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Status of Non-native Freshwater Fishes in Tropical Northern Queensland, Including Establishment Success, Rates of Spread, Range and Introduction Pathways

ALAN CHARLES WEBB

Abstract: At least 20 non-native fishes have been reported from northern Queensland fresh waters, a 75% increase since 1994. Eleven of these species have established breeding populations and some are locally abundant and highly invasive, such as the tilapiine cichlids (*Oreochromis mossambicus* and *Tilapia mariae*) and the poeciliids (*Gambusia holbrooki* and *Poecilia reticulata*). Besides the continued introduction of non-native species, of great concern is the further spread of the tilapias, especially *Oreochromis mossambicus* and its hybrid form, and of another invasive, the three-spot gourami, *Trichopterus trichogaster*. Initial introductions are most probably releases of unwanted aquarium fish directly into open waters, or indirectly from ornamental ponds by flood waters. While natural dispersal is occurring, most of the range expansion of the tilapiine cichlids, particularly into impoundments in flood-prone areas, has been as a result of human translocation, and possibly the use of live bait by anglers.

Keywords: Cichlidae, distribution patterns, Gambusia, Gourami, introduction pathways, invasive fishes, *Oreochromis mossambicus*, Poeciliidae, Tilapia

INTRODUCTION

The history of non-native fishes, i.e., those originating from overseas, introduced into northern Queensland fresh waters has been well documented (McKay 1978, 1984, 1989; Arthington et al. 1984, Lear 1987, Blühdorn et al. 1990, Arthington and Blühdorn 1994, Milward and Webb 1990, Webb 1994, Webb et al. 1997, Canonico et al. 2005). Introductions began in the early 1940s with the widespread release of the poeciliid, *Gambusia holbrooki*, for biological control of mosquito larvae (McKay 1984). In the 1950s and 60s there was a massive expansion in numbers of non-native fishes imported into Australia for the aquarium trade as the keeping of tropical fishes increased in popularity. There was subsequently a large increase, especially in the late 1970s and onwards, in the number of species, notably cichlids, reported from open fresh waters in tropical northern Queensland.

Five non-native species (*G. holbrooki*, *P. reticulata*, *X. maculatus*, *Hemichromis* sp. (cf. *guttatus*), *O. mossambicus* and *T. mariae*) were reported during the first surveys of non-native fishes in northern Queensland (McKay (1978, 1989, Arthington et al. 1984, Lear 1987), while McKay (1989) also referred to a previous, though unsuccessful, introduction of *Jordanella* sp. (*floridae*) (Family Cyprinodontidae) in Harvey Creek. These surveys found *P. reticulata* and *X. maculatus* to be common in several rivers, creeks, urban and rural drains north of Innisfail, while recently introduced populations of *O. mossambicus*, in Townsville and Cairns, and *T. mariae*, in Cairns, were rapidly spreading from their original points of introduction. Mather and Arthington (1991) reported that there were two genetically distinct populations of *O. mossambicus* in northern Queensland, a 'pure' strain occurring in the Townsville region and a polymorphic hybrid strain occurring in the Cairns region. Webb (1994) reported that the number of cichlids in open waters in northern Queensland had increased to at least six with the addition of the oscar (*Astronotus ocellatus*), green severum (*Heros severum*), the red devil *Amphilophus cf. labiatum (citrinellum)* and the jewel cichlid (*Hemichromis guttatus*).

This paper presents the results of surveys by the author and others conducted since 1996 between the Burdekin and Endeavour River catchments in northern Queensland. It documents the current status of non-native fishes in the region, their establishment success and current distributions, and discusses the rate and probable manner of spread, with particular reference to two tilapiine cichlids, the Mozambique mouthbrooder (*O. mossambicus*) and the spotted mangrove cichlid (*T. mariae*), and the osphronemid, the three-spot gourami (*Trichogaster trichopterus*).

METHODS

Between January 1997 and February 2007, 321 sites were surveyed between the Burdekin and Daintree catchments by the author, including 84 sites by others (see Acknowledgements). The location, GPS coordinates, habitat type, habitat condition and exotic species present were recorded at each site. A variety of survey methods was used including seine and gillnets, electroshocking, bait-traps, underwater snorkelling and visual observation from the water's edge using binoculars fitted with polarised lenses when water conditions allowed.

Establishment success was defined as successful and continued breeding of a species observed during the survey period. The relative occurrence of each species was defined as the number of sites where a species was observed as a percentage of the total number of sites where non-native species were present. An estimate of the distribution of each tilapiine species was calculated as the percentage occurrence in the total catchment area, including Cape York Peninsula, for all the major river systems in the North East Coast Drainage Division north of the Burdekin River (Table 1; catchment area data from Jacobson et al. 1983).

River System	Catchment Area (km^2)	Occurrence of Tilapia OM	TM
Jacky-Jacky	2770		
Olive-Pascoe	4350		
Lockhardt	2825		
Stewart	2795		
Normanby	24605		
Jeanie	3755		
Endeavour	2200	✓	
Daintree	2125		
Mossman	490		
Barron	2175	✓	✓
Mulgrave-Russell	2020		✓
Johnstone	2330		✓
Tully	1685		
Murray	1140		
Herbert	10125	✓	
Black-Alice	1025	✓	
Ross	1815	✓	
Haughton-Barrattas	3650		
Burdekin	129860	✓	
$\sum$ catchment area	201740		
$\sum$ % OM occurrence	73.0		
$\sum$ % TM occurrence	3.2		

Table 1. Catchment areas of major rivers in the North East Coast Drainage Division, north of the Burdekin River and reported occurrence of tilapia, *O. mossambicus* (OM) and *T. mariae* (TM); data from Jacobson et al. (1983).

RESULTS

Nineteen non-native fish species were recorded during surveys (Table 2). These included 12 cichlids, five poeciliids, one osphronemid and one cyprinid. The distributions of these species are shown in Figures 1 to 4. Poeciliids were the most frequently encountered group (60.4% of all sites surveyed) compared with cichlids (48.3%). The dominant poeciliids, as a percentage occurrence of all sites surveyed, were the Mosquitofish (41.7%) and the Guppy (19.3%), while the dominant cichlids were the Mozambique mouthbrooder (46.1%) and the spotted mangrove cichlid (7.2%). Eleven species were reported from five or fewer sites. Of the 19 species, at least 11 (58%) have established breeding populations (Table 2). The Ross River catchment had the largest number of non-native species (15) reported from all sites surveyed.

The total number of reported non-native fish species introduced into northern Queensland fresh waters (20) represents about 69% of all reported introductions in Queensland (29) and 50% of all reported introductions in Australian fresh waters (40). The number of established species (11) represents about 48% of all species known to have breeding populations in open fresh waters in Australia (23) (Kailola et al. 1999, Webb 2003, this paper, Koehn and MacKenzie 2004, T. Rayner, School of Tropical Biology, James Cook University, Townsville, pers. comm.). Between 1930 and 1980 the rate of introduction of non-native fishes into northern Queensland fresh waters was approximately linear, but during the past 25 years has entered an almost exponential phase (Figure 5). This pattern is comparable with other tropical regions (e.g., Hawaii and Florida) with similar introduction histories and well-established domestic aquarium fish industries (Figures 6 and 7). The majority of countries in tropical regions (e.g., Sri Lanka, Indonesia, and Taiwan), also have experienced increased post-1945 rates of fish introduction, but with imports principally for fisheries production rather than for a domestic aquarium trade, which is either lacking or in an early phase of development (Figures 8, 9 and 10. Data for Figures 6 to 10 obtained from De Silva 1989, de Zylva 1999, Radtke 1995, Froese and Pauly 2007).

Family	Genus/Species	Common Name	Estab	% sites
Poeciliidae	*Gambusia holbrooki*	Mosquitofish	⇝	50.4
	Poecilia reticulata	Guppy	⇝	27.8
	P. latipinna	Molly		0.4
	Xiphophorus maculatus	Platy	⇝	10.0
	X. helleri	Swordtail	⇝	1.7
Cichlidae	*Oreochromis mossambicus*	Mozambique tilapia	⇝	40.7
	Tilapia mariae	Spotted mangrove cichlid	⇝	10.4
	Thorichthys meeki	Firemouth		0.4
	Hemichromis sp. (cf. *guttatus*)	Jewel cichlid	⇝	0.8
	Haplochromis burtoni	Burton's haplochromis	⇝	0.8
	Astronotus ocellatus	Oscar	⇝	2.6
	Aequidens rivulatus	Green terror		0.4
	Heros severus	Green severum		0.4
	Archocentrus nigrofasciatum	Convict cichlid		1.3
	Amphilophus citrinellum	Midas cichlid	⇝	3.0
	Geophagus brasiliensis	Pearl cichlid		0.4
	Archocentrus spilurus	Blue-eye cichlid		0.4
Belontiidae	*Trichogaster trichopterus*	Three-spot gourami	⇝	7.0
Cyprinidae	Cyprinid sp. A	Unknown 'carp' species		0.4
Cyprinodontidae	*Jordanella* sp. (*floridae*)	Flagfish		-

Table 2. Non-native fish species reported from northern Queensland fresh waters (⇝= established breeding population).

Tilapiine Cichlids (O. mossambicus and T. mariae)

Between 1978 and 2000, the range of *O. mossambicus* and *T. mariae* has increased from approximately one per cent (Ross River catchment) to about 75% of the total catchment area in the North-East Drainage Division. Of the two species, *O. mossambicus* is more widespread. It has been reported from six of the major river systems (about 73% of total catchment area; Table 1) and with a latitudinal range of 3.9°, extending between the Endeavour and Burdekin Rivers. The main populations occur in the Barron River, including Lake Tinaroo, in some small creeks to the north and south of Cairns and in almost every waterway in the Townsville-Thuringowa region.

The rate of new site reports for the species in northern Queensland has also accelerated since its initial introduction to the Ross River in the late 70s (Arthington et al. 1984), and especially since 2000 (Figure 11). Based on morphology and colour pattern, most of the recent range expansion of *O. mossambicus* is possibly of the hybrid form. Fish collected from the upper Barron River, Herbert River and Burdekin River catchments tend to have more orange-red body colour, a shallow body depth, and long posterior anal and dorsal fin extensions, while Townsville fish tend to have a dull grey-green body colour, a deeper body and shorter posterior anal and dorsal fin extensions.

O. mossambicus has established large populations in the Ross River, Townsville, and neighbouring Black and Alice River catchments, Thuringowa, and virtually all smaller creeks between Sleeper Log Creek to the north and Alligator Creek to the south of Townsville. The species was observed by the author in farm dams in 2001 in the upper catchment of Sachs Creek and then in Ross River Dam in 2004 following downstream dispersal. Other local reports of the species from farm dams at Cungulla and Harvey's Range in 2001 and 2004, respectively, were also confirmed by the author.

In 2003, a single specimen of *O. mossambicus* was collected from Jensen's Crossing, Endeavour River, near Cooktown, and is the first confirmed report of the species north of the Daintree River (J. Russell, Northern Fisheries Centre, Cairns, pers. comm.). In 2004, the species was found in weirs in the upper reaches of the Herbert River (A. Hogan, QDPI&F, Walkamin, Atherton Tablelands, pers. comm.). Between February 2004 and March 2005, the species was confirmed from the Burdekin River catchment in Keelbottom Creek (D. Burrows, ACTFR, pers. comm.) and its feeder streams (Speed Creek and Two Mile Creek), and from Gladstone and Milchester Creeks, Charters Towers, that flow into the Burdekin River approximately 50 km downstream from its junction with Keelbottom Creek.

Further surveys between March 2005 and November 2006 found *O. mossambicus* in the main channel of the Burdekin, in the Star River, Fanning River, Kirk River, Basalt River, Allingham Creek and Fletcher Creek (ACTFR and QDPI&F, unpublished data). The species has spread through more than 300 km of waterways in the middle reaches of the Burdekin River catchment over a period of at least three years, although the exact timing of the first introduction is not known. These reports suggest that the species is rapidly dispersing throughout the Burdekin catchment from one or possibly a few points of introduction. Observations were made during a period of low but consistent flow in the Burdekin River, with above average dry season rainfall in the Running River, Star River and Keelbottom Creek catchments in 2006, but below average wet season rainfall in 2004/5 and 2005/6. As a result of the low flows, upstream migration has probably been restricted by natural barriers such as rock bars on the Burdekin River adjacent to Mt Foxton and in the Basalt River, Fletcher Creek and Lolworth Creek (see Figure 1). It is likely that *O. mossambicus* will continue to disperse further downstream and upstream beyond such barriers when these are drowned out during wet seasons with higher rainfall. It is also probable that the species will spread to neighbouring catchments, either by 'creek-hopping' via coastal waters or during localised flooding.

In April 2005, two adult male specimens were collected from the irrigation channel leading from Lake Tinaroo into the Mitchell River

irrigation system, fortunately upstream from a screening station installed to prevent downstream passage of eggs or fry of tilapia. According to A. Hogan (QDPI&F, Walkamin, Atherton Tablelands, pers. comm.), the location of the fish suggested that they were deliberately released rather than the result of accidental translocation (e.g., by fish-eating birds) or natural dispersal from Lake Tinaroo.

Tilapia mariae has a more restricted latitudinal range (0.7°) than *O. mossambicus* and occurs in three of the major river systems (about three per cent of total catchment area) (Table 1). The species occurs in the Barron River catchment, including Lake Tinaroo, and small creeks in the Cairns region (Lear 1987, Mather and Arthington 1991, Webb et al. 1997), and with large populations also in the Russell-Mulgrave Rivers system and Johnstone Rivers system (Russell and Hales 1993, Russell et al. 1996). Figure 12 shows a relatively rapid, approximately linear rate of new sites reported for *T. mariae* over a period of 20 years, but with no new site locations confirmed in the last four years. In February 2005 there were unconfirmed reports of tilapia in marine conditions – observed by divers about 1 km north of the mouth of the Russell River (possibly *T. mariae*) and caught by fishers off Fitzroy and Double Island (possibly *O. mossambicus*) (B. Rossi, Marine Advisory Group, Cairns, pers. comm.).

Other Cichlids

Of the ten, non-tilapiine cichlids, six species (*T. meeki*, *A. rivulatus*, *H. burtoni*, *A. nigrofasciatum*, *A. ocellatus* and *A. citrinellum*) were reported only from the Townsville region, the majority from the Ross River weirs. A jewel cichlid, *Hemichromis* sp. (cf., *guttatus*), was found at two locations (Cairns and Ross River Townsville), while two species (*G. brasiliensis* and *A. spilurus*) were found at only one location (Didgeridoo Lagoon, Lower Burdekin region). Of these ten species, at least four (*Hemichromis* sp. (cf., *guttatus*), *A. citrinellum*, *A. ocellatus*, *H. burtoni*) have established breeding populations, while the other species were reported in very low numbers.

Unidentified Cyprinid sp. A

In March 2003, an approximately 4 kg specimen of a cyprinid was found among a large number of dead fish in Gleeson's Weir, Ross River (M. Cappo, Australian Institute of Marine Science, Townsville, pers. comm.). These fish were presumably killed by anoxic conditions created by a combination of bacterial decomposition of aquatic vegetation, high water temperatures and lack of flushing of the weirs. The fish was identified as a cyprinid, possibly a wild variant of the European carp, *Cyprinus carpio*, or a member of the African-Asian carp genus, *Labeo*. Full identification, however, was not possible as the fish was in an advanced state of decomposition when found. Further surveys by QDPI&F personnel using a boat-mounted electroshocker failed to detect any further specimens.

Three-spot Gourami

The species was first reported in 1998 from a sugar cane channel and several lagoons associated with Sheep Station Creek (C. Perna, Australian Centre for Tropical Freshwater Research, Townsville, pers. comm.) and has now established breeding populations in the lower Burdekin region. A new introduction was reported by Webb (2003) from Aplin Weir, Ross River, and in 2005 the species was collected from Didgeridoo Lagoon that flows into East Barrattas Creek (M. Pearce, Department of Primary Industry & Fisheries, Mackay, pers. comm.) and from Upper Barratta Creek (Woodhouse Lagoon) a neighbouring catchment to Sheep Station Creek (C. Perna, pers. comm.). In February 2007, the species was reported from Horseshoe Creek to the north of the Barrattas system and in close proximity to the Haughton River and its catchment (V. Veitch, Australian Centre for Tropical Freshwater Reseasrch, pers. comm.).

Poeciliids

The mosquitofish, *G. holbrooki* and the guppy, *P. reticulata*, were the most widespread and abundant poecillids observed. Apart from populations in a stormwater drain and in Avondale Creek, Smithfield, in northern Cairns, *G. holbrooki*, was the dominant poeciliid south from Ingham, while *P. reticulata* was dominant north of Ingham, although several populations of the latter species were present to the south, in the Townsville-Thuringowa region (Little Crystal Creek, Alice-Black River, Campus Creek and Alligator Creek), with new site records for Charters Towers and Didgeridoo Lagoon, in the Lower Burdekin region.

G. holbrooki was reported for the first time in May 2004 from the upper reaches of the Burdekin River at Reedybrook, approximately 250 km upstream, and Blue Range, approximately 105 km upstream from the junction of the river with Keelbottom Creek (B. Pusey, Griffith University, Brisbane, pers. comm.). The species was observed after heavy rains in mid-December in the lower reach of Keelbottom Creek and approximately 8 km downstream in the Burdekin River at Deep Bend. In March 2005, the species was found in the lower reach, but not in the middle or upper reaches, of Sheep Station Creek, at its junction with the Burdekin River, approximately 25 km downstream from Deep Bend. The species was also reported by the author for the first time from the upper catchment of the Herbert River, in the Wild River and The Millstream, Atherton Tablelands, in December 2005, although the origins and residency time of this population are unknown.

X. maculatus was found mainly in Cairns and in several creeks southward to Innisfail and in small creeks and stormwater drains in the Townsville region. Small populations of *X. helleri* were found at two sites in Cairns (Delaney's Creek and Saw Pit Gully), at one site in Townsville (Cranbrook Creek) and a large population in ponds at a crocodile farm at Flying Fish Point, Innisfail, and in adjoining cane drains. Of the five poeciliid species reported, only the sailfin molly has not established a breeding population. The species was found at only one site in Majors Creek, approximately 50 km to the south-east of Townsville.

DISCUSSION

The number of non-native fish species reported from open waters in northern Queensland has increased by 75 percent during the past decade with many of these fish establishing breeding populations. Northern Queensland now has approximately half of all reported non-native species introductions and half the number of all established exotic species recorded from Australian fresh waters. To date, all exotic species in northern Queensland have been reported from fresh waters in the North-East Drainage Division and none from the Gulf of Carpentaria Drainage Division. The Ross River, Townsville, now has the highest percentage of reported species introductions (15) and number of established species (11) in Australia. In comparison, the Burdekin River system has three non-native species, the Brisbane River in south-eastern Queensland has six non-native species (McKay and Johnson 1990, J. Johnson, Ichthyology Section, Qld Museum, Brisbane, pers. comm.), while Australia's largest river system, the Murray-Darling, many times larger than the Ross River, has 10 non-native species present (Clunie et al. 2002, Murray Darling Basin Commission 2004).

Genetic evidence indicated at least three separate introductions of tilapias in northern Queensland (Mather and Arthington 1991), while human translocation has clearly been responsible for the subsequent large-scale spread of these fishes in the region. In many instances tilapia have been released into standing water bodies such as ornamental ponds or farm dams and weirs with fish escaping into open waterways in floodwaters, e.g., tilapia in the upper Barron River, Atherton Tablelands (Webb et al. 1997), in Ross Creek (Arthington et al. 1984), Ross River (McKay 1984, Blühdorn et al. 1990) and Sachs Creek and Ross Dam, Townsville (Webb, this paper). The majority of new reports of non-native species introductions are probably a result of dumping unwanted aquarium fishes (e.g., several cichlids in the

Ross River weirs) or are due to other human activity, including use of the fish as live bait and stocking for aquaculture.

Tilapia collected in the Cairns region were used as live bait by anglers in Cape York rivers (M. Tilse, Cairns, pers. comm.). The *O. mossambicus* specimen collected from the Endeavour River in 2004 may have been used, or intended for use as live bait, but either escaped or was discarded. (J. Russell, Northern Fisheries Centre, Cairns, pers. comm.). The report of tilapia (*O. mossambicus*) from Gladstone Creek, Charters Towers, in March 2005 was also due to a local angler collecting fish for live bait. Fortunately, a colleague recognised tilapia among the catch and these fish were then destroyed and thus prevented from possible further spread.

While some stocking may occur inadvertently, it is possible that these releases, along with those directly into open waters, are deliberate. Such stocking may be for production of fish (e.g., tilapias) for domestic consumption, or harvesting ornamental species for sale. In the case of tilapia, some individuals may have opportunistically exploited the concern about the spread and impacts of the species, and even assisted the process by deliberately releasing fish, the objective being to apply political pressure so that removal of the prohibited status of the species is viewed as an environmentally and economically beneficial management option, i.e., to allow harvesting from open waters to get rid of a pest species and to establish an aquaculture industry based on tilapia providing rural employment opportunities.

The recent unconfirmed reports of tilapia observed about 1 km north of the mouth of the Russell River and caught by fishers off Fitzroy and Double Island are not unexpected as both tilapiine species are euryhaline and *O. mossambicus*, in particular, can survive in marine and even hypersaline conditions (Whitfield and Blaber 1979, Stickney 1986). It is possible, therefore, that both species may eventually spread throughout all of the northern section of the North East Drainage Division by creek-hopping along the coast, especially after heavy rains lower salinities in coastal waters. It is probable that *O. mossambicus* dispersed throughout the small creeks to the north of Townsville by this process (see Arthington et al. 1984, 1994, Webb 2003).

Of particular concern is that the recent, major range expansion of *O. mossambicus*, is possibly that of the Cairns hybrid now present in the upper Barron and Herbert Rivers and the Burdekin River system. The genetic identity of these populations needs to be confirmed, although the general morphology and colour of these fishes are quite different from those of the 'pure' strain of *O. mossambicus* from the Townsville region. The study by Mather and Arthington (1991) indicated that genes from one or more of *O. aureus*, *O. niloticus* and *O. honorum* were present in the Cairns hybrid. *O. aureus* has been used to improve cold tolerance (Cnaani et al. 2000), *O. niloticus* to increase growth characteristics (Kamal and Mair 2005) and *O. honorum* to alter sex ratios (Lovshin 1982) of *O. mossambicus*. Mather and Arthington (1991) argued that this species, due to hybrid vigour, may pose an even greater threat than the pure mossambicus strain, and suggested that there was potential for spread of tilapia to parallel that of hybrid carp in southern states in the 1970s. To date, there has been no examination of the ecological attributes of the *O. mossambicus* hybrid and assessment of its invasive potential or impacts.

The three-spot gourami is another popular aquarium species and has established breeding populations at two locations in the lower Burdekin and Townsville regions. The recent report from Didgeridoo lagoon may be another aquarium release as guppies and a small number of two cichlid species (*G. brasiliensis* and *H. spilurus*) were found at this site. Rapid natural dispersal of the species in floodwaters is occurring throughout the system of lagoons and low-lying coastal areas especially to the north of the Burdekin River, and is likely to continue dispersal into the Haughton River system and its catchment. Gouramis are anabantids with special respiratory structures associated with the gills that allow air breathing (Burggren 1979). This species is therefore well-adapted to survive in many of northern Queensland

waterways that have been highly modified by human activity, for example, where eutrophic conditions result in excessive aquatic plant growth, and subsequent high biological oxygen demand creating virtually stagnant water, conditions that are unfavourable for many native fish species. The three-spot gourami is likely to disperse during floods throughout the network of drains and irrigation channels and lagoons in the lower Burdekin region. The species is carnivorous, feeding mainly on small invertebrates (Rainboth 1996), and is territorial and aggressive. According to Liao and Chiu (1989), the species was strongly suspected, as a resource competitor, to have adversely impacted on populations of the endangered Chinese barb, *Puntius semifasciolata*, although its impacts on resident aquatic communities, in Queensland or overseas, are unknown.

The poeciliids as a group are the longest established non-native fishes in northern Queensland, with introductions beginning about sixty years ago (McKay 1978, 1984). The mosquitofish, *G. holbrooki* and the guppy, *P. reticulata*, were the most frequently encountered and widespread non-native species surveyed, while the platy, *X. maculatus*, was largely restricted to the Cairns and Townsville regions, but with locally common to abundant populations. *G. holbrooki*, was the dominant poeciliid south of Ingham to the Burdekin, while *P. reticulata* was dominant in creeks and rivers to the north of Ingham, including the Atherton Tablelands, where, apart from recent reports from the Upper Burdekin, *G. holbrooki* are absent.

The distribution of the poeciliids, particularly of *P. reticulata* and *X. maculatus* suggests that these species were also used with *G. holbrooki* for control of mosquito larvae during World War II and in the immediate postwar period. McKay (1984) stated that only *G. holbrooki* was introduced by military personnel in the 1940s, although the largest concentration of Allied troops in northern Queensland was located on the Atherton Tablelands where *G. holbrooki* is virtually absent, but *P. reticulata* is widespread. This suggests that both species may have been used during this period as biocontrol agents. Other poeciliids, *X. maculatus* and *X. helleri*, may also have been introduced at this time, or in the immediate post-war period, by local councils that continued introductions, while some populations may have originated during this time from aquarium releases. Swordtails, along with guppies were found in the ponds of a crocodile farm near Innisfail, and escapees from these ponds were found in cane drains adjacent to the farm. The farm manager stated that these fish had been stocked in the ponds to 'eat the mosquito larvae'.

The recently reported populations of *P. reticulata* from Charters Towers may also be long-established and have simply gone unreported because of a lack of surveys in the area. The population of *G. holbrooki* observed in the mouth of Sheep Station Creek near Charters Towers is more recent and probably derived from fish moving downstream from the upper Burdekin, although the timing of original introductions into this catchment is unknown. The few specimens of the sailfin molly, *Poecilia latipinna*, found at one location in Majors Creek, were undoubtedly an aquarium dumping. No further specimens or other exotic species were detected during subsequent surveys at this site.

Since the vast majority of fish species used in the aquarium trade are tropical species, northern Queensland is at a greater risk from these fish, which, if released into open tropical waters, are likely to develop self-maintaining populations. This is evidenced by the relatively high proportion (55%) of species that, once introduced, have established breeding populations. While the focus tends to be upon those species that become 'invasive' – that rapidly spread and become a dominant component of fish communities in receiving waters – the cumulative impact of all non-native species on aquatic biodiversity and ecosystem function within a catchment needs to be considered. The rate of introductions into tropical northern Queensland fresh waters is alarming and could result, if the trend continues in the coming decades, in many freshwater fish communities being dominated by these and probably other exotic species.

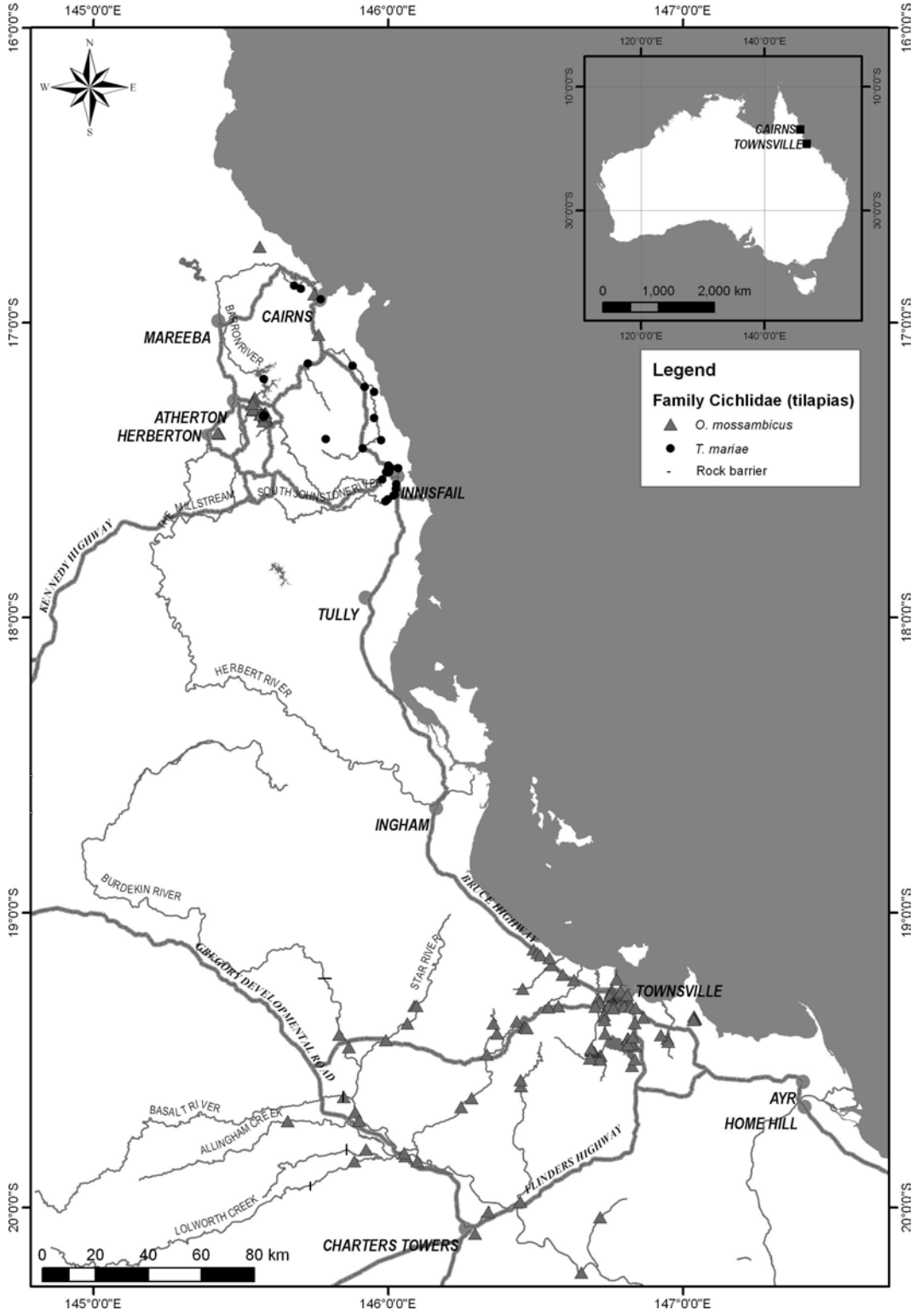

Figure 1. Distribution map for tilapiine cichlids, *O. mossambicus* and *T. mariae* (Family Cichlidae), in fresh waters of tropical northern Queensland

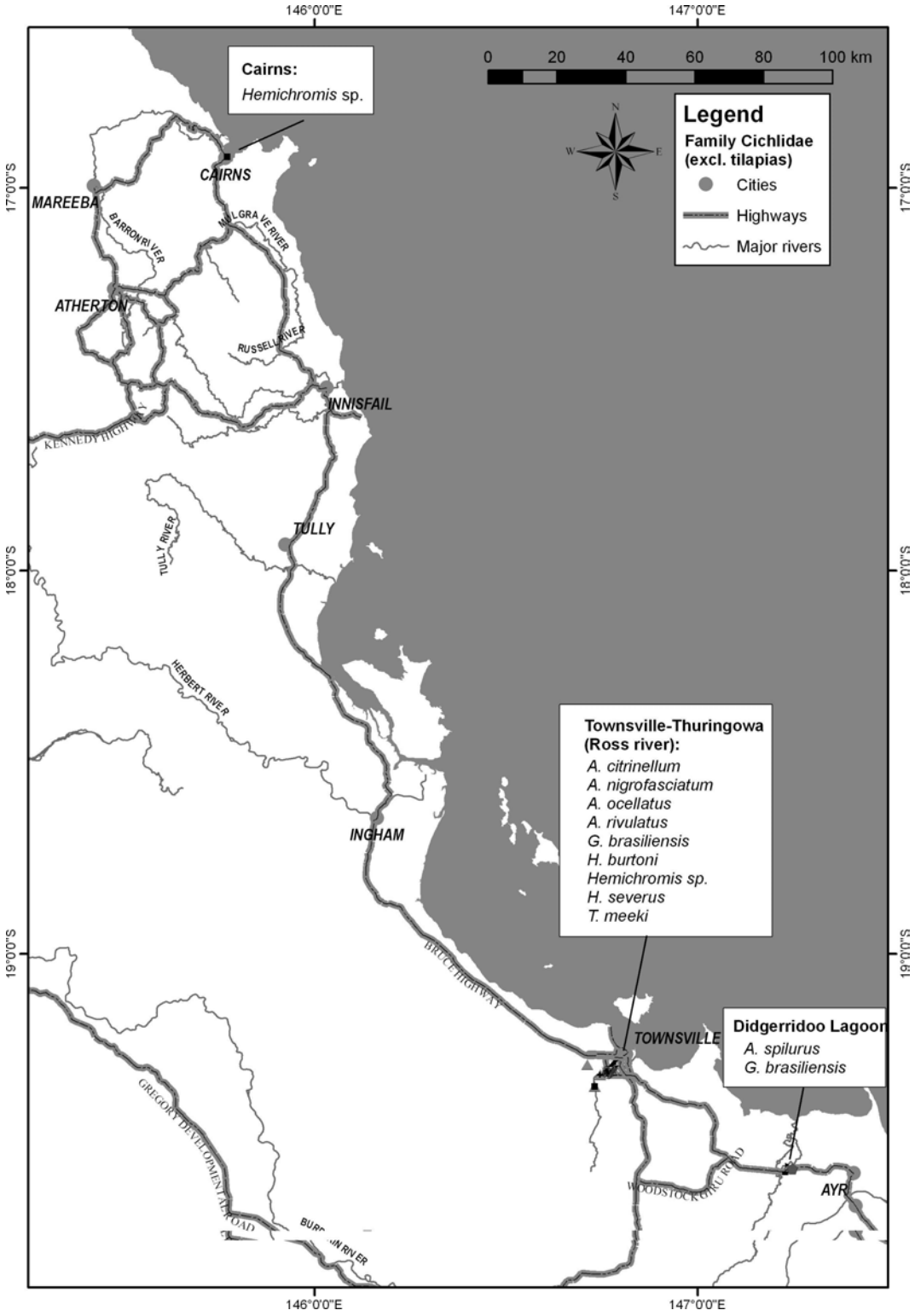

Figure 2. Distribution map for cichlids (excluding tilapias) (Family Cichlidae) in fresh waters of tropical northern Queensland.

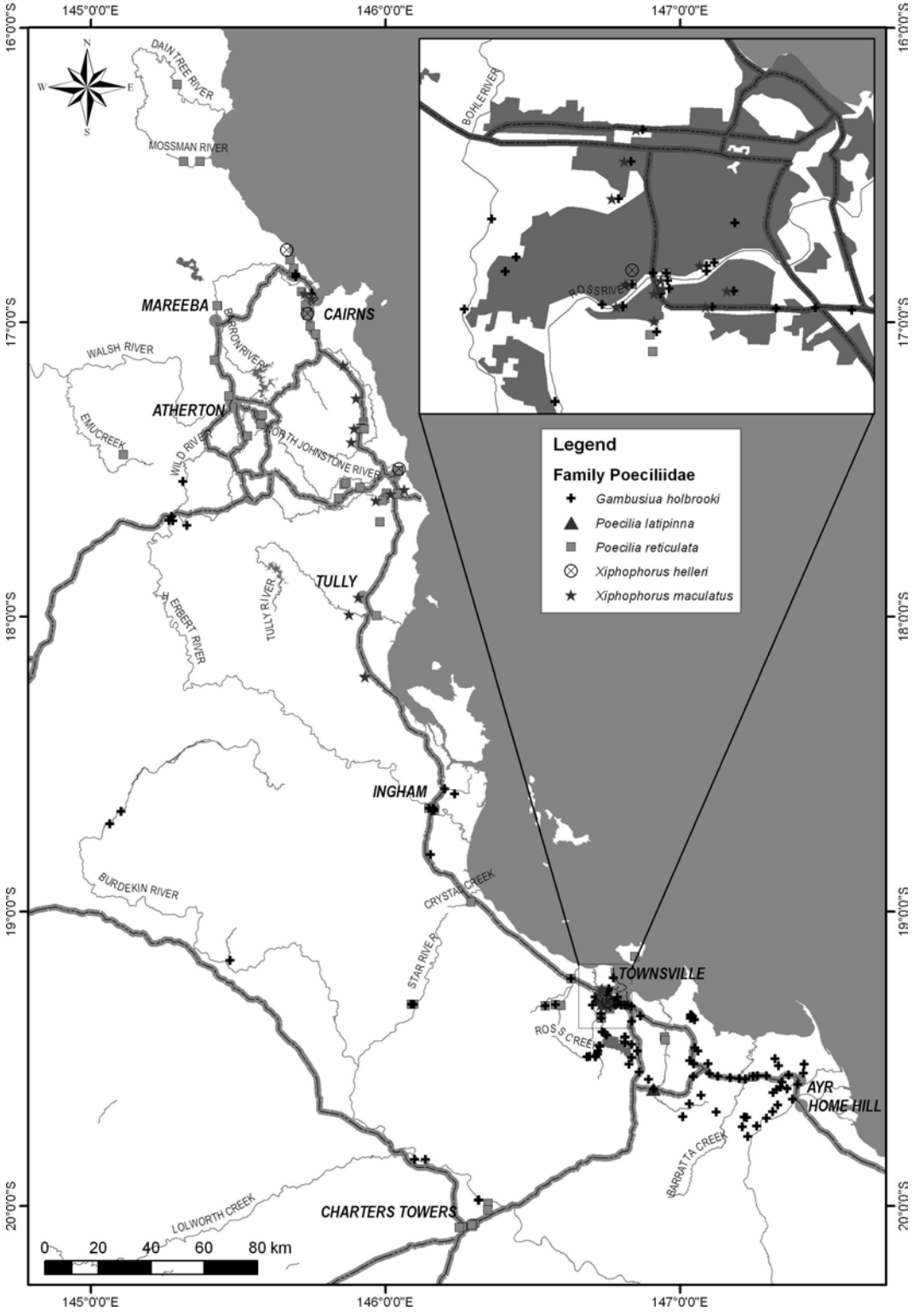

Figure 3. Distribution map for live-bearers (Family Poeciliidae) in fresh waters of tropical northern Queensland.

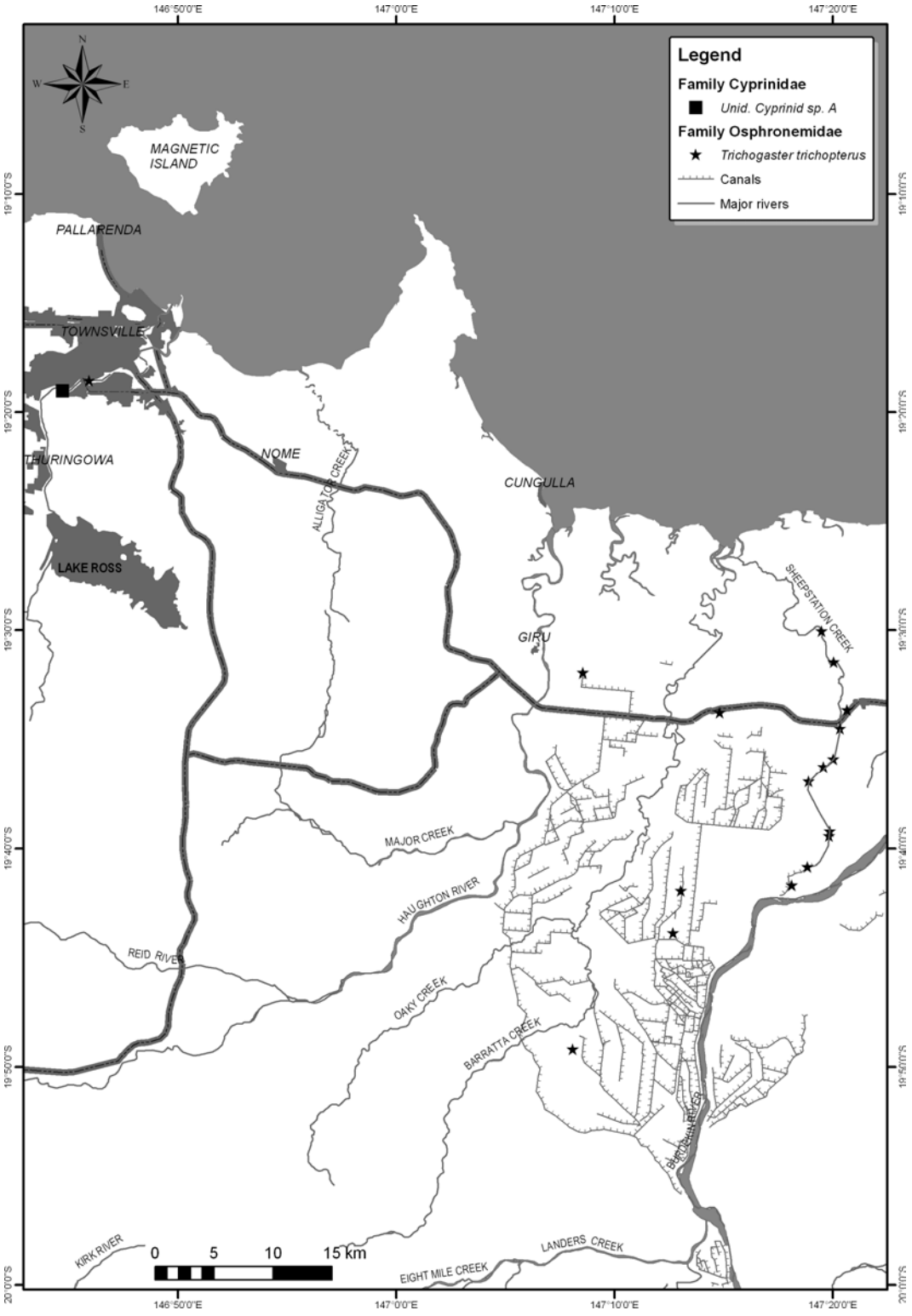

Figure 4. Distribution map for unidentified cyprinid sp. A (Family Cyprinidae) and three-spot gourami, *T. trichopterus* (Family Osphronemidae), in fresh waters in tropical northern Queensland.

Figure 5. Cumulative number of non-native freshwater fish species introduced per decade into northern Queensland.

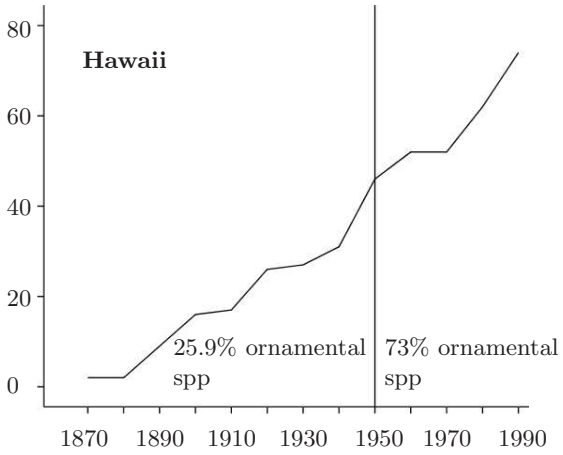

Figure 6. Cumulative number of introduced fish species per decade for Hawaii.

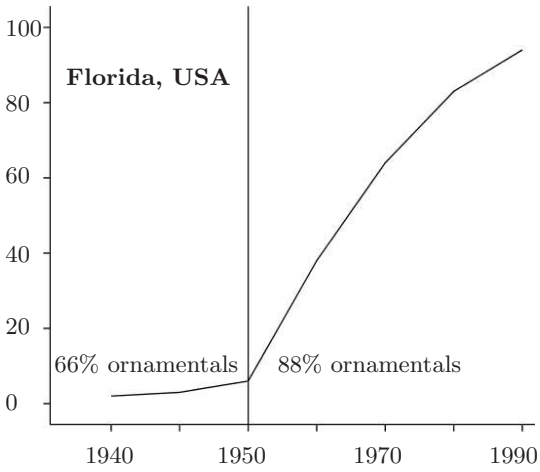

Figure 7. Cumulative number of introduced fish species per decade for Florida, USA.

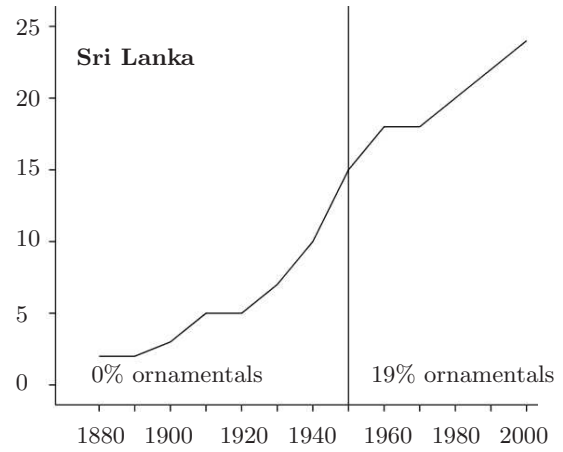

Figure 8. Cumulative number of introduced fish species per decade for Sri Lanka.

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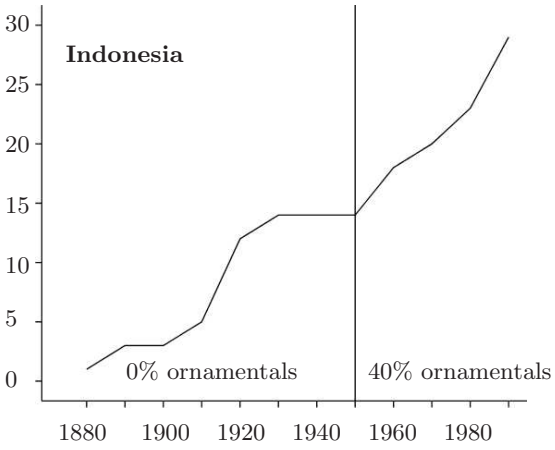

Figure 9. Cumulative number of introduced fish species per decade for Indonesia.

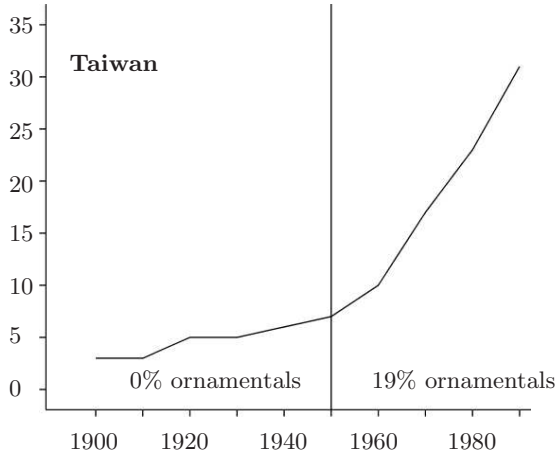

Figure 10. Cumulative number of introduced fish species per decade for Taiwan.

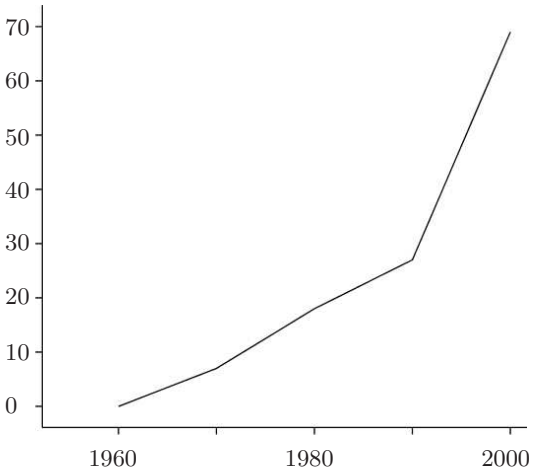

Figure 11. Cumulative number of new site reports per decade for the Mozambique tilapia, *O. mossambicus*, in northern Queensland fresh waters.

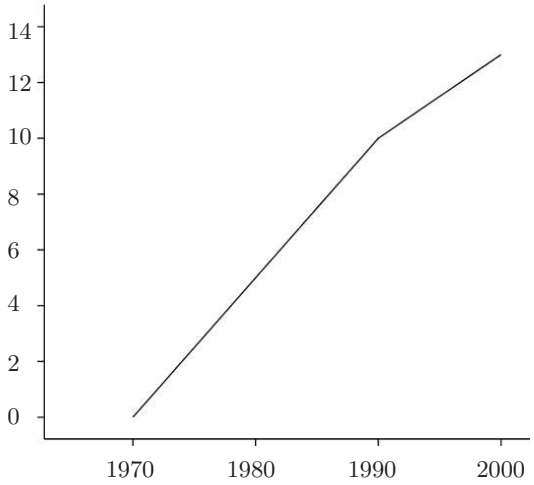

Figure 12. Cumulative number of new site reports per decade for the spotted tilapia, *T. mariae*, in northern Queensland fresh waters.

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Alan Charles Webb
Australian Centre for Tropical Freshwater Research
Kevin Stark Building
James Cook University
email: alan.webb@jcu.edu.au

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