

Research Article

Evidence of naturalisation of the invasive jaguar cichlid *Parachromis managuensis* (Günther, 1867), in Queensland, Australia

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Abstract

The introduction and spread of non-native species poses a significant threat to the health of freshwater ecosystems, and has recently been identified as the single biggest danger to threatened species survival in Australia. Notwithstanding, the importation, trade and keeping of exotic and potentially invasive freshwater fishes in Australia is significant, resulting in greater propagule pressure and higher risk for deliberate or incidental release into native waterways. The jaguar cichlid (*Parachromis managuensis*) is an invasive cichlid that has established non-native populations in many countries throughout the world. In December 2014, the Department of Agriculture and Fisheries in Queensland was notified of an incursion of jaguar cichlids in a stormwater retention dam in the Pioneer River Catchment, Mackay, Queensland. Rotenone was applied to the dam in January 2015, and around 200 jaguar cichlid specimens at various life history stages were destroyed. Follow up surveys into mid-2015 did not detect the presence of any jaguar cichlid in the dam or in nearby creeks. In September 2017, the Department was notified of a wild capture of a mature jaguar cichlid in Fursden Creek, 1.5 km from the original incursion site. Follow up surveys in 2018/19 have also detected jaguar cichlid juveniles in surrounding tributaries, indicating successful establishment and naturalisation of the species in Australia for the first time.

Key words: establishment, invasion, freshwater, teleost

Introduction

The risks posed by potentially invasive species associated with keeping and live trading of ornamental fish is a growing concern globally (Whittington and Chong 2007). The popularity of keeping ornamental fish and reducing import costs has seen a marked increase in the demand and trade of exotic species (McNee 2002). In Australia, the ornamental aquarium fish trade is estimated to be worth approximately \$350 million annually, encompassing fish breeders, wholesalers and traders, retail outlets and hobby sales (Moore et al. 2010). Approximately 8.7 million pet fish are estimated to be kept in Australia (Animal Medicine Australia 2016), with yearly imports of non-native fish exceeding 15 million individuals per annum (Morrisey at

al. 2011). Of the ~ 2000 species that are traded nationally, most are exotic to Australia, with many species having particular life history traits that render them suitable for naturalisation in Australian freshwater ecosystems (Moore et al. 2010). Of these species many are highly invasive, with the potential to impact directly on native biodiversity through predation or outcompeting for resources, or indirectly by altering vegetation structure, ecological and physical processes or landscape resilience (Corfield et al. 2008; Ayers and Clunie 2010; Wilson et al. 2019). This can result in widespread environmental degradation, loss of biodiversity and creation of monospecific fisheries, loss of genetic purity (through hybridisation), and localised fish and/or invertebrate extinctions (Corfield et al. 2008).

The impacts of invasive species are mediated through complex biotic and abiotic interactions that occur habitat-wide, often altering ecosystems and community assemblages irrecoverably (Murray-Darling Basin Commission 2004; Harris 2013). Recent research has indicated that the introduction of invasive species poses a higher risk to threatened species than other anthropogenic factors such as agricultural or human disturbance, ecosystem disturbance, pollution or climate change (Kearney et al. 2018; Díaz et al. 2019). Indeed the detrimental effects of non-native species introductions have been cited as a contributing factor in 68% of North American fish extinctions in the last 100 years, and an instrumental factor in the threatened status of up to 55% of Australian endemic freshwater fishes (Miller et al. 1989; Wagner and Jackson 1993; Lintermans 2004, 2013). In aquatic environments, once established in the wild invasive fish are almost impossible to eradicate, with methods limited to poisoning whole waterbodies and subsequently destroying all local fish and invertebrates in the process. It is also an expensive process in which complete eradication is rarely achieved. Once an invasive fish has naturalised, there may also be larger ongoing costs associated with mitigating spread, including funding alternative measures of containment (i.e. installing fish screens), conducting long term fish-down activities, and providing industry subsidisations. The environmental cost can rarely be quantified.

The jaguar cichlid *Parachromis managuensis* (Günther, 1867), also known as the guapote tigre, is one of the largest members of the cichlidae family, growing to around 55 cm total length (TL) in the wild (Conkel 1993; Agasen et al. 2006). Native to the freshwater ecosystems of Central America from Honduras to Costa Rica, it is a highly aggressive piscivorous species that prefer warm, highly eutrophic lakes and ponds with mud and silt benthic substrates (Marsh et al. 1989). The species is sensitive to cold temperatures, only able to withstand with lower lethal temperatures to around 12 °C (Shafland 1996), but can thrive in temperatures up to 33 °C (Agasen et al. 2006). It is a fecund fish, and females reach sexual maturity at around 10 cm total length (TL), and can deposit several thousand eggs on rocks or other hard substrates each spawn. Both parents will guard eggs

Table 1. History of non-native establishments of jaguar cichlid worldwide, in chronological order (where known or reported).

Introduced to	Introduced from	Year	Purpose	Reference
Honduras	Nicaragua	1956	aquaculture	Welcomme 1988
El Salvador	Nicaragua	1958	aquaculture	Welcomme 1988
Guatemala	El Salvador	1958	aquaculture	Welcomme 1988
Panama	Costa Rica	1972	aquaculture	Welcomme 1988
Cuba	Nicaragua	1983	aquaculture	Welcomme 1988
USA – Florida	unknown	1986	ornamental	Shafland 1996
USA – Utah	unknown	1988	ornamental	Marsh et al. 1989
China	Taiwan	1989	ornamental	Ma et al. 2003
USA – Hawaii	unknown	1992	ornamental	Mundy 2005
Mexico	unknown	unknown	ornamental	Reis et al. 2003
Singapore	unknown	2003	ornamental	Pallewatta et al. 2003
Philippines	unknown	2003	ornamental	Agasen et al. 2006
USA – Louisiana	unknown	2004	ornamental	Nico et al. 2016
USA – Nevada	unknown	2004	ornamental	Nico et al. 2016
Puerto Rico	unknown	2007	ornamental	Nico et al. 2016
Singapore	unknown	2011	ornamental	Barros et al. 2012
Australia	unknown	2014	ornamental	This paper

and resulting fry (Yamamoto and Tagawa 2000; Agasen et al. 2006). Jaguar cichlids are readily identifiable by their projecting lower jaw, prominent canine teeth, black spots on fins and body, and row of black blotches along the lateral line (Kullander 2003).

Jaguar cichlids have a long history of successful establishment in non-native ecosystems around the world. Naturalised populations were reported early on in other parts of Honduras in 1956, followed by neighbouring countries El Salvador and Guatemala in 1958, believed to be attributed to their use as an aquaculture species. In the late 1970s they were discovered in Panama, followed by Cuba in 1983 (Welcomme 1988). After the species began becoming a popular ornamental fish, the first incursion in North American waterways was reported in 1986 in Florida, followed soon after by reports of naturalisations in Taiwan, China, Hawaii, and Puerto Rico (Marsh et al. 1989; Gestring and Shafland 1997; Ma et al. 2003; Nico et al. 2016). As global trade of live fish increased significantly post-2003, more recent reports of jaguar cichlids establishing in other countries include Singapore (Pallewatta et al. 2003), the Philippines (Agasen et al. 2006), and Brazil (Barros et al. 2012) (Table 1).

The history of the arrival of jaguar cichlids in Australia is uncertain. According to Arthington et al. (1999), the species has never been permitted for importation into Australia and that illegal smuggling of fish probably occurred sometime in the early 1980s. Shortly thereafter, the aquarium industry attempted to withdraw jaguar cichlids from trade (Arthington et al. 1999), however captive populations continue to persist to present day. The first assessment on the probability of successful establishment in Australian native waters for jaguar cichlid was completed in 1999, and deemed to be moderate-high based on their history of successful establishments elsewhere at the time (Arthington et al. 1999). In 2010,

another ornamental fish risk assessment was completed by the Australian Government, which also determined that jaguar cichlids were a high-risk species based on suitable climatic matches in the tropics, and the potential for impact on habitats and other species in Australian freshwater ecosystems (Moore et al. 2010).

Mackay is a small coastal city located in central Queensland (21°08'28"S; 149°11'10"E) in north eastern Australia, and has a humid sub-tropical climate. The city sits within the Pioneer River catchment, which covers an area of around 1550 km², and incorporates as many as 10 major tributaries that are used for agricultural irrigation in the region. The Pioneer River itself also has a number of water storage facilities built along its course, including Teemburra and Kinchant Dams, the Mirani, Marian and Dumbleton Rocks Weirs, as well as off stream wetland lagoons that are popular with locals. In December 2014, the Department of Agriculture and Fisheries (DAF) in Queensland was first notified of a potential incursion of jaguar cichlids in a stormwater retention dam in Mackay. This study reports the identification and attempted eradication of this species in the dam, outlines the post-treatment survey and results, and documents successive captures of jaguar cichlid in the nearby tributaries of the Pioneer River in subsequent years, indicating successful establishment of this invasive species for the first time in Australian waters.

Materials and methods

Pre-treatment dam survey

The incursion site was located between the Pioneer River and Fursden Creek (21°8'21.73"S; 149°8'45.09"E) in Mackay, Queensland, Australia (Figure 1). The stormwater retention dam, averaging 1.5 m deep and approximately 1375 m², was designed to capture potentially contaminated stormwater from the site to prevent run off into the nearby watercourses, although in times of significant rainfall the dam has the potential to overflow into these systems. In early January 2015, a pre-treatment fish survey was undertaken to confirm the presence and delimit the spread of jaguar cichlid in both the dam and adjacent creeks using 10mm mesh seine nets. A single pass of each side of the dam at 1.5 m depth was made, approximately 2.5 m from the bank. As jaguar cichlid is readily identifiable from Australian native species, the specimens captured were identified morphologically by fish biologists on site. Fish and crustacean species composition of the catch was also recorded. There was no detection of jaguar cichlid in any section of creek sampled outside of the retention dam, suggesting the population remained confined to the single waterbody.

Rotenone treatment and eradication

In early January 2015 an assessment of risk was conducted based on the overflow potential of the dam to nearby waterways, and the population

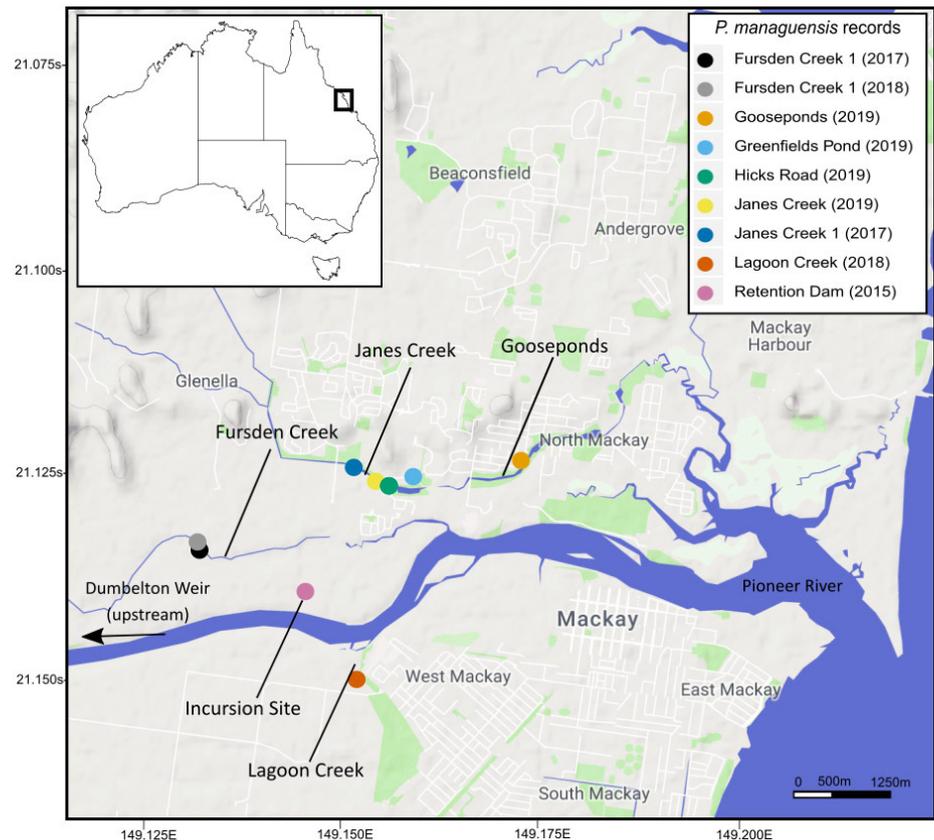


Figure 1. Regional map showing capture locations of jaguar cichlid since 2015 in Mackay, Queensland.

contained within presenting a source for further infestation throughout the catchment. After consultation between local project facilitators (Catchment Solutions Pty. Ltd.), site owners and the DAF freshwater fisheries biologists, on 27 January 2015 the site was restricted to access and powdered rotenone was mixed and applied as an eradication treatment to the dam, and the removal of deceased fish were collected over the subsequent five days. Species composition and a sub-sample of the total catch was measured for fork length (FL) (cm) to identify size classes and life history stage. Application of rotenone was conducted under the Australian Pesticides and Veterinary Medicines Authority (APVMA) permit number PER13011 and based on meeting the guidelines set out in the *Manual for the use of rotenone for Queensland Department of Primary Industries and Fisheries* (Department of Primary Industries and Fisheries 2005).

Post-treatment surveys

Post-treatment fish surveys were conducted in March, April and June 2015 in the retention dam to determine proof of freedom of the infestation. Surveys utilised a boat mounted electrofishing unit consisting of a 7.5 GPP Smith-Root electrofisher, two dropper anode array and hull cathode. The effective field of this unit was approximately a 3 m radius centred on each anode. Multiple passes of the entire site were performed using a power on, power off technique to ensure the waterbody was sampled in its entirety.

Native fish species that were removed as a result of the rotenone treatment were re-collected from nearby waterways and reintroduced to the site in June 2015.

Recreational fish capture and fish monitoring

Longer term monitoring of the Pioneer River tributaries, including Fursden Creek, Janes Creek, McCreadys Creek and the Gooseponds (Figure 1) were conducted by Catchment Solutions Pty. Ltd. as part of other ongoing riverine and fishway monitoring projects in the region. Surveys utilised boat mounted and back pack electrofishers, and to a lesser extent fyke, seine and cast nets. DAF community education initiatives regarding the jaguar cichlid incursion were promoted through local fishing clubs and tackle stores, where fishers were encouraged to report all invasive fish captures to the department's online "report a pest fish" page, or to local Queensland Boating and Fisheries Patrol (QBFP) and biosecurity officers.

Results

Pre-treatment dam survey

The presence of jaguar cichlid was confirmed when the project staff deployed seine nets in the pre-treatment dam survey. *Gambusia* (*Gambusia holbrooki*) was the only other invasive teleost captured. Native species included flyspecked hardyhead (*Craterocephalus stercusmuscarum*), tarpon (*Megalops cyprinoides*), eastern rainbowfish (*Melanotaenia splendida splendida*), bony bream (*Nematolosa erebi*), and spangled perch (*Leiopotherapon unicolor*). Freshwater prawns (*Macrobrachium* spp.) were the only crustaceans caught, and invasive cane toads (*Bufo marinus*) were the only amphibians captured.

Rotenone treatment and eradication

The surface area of the dam was estimated around 1375 m², with an average depth of 1.5 m. The deepest point was 2.4 m. Water temperature ranged between 30–31 °C. In addition to the species recorded during the pre-treatment survey, four large non-native goldfish (*Carassius auratus*) (Figure 2), and over 40 Agassiz's glassfish (*Ambassis agassizii*) were also recorded. *Gambusia* were the most abundant species destroyed (1500), with approximately 200 specimens of jaguar cichlid also removed (Figure 2). A sub-sample of 16 jaguar cichlid were measured for fork lengths (FL), which ranged between 3 cm–18 cm FL, indicating a breeding population. Individual sexes were not recorded.

Post-treatment surveys

An initial post-treatment survey in the dam was conducted on 4 March 2015. A single tarpon was recorded, resulting in further sampling rather

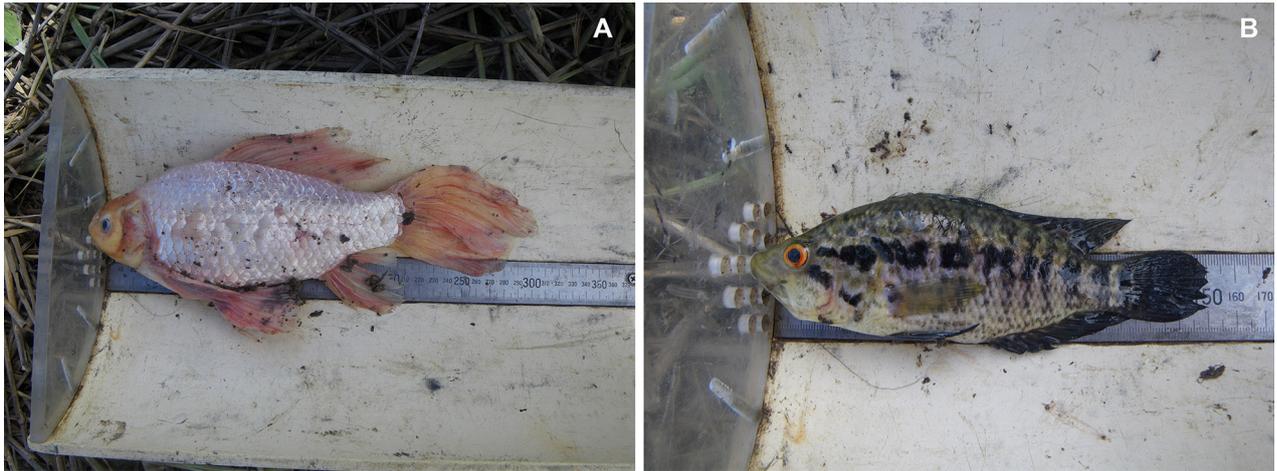


Figure 2. A) a 30 cm TL goldfish, and B) a 15 cm TL jaguar cichlid, both captured as part of the eradication procedure. Photo: Catchment Solutions Pty. Ltd.

than the reapplication of rotenone at the site. Follow-up surveys were conducted in April and June 2015, with the same tarpon recaptured each time. The lack of jaguar cichlid captures during all post treatment surveys indicated that the eradication was successful, and restocking of the dam was undertaken with local native fish.

Recreational fish capture and fish trapping

Between February 2015 and June 2016 numerous fish surveys were undertaken throughout the lower Pioneer River catchment (Figure 1), with no captures of jaguar cichlid being recorded. In June 2017, DAF were notified of a wild capture of a ~ 20 cm TL jaguar cichlid by a recreational fisher in Fursden Creek, a tributary of the Pioneer River approximately 1.5 km from the original incursion site. The capture was validated with photographs and the site location confirmed by local biosecurity officers. Three other recreational captures were subsequently reported from Janes Creek (1) and the Gooseponds (2), in December 2017 and February 2019, respectively. In April 2018, several jaguar cichlid (~ 10 cm TL) were caught in fishway monitoring traps in Fursden Creek and Lagoons Creek. By March 2019, three juvenile jaguar cichlid (~ 3.1 cm TL) were also captured in fishway monitoring traps in Janes Creek (Figure 3).

Discussion

The introduction and spread of non-native species poses a significant threat to the health of freshwater ecosystems, and is the single biggest danger to threatened species survival in Australia (Kearney et al. 2018; Díaz et al. 2019). It has been well documented that the ornamental keeping of exotic fish is a high-risk pathway for accidental and deliberate release of fish and other aquatic animals, and almost all new establishments of exotic fishes since the late 1970s in Australia have been attributed to ornamental keeping (McNee 2002; Lintermans 2004; Webb 2007). As at 2010, there were



Figure 3. A 3.1 cm TL juvenile jaguar cichlid captured in fishway monitoring traps. Photo: Catchment Solutions Pty. Ltd.

reportedly 30 non-native ornamental (aquarium) fish species known to have established in Australian freshwater ecosystems, and of these, only 10 (33%) of these are currently listed on the List of Specimens taken to be Suitable for Live Import (Moore et al. 2010). This “Live Import List”, made under Section 303EB of the *Environment Protection and Biodiversity Act 1999* (EPBC Act), currently contains 260 freshwater fish species permitted for importation, even though an estimated 2000 species are currently traded. In addition to the illegal imports (approximately 5–10%; McNee 2002), there are “legacy” species that have been present in Australia for many years, some of which were once permitted under previous statutory arrangements. It is likely some of these legacy species have persisted as captive populations, despite technically no longer being permitted. There is also currently speculation among fish enthusiasts that progeny of these fish are legally able to be kept and traded, as they were here “prior” to changes in the statutory arrangements and implementation of the Live Import List. This is a common misconception, and in Queensland it is an offence under the EPBC Act, and the Queensland *Biosecurity Act 2014*, to have any freshwater fish or invertebrate species or progeny of these species in possession that are not on the Live Import List. These are considered biosecurity matter in Queensland and fall under a general biosecurity obligation offence provision.

Despite never historically being approved for live importation and possession, jaguar cichlids are openly traded in Australia through aquarium stores, online marketplaces, and hobbyist forum transactions. While in captivity they pose little threat to native ecosystems, the risk of naturalisation increases significantly through ornamental dumping of unwanted live fish, deliberate fish introductions to create new “fisheries”, and use as bait, which are all common vectors for the invasion and establishment of non-

native fish in Australia (Lintermans 2004). Given the species long history of successful establishments elsewhere, the tropical climate match, abundant invasion pathways, and considerable trade in the species, it is not unexpected that establishment has occurred. Once established, invasive fish are almost impossible to eradicate in open water systems (Simberloff 2003), and ongoing management costs can be considerable. Implementing management regimes that focus on preventing or reducing opportunities for the establishment of fish species in the first instance is essential (Lintermans 2004), and needs to be underpinned by a sound understanding of what species are being traded, how many are here, and where the population “centres” of the keeping of these fish are occurring. Further to this, understanding pathways of introduction (the means and routes a species is introduced), as well as vectors (biological pathways for diseases or parasites) and propagule pressure (numbers released that increase likelihood of establishment) are critical, yet significantly understudied in Australia (Lockwood et al. 2005; Hulme 2015).

Extensive fish surveys in the two years following treatment at the incursion site failed to detect jaguar cichlid from waterways throughout the lower Pioneer Catchment. This highlights the limitation of traditional survey apparatus (electrofishing and netting) and the need for complimentary methods of detecting fish populations of low densities. Environmental DNA (eDNA) monitoring has gained widespread use as a surveillance tool for other invasive cichlid species in tropical Australia. Controlled trials found that DNA of a single fish could be detected for up to four days after being removed from a 0.4 mega litre water body (Robson et al. 2016). With greater sensitivity the likelihood of false negatives during detection monitoring can be reduced, allowing for more accurate tracking of the spread of invasive fish and early detection of new incursions. Containment initiatives may also be improved using eDNA as a monitoring tool, with earlier detection capabilities providing managers with the chance to deploy physical barriers (i.e. fish screens) to exclude the invaders from waterways reaches, and creating native refuges (Bylemans et al. 2016). With the threat exotic species pose to the natural systems, the development of eDNA monitoring methods should be prioritised for other high risk aquarium species known to occur in Australia.

The Pioneer River Catchment area is regulated through the operation of both the Teemburra Dam and the Kinchant Dam, with flows managed via the Mirani, Marian and Dumbleton Rocks Weirs on the Pioneer River. The current established range of jaguar cichlid appears to be limited to the lower portion of the river and its tributaries below the Dumbleton Rocks weir. Natural upstream dispersal of the species under normal conditions will be hampered by the series of weir walls, however drownout of these barriers does occur during times of heavy rainfall. As such, there may be

worthwhile prevention and control efforts applied to successfully contain the spread of the species further in this region, providing complementary community education activities are undertaken to mitigate human-assisted translocation within and beyond the catchment boundaries. Other population centres in Brisbane, Townsville and Cairns should also be targeted for these activities to reduce the likelihood of a “multiple release scenario”, akin to the 1978 (Brisbane) and 1979 (Townsville) releases of the Mozambique tilapia (*Oreochromis mossambicus*).

The ecological impacts from the introduction of this species are yet to be realised. Research that predicts the invasive success of jaguar cichlid should be undertaken, and include a range of environmental tolerance testing, prey preferences, and interactions with native and other non-native conspecifics to enable predictions about suitable habitat and rates of spread. Recent studies on other non-native cichlids also highlight ornamental fish dumping as a vector for exotic parasites being introduced to native fish populations (Lymbery et al. 2014; Wilson et al. 2019), a contemporary field of research that is significantly lacking in the Australian context. Given the use of jaguar cichlid to control Mozambique and Nile tilapia in aquaculture ponds in other parts of the world, there may be unintended consequences from the introduction and naturalisation of this species in the Pioneer catchment (COPESCAL 1984, 1986). As a piscivorous species, jaguar cichlids are also reported to prey upon spotted tilapia (*Tilapia mariae*), oscars (*Astronotus ocellatus*), and gambusia (*Gambusia affinis*) (Agasen et al. 2006). Given that the Pioneer River catchment area is heavily infested with *O. mossambicus* and *G. holbrooki*, there may be conspecific interactions here that result in unintended reductions in tilapia and mosquitofish abundances. This highlights a unique opportunity to undertake research to better understand the ecological niches these invasive fish species inhabit, leading to better integrated pest management strategy development at a local scale.

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