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The Invasion of Australia's Aquatic Ecosystems by Tilapia: Consequences of the 'Free-Ride'

Tilapia were first introduced to Australia in the 1970s for the aquarium industry. Since then they have steadily expanded their range in Queensland and Western Australia, and have recently been reported from the northern rivers of New South Wales. The geographic range of tilapia in Australia has primarily been expanded by recreational fishers. However, biological and behavioural characteristics, including traits such as aggressive behaviour, broad environmental tolerances and high fecundity, have aided the spread and subsequent establishment of new populations.

Many highly valuable aquatic ecosystems in Australia are at risk from the invasion and proliferation of tilapia. Consequently, preventing, controlling and mitigating their spread is an important environmental management issue.

The Invasion Success of Tilapia: Biological Factors and the 'Free Ride'

Tilapia are members of a diverse group of fish in the Chichlidae family, and include the genera *Oreochromis*, *Tilapia* and *Sarotherodon*. There are approximately 64 known species of tilapia in these three genera. All of these species are endemic to Africa, where they are part of diverse freshwater fish assemblages and support subsistence fisheries.

While some species of tilapia have economic value as ornamental specimens in the aquarium industry, globally, their main economic value is in subsistence, recreational and commercial fisheries, and in the aquaculture industry. Some species are also valuable biological control agents that control the prolific growth of invasive aquatic plants.

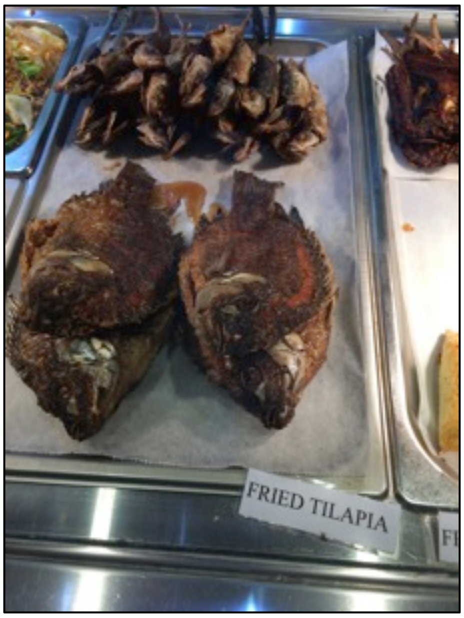
Mozambique tilapia (*Oreochromis mossambicus*) and Nile tilapia (*Oreochromis niloticus*) have been particularly successful in aquaculture ventures around the world. However, feral populations of these species have become established in over 100 countries. Within their natural ranges, both of these species co-exist with numerous other species in diverse freshwater fish assemblages, although Mozambique tilapia dominate fish assemblages in modified water bodies (i.e. impoundments) within its natural range. Where these species have become established in water bodies outside their natural range, they have become highly invasive and tend to dominate fish communities. Tilapia are aggressive and can outcompete native species for food and habitat resources, and can interrupt the breeding cycle of native species. They cause significant damage to aquatic ecosystems and water quality, especially when bed sediments are disturbed when buidling nests, and they often uproot significant areas of aquatic plants. In some regions of the world local fisheries based on native species have been lost as a result of tilapia displacing the native species. Nile tilapia is considered the most aggressive invader of all tilapia species, although Mozambique tilapia and three other species (*Tilapia sparrmanii, T. zillii and T. rendalli*) are also powerful invaders of aquatic ecosystems outside their natural range.

In Australia, two species of tilapia, Black mangrove or spotted tilapia (*Tilapia mariae*) and Mozambique tilapia (*Oreochromis mossambicus*), have established feral populations. A third species (*T. zillii*) was found in the Swan River Catchment in Western Australia in 1975, and was successfully eradicated by seine netting and the use of rotenone. To date, Nile tilapia have not been recorded in Australia; thus, preventing entry of Nile tilapia to Australia is a biosecurity priority. All species of tilapia are declared noxious in most states of Australia.

Black mangrove tilapia was introduced to Australia in the 1970s for the aquarium trade, and is now established in about three catchments in the Cairns and Cooktown region. Mozambique tilapia was also introduced to Australia in the 1970s for the aquarium industry. However, the current widespread distribution of this species in approximately 20 of the 76 catchments in Queensland, several catchments in the Pilbara region of Western Australia and in the Northern Rivers region of NSW has been substantially aided by recreational fishers, although tolerance of high salinity has also likely aided range expansion among nearby coastal drainages in some instances. Recent genetic studies have shown that range expansion by Mozambique tilapia in Queensland has been accompanied by the introduction of several new strains since the original introduction of Mozambique tilapia in the 1970's, suggesting that these additional strains were brought to Australia more recently to support the illegal recreational fishery. In one instance (at Sir Leslie Harrison Dam near Brisbane), a new strain of tilapia has replaced the original strain that was detected in the 1980s. The sale of cooked, whole Mozambique tilapia at a take-away food outlet in Brisbane's Fortitude Valley (Figure 1) demonstrates there is a market value for this illegal fishery in Queensland.

Figure 1

Whole cooked Mozambique tilapia for sale at a take-away outlet in Brisbane's Fortitude Valley (27 April 2015) (photo: B. Cook).



The biological traits that make tilapia well-suited to aquaculture also enable them to thrive in a wide range of aquatic ecosystems to which they are not native. These traits also make tilapia harmful to aquatic ecosystems and a significant threat to Australian native fish species. These traits include:

- Parental care, which increases the survival of eggs and the recruitment of juveniles:
  - male and female black mangrove tilapia aggressively defend benthic nests until juveniles are approximately 40 mm (total length).
  - female Mozambique tilapia mouth brood eggs until the young are approximately 2 weeks old.
- Agonistic territorial behaviour. Both black mangrove and Mozambique tilapia are aggressive to their own kind and to other species of fish, including Australian native species. Tilapia aggressively guard both breeding and non-breeding territories, which leads to the competitive exclusion of native fish and the disruption of the breeding cycles of some native fish species.
- Plastic reproductive strategy. This includes multiple spawning events throughout the year, which increases reproductive potential relative to native species that have fewer reproductive events. In addition to year-round spawning events, plasticity in reproductive strategy is reported as:

  - a shift from monogamy to bigamy or polygamy in black mangrove tilapia
  - early maturation and reproduction (rather than continued growth) when environmental conditions are sub-optimal for Mozambique tilapia
- Wide environmental tolerances, including tolerance to:
  - high salinity. Both black mangrove and Mozambique tilapia inhabit estuaries in Australia, and the Queensland Museum has a record of Mozambique tilapia from Moreton Bay (near the Manly boat harbour). Mozambique tilapia are also known from marine waters in some western South Pacific countries, and there are unconfirmed reports of tilapia colonising waterways on some near-shore islands in North Queensland. Salinity tolerance enables tilapia to disperse between nearby coastal watercourses, especially during times of flood.
  - low dissolved oxygen. Tilapia are tolerant of low concentrations of dissolved oxygen (which many other introduced fish are not), meaning that tilapia will compete with native fish during adverse times when most other pest fish would succumb to low concentrations of dissolved oxygen.
- Wide variety of dietary components and feeding behaviours (benthic feeding, surface feeding, filter feeding), allows them to compete directly with a wide range of native fish and invertebrate species. Phytoplankton and benthic algae are also consumed by both species. Exploitation of a wide range of food resources enables rapid growth by tilapia, which, coupled with aggressive behaviour, enables them to dominate other species of fish.
- Destructive nest building activities. Both species of tilapia disturb bed sediment to construct nests (in the case of black mangrove tilapia) or leks (in the case of Mozambique tilapia, with leks being temporary spawning areas where eggs and sperm are deposited before the females takes the eggs into her mouth). The construction of these nests and leks disturbs benthic habitats and aquatic plants and impacts water quality (increasing turbidity and total suspended solids), thereby reducing habitat quality for other fish and macroinvertebrate species.

Which Australian Aquatic Ecosystem Assets are at Risk from Tilapia?

Within regions where tilapia have established populations, high value aquatic ecosystems are the priority for protection from future incursion. The value of a given aquatic ecosystem is scale dependent. At national and state levels, high ecological value ecosystems include those that provide habitat for threatened species or ecosystems listed in the *Environment Protection and Biodiversity Conservation Act 1999*, or aquatic ecosystems that satisfy world or national hertiage criteria. At local scales, high value aquatic ecosystems include those that provide habitat for threatened species, but they may also satisfy other criteria that make them locally important, including social criteria. However, as all waterways and waterbodies may provide dispersal pathways for tilapia to aquatic ecosystems that have high ecological or social values, the incursion and establishment of new feral populations of tilapia in any aquatic ecosystem creates further risk to high value aquatic ecosystems. Tilapia can even disperse through marine waters, and unconfirmed records of the species from nearshore islands in north Queensland suggests the possibly that some unexpected high ecological value ecosystems could be at risk. Could the sand islands of south-east Queensland (Fraser, Moreton and North Stradbroke Islands) be colonised by tilapia?

Regions that currently do not have tilapia, but are adjacent to regions where tilapia are established, are also at risk from incursion and subsequent establishment. In particular, the Murrary-Darling Basin (MDB) and the Gulf of Carpentaria, are considered to have elevated risk of incursion by tilapia.

The MDB is the largest river system in Australia and is highly modified by water resource development. Most species of native fish in the Murray-Darling Basin are threatened due to water resource development and proliferation of carp (*Cyprinus carpio*) in the system. The establishment of tilapia in the MDB, could be the tipping point for many native species in the Basin: a single incursion of Mozambique tilapia into the MDB may result in the dispersal of tilapia throughout the northern half of the MDB. Further, if minimum water temperature increased by 2°C with climate change, then tilapia could invade the lower part of the Basin. The nearest known population of Mozambique tilapia to the MDB is in the upper Burnett River, only 10 km from the divide between these basins.

In the Gulf of Carpentaria, which includes western Cape York Peninsula, the black mangrove tilapia has already colonised Eureka Creek in the upper Walsh River (part of the Mitchell River system). While it was fortunately detected early and eradicated, this demonstrates that tilapia can enter the Gulf of Carpentaria region from populations on the east coast. Furthermore, Mozambique tilapia are established in a water supply scheme that distributes water to irrigators from a reservoir (i.e. Lake Tinaroo) on an eastern flowing river (the Barron River) to the Mitchell River Catchment in the Gulf of Carpentaria. Screens and other tilapia exclusion devices have been installed to prevent the transportation of tilapia through the water supply scheme, and to date, Mozambique tilapia have not been translocated through the infrastructure of the supply scheme. A single incursion of tilapia into the Gulf of Carpentaria could eventuate in its spread through the region, aided by increased hydrological connectivity among watercourses during the monsoon season.

What are the Prevention, Control and Mitigation Options?

Appropriate management of tilapia includes (Table 1):

- prevention
- surveillance
- control and mitigation, and
- on-going monitoring.

Table 1 Measures for managing tilapia.

prevention	awareness and education legislation and penalties screens on water resource infrastructure
surveillance	appropriate survey design and method (fishing census, environmental DNA approaches, bioacoustic monitoring) emergency response protocols centralised data base
control and mitigation	physical removal chemical methods biological control flow management and ecological restoration
on-going monitoring	assess effectiveness of control detect secondary incursion identify need for any follow-up control

Prevention

Most new incursions of tilapia result from people translocating them between waterways or stocking farm dams for recreational fishing. Thus, legislative controls and associated penalties relating to the spread of pest fish is an important deterrent to illegal stocking. However, laws must be supported by awareness programs aimed at educating people about the serious consequences of releasing tilapia. The National ‘PestSmart’ program and Queensland’s ‘Stop the Spread’ campaign, are examples of community awareness programs that aim to educate people about the ecological and economic impacts of tilapia and other pest fish on aquatic ecological assets.

Preventing the spread of tilapia also includes fitting screens and traps to pipes, pumps and other water infrastructure within waterways that are known to contain or are likely to contain feral tilapia populations.

Surveillence

Surveillance, coupled with an emergency response, is a key determinant of the success of eradicating an incursion by tilapia to a new region, as tilapia cannot be effectively removed by current methods where they have already become established. Traditional surveillence involves periodic fish surveys (e.g. electrofishing or netting) at key locations. Emerging environmental DNA methods that can detect the DNA of tilapia in water are proving to be sensitive complementary approaches to fish surveys that can potentially rapidly provide presence / absence data of tilapia from a relatively large number of sites.

A central database of known and newly reported populations of tilapia is critical for the on-going tailoring of surveillance programs on a regional basis.

Control and Mitigation

Once a feral population of tilapia has become established, control and impact mitigation options include:

- physical removal, such as electrofishing and netting. While heavy fishing pressure can substantially reduce the census population size, the few remaining individuals enable rapid population recovery after fishing interventions cease. Trials have shown electrofishing to be more effective at capturing adults, and fyke nets at capturing juveniles. Warm water 'traps', or use of water quality meters to find the warmest places of a waterbody, may improve the effectiveness of physical removal of tilapia, as tilapia seek out the warmest part of a waterbody, especially in winter.
- chemical methods, such as the use of rotenone in conjunction with temporary dams and physical barriers. The use of piscicides is one of the most effective ways to eradicate pest fish from small, discrete waterbodies, although it is not an option for some waterbodies, such as those used for water supply, and is less effective in large waterbodies.
- biological control. There are currently no known traditional biological control options (i.e. pathogens or predators) for tilapia, although an emerging option involves the release of genetically modified tilapia. These sterile or 'daughterless' individuals only produce male offspring, thereby potentially reducing the reproductive output by future generations of feral tilapia at key infestation sites.

- habitat manipulations, such as flow management and ecological restoration of aquatic ecosystems. While habitat manipulations may not lead to eradication of pest fish, they can increase the resilience of native fish to predatory or competitive interactions with pest fish, and thus may mitigate the impact of pest fish on native fish.

On-going Monitoring

On-going monitoring is essential to assess the effectiveness of control, detect secondary incursions, and identify if any follow-up control actions are needed. Such monitoring programs could be incorporated within the scope of survellience programs, with monitoring results stored in a centralised database.

Summary

Tilapia have established widespread feral populations in north-eastern Australia, where they threaten the ecological values of both freshwater and estuarine ecosystems. There is no simple fix to control feral tilapia populations, and it is likely that they will continue to expand their range. However, prevention of incursions in new regions (e.g. MDB and Gulf of Carpentaria) is a key biosecurity priority. Existing community awareness programs and legislative controls that deter the release of tilapia, and water infrastrure that includes screens and traps, are aimed at preventing the further spread of tilapia. Robust and diligent surveillence, coupled with appropriate emergency reponse plans, is also essential to safeguard the ecological values of aquatic ecosystems in these regions. Technological advances (e.g. environmental DNA monitoring), if implemented appropriately, are likely to greatly enhance the capacity of future surveillance programs to detect new incursions of tilapia.

In regions where tilapia have already establied feral populations, sound environmental management requies high value aquatic ecosystems to be formally identified and protected from alternative forms of disturbance to the greatest extent possible. Traditional control of established populations (i.e. fishing, chemical application) can be augmented by increased knowledge of the ecology of feral tilapia; for example, research that found tilapia prefer the warmest part of a waterbody during winter has indicated that warm water ‘traps’ used during winter may increase the efficiency of fishing/poisoning programs. Genetic technology is also likely to have a significant role in control programs in the future, with the release of sterile or daughterless individuals at key infestation sites having potential to reduce the reproductive output of future generations and thus reduce the dominance of tilapia in those ecosystems.

Finally, as it is unlikely that tilapia will be erradicated in regions where it is now established, ecological restoration and improved environmental flow management will have an important role in mitigating the impact of feral tilapia populations on native fish.

References and further information

http://www.pestsmart.org.au/pest-animal-species/tilapia/

Fulton, W. & Hall, K. (eds) 2014. *Forum proceedings: Tilapia in Australia – State of Knowledge*. 15–16 May 2012, Brisbane. PestSmart Toolkit publication, Invasive Animals Cooperative Research Centre, Canberra.

Russell, D.J., Thuesen, P.A. & Thomson, F.E. 2010. *Development of Management Strategies for Control of Feral Tilapia Populations in Australia*. Queensland Department of Employment, Economic Development and Innovation, Brisbane, Queensland. 55 p.

Russell, D.J., Thuesen, P.A. & Thomson, F.E. 2012. 'A review of the biology, ecology, distribution and control of Mozambique tilapia, *Oreochromis mossambicus* (Peters 1852) (Pices: Cichlidae) with particular emphasis on invasive Australian populations', *Reviews in Fish Biology and Fisheries* **22**: 533-554.