Continued invasion: New detections of non-native freshwater fish in wetlands of the Swan Coastal Plain, Western Australia, and management recommendations

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Abstract

Introduced fishes are a major environmental problem worldwide and correlate with increasing human populations; this is not surprising as many introduced species originate from the ornamental trade and are released by hobbyists. The current survey of wetlands on the Swan Coastal Plain within the Perth metropolitan region detected three introduced species previously not recorded in the State: the long-finned eel *Anguilla reinhardtii* Steindachner 1867, the jaguar cichlid *Parachromis managuensis* (Günther 1867), and the southern platy *Xiphophorus maculatus* (Günther 1866). Whereas *X. maculatus* has established a self-sustaining population only single specimens of *A. reinhardtii* and *P. managuensis* were captured. The study highlights the importance of ongoing monitoring to facilitate early detection and eradication of introduced fishes, along with continued investment in public education to change behaviour that reduces the risk of further introductions of new species.

Keywords: Alien species, *Anguilla reinhardtii*, *Parachromis managuensis*, *Xiphophorus maculatus*, Southwestern Province, Swan Coastal Plain

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INTRODUCTION

Freshwater ecosystems worldwide have undergone rapid biodiversity loss (Dudgeon *et al*. 2006). In some freshwater systems rates of extinction have been calculated as up to five times higher than that for terrestrial faunas (Ricciardi & Rasmussen 1999). One of the largest impacts on freshwater systems, and a major cause of extinction in such environments, is the establishment of introduced fish species (Miller *et al*. 1989, Courtenay & Stauffer 1990, Richter et al. 1997, Sala 2000, Rahel 2002, Canonico *et al*. 2005, Dudgeon *et al*. 2006, Newman & Reantaso 2010). The rate of fish introductions is increasing (Courtenay & Stauffer 1990, Bunn & Arthington 2002, Lintermans 2010) with many resulting from the release of ornamental species sold in the aquarium trade (Courtenay & Robins 1973, Courtenay 1990, Courtenay & Stauffer 1990, Koehn & Mackenzie 2004). Within Western Australia, the majority of freshwater fish introductions originate from the ornamental sector (McKay 1984, Beatty & Morgan 2013).

Following introduction, several factors may determine whether the species establishes a self-sustaining population. These include: biological, physical and chemical properties of the waterbody; structure of the ecosystem; and the ecology of the species released (Moyle & Light 1996, Bomford 2008). Whereas not all release events result in self-sustaining populations, such instances are unlikely to be detected without active surveillance (see Duffy *et al*. 2013). Typically, it is only when a population of introduced fish becomes large, and/or causes an environmental impact, that the species is detected. By this time, it is often too late for eradication attempts as the chance of success is extremely low (Myers *et al*. 2000).

Wetlands in urban areas are at particular risk to the establishment of pest species. With increased population, not only do more people keep fish, but wetlands in urban areas are often highly modified, which can enhance the establishment of introduced species (Ross 1991, Gehrke *et al*. 1995, Walker *et al*. 1995, Moyle & Light 1996, Bunn & Arthington 2002, Rahel 2002). Within Western Australia, wetlands in the Swan Coastal Plain contain most of the State's introduced freshwater species (Beatty & Morgan 2013, Morgan *et al*. 2014) coincident with the highest human population in the State (Australian Bureau of Statistics 2011). Prior to the current survey, 13 introduced species were known from the Swan Coastal Plain, outnumbering the 11 native freshwater fishes from Australia's entire Southwestern Province (Morgan *et al*. 2004, Beatty & Morgan 2013, Duffy *et al*. 2013, Hourston *et al*. 2014, Morgan *et al*. 2014).

The Western Australian Department of Primary Industries and Regional Development actively educates the public on the risks of releasing unwanted aquarium fish into waterbodies, and has multiple avenues for the reporting of introduced fish sightings. A combination of recent field surveys (Duffy *et al*. 2013) and new reports of pest species has highlighted a lack of information on the distribution of introduced fish in waterbodies of the Perth metropolitan region. The lack of information hinders

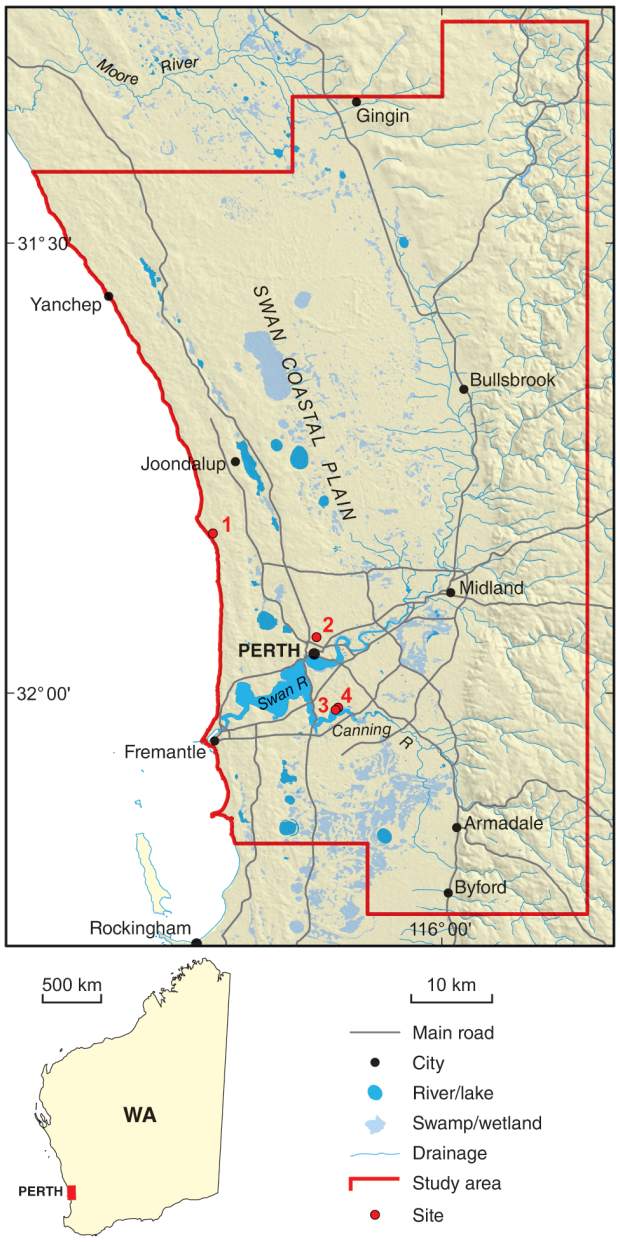

Figure 1. Study area containing waterbodies sampled and the location of new findings of: 1) *Anguilla reinhardtii*, Lacepede Park, Hillarys; 2) *Parachromis managuensis*, Hyde Park, North Perth; 3) & 4) *Xiphophorus maculatus*, Bodkin Park, Waterford and Sandon Park, Waterford, respectively.

informed decision making and the implementation of response actions. To address this, a comprehensive survey of metropolitan wetlands was undertaken. This paper describes the detection of three introduced species not previously recorded within Western Australia.

METHODS

A survey of fish assemblages in approximately 300 water bodies in the Perth metropolitan region was undertaken between January 2012 and January 2015. Fyke nets were utilised to sample water bodies; however, the particular specifications of the nets deployed depended on the physical characteristics of the water body. The net used most frequently was a D-mouth galaxid fyke (60 cm height) with a single 5 m wing made from 4 mm knotless woven mesh. In small or shallow water bodies smaller D-mouth galaxid fykes either 50 cm high with a 2.4 m wing or a 40 cm high with a 1.9 m wing were deployed. After the survey had commenced an additional large mesh (40 mm stretched) monofilament D-mouth fyke (60 cm height) with a 5 m wing was introduced to target larger species that may have avoided capture in the small meshed fykes.

The nets were deployed perpendicular to the bank. Where the size of the waterbody permitted, nets were set in a paired arrangement with an inner (closest to the bank) and an outer net by attaching the wing of the outer net to the cod end of the inner net. Nets were deployed from a kayak in the afternoon by 6 pm and were left overnight. To standardise soak time nets were retrieved the following morning from 7 am in the same order as deployment. The number of fyke nets deployed was dependent on the lake area and accessibility around its perimeter. DNA barcoding was used to confirm the identity of species not previously detected in Western Australia; the method is described in Duffy *et al* (2013).

RESULTS

Three species of fish not previously recorded in waterbodies in Western Australia were detected between January 2012 and January 2015: the long-finned eel *Anguilla reinhardtii* Steindachner, 1867, the jaguar cichlid *Parachromis managuensis* (Günther 1867), and the southern platy *Xiphophorus maculatus* (Günther 1866) (Table 1).

The two lakes in Bodkin Park next to the Canning River and their connecting channel containing *X. maculatus* were sampled on three occasions in winter,

Table 1. Newly detected species in the Perth metropolitan region. D = detected, but no evidence of juvenile recruitment or additional specimens in follow up sampling; E = established breeding populations.

Family	Species	Date of initial detection	Lat.	Lon.	Lake	Status
Anguillidae	*Anguilla reinhardtii*	25/9/14	-31.822376	115.745640	Lacepede Park, Hillarys	D
Cichlidae	*Parachromis managuensis*	8/1/2015	-31.937779	115.860806	Hyde Park, North Perth	D
Poeciliidae	*Xiphophorus maculatus*	5/6/2013	-32.015773	115.884579	Bodkin Park, Waterford	E
		5/6/2013	-32.018354	115.881834	Sandon Park, Waterford	E

summer and spring. The lowest abundance was in winter (<=3 fish/fyke), the highest in summer (up to 58 CPUE) with an intermediate abundance in spring (<=10 CPUE). Follow-up sampling for *Anguilla reinhardtii* and *Parachromis managuensis* failed to capture additional individuals.

DISCUSSION

The current study has revealed that an additional ornamental introduced fish species has become established in Western Australia adding to those known in the region (Beatty & Morgan 2013, Duffy *et al*. 2013, Hourston *et al*. 2014). Although two additional species were detected, they have not become established. The southern platy, *Xiphophorus maculatus*, is a popular aquarium fish that originates from Central America and can survive in a wide range of habitats (Kallman 1975). Although a tropical species, experimental trials have shown it can tolerate waters of approximately 9.5°C to 40°C (Prodocimo & Freire 2001). At the times of sampling, water temperatures were between 18.5°C and 31.1°C, well within the tolerance limits for this species (Prodocimo & Freire 2001). The fluctuations in catches between seasons, indicates abundance may be related to season and/or water temperature and associated reproductive cycles (Milton & Arthington 1983).

X. maculatus was captured in Bodkin Park, Waterford, within an up-steam and downstream lake, as well as the connecting channel, all of which drain directly into the Canning River during flow events, and also in nearby Sandon Park. As an ornamental species, the introduction pathway is likely to be through aquarium release/s. The Canning River is likely to provide a barrier to its spread for much of the year with salinity levels at the confluence well above 3 ppt (Department of Water – Water Science Branch 2013), significantly greater than the species' salinity tolerance (e.g., Englund 2002). However, following heavy rains, salinity at this point can drop below 3 ppt (Department of Water – Water Science Branch 2013), such that *X. maculatus* could spread into the river and other connected waterbodies.

X. maculatus has been assessed as having a very high risk of establishment (Bomford & Glover 2004, Bomford 2008) and where it has established in Queensland, it is assessed as a high risk to native species as it consumes fish fry (Mackenzie *et al*. 2001). It has also established populations in several other countries; however, there is very little information on their impact. Given the potential for the species to spread into the Canning River, and its current restricted distribution, an eradication effort utilising rotenone is urgently required.

A single adult specimen of *A. reinhardtii* was captured in the lake at Lacepede Park, Hillarys. This species occurs naturally on the east coast of Australia from Cape York to Tasmania as well as Lord Howe Island, New Guinea and New Caledonia (Beumer 1996, Allen *et al*. 2003). It is a large species that can reach over 1.6 m and weigh up to 22 kg (Beumer 1996). The species is catadromous and migrates from freshwaters to the sea to spawn with the larvae and then juveniles making their way back to the coast and upstream into freshwater (Merrick & Schmida 1984). Therefore it is unlikely that this species would have been able to establish a population in Western Australia, even if more than one specimen was present.

Compared to the more popular *Anguilla australis*, the international and domestic market for *A. reinhardtii* as a food item is small (Harrington & Beumer 1980) and it is not thought to be in the aquarium trade in Western Australia. Therefore, there appears to be two possible explanations for the presence of this eel in Western Australia: natural range expansion or illegal release from the restaurant trade. A natural range expansion seems unlikely; however, it has shown previous large increases in range with new detections in New Zealand (a 400 km eastward range expansion, Jellyman *et al*. 1996). Similar occurrences are known in both the Galapagos (McCosker *et al*. 1997) and Hawaii (James & Suzumoto 2006). The species had not previously been recorded from either island and whilst the Galapagos occurrence was deemed a natural range expansion (McCosker *et al*. 1997), its presence in Hawaii was concluded to be a result of a natural migration (James & Suzumoto 2006). Given the distance from the source population, and the lake in which the animal was caught in Western Australia has no connection to the ocean, it is unlikely that the presence of this species is due to migration but is almost certainly the result of the release of a captive specimen probably imported for the restaurant trade.

The tropical cichlid, *P. managuensis*, a piscivorous species originally from Central America (Bussing 1998), was found in the lake at Hyde Park, North Perth. This is the first record of this species in the wild in Australia. One characteristic that is unfavourable for the establishment of this species in the Perth region is its tolerance to waters between 25°C and 36°C in its native habitat (Bussing 1998). Winter temperatures of waterbodies in Perth during this survey were as low as 11.7°C and at the time of capture was 27.5°C, so it is possible that the fish was a recent release that had not been present in the wild over winter. However, assessment of temperature tolerances should be used with caution when based on natural ranges as the actual tolerance of a species may be much lower than that reported from its native range and it may simply not have been tested. For instance, the tropical cichlid *Geophagus brasiliensis* has become established in Perth waterways, despite the Mediterranean climate (Beatty *et al*. 2013).

As only a single specimen of *P. managuensis* was caught by the initial sampling, and follow up sampling failed to detect further specimens, the initial detection may also represent its eradication. Nevertheless, if a population of this species were to establish within Western Australia it would present a serious threat. It grows to more than 45 cm (Bussing 1998), much larger than most of the native species in the south-west of Western Australia (Morgan *et al*. 2014), is highly predatory (Dunseth & Bayne 1978, Acosta-Nassar & Günther-Nonell 1992) and can survive in environments with low oxygen (Acosta-Nassar & Günther-Nonell 1992) including stagnant pools (Bussing 1998). The species aggressively defends breeding territories (Günther-Nonell & Boza-Abarca 1994), is highly fecund with a single female able to produce up to 6000 eggs in a single spawning event (Günther-Nonell & Boza-Abarca 1994) and can spawn multiple times throughout a year, as frequently as every 25 days (Günther-Nonell & Boza-Abarca 1994).

The current study has again highlighted that the deliberate release of aquarium fish into waterways poses a significant threat to the Western Australian environment (Morgan *et al*. 2004, de Graaf & Coutts 2010, Beatty & Morgan 2013, Beatty *et al*. 2013, Duffy *et al*. 2013, Hourston *et al*. 2014, Morgan *et al*. 2014). Early detection is the key to eradication—without early detection, there is little chance of a successful eradication as experienced with *Geophagus brasiliensis* in Perth. This species was first reported in 2006 (de Graaf & Coutts 2010, Beatty *et al*. 2013) but early containment and control attempts have been unsuccessful, despite continuing efforts. In 2009, specimens were reported from the Swan River, and by 2013 the species had spread over approximately 20 km. By that stage any control within this system was impossible so efforts then focussed on closing connections to other catchments to prevent it spreading further.

Whilst early detection is essential for eradication, it is problematic due to the cost of physically sampling fish assemblages in the large number of waterbodies present in the both the metropolitan region and the State, including the need for constant and repeated efforts. To reduce costs associated with physical sampling, current attempts are focused on developing cheaper indirect methods of detecting species presence through the use of environmental DNA (Thomsen *et al*. 2012). Although a potential improvement, one disadvantage of this approach is that it is still reactive and does not prevent the initial release, establishment or spread of introduced species.

Community education is an important tool to prevent new freshwater fish introductions globally (Strayer 2010). Approved fish species allowed for import into Western Australia are on the Australian Government, Department of Environment "Live Import List". There are, however, many species already in circulation in the aquarium industry within the State that are not on this list. In an attempt to mitigate the potential impacts of these species, the Western Australian Department of Primary Industries and Regional Development has utilised an education campaign, i.e. the "Don't dump that fish" program. This campaign aims to raise awareness of the potential impact of released aquarium fish and provide education about the options for the disposal of unwanted specimens. Whilst education is a useful tool, the problem remains that a single release can lead to establishment and spread of introduced species, therefore additional options need to be considered.

The continued construction of wetlands in urban areas provides more habitats for the release of unwanted fish, putting native species at risk if introduced species spread. If lakes are to continue to be included in urban developments, several aspects need to be addressed to reduce the opportunity for establishment and spread of introduced fish species in these systems. Options include stocking permanent lakes with native species to provide better control of mosquitos (Lawrence *et al*. 2016) and aquatic life for people to observe. Lakes should be designed to minimise chance of survival or reproduction of non-native species through manipulation of depth, structure, shading and temperature; regular surveys should be undertaken and species eradicated/restocked if required; and ongoing education campaigns using community media and signage should be implemented to highlight the damage caused by releasing introduced species. In addition, alternate designs for storm water management should be considered such as underground stormwater capture and storage; introduced fish cannot establish populations if there are no options for release.

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