mesh sizes with the aperture openings of 0.75 mm, 0.5 mm and 1.0 mm were tested for various life stages of the Tilapia. The screens were inserted into a tilted flume at right angles to the flow at SunWater's Rocklea facility. The initial flow conditions were set to represent field conditions. In these experiments, eggs were excluded by 1 mm mesh and free swimming larvae by 0.5 mm mesh. However a small proportion of late stage yolk sac larvae passed through the 0.5 mm mesh.

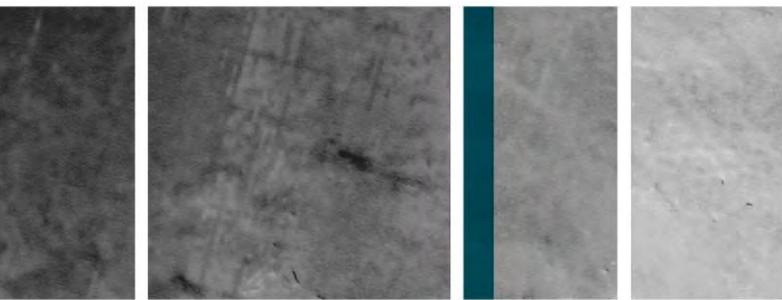
The second phase of testing was carried out utilising the Coanda-effect screen. Once again, three stainless steel mesh sizes with the following aperture opening of 0.75 mm, 0.5 mm and 0.4 mm were tested for various life stages of Tilapia. With this arrangement the 0.5 mm screen was successful in excluding late stage yolk sac larvae and free- swimming larvae.

The 0.5 mm aperture Coanda effect screen was adopted.

Design

The Coanda screen was located in West Barron Main Channel as far downstream as possible (to minimise the volume to be screened), but still completely within the Barron catchment. The filtrate is piped back to Mareeba Channel, which is completely within the Barron catchment. The Mareeba Main Channel runs parallel to the West Barron Main Channel and at the location of the screen is approximately 800 m from the West Barron Main Channel.

The screen is capable of screening 1,200 ML/day and is made up of 24 screen panels with independent control gates enabling partial shutdown of the screen for cleaning.



The installation consists of the civil works structure, a conduit for redirecting the screened water back into the channel, a diversion pipe to dispose of the filtrate water containing weed and fish, and the final main component is the metalwork incorporating the walkways, access, control gates and the combined weir and screen (Figure 3). The screens are intended to be generally self-cleaning.

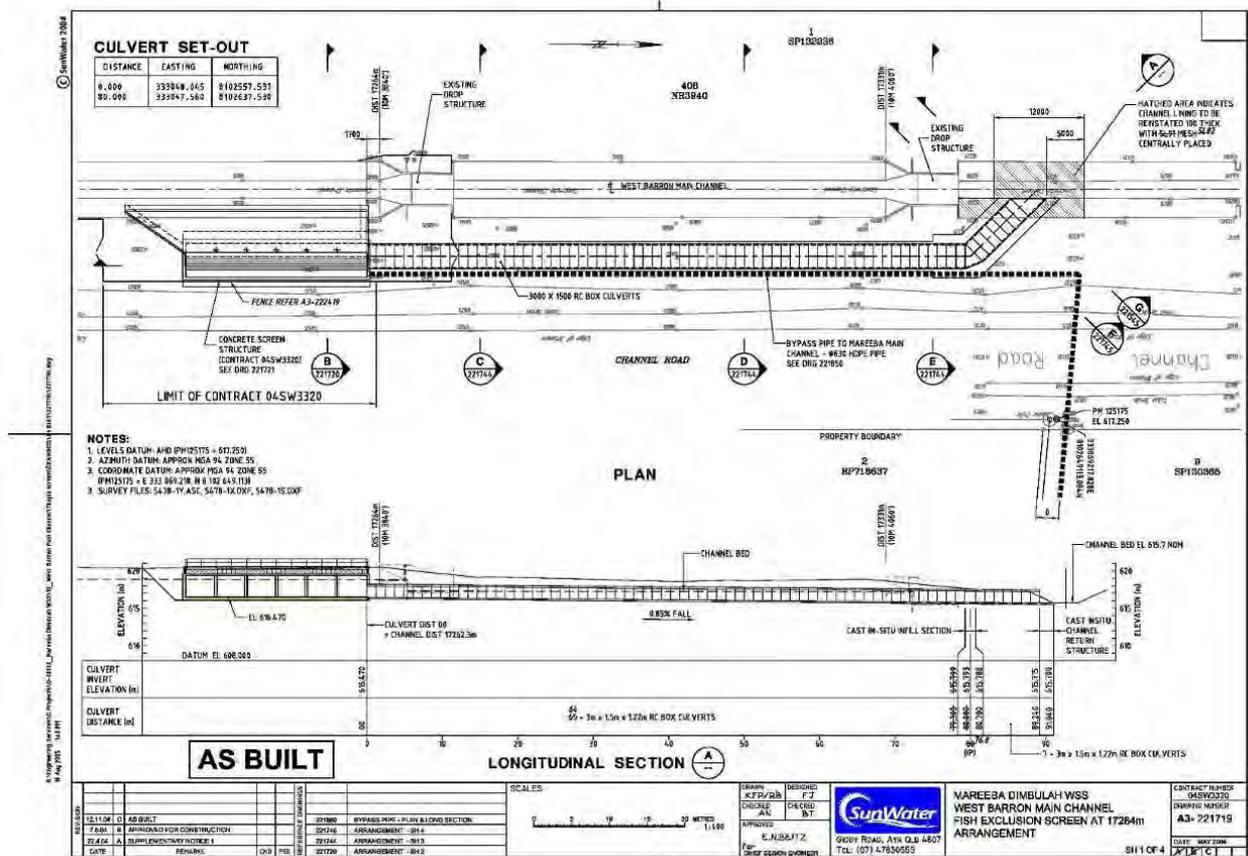


Figure 3: General arrangement of the West Barron Main Channel fish exclusion screen.

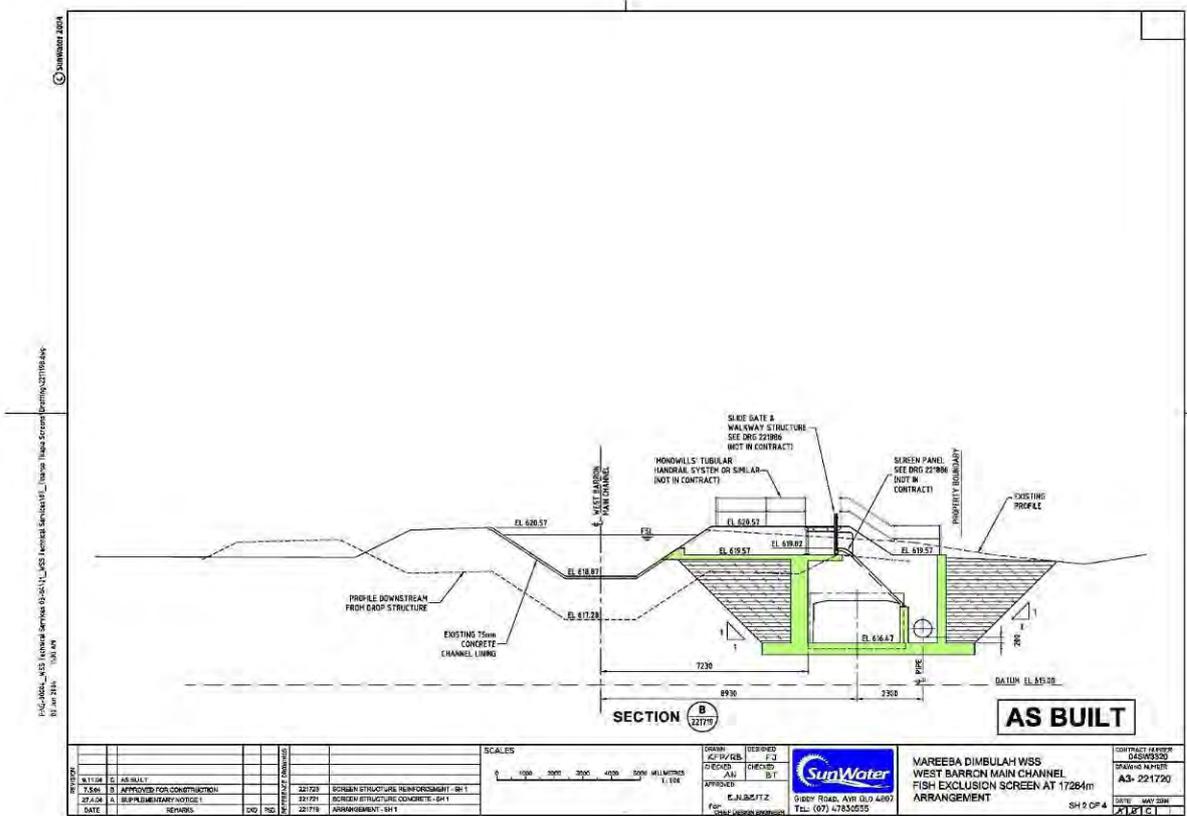
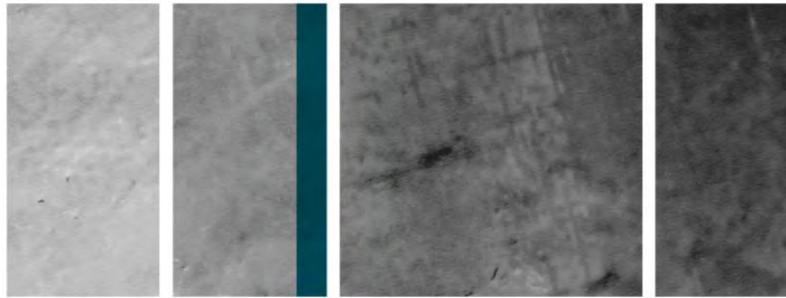


Figure 4: Cross section of the West Barron Main Channel fish exclusion screen

Construction

Construction of the screen commenced in May 2004 with the first objective being to string together lengths of the 630 mm (diameter) Polyethylene pipes intended for final installation as the filtrate pipe for use as a temporary water supply to bypass the construction works (Figure 5). As water is required within the Water Supply Scheme all year round the shut down for the works was only able to extend for several days at a time. This temporary bypass pipe enable partial but still significant water supply during this construction period.

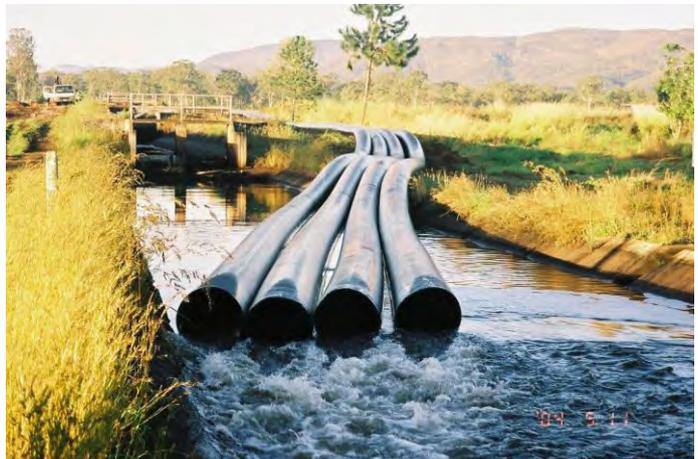
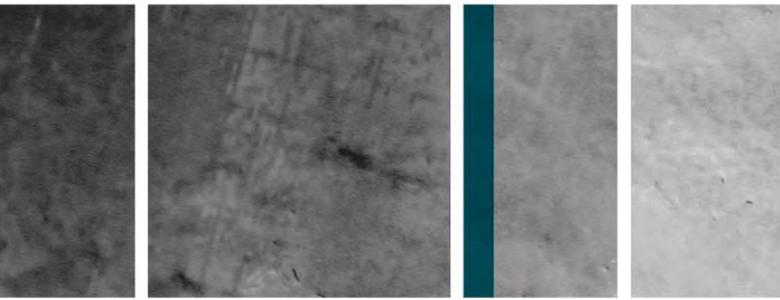


Figure 5: Bypass temporary supply pipes



The construction phase of the works took seven months and consisted of the construction of:

- reinforced box culvert screened water conduit (Figure 6)
- concrete screen structure (Figure 7)
- bypass filtrate pipeline (Figure 8)
- screens (Figure 9), walkways and gates.

The screen was completed and put into operation on 8th December 2004 (Figure 10). At this stage the screen was screening water at the efficiency rates it was designed for.



Figure 6: Construction of box culvert outlet.



Figure 7: Completed concrete screen structure before screens installed.



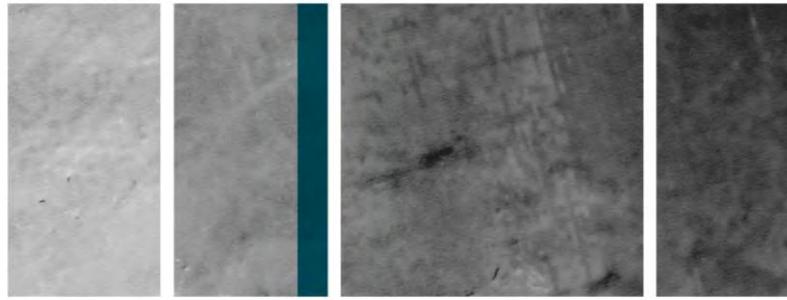
Figure 8: Filtrate pipeline from fish screen at road crossing.



Figure 9: Under Coanda screen.



Figure 10: First minutes of operation of the completed screen.



Management / Research recommendations

Initial operations

Following the completion of the screen, operations did not have a high focus on the management of the screen – as it was intended to be a fairly simple self-operating and self-cleaning installation. Operators would pass the screen daily and the bulk loose weed would in fact self-clean and the screen would pass water.

Very soon though the screen started to build up with finer material and so the operators would stand on the top walkway and attempt to clean this by brooming of this matter. This only worked partially for a while.

Dirty screen and overflows

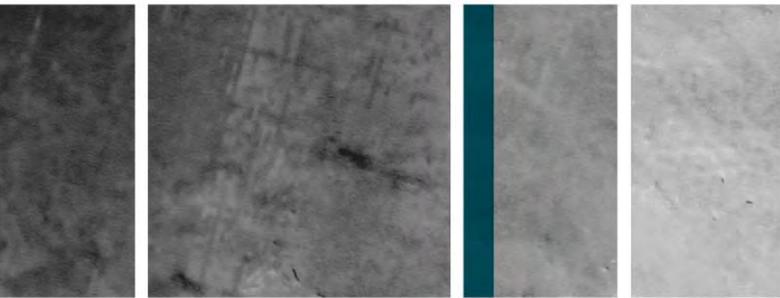
To make matters worse, algae started to bloom on the screen and once the weather and water temperature conditions were right this algae bloomed to the extent that the screen overflowed.

The initial overflow occurred in 2005. The overflow occurred because the screen became blocked to the extent that the full flow required to pass would not go through the screen. This caused the filtrate pipeline capacity to be exceeded which then filled up the filtrate chamber of the structure and inundated the lower part of the screen. Once the lower part of the screen was submerged the ‘Coanda’ effect of the screen stopped and the ability to pass water through the screen was greatly reduced and then the whole screen structure overflowed (Figure 11). There was nowhere else for the water to go to except over the structure and down the road.

This initial overflow caused damage to the road, farmers’ crops, farmers’ sheds and caused a traffic hazard. It is not thought that any unscreened water made its way back into the channel although had the flows been higher this may have been a possibility.



Figure 11: Screen overflow 2005.



The channel system was shut down and the screen was cleaned as well as it could be at that time.

Cleaning trials and research

The period following the overflow was a period of high strain for the operators as the screen was blocking up more often causing more regular cleaning and there were several instances where the screen showed signs that it may overflow again.

Monitoring and cleaning of the screen was still quite ad hoc at this stage.

It was initially thought that algae was the main problem, so trials were done to inject copper sulphate upstream of the screen to reduce the algae being deposited onto the screen. Trials were also conducted to shade the screen using shade cloth and black high density polyethylene (HDPE) plastic sheeting to reduce the heat and sunlight conducive to the algae growth (Figure 12). Neither of these trials worked.

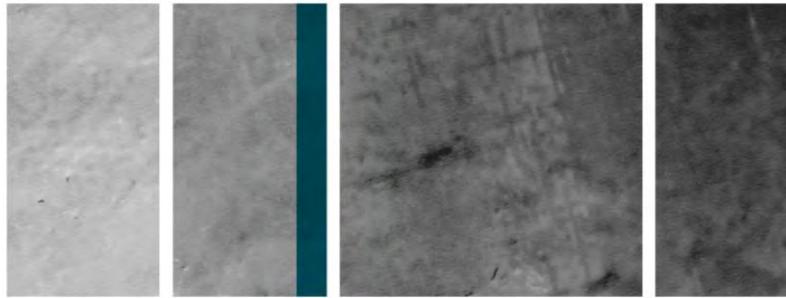


Figure 12: HDPE algae cover trial.

A black solid substance was also being deposited on the screen which slowly reduced the aperture size of the screen further reducing the ability to efficiently screen the water.

Further trials assessed the effects of various chemicals to clean the screen of this built up substance and to kill the algae. Initially nothing worked and in fact one trial using chlorine actually caused the screen to clog further. Throughout these trials care was taken to ensure that no physical damage occurred to the screen.

A further overflow event occurred in 2006 which also caused similar damage to the previous event.



Engineering design investigations were also undertaken to attempt to find a solution to manage the actual overflows. This included options to install overflow channels, drains and pipeline. All solutions were quite expensive as they had to deal with large flows. This only dealt with the result of failure and not the cause.

An early warning SCADA system was also investigated but this was rejected due to the fact that when overflow occur they occur in a matter of minutes and the response time to SCADA alarm to shut the water supply down would not prevent the overflow and resultant damage.

Breakthrough

The breakthrough in the trials was the use of a biodegradable cleaning product called 'Rydlyme'. This product broke down the black deposit that was blocking the screens and allowed the screens to be pressure washed and cleaned.

The introduction of the use of this product gave confidence that the screens could be cleaned. Once it was proven that the screen could be cleaned it was initially planned to install an automatic mechanical cleaning device which swept, sprayed the cleaning chemical and pressure cleaned the screens. Concept designs were done but there were some concerns about the complexity, cost, and ongoing maintenance of this device.

Prior to fully developing and installing this cleaning device it was proposed to undertake the process in stages. The initial stages of this were:

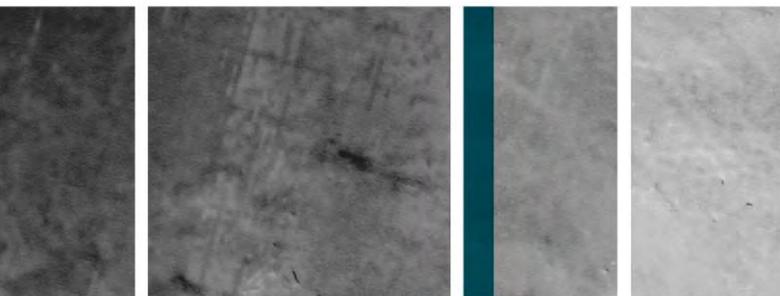
- install low level support frame and access for the cleaning device
- trial different rotary head pressure cleaners

These first stage modifications to the screens were undertaken in 2007-2008 with great success. A new low level access walkway was installed to enable operators better access to the screen in a safe way. This allowed them to effectively clean the screen using manual cleaning methods and rotary 'street sweeper' pressure units (Figure 13). For the first time since the screen was built the screens could be cleaned to give full efficiency of water flow.

At this stage it was decided that a fully automated mechanical cleaner was not required and that the reliance on the mechanical device would introduce additional maintenance issues and risk of the screen overtopping if it broke down.



Figure 13: Cleaning screen



Management and refinement

In 2007, during the period when the screen was still blocking up and overflows were a high risk, it was determined that the only way to be sure that overflows could be avoided was to be vigilant and to monitor and clean the screen at regular intervals.

Initially operators were monitoring on an ad hoc basis, but when asked they believed they were monitoring to high levels. To overcome this perception stringent inspection and cleaning schedules were put in place – the screens are now inspected on at least a daily basis and cleaned on a routine basis with additional cleans if conditions require. Each inspection is recorded on site making staff accountable for the frequency of the inspections as well the diligence in carrying out the cleaning (Figure 14).

This monitoring and cleaning schedule has proven to be the most effective mechanism to ensure that the diligence required is carried out. Since the introduction of this schedule no overflow events have occurred.

	Minimum Cleaning Procedure				
	Inspect	Broom Screens (remove weed)	Pressure Clean, or	Pressure Clean / RydLyme Treatment / Pressure Clean	Flush weed from sump ****
High Flow >450 ML/day	Twice Daily ***	Daily* ***	Fortnightly* ***	Monthly** ***	on inspection
Medium Flow 200ML to 450 ML	Once Daily ***	Daily* ***	Fortnightly* ***	Monthly** ***	on inspection
Low Flow <200ML/day	Once Daily ***	Daily* ***	Fortnightly* ***	Monthly** ***	on inspection

* Additional cleaning may be required based on Inspection

** Rydlyme treatment must be done once monthly at a minimum, but may be required more frequently, based on inspection

Figure 14: Extract from cleaning procedures.

Additional modifications were undertaken to the fish screen to enhance the cleaning process:

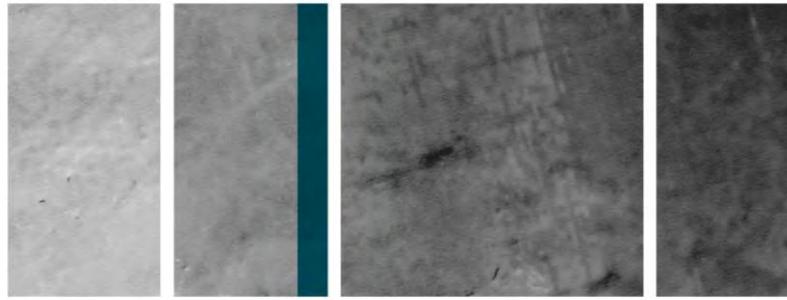
- further improvement to access
- permanent on site pressure water pump to drive cleaning head.
- pressure lines with tapping points for pressure cleaner attachment
- flush pipe to increase flow to remove weed in filtrate sump.
- removal of lifting lugs to ensure flow on screen remain laminar

Fish sampling surveys

Following construction of the fish exclusion screens, baseline fish movement surveys were conducted in order to determine the effectiveness of the screens. During this electro fishing survey a single male tilapia was found in West Barron Main Channel (13/4/2005).

Fortunately the tilapia was found upstream of the exclusion screens. More exhaustive electro-fishing surveys were then undertaken, upstream and downstream of the screens, and in the Walsh River, with no further tilapia found. It would appear that the screens have been effective in controlling the spread of tilapia.

We may never know how the tilapia got into the channel system. Given that successful passage through the outlet work of Tinaroo Falls Dam was quite unlikely, it is suggested that human translocation is to blame. As the tilapia was found within the same channel bay as the Kennedy Highway crossing (ie a very public location), it is reasonable to suggest that a careless individual has introduced the tilapia into the channel either intentionally or unintentionally.



Despite the apparent effectiveness of the screens it was considered appropriate to treat the channel system from Tinaroo Dam to the fish screens with Acrolein as an extra precaution. Acrolein is an aquatic herbicide used to control weeds in irrigation channels. Fish death is usually an unintended side effect of Acrolein. However in this instance, fish death was an intended consequence. The section of channel treated was experiencing considerable weed problems at the time. As such the Acrolein injection served the dual purpose of eradicating aquatic weed and tilapia.

It was estimated that the mortality rate associated with the treatment was 200-300 fish, including one additional male tilapia. Electrofishing surveys conducted directly after the treatment found no fish at all, indicating that all fish in the channel were successfully eradicated.

Further sampling is conducted in the channel system at various locations on an ongoing annual basis. No tilapia have been found downstream of the fish screens. Tilapia have been found at several locations upstream of the fish screen which further demonstrates that the fish screen is effective in preventing fish passing downstream of the screen.

Key messages

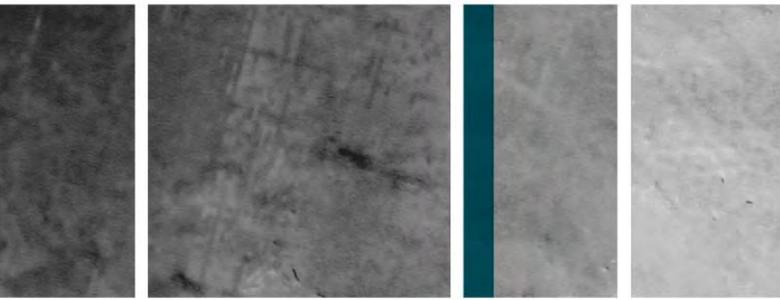
- Tilapia can be effectively screened from a channel system
- Effective screen cleaning procedures and overflow fail safe mechanisms must be incorporated into future screen designs and operating procedures.
- Vigilance and diligence must be followed to ensure the screens remain effective and efficient.
- Ongoing Sampling must be carried out to ensure effective screening.
- The major risk to the spread of tilapia is human intervention.

Knowledge gaps

- It is not fully understood how tilapia are surviving being released from high depths from Lake Tinaroo and going through the outlet works or the hydrogeneration turbine.
- The identification of the deposits that form on the screen is not complete or well defined.

Acknowledgments

Acknowledgements must be given to the operations and maintenance staff of the SunWater Mareeba Depot who have developed the solutions to the operations and cleaning of the fish exclusion screen. It was through their patience, trials, innovation and efforts that the facility has been improved such that the integrity of the screening is maintained, while now being able to be cleaned and operated in a safe and efficient manner.



References

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Jacobson F and Mohand A (2004). Hydraulic Model Study of Tilapia Fish Exclusion Using Coanda Screens. Institute of Engineers Australia 8th National Conference, July 2004.

Stevenson B (2005). Tilapia and the Mareeba Dimbulah Water Supply Scheme.

Questions

Q: It was over 15 years ago when the screens first went in, can you tell us a little about the process of working with the other organisations to get this done.

A: There were several groups formed when Tilapia was first found in Tinaroo. The Mitchell River watershed management group had major concerns, Sunwater was concerned because of the transfer of water from one catchment to another, there was also quite a bit of public consultation involved over about a two year period. The initial response was to just monitor it and there were some doubts that the fish would go through because of depth and pressure differences. That view changed.

Further comment; Queensland Fisheries was tracking tilapia monitored spread of Tilapia in Tinaroo and looked at a lot of options with funding from Sunwater for control including electric barriers. No options were viable so Sunwater went ahead with the screens.

Q: We are looking at putting screens on irrigation pumps on the Condomine River, will cleaning be an issue?

Charlie: Cleaning will always be an issue, that is why we have set up model trials using water from the system. You need to assess the particular situation by trials.

Q: What is the lifetime of the screens and do you have any idea of establishment and ongoing costs for them?

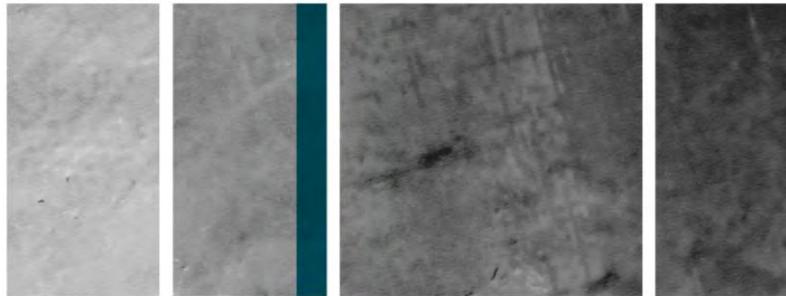
Charlie: Initial installation cost in 2004 dollars was about \$1.4million with about \$100000 also spent prior to that. The screens have a notional life of 20 years but they are not really the most expensive element.

Q: Normally when you release water it is controlled, have you had a situation where due to floods you have had to allow more water through and can the screens cope with this?

Charlie: It is flow controlled, the allocation is about 17km from Tinaroo Dam and there are other control spots before the screens for diversions.

Q: You said you found no tilapia downstream, what was the environment for tilapia in this area?

Charlie: We get DEEDI to check this each year at a number of locations



Case study: Eureka Creek tilapia management

Malcolm Pearce¹

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The problem - back ground issues

A Surveillance Program for the early detection of exotic pest fish in the Gulf of Carpentaria was developed in the 2006/2007 (Pearce 2009a) financial year, trialled in 2007/2008 (Pearce 2009b) and implemented in 2008/2009 (Pearce and Hedge 2009). The Surveillance Program consisted of an active, scientific structured program and a passive, community based program.

On Friday 18 January 2008, Queensland's Department of Agriculture, Fisheries and Forestry's Fisheries Queensland fisheries officers captured five juvenile spotted tilapia (*Tilapia mariae*) (Fig 1) also known as black mangrove cichlid, during routine pest fish surveillance in Eureka Creek, approximately 80 kilometres south-west of Cairns.



Figure 1: Juvenile *Tilapia mariae* that were caught during the surveillance program.

Eureka Creek is a small western flowing waterway that is connected to the Walsh River, and is part of the Mitchell River Catchment which flows into the Gulf of Carpentaria. This was the first instance where tilapia have been detected in a western Gulf of Carpentaria flowing waterway (Fig 2).

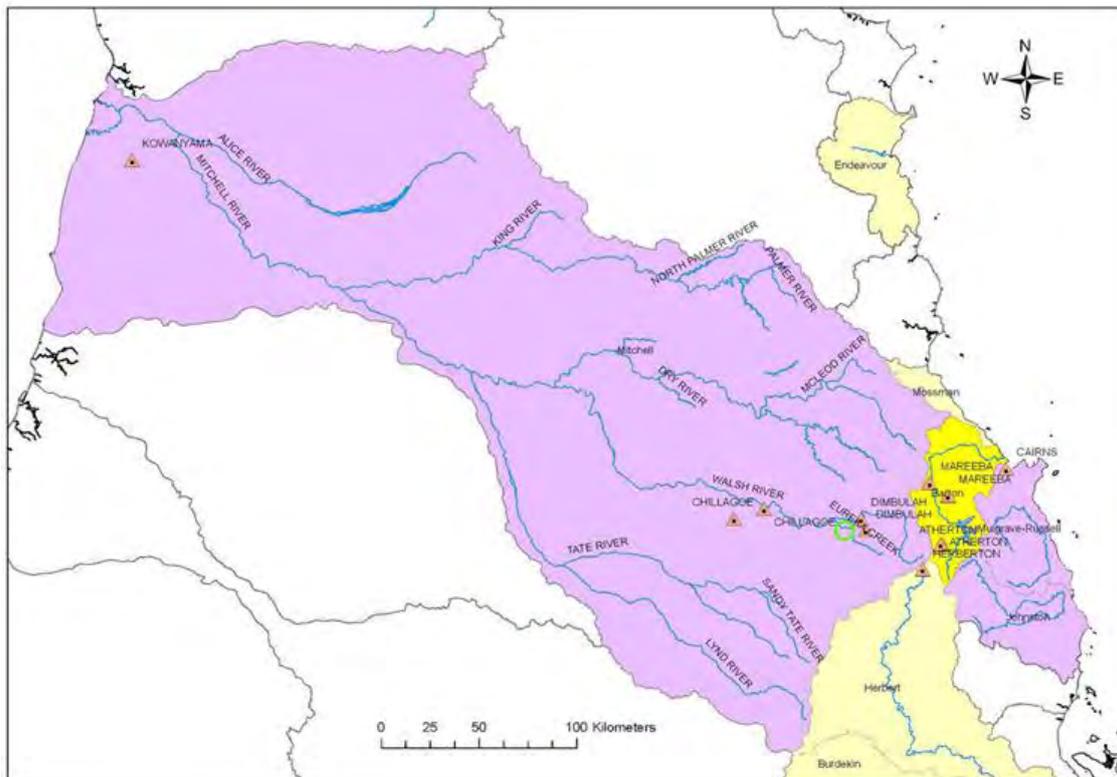
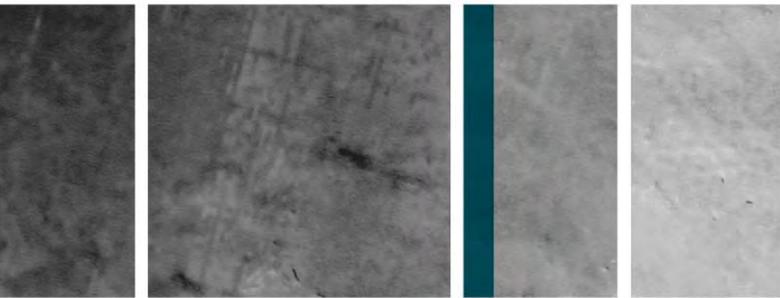


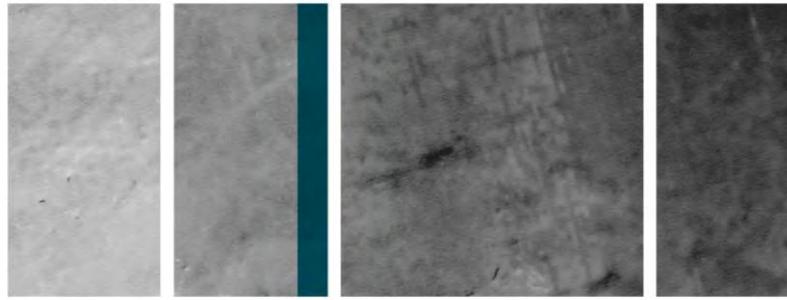
Figure 2: Location of Eureka Ck. Light yellow coloured catchments; Mozambique tilapia only present in catchment. Light purple; Spotted tilapia only present in catchment. Yellow colour both species present in catchment.

Although Fisheries Queensland immediately made a decision to carry out fortnightly surveillance and electrofishing to remove tilapia from Eureka Creek, the ability to respond to the incursion over the January to April 2008 period was restricted due to the seasonal flooding associated with the wet season. Only juveniles of a single year class were found during the surveillance for this period.

More regular fortnightly surveillance commenced after the wet season floods had subsided. During that time no tilapia was observed or caught either in the Walsh River or in the lower section of Eureka Creek. However, two (2) adult sized tilapia were removed and a further two (2) observed in a pool immediately downstream of the Chillagoe Road crossing of Eureka Creek. Two nests of juvenile tilapia were also removed from this site. By August 2008, a total of 308 tilapia had been removed from Eureka Creek, with 275 of these removed from the nests. The surveillance and monitoring activities indicated that the tilapia were confined to a 3km stretch of Eureka Creek upstream of the Walsh River junction. Removal of a large number of juveniles indicated that tilapia infested Eureka Creek at least one season before and in August 2008 there was an established breeding population in the area.

Management Options

- Do nothing
- Continue fish down: Electrofishing
- Attempt eradication through use of a piscicide in the creek waters



Intensive manual removal by electrofishing provided some control of tilapia numbers over the short term, but it was recognised that subsequent wet season floodwaters could quickly spread tilapia over a large area making their control or eradication impossible. The decision was made to attempt eradication.

Preparation

Eureka Creek is part of the water distribution network of the Mareeba Dimbulah Irrigation Scheme and is managed by SunWater Inc. A proposed procedural plan was developed in conjunction with SunWater Inc for the application of rotenone to a five kilometre section of Eureka Creek. The proposed procedure was as follows:

1. Turn off water supply and allow to stop flowing and form pools.
2. Remove as many native fish as possible from the area being treated
3. Install bund walls (top and bottom of 5km)
4. Apply rotenone (piscicide)
5. Cleanup and bury dead fish
6. Test for rotenone presence
7. Turn on water supply and notify landholders
8. Re-survey Walsh River and Eureka Creek

Consultation on the procedural plan was then undertaken with Commonwealth, State and Local Government Agencies (Sunwater, Environment Protection Agency, Natural Resources and Water, Wet Tropics Management Authority, and Tablelands Regional Council), Stakeholders and Non-Government Organisations (North Queensland Pest Fish Committee, Cape York NRM groups, catchment groups, James Cook University, CSIRO, Mitchell River Catchment Group, Northern Gulf Natural Resource Group), local landholders and traditional Indigenous owners downstream and upstream and through who's traditional lands Eureka Creek flows. Bank side meetings and demonstrations of techniques were also undertaken during these consultation processes. Information on water requirements for domestic, agricultural and stock use was obtained and concerns addressed. Permission was obtained from landholders for access and burial of dead fish.

Field operations

The agreed procedure commenced on 12th October 2008 with the irrigation supply water being turned off at the inflow feeding the Solanum Weir to the junction with Walsh River section of Eureka Creek. Bund walls were placed at the upstream site of Eureka Creek road crossing and at the top of the pool above Pinnacle Creek junction with Eureka Creek as the downstream site. Installation of bund walls was delayed due to ground water seepage taking longer than expected to stop flowing. Native fish were removed from four main water holes with 500 removed over 5 hours from these pools. The piscicide rotenone was applied to all water at the permitted maximum concentration. Application of the rotenone to all the water in the stream section being treated took a total of two days despite the Plan allocating one day.

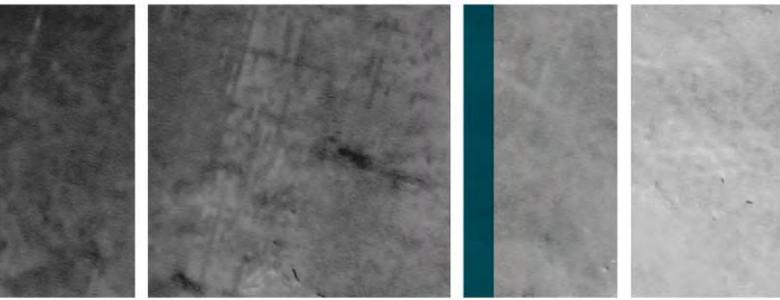


Figure 3: Rotenone being mixed and pumped to required tanks.



Figure 4: Applying rotenone to a larger sized pool.

An Application Coordinator was responsible for predetermined volumes of rotenone to be added to each pool and coordinating water bodies to be treated. Two people were responsible for positioning a vehicle with mixing tank near the application site, mixing the rotenone and providing the allocated volume to the application tanks. A large 800-L application tank and pump mounted on a vehicle was used by three people applying the rotenone to the larger water bodies. Two quad bikes with 30-L tanks mounted were used by four people to apply the rotenone to smaller water bodies.

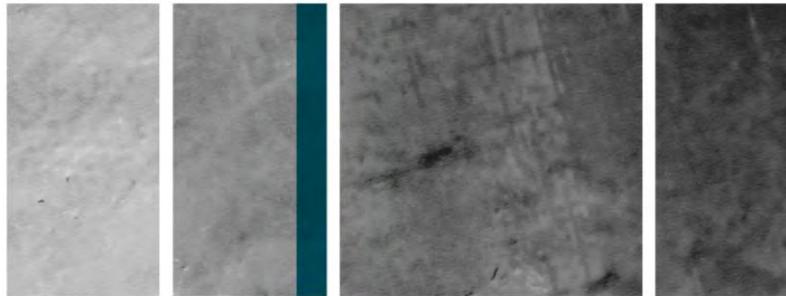
After this the following operations were carried out;

- Removal and burial of dead fish was carried out over two days.
- Water and soil samples were collected from the furthest upstream and downstream pools in the treated stream and sent for testing the presence of rotenone.
- Electrofishing was undertaken in four sites to sample for any live fish present.
- The water flow was resumed in the stream and the bund walls allowed to be breached. Full flow returned to the stream in two days.

Brief results

The eradication of tilapia from Eureka Creek using rotenone resulted in removal of 34 tilapia. All the tilapia belong to the species *Tilapia mariae* (spotted tilapia or black mangrove cichlid) except one which was an adult size Mozambique mouthbrooder (*Oreochromis mossambicus*). Electrofishing surveys carried out after the application of rotenone did not result in any live tilapia or any other fish species. The effect of the application of rotenone on those native fish that were not removed prior to the application of rotenone was devastating with over 10000 individual native fish removed and buried.

Approximately 60 freshwater turtles were also affected by the application of the rotenone. These turtles were identified as sawshell turtle (*Wollumbinia latisternum*) which are common in Queensland waters. The most affected turtles were mainly adults and sub-adults from both sexes. Twenty (20) turtles were rescued, successfully nursed back to health and were relocated upstream of the treated area.



Post application electrofishing surveys showed the number of native freshwater fish species returned to pre-application levels within one month of the event. Subsequent surveys up to two years after the application of the rotenone have found no further occurrence of any species of tilapia in Eureka Creek.

Key findings

The Eureka Creek tilapia incursion exercise shows that there are certain scenarios where a piscicide can be used in the eradication of a pest fish. Use of a piscicide for eradication of a pest fish is not, however, for every pest fish incursion.

Dealing with the large amount of collateral damage that results from the application of a piscicide to a natural waterway needs to be considered carefully. In this case, physical removal of every dead fish could not be achieved. Engaging more help in cleaning up after the application of the rotenone would have resulted in cleaner conditions when the water flow was resumed in the water course.

This scenario showed that the proposed procedure needs to be very clear. When discussing the procedure with stakeholders, government departments, land holders and indigenous groups, there needs to be a high degree of flexibility with outcomes to suit all. Because there is the need to consult widely to all stakeholder levels, there needs to be a lot of time allocated for discussions and agreed processes.

References

- Pearce MG (2009a). Development of a Surveillance Program for Catchments Vulnerable to the Spread of Freshwater Exotic Fish with particular reference to the Gulf of Carpentaria Catchments.
- Pearce MG (2009b). Results of the Pest Fish Surveillance Program: 2006/2007.
- Pearce MG and Hedge S (2009a). Results of the Pest Fish Surveillance Program: 2007/2008.
- Pearce MG and Hedge S (2009b). Results of the Pest Fish Surveillance Program: 2008/2009.

Questions

Comment: This case study is really, really important for us nationally for pest fish control and emergency response, because too often, the response from decision makers is that it is too hard and we cannot do anything. This is the only case I know about where something has happened and it has worked so it is really important to produce a document that can be tabled and we can say it has worked and it has cost this much money, and it is possible.

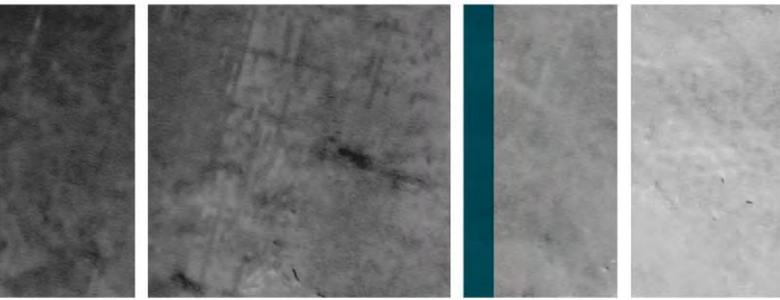
Malcolm: We will be producing a Case Study through the IA CRC and it will be available for people through the PestSmart website (see www.feral.org.au ed.)

Q: Where do the tilapia go during the rainy season when the rivers are flowing?

Malcolm: The rainy season is a problem for movement. There is not much information for *T. mariae* on that. For *O. mossambicus*, we had our experience from the Burdekin River that they move a fair way. What we know now is that for *T. mariae* they do not need the flow stimuli.

Q: You said that the local people fish, do they fish for tilapia and do they eat it?

Malcolm: Local people were not particularly targeting tilapia in Eureka Creek but we know that in other areas where they have been established for a long time there is fishing for them, both for bait for barra and reef fishing, and for food as well



Q: The costs of surveillance for pest fish are a significant issue, do you think you can hand over the role of surveillance to the community and would this work in terms of getting an early warning?

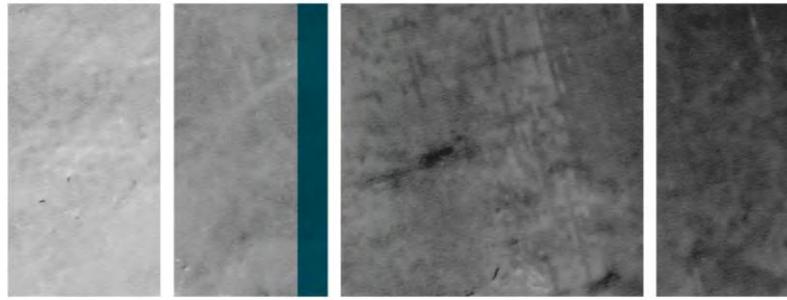
Malcolm: That is something that we have been exploring in talking to catchment groups and one of the things that we are hoping to get out of these sessions is new tools for surveillance.

Q: Based on your experience, if we had to launch a rapid response somewhere, given the amount of consultation that is required, how soon could you actually get out and rotenone an area?

Malcolm: The way I would define a rapid response is getting to the incursion and finding out if it is breeding and starting a fish down, that is the rapid part. Everything else is the negotiation phase.

Q: Do you think that this project could have proceeded if SunWater was not able to turn off the water into the stream:

Malcolm: We explored that with land-holders and EPA and others and we felt that it would not have happened.



Tilapia in a potable water supply – an overview of potential water quality and operational risks

Rob Hunt¹

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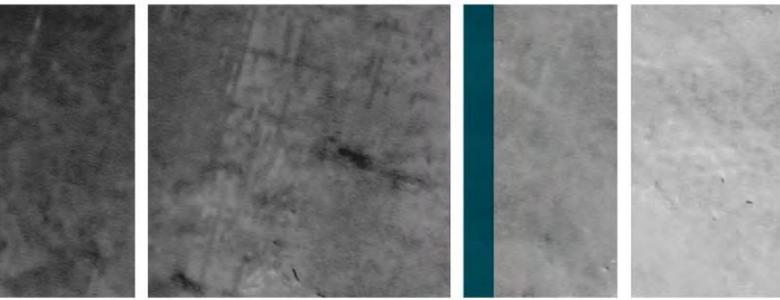
Overview of Townsville's water supply system

Lake Ross is a 236,000 ML waterbody located on the Ross River immediately upstream of the City of Townsville. Impounded by Ross River Dam, it provides significant flood mitigation and water supply benefits to the Townsville community (Figure 1).



Figure 1: Location of Lake Ross and other important water supply infrastructure in the Townsville Region.

Lake Ross provides approximately 80% of the water supply for the city, making it an essential supply source. The remaining 20% of supply comes from the Mt Spec system fed by Paluma Dam and stream flow from the Paluma Range to the north of the city. During extended drought periods when the storage levels in Lake Ross reach 5%, the supply is supplemented by pumping Burdekin Dam water via the purpose built Haughton pipeline. This water is delivered to a feeder stream of Lake Ross, mixing with the lake water before being treated at Douglas Water Treatment Plant. Deferral of pumping is primarily to avoid high water and electricity costs wherever possible. Historically the 5% trigger for pumping has been reached 1 in 10.6 years.



Physical and ecological attributes of Lake Ross

Lake Ross is a large shallow storage with an average depth of less than three metres when full. The lake has extensive shallow margins with around 54% of the storage supporting dense beds of submerged or semi submerged aquatic macrophytes. These shallow habitats are considered highly suitable tilapia habitat and no known chemical or physical barriers exist to prevent rapid colonisation.

Fisheries assemblages of Lake Ross

Comprehensive fisheries surveys undertaken in 1982 and 1999 indicated that no tilapia were present in Lake Ross, despite there being infestations in the lower Ross River since the 1970's. Ross River is renowned for its diverse population of introduced fish species. The absence of Tilapia and all other introduced species (with the exception of gambusia, or mosquito fish) is attributed to Lake Ross being closed to public access.

Tilapia (*Oreochromis mossambicus*) were first recorded in a feeder stream (Sachs Creek) in early 2005 and their presence in Lake Ross was immediately confirmed by Fisheries surveys. The suspected source was tilapia held in a private dam in the nearby Oak Valley Rural Residential sub-division moving downstream during the wet season. By late 2005 tilapia were being sighted in most feeder streams, and studies by James Cook University Fisheries Biologist Allan Webb indicated that tilapia already contributed the dominant biomass in gillnet sampling. Based on comparable infestations a significant population increase was expected over a five year period.

A significant dam upgrade undertaken between 2004 and 2007 (during which time the dams full supply level was temporarily reduced to 36%) may have temporarily prevented tilapia numbers from reaching their potential. During the upgrade, a high proportion of the dams' shallow margins were not available as breeding habitat and may have prevented the early establishment 'boom' seen in other locations. Nonetheless tilapia numbers are increasing and since 2007 the lake has filled every wet season and water levels have not dropped below 60%.

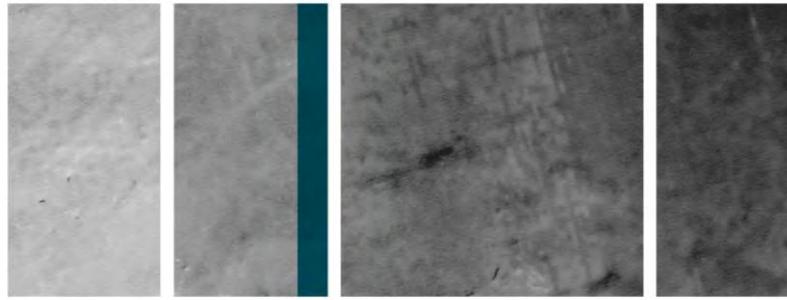
There is anecdotal evidence that earlier reports of tilapia in a farm dam in the (uninfested) Ross Dam catchment may have been confused by the presence of tilapia in the Ross River below Ross Dam. A further fishery survey is proposed to quantify the proportion of biomass that tilapia represents.

Risk to water quality and water supply

There is a relatively small body of research on the impacts of Tilapia on water quality. Nonetheless some studies indicate that tilapia infestations can have a significant impact on water quality, and pose a potential threat to water supply. Impacts include:

- Enhanced nutrient cycling
- Increased turbidity through disturbance of sediments, and consumption of aquatic macrophytes
- Eutrophication via phosphorus excretion
- Increased total phosphorus, chlorophyll a and cyanobacteria levels
- Very high respiration rates leading to dissolved oxygen decline.

Tilapia are known to have a potential biomass of >1,000 kg/hectare, placing significant pressure on native fish stocks and aquatic environments. Current operational procedures involve drawing down Lake Ross to 5% prior to supplementary pumping from the Haughton pipeline. Concentrating a large biomass of fish to a relatively small waterbody during drought



poses a potential risk to water quality. The potential impacts on dissolved oxygen levels, and resulting fluctuations in water chemistry could lead to mass fish kills and significant decline in raw water quality. If water quality parameters were to exceed critical design limits of the existing water treatment infrastructure, continuity of water supply may be affected.

In addition, recent water supply modelling which includes moderate population growth forecasts and climate change influences, indicates Townsville can expect more frequent and prolonged drought periods and subsequent reliance on supplementary supply from the Haughton pipeline.

Impacts on future water supply management

Whilst not a driving factor in any detailed options analysis, raw water quality risks have been incorporated into Townsville City Councils' Integrated Water Use Strategy to plan for future water source management. Growth in demand will inevitably drive capital upgrades in supply and treatment capacity. This is a key factor in ensuring Townsville City Council delivers an acceptable level of service for its customers.

A Multi-Criteria Assessment was undertaken by council to assess the net present value of a range of supply options and risks to supply reliability. The results indicate that supplementing Lake Ross earlier by changing the pumping trigger to 10%, will help to defer capital upgrades, with the added benefit of reducing the risks of water quality decline by delaying the drawdown of water levels in Lake Ross.

The Multi-Criteria Assessment has been fed into the Water Supply Strategy to guide the order of infrastructure development to deliver the acceptable level of service. The preferred option to commence pumping at 10% storage volume provides significant capital saving and an improved level of service to approximately 1 in 22 years. The option also partly addresses the tilapia risks to raw water quality by deferring drawdown of the lake water level. However some residual risk remains during periods of prolonged drought when water levels will still decline to 5% and less. The current wet cycle has effectively deflected any significant threat posed by tilapia to this water source.

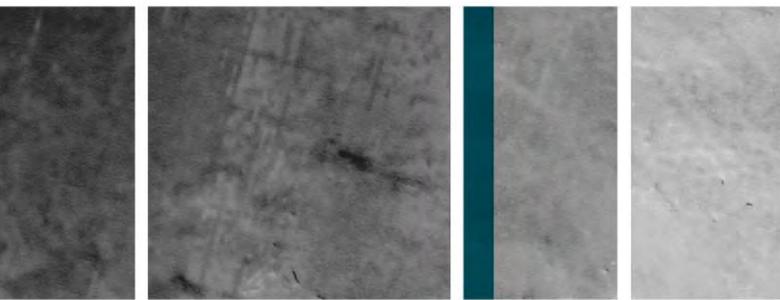
Recommendations for future management of Tilapia in Lake Ross

Water Industry legislation obligates water suppliers to formally identify, assess and manage risks to all aspects of the water supply chain. Based on the limited body of literature focused on water quality impacts, it is impossible to quantify the risk that tilapia pose to raw water quality of Lake Ross. A risk review of tilapia has concluded that the consequences of an interruption to supply are significant and the overall risk justifies further monitoring. A greater understanding of water quality impacts as the tilapia infestation matures is highly desirable.

Accordingly, Townsville Water propose to monitor the tilapia population in Lake Ross and conduct a follow up population and biomass assessment in the future, now that water levels have returned to full supply level. Existing water quality monitoring is being continued and will be closely analysed during the next drought period when lake water levels recede.

In addition Townsville Water has reviewed management and intervention options:

- Biomanipulation via predatory fish stocking is an as yet unproven method of tilapia control. Further, Lake Ross is closed to public access to protect potable water quality, so there is little incentive to undertake fish stocking.
- Recreational fishing of tilapia is currently not permitted in Queensland and again due to the lack of public access to protect water quality, there is no means of

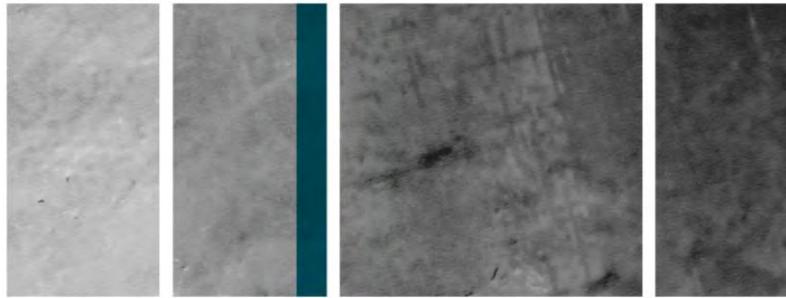


implementing this method without significant policy changes at the state and local government level.

- Trapping of tilapia has been inadvertently undertaken by Townsville Water during spillway flow events in 2007 and 2008. Large numbers of tilapia (up to eight tonnes) were killed and removed from below Ross Dam Spillway following closure of spillway radial gates. However such incidents are now avoided by modifying gate closure sequences to avoid non-target species being harmed and to prevent workplace health and safety risks to staff undertaking clean-up of fish kills. These incidents do however highlight that tilapia have a strong attraction to flow and can be trapped in large numbers.
- Commercial fish down is generally considered more effective and manageable than recreational fishing. However it is inconsistent with the existing state government policies on commercial fishing in freshwater. The success of any fish down program would be reliant on proving the effectiveness of a fishing apparatus to catch tilapia while minimising the take of non-target native fish and other fauna. The research and development of lures or attractants for tilapia would be of considerable value to progress this option.
- Beneficial re-use of tilapia taken via commercial fish down is also worthy of consideration. Townsville is a large regional centre located immediately adjacent to the significant agricultural districts of Hinchinbrook and Burdekin. Beneficial re-use of fish for biofuel, fertiliser and soil improver have been proven in Australia and internationally.

General tilapia management recommendations

- Containment of tilapia infestations should continue to be a high priority for fishery managers, in particular the prevention of spread into the Gulf and Murray-Darling Basins. However the importance of local un-infested sub catchments should not be discounted. These areas are typically above fish movement barriers such as waterfalls and provide important refuges free of tilapia. They often contain high levels of endemic species that further justify their preservation.
- Further consideration of 'active intervention' where exceptional circumstances or unacceptable risks exist should be facilitated.
- Depending on the outcome of water quality and tilapia population monitoring, Townsville Water may need to enter into discussions with state government fisheries managers regarding the impact of existing policies on commercial fishing and beneficial re-use options.



Questions

Q: Has Council looked at possibly using the tilapia for compost for parks and gardens?

Rob: No we haven't. We are looking at managing to avoid the scenario where we would need to do that. We may explore some of those type of options in the future.

Q: What happened with the large fish kill and was there any community involvement or response?

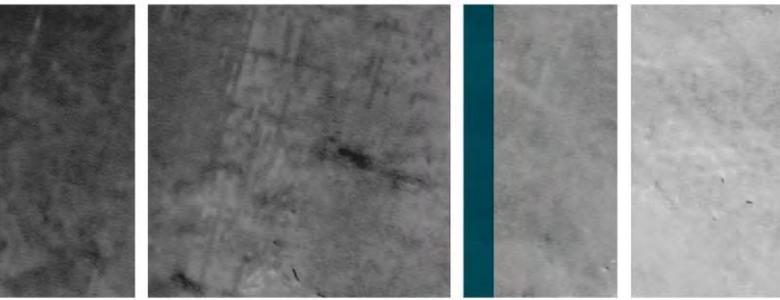
Rob: There was a lot of community involvement. The fish kill was driven by DO, the biomass was 95% tilapia and the rest was natives. They had to be physically manhandled out of the waterway, put into skip bins and taken to the tip and buried. Regarding community involvement, when we knew the fish kill was going to happen we got the fish kill trailer and rescued a lot of native fish such as barra and other natives.

Q: In terms of how the tilapia may have ended up in there, was that based on observations of dams upstream with tilapia in them?

Rob: There was anecdotal evidence that the outbreak within the rural residential area was actually reported a couple of years prior. I can understand if that is true why it wasn't acted on because you report it to an 1800 number in Townsville and Townsville has got them already so the response is forget it. So that is why I emphasise the point that we need to be really careful about where they are because there are parts of catchments that aren't actually infested because there are natural barriers to their movement, and they will remain so provided people don't move them in there.

Q: Don't you think that the Mozambique tilapia can actually play the role to keep the lake water quality relatively high? I understand that half the lake is covered with aquatic vegetation which tells me that the water is tending towards eutrophic. You have a balance between algae and water plants and presently most of the nutrients are locked into the water plants. If the algae take over which can happen in a eutrophic situation you suddenly have a bloom of algae then it would be nice to have fish that can consume the algae and convert it again. That is the kind of situation we have seen in eutrophic dams in South Africa that are also used for drinking water where the fish actually play a positive role in maintaining open water. Water plants and algae are channelled through the fish.

Rob: Valid point but the systems are not eutrophic is one point. There has also been no data to show that response in this system. We would need to model that response to be confident in forecasting that. There have also been some systems where the opposite response has occurred and there have been increases in turbidity. So it could be positive.



Electrofishing control of an invasive tilapia (*Oreochromis mossambicus*) population in northern Australia

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Objectives / Background

Combating the spread of invasive fish is problematic, with eradication rarely possible and control options varying enormously in their effectiveness. In two small impoundments in north-eastern Australia, an electrofishing removal program was conducted to control an invasive tilapia population. We hypothesised that electrofishing would reduce the population density of *Oreochromis mossambicus* (Mozambique tilapia), thereby limiting the risk of their downstream spread into areas of high conservation value.

Summary of findings

We sampled the impoundments by electrofishing monthly for 33 months. Over this period, there was an 87% decline in catch per unit effort (CPUE) of mature fish, coupled with a corresponding increase of 366% in the number of juveniles, suggesting a density-dependent response in the stock-recruitment relationship for the population. Temperature was inversely related to CPUE ($r = 0.43$, lag = 10 days), implying greater electrofishing efficiency in cooler months. The reduction in breeding stock is likely to reduce the risk of spread and render the population vulnerable to other control measures such as netting and/or biological control.

Key messages and Management / Research recommendations

The study suggests routine electrofishing may be a useful control tool for invasive fish in small impoundments when the use of more destructive techniques, such as piscicides, is untenable.

Questions

Q: Did you play with some of your electrofisher settings to see if you could improve catchability?

Paul: Yes, with *T. mariae* a lower frequency (Smith-Root equipment) seems to work but with *O. mossambicus* you are looking at full power of 1000V, 120 and 80%, pretty much cranked right up, which can be a problem for native fish.

Q: Do you have any idea why tilapia are having this flight or spin response to the electrofisher that you don't see with the native species. If you do know why, is there any way you can improve it to make it easier to catch them?

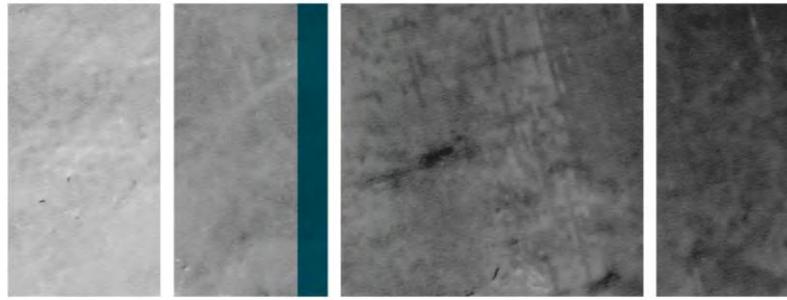
Paul: There have been a couple of studies that have looked at it also some tank trials have been done. I think it might have something to do with the conductivity of their flesh and their body shape but I don't have a definite answer.

Q: Does their response dramatically cut down the number of fish that you are able to catch?

Paul: Definitely, we found *T. mariae* harder than *Oreochromis* to electrofish and it would not be a good reduction method in an open stream.

Q: Is it the *Oreochromis* adults, juveniles or both that move and does this offer potential for control?

Paul: I don't think we really know. In the literature it is usually the juveniles that move and the adults have home ranges, but then you will get an adult that up and moves some distance.



Can sterile males be used to stop the spread of tilapia into the Murray-Darling Basin? Testing the options

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³Murray-Darling Basin Authority, Canberra, Australia

Objectives / Background

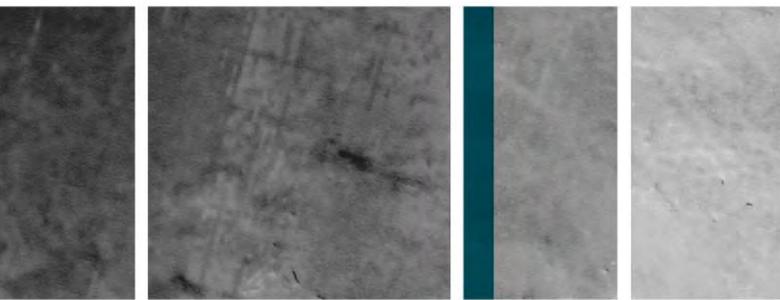
Tilapia has dominated natural waterways into which it has been introduced and populations are established in close proximity to the Murray-Darling Basin (MDB). The Murray-Darling Basin Authority (MDBA) recently commissioned Queensland Department of Agriculture, Fisheries and Forestry (QDAFF) to estimate the potential range tilapia might attain in the Murray-Darling Basin and to undertake an impact assessment to investigate the likely impacts on natural, social and economic assets (Hutchison et al 2011). Key findings are:

- Based on conservative estimates, tilapia would occupy a core distribution equating to at least 50% of the MDB from the northern Basin in Queensland to the Lower Lakes and lower Murray in South Australia.
- If minimum water temperatures rise by just 2°C (plausible under moderate climate change scenarios), then Tilapia could colonise the entire lowland region of the MDB, including most of the southern region.

Key Tilapia impacts recorded both in Australia and overseas include major declines in commercial and traditional fisheries (up to 67-80%), fish extinctions, destruction of aquatic plants and declines in water quality (including potable water supply). It is likely that an introduction of tilapia would lead to reduced abundance of at least two recreational fish (Freshwater catfish and Silver perch). Tilapia are expected to produce stunted, high-density populations under ephemeral conditions in the MDB. This may cause food chain effects that flow on to other recreational fish (Murray cod and Golden perch) and aquatic fauna and they are likely to dominate drought refuge areas. Tilapia may have negative effects on Basin water quality, including potable sources, due to their feeding habits and regular die-offs of tilapia under cold winter conditions.

The key recommendation from this report is that programs promoting early detection and prevention of tilapia infestation of the Basin should be made a high priority.

The use of sterile males as barriers to range expansion has a long and successful history in insects, and has been proposed in fish (eg at a 2010 international workshop on genetic biocontrol of invasive fishes), but never attempted. We have submitted a proposal to the Commonwealth government Biodiversity Fund to test this option in tilapia. If successful, this project will contribute to developing a new tool to minimise the rate of spread of not just tilapia, but possibly a wide range of other lower vertebrate pests, both aquatic and terrestrial, most of which are currently spreading in a largely, if not wholly uncontrolled manner. Successfully developed, this technology could also be used to reduce the rate of spread of tilapia into the Gulf of Carpentaria and northern Australia, where it threatens both environmental assets and wild fisheries. It also has potential as a new option for a "rapid response" eradication effort against this and other pest fish species when new invasions are



detected, particularly in situations where other available methods (eg broad-spectrum piscicides) are not desirable (eg in areas with threatened or endangered species).

The central activities of the proposed project are;

1. production of chromosomally manipulated tilapia using a suite of more-or-less off-the-shelf methodologies,
2. pairing them with wild-type females with and without the presence of competing wild-type males to assess the acceptability of the manipulated males to females.

The work will be done in small aquaria at the CSIRO/QDAFF facilities on Bribie Island (Queensland). Chromosome manipulations will be done using both temperature/shock treatment, to produce triploid males, and a combination of hormone treatment and backcrossing to alter ratios of X and Y chromosomes. Both techniques are well established, have been applied previously to tilapia and are a common practice internationally in aquaculture (in order to produce all-male populations). However, the use of this technology in pest fish management is untested, therefore the reproductive fitness of these fish in competitive situations has never been determined. We will do this assessment by pairing chromosomally manipulated fish with wild-type partners and determining whether or not they breed, how frequently they breed and the viability of any eggs produced (they should all be infertile), comparing the results with wild-type control pairs. We will also put chromosomally manipulated fish in with a wild-type male and female, to determine if the latter shows any preference between the two male types.

Summary of findings

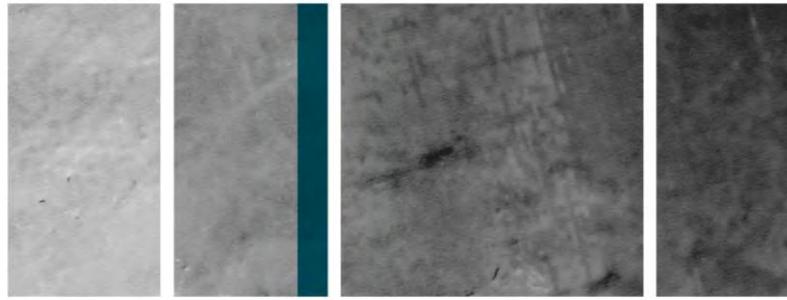
Chromosome manipulations have previously been done in tilapia using both temperature/shock treatment, to produce triploid males, and a combination of hormone treatment and backcrossing to alter ratios of X and Y chromosomes. Both techniques are well established. No work has yet been done on the possibility/viability of YY females, though there is an unconfirmed report of YY females having been produced in *Oreochromis niloticus*. Production of YY *O. mossambicus* will depend in large part on the nature of chromosomal sex determination in the species. Most reports describe it as male heterogametic, but there is one recent study suggesting it is female heterogametic. That same study noted, however, that the fish examined might have been hybrids.

Key messages

- The release of sterile male tilapia, produced using conventional chromosome and hormone treatments, could be an effective way to slow the spread of tilapia. A project to develop these males and to test their competitiveness against wild type males has been submitted for funding to the Commonwealth government and, if successful, will be carried out at Bribie Island.
- YY females could be a useful intermediate stage in developing a long-term control strategy against tilapia nationally, but is critically dependent on the viability/fitness of the females. We propose to test this as part of the proposed project.

Management / Research Recommendations

Few options exist to slow the spread of tilapia. Sterile male release is an environmentally benign and cost-effective option that should be explored.



Knowledge gaps

Fitness of sterile male and YY female tilapia, which could have a huge impact on the viability of the approach.

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Questions

Q: For the triploid males you said the density of stocking is really important especially if you are going to use it as a barrier, so one of the things that jumps out at me, especially for *Oreochromis*, is how you would maintain the densities you need?

Ron: We haven't looked all the behavioural issues. If you decide to do it, then it gets down to the where, when, how questions. If you have high mobility of males and they don't stay where you want them, then it may not work as well. So it may work better for *T. mariae*.

Q: Second question is about the daughterless procedure. You said you need to know the genetic code of the species to insert the genes. How does the hybridisation potential of these species affect what you can do with daughterless technology?

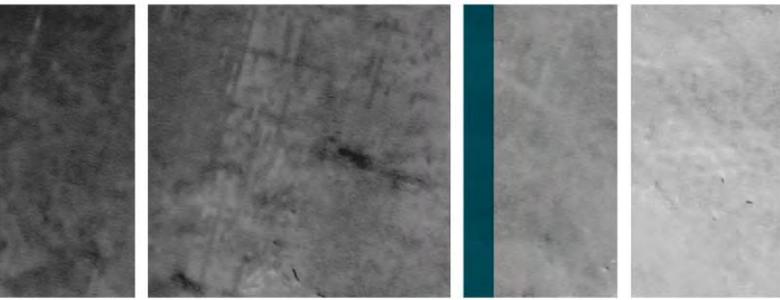
Ron: Short answer is until we look carefully we don't know. The longer answer is that the promoter sequence that we use to turn on the gene is usually about 500 to 1000 base pairs. Usually there is a conserved section that is going to be very similar across a range of species, so we may be able to come up with a generic tilapia control option or we may opt for something that is very species specific.

Q: At least four of the tilapia populations have really low allelic diversity, so they essentially lack heterozygosity. Does that mean that it would probably be easier to establish the daughterless technology in these populations?

Ron: Yes, it probably would do because we would only have to get a single copy or a single sequence of the gene to work. So it should be easier to build the construct. Getting the construct into the fish before you can start releasing them into the wild takes 2 or 3 generations.

Q: Trojan Y was developed in the US, has it been used on anything yet?

Ron: No, the (US) states are not prepared to push the envelope. They are probably waiting for someone else to get it up and running.



Case study: Lake Barrine tilapia management

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The spotted tilapia, *Tilapia mariae*, was first detected in Lake Barrine, a maar crater lake located on the Atherton Tablelands in declared World Heritage and National Park area, in 2006 by staff of the local teahouse. A management plan was developed in consultation with traditional owners, National Parks staff and the local teahouse staff. The management plan options included (1) Do nothing, (2) Removal and control, and (3) Eradication. Traditional Owners and the local teahouse staff were not supportive of “doing nothing” as they were worried about the effects of tilapia on the environment in Lake Barrine. Use of the piscicide, rotenone, and explosives were considered as methods for eradication though both were rejected due to the size of the lake and National Park legislation covering the lake. The tools of electrofishing, line fishing and netting were assessed as methods for controlling the tilapia population. These tools were found to be ineffectual in controlling the tilapia population. The lakes’ yearly temperature profile was monitored to predict spawning behaviour, including timing and duration and maximum depth for spawning by tilapia. Further methods were explored to remove and control the tilapia numbers by targeting the different stages of the tilapia life cycle. Spawning structures were trialled to control egg numbers which showed that this species of tilapia would lay on an artificial substrate. Further work is required on trialling other types of substrate to improve efficiency of this method. Management tools were identified for controlling larvae and juvenile numbers of tilapia, however, further research is needed to refine and examine cost effectiveness of these tools. Spearfishing was trialled as a management tool for controlling numbers of sub-adult and adult tilapia. The spearfishing trial showed spotted tilapia are easily spearfished and significant numbers of tilapia can be removed using low numbers of spearfishers.

[Abstract only provided]

Questions

Q: Thinking about their strengths and turning them into weaknesses, these fish are so successful because both the male and the female guard the nest and they both do it in slightly different ways, could you selectively take out one sex by spear fishing to enable predation by other species and also skewing the sex ratio?

Malcolm: I would agree that it is possible but it still may be possible for the other sex to defend the nest because of the aggressive nature of these fish.

Comment: As this is a control strategy rather than eradication, you need to know what level the populations need to be reduced to so that they do not have an environmental impact, so you would need to be doing some monitoring.

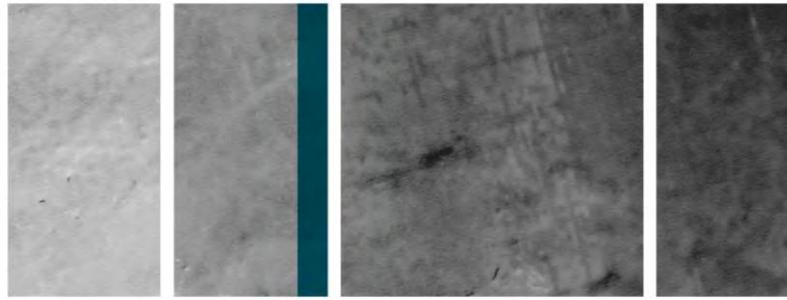
Malcolm: Yes we are aware of that and we do not actually know what the impacts of reducing populations will be, will it be through water quality or macrophyte growth

Q. What did you do with the fish you caught?

Malcolm: When we were electrofishing the system and catching quite a few fish, National Parks were concerned about the loss of nutrients from the environment through removal of the fish. Putting them back in the water would compromise fisheries legislation so we agreed to bury them on the edge of the lake.

Q: My question was whether they can be taken by the local communities to eat?

Malcolm: No, not out of the National Park.

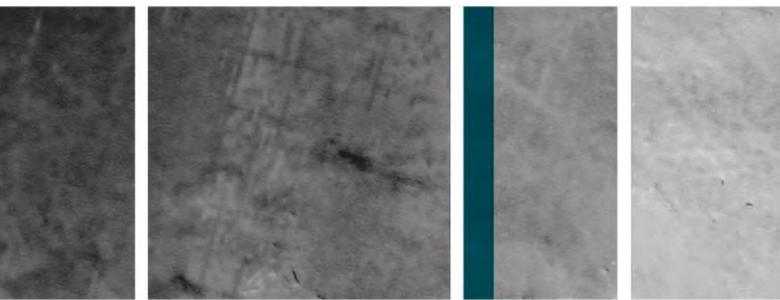


Q: You mentioned the use of Derris Dust or Derris root, which is found in local plants, does the local community have any knowledge of this or do they use it?

Malcolm: The traditional owners of the area do talk about a vine that they had used traditionally for fishing. They had forgotten that knowledge and it took them some time but they did eventually identify a species in the rainforest environment. It has subsequently been checked by JCU and it works well, although concentrations are a bit of an issue.

Q: In this case where you identified a relatively small number of main spawning sites, is it practical to try and exclude the fish from those sites and what impact that may have?

Malcolm: We did not get to that point and there may simply be other areas that they can use.



Overview of the Invasive Animals Cooperative Research Centre Freshwater Program pest fish research extension activities

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Summary

The Freshwater Products and Strategies Program within the Invasive Animals Cooperative Research Centre has been responsible for a portfolio of projects on freshwater pest fish over the past seven years. Projects included product development, field demonstration, and national and offshore collaborative research on carp and tilapia. The research program was designed to incorporate all areas of an integrated pest fish program:

- prevention and detection
- control options/techniques
- target species information
- support framework
- education/community engagement.

Research projects within all of these categories were initiated on both carp and tilapia in various parts of Australia.

The Invasive Animals Cooperative Research Centre (Phase one) concluded at 30 June 2012 and in the final six months primarily concentrated on concluding research projects and reporting and extending the results. The processes for extension of the Freshwater Products and Strategies Program included:

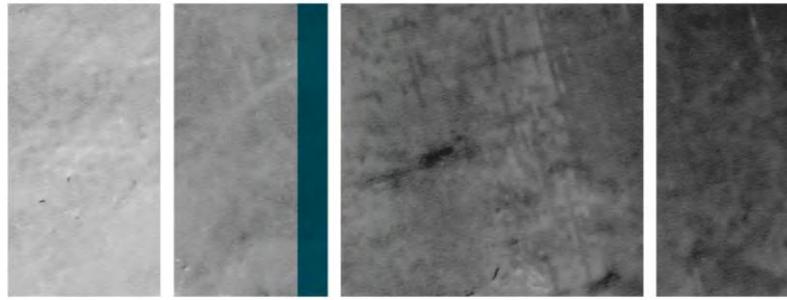
- the PestSmart RoadShow (National extension activities to directly demonstrate the use and benefits of new products to land managers and farmers, January to June, 2012)
- Pest Fish Management Forums for both tilapia and carp (May and June, 2012)
- pest fish toolkit initiatives (focusing on carp and tilapia).

The PestSmart toolkits

The PestSmart toolkits projects aimed to develop a web-based information package of factsheets and case-studies (in addition to reports and scientific journal manuscripts) on best-practice pest animal management. These were designed to guide and inform next users and assist them to utilise the research findings of the Invasive Animals Cooperative Research Centre work. The toolkits aimed to distil the seven-year research program findings to provide a legacy of innovations through an easy to use tiered approach. The 'toolkit' of information is accessed through the IA CRC PestSmart Toolkit website: www.feral.org.au/pestsmart/

The information available can be accessed in different ways, for example, by pest species, by information type (eg factsheet or report), or by relevance to different categories of user (eg land managers, community groups or students).

As new material has been added to the website, updates have been broadcast in 'Feral Flyer' the email news broadcast of the Invasive Animals Cooperative Research Centre (subscribe online at www.invasiveanimals.com), also via the PestSmart facebook page at facebook.com/Pestsmart, Twitter @PestSmartCRC twitter.com/PestSmartCRC and via the PestSmart Youtube channel: youtube.com/PestSmart



Tilapia toolkit materials

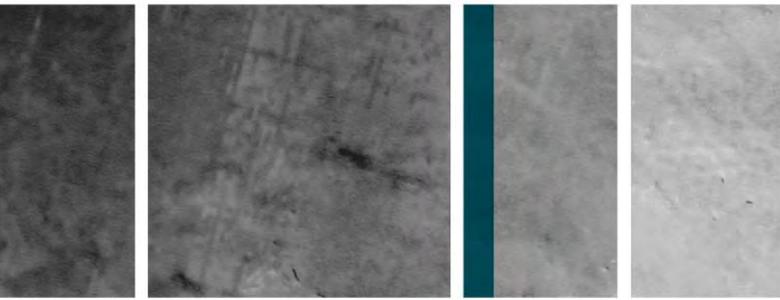
The tilapia toolkit consists of general pest fish management factsheets and a pest fish incursion decision support tool, specific *Oreochromis mossambicus* and *Tilapia mariae* information factsheets eg impacts of tilapia, biology and distribution. Management information is provided in the form of pest fish control case studies and research reports and journal articles.

Success

It is hoped that the toolkit will be accessed by individuals, fisheries managers, natural resource and catchment management officers, policy makers, funders, scientists. The toolkit has the potential to increase the awareness of the pest fish problem in Australia and options for control and management. It is anticipated that fisheries managers, natural resource and catchment management officers, policy makers, funders and scientists will use the information from the Invasive Animals Cooperative Research Centre work, accessed via the toolkit, to change operations, policy and investment.

Acknowledgements

The PestSmart toolkit writing team is acknowledged, as are the contributions of the Invasive Animals Cooperative Research Centre editorial and communications team.



Helping the community help us stop pest fish

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Objectives / Background

Mozambique tilapia (*Oreochromis mossambicus*) was illegally introduced into Queensland waters in the late 1970's and is now established within 19 of the 76 catchments throughout the state. Spotted tilapia (*Tilapia mariae*) have also been established in our waterways long term, however only 3 catchments have been compromised.

Tilapia infestations have largely remained on the east coast of Queensland and there is still a significant amount of water within the state that remains tilapia free. Some of Australia's most iconic waterways have remained unaffected, such as the Murray-Darling Basin, Lake Eyre and the Gulf catchments. These catchments are however extremely vulnerable to tilapia invasion, particularly the MDB as 3 of the 19 infected catchments border it. Fish surveys after the 2010/2011 floods identified tilapia within 3 kilometres from the upper Balonne-Condamine catchment in the upper Burnett River. As most tilapia invasions in Queensland are the result of human assisted translocation, these catchments are considered to be at high risk of infestation via illegal stocking, live bait escapees or ornamental fish dumping.

There have been new reports of tilapia in coastal catchments within Queensland that had not previously known to be infected by tilapia. *Oreochromis mossambicus* has recently been identified in the Mary, Don and Fitzroy River catchments as well as Baffle Creek. It is encouraging that a community member has reported all of these 'new' incidences of tilapia, suggesting that communication material is conveying the message to report pest fish sightings. However detection, albeit early in some of these cases, has not resulted in eradication options due to the location of the reported fish.

[Abstract only provided]

Questions

Q: Have you looked into the citizen's science research in the US. They are doing the very same things that you are interested in doing and they are focussing on the applications for both the management and the education side. We also trained hikers to identify invasive plant species.

Dani: Thanks for the information

Q: As there are some issues with using invasive species as bait for fishing, has there been any discussion at least in the M-DB about banning the use of fin fish as live bait?

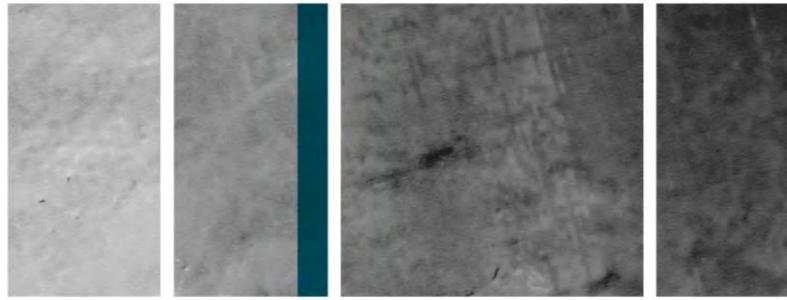
Dani: In Queensland we haven't got there yet as it is seriously opposed by recreational anglers. It may get there at some stage but not yet.

Q: The resources coming out are great and I am pleased that climbing perch is in there. At a community level we run a tilapia busters and we know it is not an eradication tool but it is done for education but even within the community group I am frequently hearing "they are in the river what is the point?"

Dani: The response should be that they are not everywhere, they are only in 19 of 76 catchments and you need to keep repeating that message. There are still some major systems and significant environments that they are not present in.

Q: Do you have any mechanism for formally assessing the uptake of the information?

Dani: We do not have the funding for it.



Social research to understand knowledge of, and attitude towards tilapia in communities within or nearby to the Murray-Darling Basin

Debra Doolan¹

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Objectives / Background

Tilapia are listed as a noxious fish species in Australian jurisdictions, which means that possession and sale of live tilapia (and in Queensland, live and dead tilapia) is illegal. Despite these legislative powers, tilapia have continued to spread throughout south-east Queensland to catchments that boarder the Murray-Darling Basin (MDB), and it is apparent that improved education programs are needed to increase community awareness of tilapia and other pest fish issues.

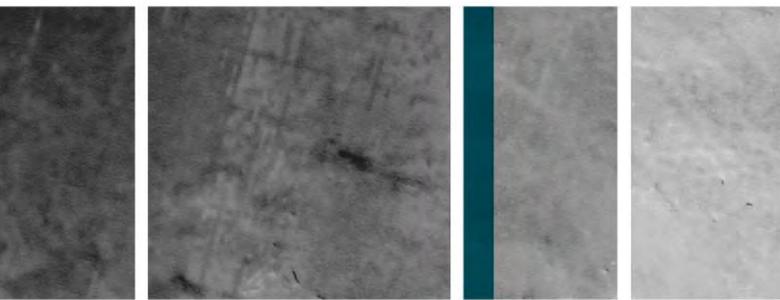
Environmental education programs are rarely assessed for their effectiveness, and there is often no information available on the background level of community knowledge and awareness of specific environmental issues. To aid the development of a tilapia education program, and to determine the program's success, social research was undertaken in areas adjacent to the boundary of the M-DB considered at high risk of tilapia incursion.

Social research surveys were conducted in both northern New South Wales and southern Queensland communities, in conjunction with a targeted education program. The survey data collected were used to determine knowledge of and attitude towards tilapia and other pest fish issues, which then helped to inform the development of an education program. This program was subsequently implemented in half of the surveyed communities, thereby creating 'tilapia educated' and 'not tilapia educated' communities. An additional 'after' survey followed the education program and was conducted to determine changes in tilapia knowledge in communities that were tilapia educated compared with those that were not.

The social research survey was developed to engage participants from three types of community groups. The first two groups were from the general (adult) community and were either selected randomly from within the community, or were targeted based on an interest or participation in activities or work relating to freshwater environments. In this report, these two groups are referred to as 'random' or 'targeted' survey participants respectively. The third group of survey participants consisted of school students in grades five and six. School students were included in the survey to determine their level of knowledge about pest fish and also to determine if the education program, which was targeted towards adults, would be effective in improving school students' knowledge of pest fish.

Summary of findings

This study has determined that the education program has been successful in increasing awareness of tilapia in tilapia educated communities, particularly in targeted respondents. In New South Wales, this group increased knowledge of tilapia by 120%. Tilapia educated communities in Queensland had a much lower percentage increase, but this is likely to reflect the relatively high level of knowledge in targeted respondents that already existed before the education strategy was implemented. The number of random New South Wales respondents from tilapia educated communities that considered tilapia to be a non-native fish also increased considerably after the education program, to a level that was comparable with the targeted groups. This indicates that the education program was effective in educating the broader New South Wales community about tilapia, not just targeted groups.



The recognised impacts of pest fish were also assessed and it was consistently observed that fewer respondents recognised that pest fish may impact local economies and reduce fishing opportunities, compared with harming river health/water quality and competition with native fish. This result suggests that while the community is generally aware that pest fish have an effect on environmental factors, they are not as aware of the impacts pest fish could have on the community.

The number of respondents that had received information about tilapia from government advisory materials increased after the education program, particularly for targeted respondents. This provides supporting evidence that the current tilapia advisory program has been successful in raising awareness about tilapia in Queensland and New South Wales communities. Random respondents advised the most important source of education was family and friends and fishing/general media, which may indicate that government advisory programs can result in indirect education of the wider community through word of mouth and the media.

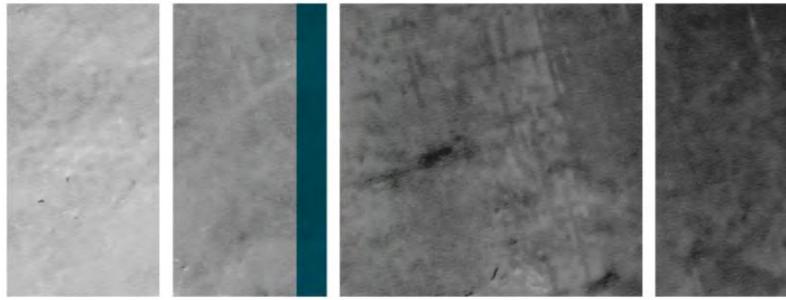
This survey determined that while many community members are aware they need to report pest fish sightings, many do not correctly know who to report them to. This issue is confounded by the fact that the relevant government departments in both states have had recent changes to their branding, and community members may not be aware of the current department name. Therefore, it is important that current contact details are prominent in all new advisory materials and/or for contact details to remain constant, where this is possible.

Survey respondents were also asked if they had stocked fish in natural waterways or farm dams, and if so where they sourced the fish from. This question highlighted the need to educate communities about permissible fish stocking activities. Approximately 8% of the respondents that had stocked fish advised they obtained their fish from local impoundments, other dams and drying water bodies. These stocking activities were unlikely to be authorised as they present a very high risk of pest fish translocation (only fish produced in accredited hatcheries are generally permitted by both New South Wales and Queensland governments to be stocked).

One aim of this study was to determine recognised terminology for use in tilapia or other pest fish advisory materials. The surveys confirmed the terms 'non-native fish', 'pest fish' and 'introduced fish' are more often recognised by survey respondents as terms that describe carp, compared with 'alien fish' and 'exotic fish'. 'Pest fish' was the most recognised term, and it is suggested that this is the most appropriate term to use in tilapia education programs.

The results of this survey have determined that 'not tilapia educated' communities often had a similar increase in knowledge compared with the 'tilapia educated' communities. Because this treatment factor is unable to be controlled, it is possible that there was a level of contamination of the data through word of mouth or individuals' travel movements. The results of future social research studies may be improved if the 'tilapia educated' and 'not tilapia educated' component is removed and the focus remains on 'before' and 'after' data collection. This would result in a more efficient use of resources and would improve replication.

Over 20% of grade five and six school students in New South Wales and Queensland advised they would let their pet fish go in a nearby creek or lake in both the initial 'before' and final 'after' surveys. In addition, general knowledge of pest fish was not greatly increased in communities that received education materials and therefore specific school education programs need to be delivered.

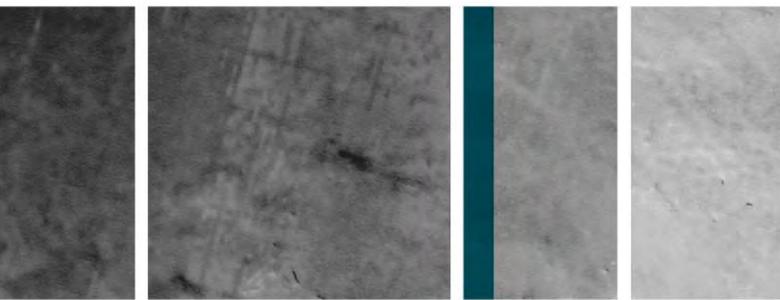


Key messages

- The level of knowledge about tilapia is very low in New South Wales communities. Queensland communities, which have been receiving tilapia education materials since 2005, have a much higher level of knowledge; however there is still a need to improve awareness of tilapia related issues.
- The education program implemented in northern New South Wales and southern Queensland was effective in increasing knowledge of tilapia, particularly in areas where knowledge was initially very low. Therefore, where an increase in stakeholder knowledge is required on a particular issue, government education programs should continue.
- The terms ‘non-native fish’, ‘pest fish’ and ‘introduced fish’ were confirmed as the most appropriate terms to describe tilapia as opposed to ‘alien fish’ and ‘exotic fish’. ‘Pest fish’ was the most recognised term by both Queensland and New South Wales communities to describe carp and therefore should be used in all future pest fish advisory materials.
- Indirect education programs delivered to the general community are not effective in educating school students. To increase knowledge of pest fish in school students, specific education programs need to be developed and delivered to schools.

Management recommendations

- Where education needs are identified for key stakeholder groups, it is recommended that relevant government (local or state) agencies continue to deliver specific targeted advisory material to increase awareness and understanding within those groups.
- This study, and others (Baker 2010), determined that people who visit freshwaters for fishing also visit freshwaters for other reasons. Therefore it is recommended that pest fish messages be targeted to a broad suite of stakeholders, including campers and picnickers.
- The terms ‘alien’ and ‘exotic’ are not well recognised or associated with pest fish. It is recommended that all future pest fish strategies, programs and advisory materials use ‘pest fish’ as this was the most recognised term. Other possible terms that could also be used include ‘introduced’ and ‘non-native’.
- This study has shown an increase in respondents’ knowledge of who to report a tilapia or pest fish incursion to after the education program. However, many community members are still unsure about whom to report sightings to. Therefore, it is recommended that in future education programs this message continues to be prominent.
- This study has determined that some fish translocations occur because people are trying to ‘rescue’ fish from drying water bodies in times of low rainfall. While intentions may be good, this practice is also illegal without a permit and may be a source of new pest fish incursions. It is recommended that legislation about



translocation of freshwater fish species is included in future pest fish advisory materials.

- The most popular activity students advised they participated in near freshwaters was fishing; however, the frequency of this activity by most students surveyed is relatively low. Therefore, it is recommended that communicating messages about tilapia to students may be more effectively delivered via class room activities, rather than through government advisory materials such as on-site (e.g. boat ramp) signs.
- In both the initial ‘before’ and final ‘after’ surveys over 20% of students in each state said they would let their pet fish go in a nearby creek or lake if they no longer wanted them. It is recommended this finding be addressed in future pest fish and ornamental fish education material developed for school children.

Acknowledgments

This project was conducted in collaboration with Queensland Fisheries and was funded by the Murray-Darling Basin Authority. The New South Wales Department of Primary Industries would also like to thank key stakeholders in each community who were instrumental in facilitating the targeted surveys.

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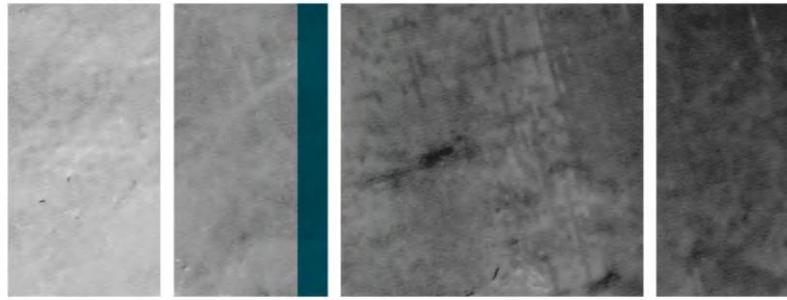
Questions

Q: What do you tell someone if they catch a tilapia by recreational fishing?

Debra: In NSW we have different legislation to Queensland and you are allowed to take them home and eat them. It does present a problem and every time I have done a workshop I get asked can you eat them and as soon as we say yes the level of interest drops. So our first message is if you see a tilapia, report it.

Q: What mechanisms are in place to act on reports of early detection and what can be done?

Debra: We have had some reports since we have been doing the education. Firstly we talk to them and try and get as much information as we can. We stay in contact and first go to the site with the person and survey it. These surveys in NSW have all turned out to be other species so far. If they were tilapia we would be doing everything we can to remove them.



Tilapia - Further Knowledge Requirements

Wayne Fulton

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As well as providing the opportunity to share current knowledge on tilapia, a forum such as this will usually also highlight what we don't know and what we need to know. A number of options were used to document knowledge gaps in relation to tilapia during this Forum;

- Authors were asked to include a section on knowledge gaps in their presentations.
- An active whiteboard was maintained during the Forum to be added to by participants at any stage.
- A brief discussion was held at the end of the Forum to bring forward further ideas.

The summary below pulls together suggestions provided through the latter two options and this is presented with no assignment of priorities. For the various authors view on knowledge gaps related to their particular subject, the reader may refer to the individual presentations. As expected there is often a fine line between what is an information requirement and a suggested management option. Where there can be an element of both in the suggestion (whether intended or not), it has been included in the summary. The general categories have been assigned during summary.

Prevention

- Community awareness of threats
- Assess risk of introduction to Australia eg from PNG: assess next pest issues
- Assess risk of spread in Australia eg inter-basin transfers
- Assess risk of spread from aquarium industry
- Determine vulnerable catchments
- Prioritise catchments and rivers

Detection/early warning

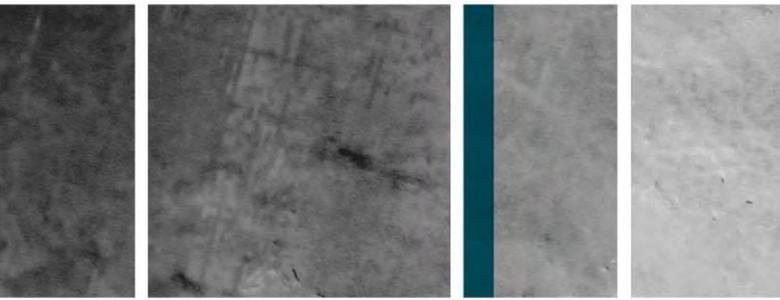
- Monitoring programs for sensitive areas
- Monitoring farm dams near sensitive areas

Response

- Emergency management system
- Further work on decision support tool

Education

- Examine best methods including cultural education
- Ethnic groups as targets (wrt identifying champions to lead)
- Vulnerable catchments communication
- Education- social research further to baseline data
- Pathway analysis targeting aquarium industry
- Community group options and community stakeholder involvement/engagement
- Champions of community work



Impacts

- How to identify if/when a control option is really necessary
- Determine reduction levels to see an effect
- Economic justification of management
- More information on impacts on native species

Environment

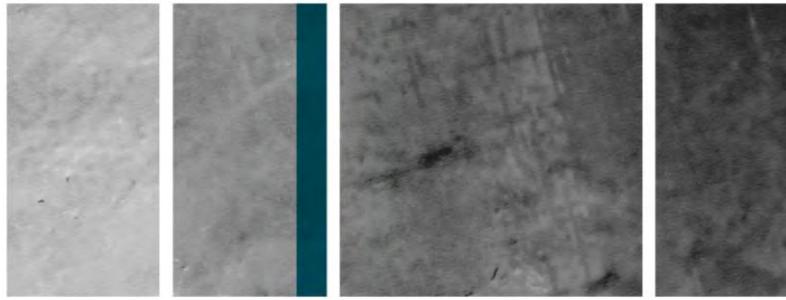
- Real effects of riparian zone restoration and snag addition
- Involvement of states...engagement for restoration
- Biology
 - understand the species in the Australian environment
 - relationships to environment

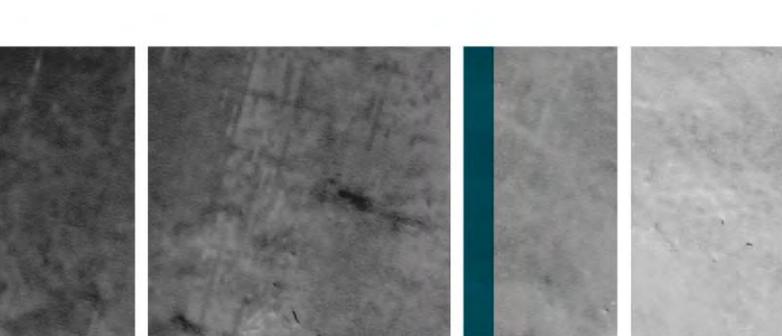
Control/management options

- Containment strategies
- Management options at various life stages
- Timing of control efforts
- Utilising cold-water gradients
- Working with water managers
- Localised effects of control - continue work on Herbeton
- **Attractants**
 - continue work on tilapia noises
 - work on 'other" attractants
- Cross reference genetics and introduction history.

Silver bullet options - do not lose sight of eradication as the preferred goal

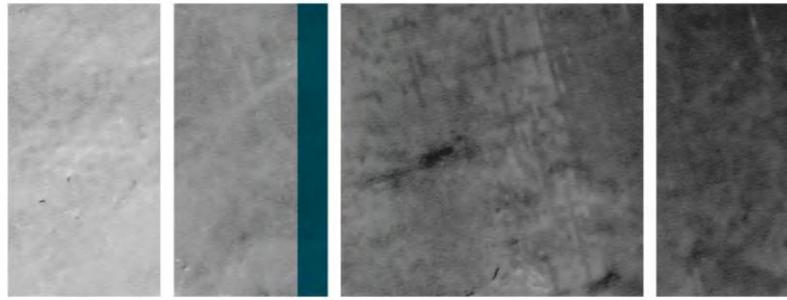
- At least some work on genetic and pathogen options





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