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Distribution and impacts of introduced freshwater fishes in Western Australia

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Abstract This paper presents comprehensive distributional data, from over 1300 sites, on introduced freshwater fishes in Western Australia. Currently, there are 10 species of introduced freshwater fish established in the inland waters of Western Australia. Most of the introduced fishes found here are those that have formed feral populations elsewhere in the world, and include members of the Salmonidae, i.e., rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*); Cyprinidae, i.e., goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*); Poeciliidae, i.e., mosquitofish (*Gambusia holbrooki*), one-spot livebearer (*Phalloceros caudimaculatus*), guppy (*Poecilia reticulata*), and swordtail (*Xiphophorus hellerii*); Percidae, i.e., redfin perch (*Perca fluviatilis*), and Cichlidae, i.e., Mozambique mouthbrooder or tilapia (*Oreochromis mossambicus*). More recently, the eastern Australian silver perch (*Bidyanus bidyanus*) (Terapontidae), which was introduced for aquaculture, has been captured in the Swan River near Perth. It is not known whether this population is self-maintaining. The majority of introduced species are confined to the south-west, although four and one species have been recorded from the Pilbara and Kimberley, respectively. Some species are extremely common and widespread, e.g., *G. holbrooki* and *P. fluviatilis*, whereas others are far more restricted and may be confined to between one and three catchments, e.g., *C. carpio*, *P. caudimaculatus*, *P. reticulata*, *X. hellerii*, *O. mossambicus*, and *B. bidyanus*. The impact of these introduced fishes on native species varies, but ranges from predation, e.g., *O. mykiss*, *S. trutta*, *G. holbrooki*, and *P. fluviatilis*, to aggressiveness, e.g., *G. holbrooki*, *X. hellerii*, and *O. mossambicus*, and competition for food and habitat.

Keywords feral fishes; *Oncorhynchus mykiss*; *Salmo trutta*; *Carassius auratus*; *Cyprinus carpio*; *Gambusia holbrooki*; *Phalloceros caudimaculatus*; *Poecilia reticulata*; *Xiphophorus hellerii*; *Perca fluviatilis*; *Oreochromis mossambicus*; *Bidyanus bidyanus*

INTRODUCTION

Western Australia, which contains three distinct ichthyological provinces, i.e., South West Coastal (south-west), Pilbara, and Kimberley drainage divisions (Unmack 2001), has had a long history of exotic fish species introductions. These introductions have essentially occurred in four stages. The first phase of introductions (species identified as potential for food and angling) began in the 1870s with the introduction of brown trout (*Salmo trutta*) from eastern Australia (Coy 1979). This was followed in the 1890s by shipments of Murray cod (*Maccullochella peelli*), golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), short-finned eels (*Anguilla australis*), carp (*Cyprinus carpio*), tench (*Tinca tinca*), and redfin perch (*Perca fluviatilis*) (Coy 1979). Rainbow trout (*Oncorhynchus mykiss*) were not introduced until the early 1900s (Coy 1979). These species were stocked into various rivers and lakes of the south-west of Western Australia with varying degrees of "success". Of the above species only five are now thought to be found within natural waterways of the region (i.e., brown trout, rainbow trout, carp, silver perch, and redfin perch).

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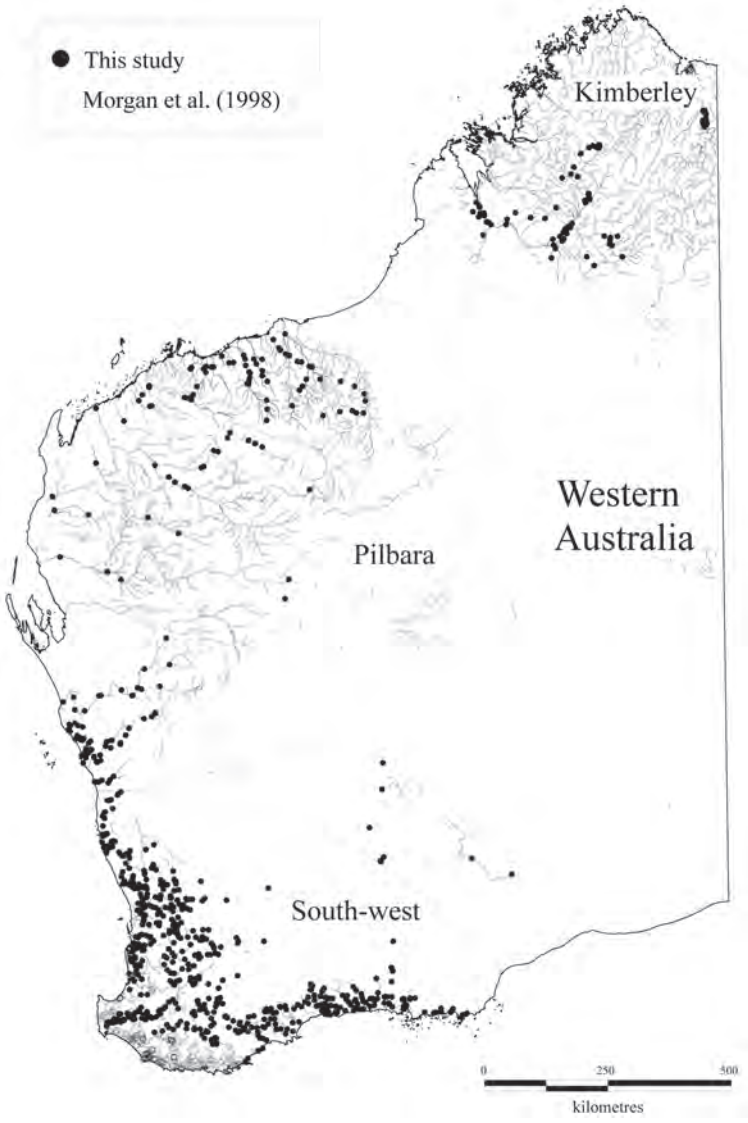

Fig. 1 Sites sampled for fish in the south-west, Pilbara, Kimberley, and arid interior regions of Western Australia.

The second phase of introductions (biological control) occurred from the 1930s until recently and resulted in the liberation of mosquitofish (*Gambusia holbrooki*) into many of the rivers and lakes of south-western Australia by health authorities (Coy 1979). This species is now firmly entrenched throughout much of the south-west and southern Pilbara. The third phase (ornamental escapes/liberations) has been occurring for at least the last four decades with a number of populations of small ornamental fishes becoming established. These include goldfish (*Carassius auratus*), koi carp (*Cyprinus carpio*), Mozambique mouthbrooder or tilapia (*Oreochromis mossambicus*), and more recently swordtails (*Xiphophorus hellerii*), guppies (*Poecilia reticulata*), and one-spot livebearers (*Phalloceros caudimaculatus*). The final stage is now occurring through escapes from the expanding aquaculture industry and through fishing practices (as bait and illegal translocations) and include the silver perch (*Bidyanus bidyanus*) and *P. fluviatilis* (Morgan et al. 2002); and decapod crustaceans, the eastern Australian yabbie (*Cherax albidus*) and redclaw crayfish (*Cherax quadricarinatus*) (this study).

Through a large-scale distribution study this paper presents information on the distribution of these introduced fishes in Western Australia, and also reviews published and unpublished literature and data on the impacts of these species on Western Australian ecosystems and sympatric species.

MATERIALS AND METHODS

Distribution of introduced freshwater fish

Over 1300 sites in inland waters between the Ord River (north-eastern Kimberley) in the north and Israelite Bay in the south-east (South West Coastal Drainage Division) were sampled for fish using seine nets, electrofishers, and gill nets (Fig. 1). Feral species were retained for future analyses and for deposition into the Western Australian Museum. The fish faunal distribution data for 410 sites collected previously by the authors (Morgan et al. 1998) are included in this total (see Fig. 1). In some instances, where records are available, additional locality sites for introduced species were provided by the Western Australian Museum, Department of Fisheries Western Australia, and Murdoch University colleagues. The latitude and longitude of each site was recorded using a Global Positioning System (GPS) and species distribution maps were constructed using MapInfo (MapInfo Corporation 1998).

Impacts of introduced species

Data presented in the paper on the impact of a number of species are adopted from relevant literature, whereas for others the results are from preliminary examination of the gut contents of fish caught during the current study.

RESULTS AND DISCUSSION

Distribution and impacts of introduced freshwater fish

From the 1300 sites sampled in the inland waters of Western Australia (Fig. 1), 10 species of introduced freshwater fish were captured (Fig. 2). Most of the introduced fishes found here are those that form feral populations elsewhere in the world, and include two members of the Salmonidae, i.e., rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), two from the Cyprinidae, i.e., goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*), four from the Poeciliidae, i.e., mosquitofish (*Gambusia holbrooki*), one-spot livebearer (*Phalloceros caudimaculatus*), guppy (*Poecilia reticulata*), and swordtail (*Xiphophorus hellerii*), one Percidae, i.e., redfin perch (*Perca fluviatilis*), and one Cichlidae, Mozambique mouthbrooder (*Oreochromis mossambicus*). More recently, the eastern Australian silver perch (*Bidyanus bidyanus*) (Terapontidae), which was introduced for aquaculture, has been captured in the Swan River near Perth.

Salmonidae

O. mykiss and *S. trutta* (Fig. 3)

Oncorhynchus mykiss and *S. trutta*, which are stocked into numerous streams of south-western Australia for recreational fishing, are generally restricted to the cooler waters of Western Australia between Perth (Canning River) in the north and the Warren River in the south (Fig. 3). The presence of several distinct cohorts, including 0+ (i.e., <1 year old) individuals, in a number of systems that had not been regularly stocked demonstrates that both *O. mykiss* (Churchman Brook Reservoir on the Canning River) and *S. trutta* (Waroona Dam on the Harvey River, Big Brook Dam on the Warren River and Fly Brook, a tributary of the Donnelly River), are capable of forming self-maintaining populations in south-western Western Australia.

Of the 92 trout stomachs examined during this study that contained food, eight contained endemic teleosts, a further 13 contained endemic decapods, and one contained a frog. Although only c. 23 % of trout examined contained endemic fishes or decapods it is worth noting that many of the trout caught were in impoundments that contained few native fish. Although this study and those of Jenkins (1952) and Pusey & Morrison (1989) in south-western Australia demonstrated that trout consumed endemic fishes and decapods, they do not indicate their impact on the highly endemic freshwater fish (80%) and decapod (100%) fauna of south-western Australia. Thus, there is an urgent need to determine the level of predation by trout on the endemic fauna through comparisons of fish and decapod communities in water bodies that currently contain few or no trout, pre- and post-stocking. Until this work is undertaken, no further stocking of trout sp. should occur in areas of high conservation value.

Cyprinidae

C. auratus and *C. carpio* (Fig. 4)

Carassius auratus was captured at 20 sites, 17 of which were on the Swan Coastal Plain between the Moore and Vasse Rivers. They were also captured


A


B


C


D


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H


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K

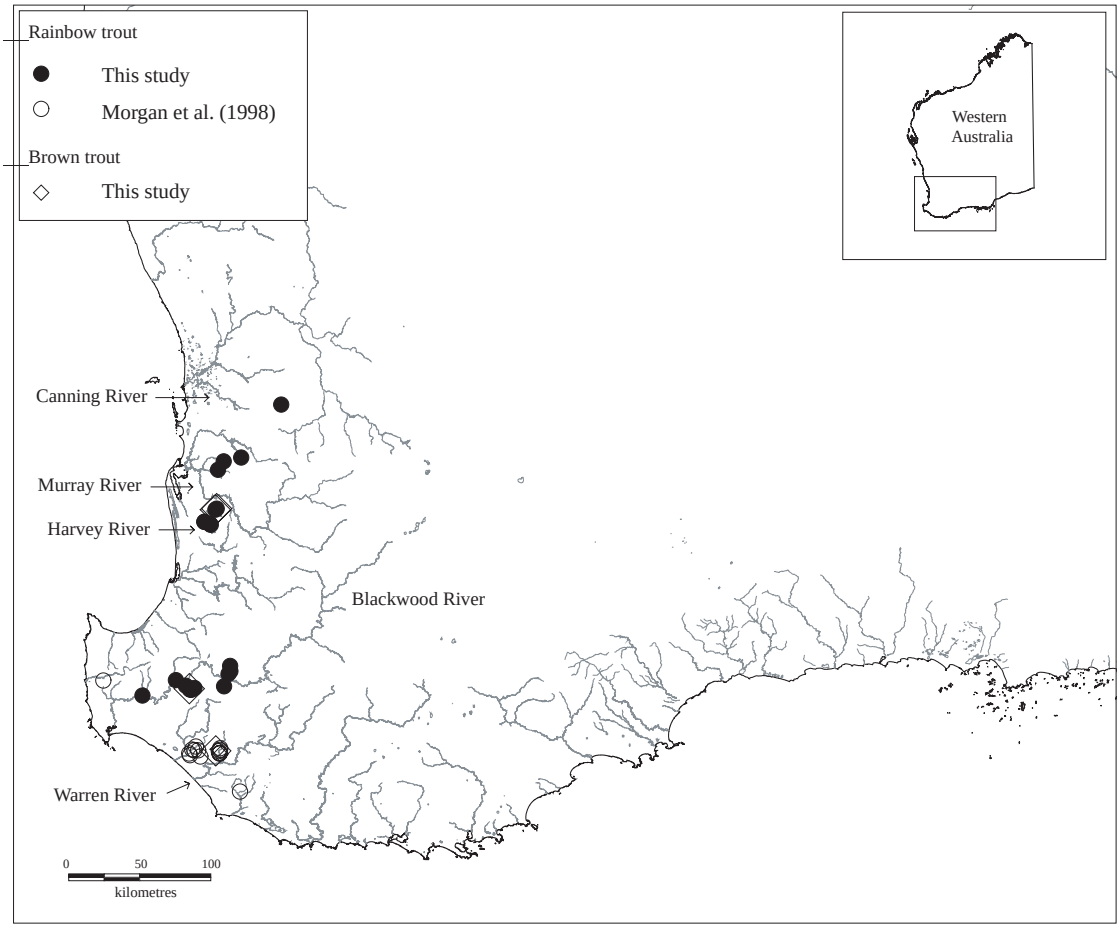

Fig. 3 Sites in Western Australia where rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) were captured.

◄ **Fig. 2** Introduced fishes of Western Australia. **A**, Rainbow trout (*Oncorhynchus mykiss*); **B**, brown trout (*Salmo trutta*); **C**, redfin perch (*Perca fluviatilis*); **D**, goldfish (*Carassius auratus*); **E**, carp (*Cyprinus carpio*); **F**, mosquitofish (*Gambusia holbrooki*); **G**, one-spot livebearer (*Phalloceros caudimaculatus*); **H**, guppy (*Poecilia reticulata*); **I**, swordtail (*Xiphophorus hellerii*); **J**, Mozambique mouthbrooder (*Oreochromis mossambicus*); and **K**, silver perch (*Bidyanus bidyanus*). Photographs: David Morgan (A, B, C, D, F, G, H, I, and J); Neil Armstrong (E and K).

at only one of more than 150 sites sampled in the Blackwood River, and two sites in the arid interior of the south-west (Fig. 4). Many of the sites on the Swan Coastal Plain were irrigation drains that are typically devoid of habitat suitable for native fishes. At many of these sites *C. auratus* was present in considerable numbers that represented several different size/age classes, suggesting that these populations are self-maintaining. In contrast, during the current study only one self-maintaining population of *C. carpio* was discovered, in a small artificial lake in metropolitan Perth, and one *C. carpio* was recorded at a single site in Margaret River. The Western Australian Museum has records for two localities in the metropolitan area and anecdotal evidence suggests that carp may also be present in small numbers in the Canning and Blackwood Rivers.

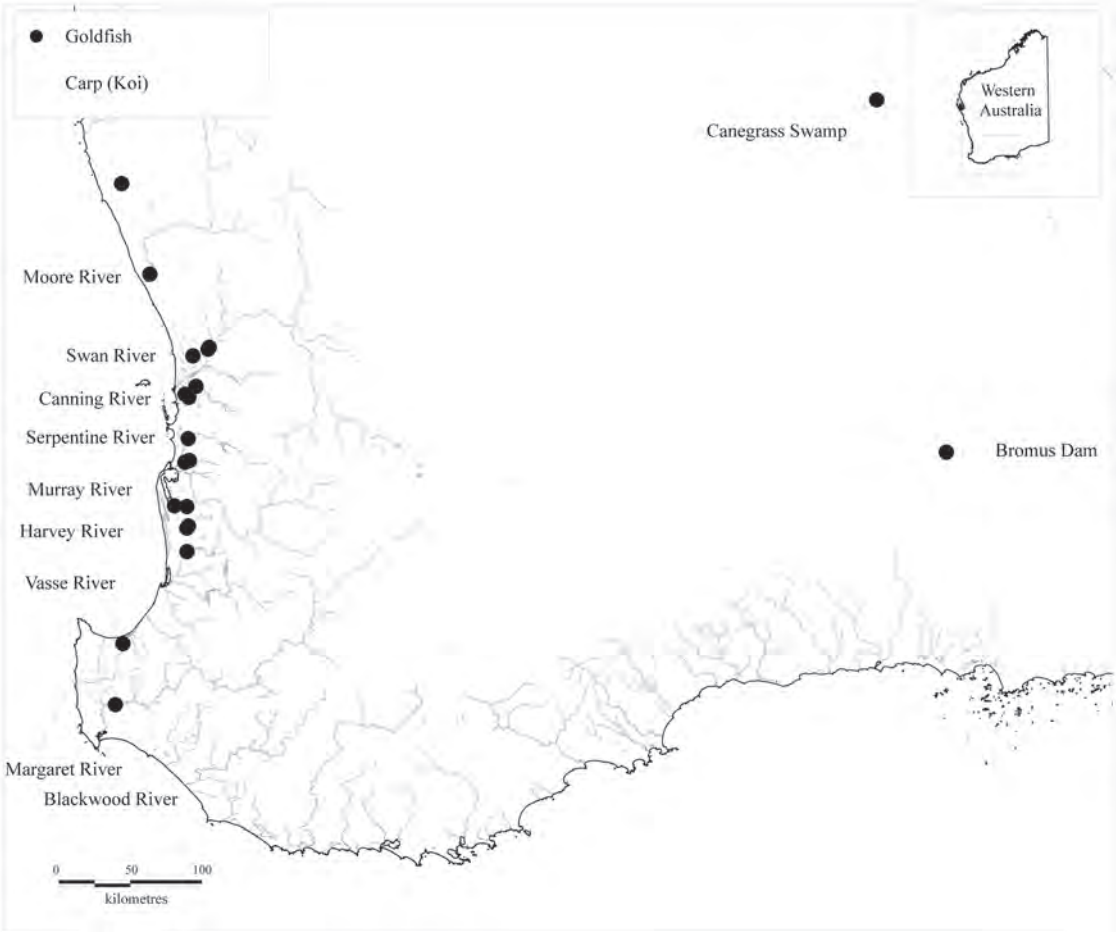

Fig. 4 Sites in Western Australia where goldfish (*Carassius auratus*) and carp (*Cyprinus carpio*) were captured.

Although *C. auratus* and in particular *C. carpio* are considered a major pest in other areas of Australia, their restriction to artificial or highly modified water bodies in and around major population centres suggests that they currently pose little threat in Western Australia. However, the popularity of both species as ornamental fish is likely to lead to further releases and the possibility that they will become well established in the future.

Poeciliidae

G. holbrooki (Fig. 5)

Gambusia holbrooki were extremely abundant in the south-west (Hill River to Pallinup River) and southern Pilbara (Hutt, Chapman, and Greenough Rivers), and a population has also been recorded by the Western Australian Museum and Northern Territory Museum in an isolated region of the Kimberley, i.e., Beagle Bay (Fig. 5). This species' ability to survive in an array of habitats, including highly degraded waters with high salinities (up to 58.2 parts per thousand (ppt) during this study), has allowed them to flourish throughout most of southern Western Australia. *G. holbrooki* dominated the fish fauna of the largely cleared catchments that had become salinised, e.g., Blackwood River (Morgan et al. 2003). Their absence from much of the Kimberley, Pilbara, and all rivers east of the Pallinup River suggests that they are yet to be released into these systems (Fig. 5).

The impact of *G. holbrooki* on the endemic fishes of south-western Australia was highlighted by Gill et al. (1999). Those workers demonstrated in tank experiments that the degree of caudal fin damage to western pygmy perch (*Edelia vittata*) and death caused by *G. holbrooki* was directly related to the

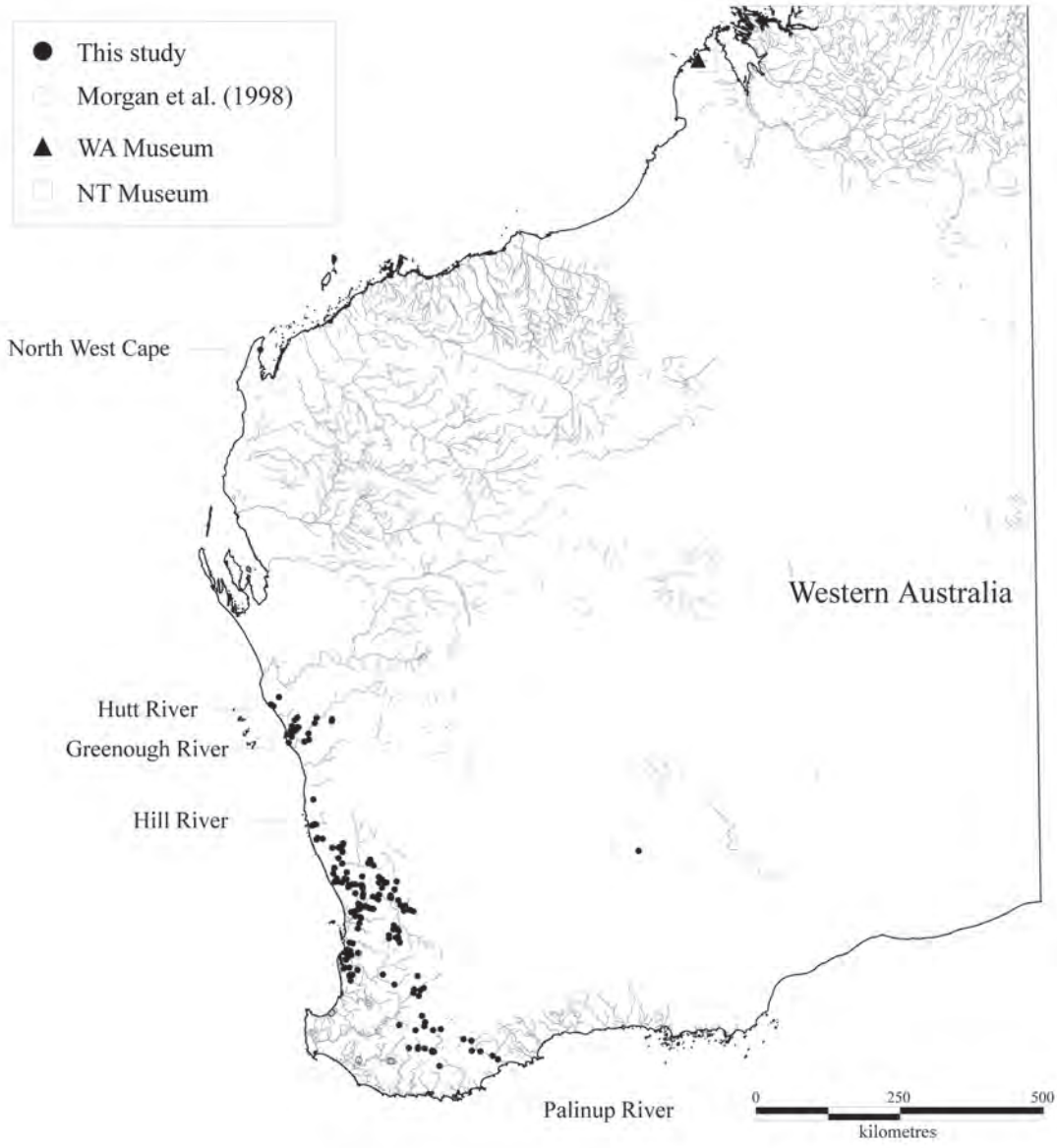

Fig. 5 Sites in Western Australia where mosquitofish (*Gambusia holbrooki*) were captured. Also included are the Western Australian Museum and Northern Territory Museum sites in the Kimberley.

density of *G. holbrooki*. The relative degree of caudal fin damage in wild populations of the south-west Australian endemic *E. vittata*, nightfish (*Bostockia porosa*), and western minnow (*Galaxias occidentalis*), was found to be most severe in 0+ (<1 year old) fish for all species, but was also relatively high in older *E. vittata* (Gill et al. 1999). Of 1322 fish examined for caudal fin damage, c. 17% showed no sign of attack, c. 38% had minor damage, c. 25% had moderate damage, and c. 20% had major damage. Evidence was also provided to suggest that in lentic habitats lacking cover and containing *G. holbrooki*, native fishes were seldom captured. In contrast, habitats that provided cover and also contained *G. holbrooki* often (63%) also contained native fishes. Griffiths (1972) reported fin-nipping attacks on native fishes in south-western Australia during aquarium trials, and found 100% mortality for

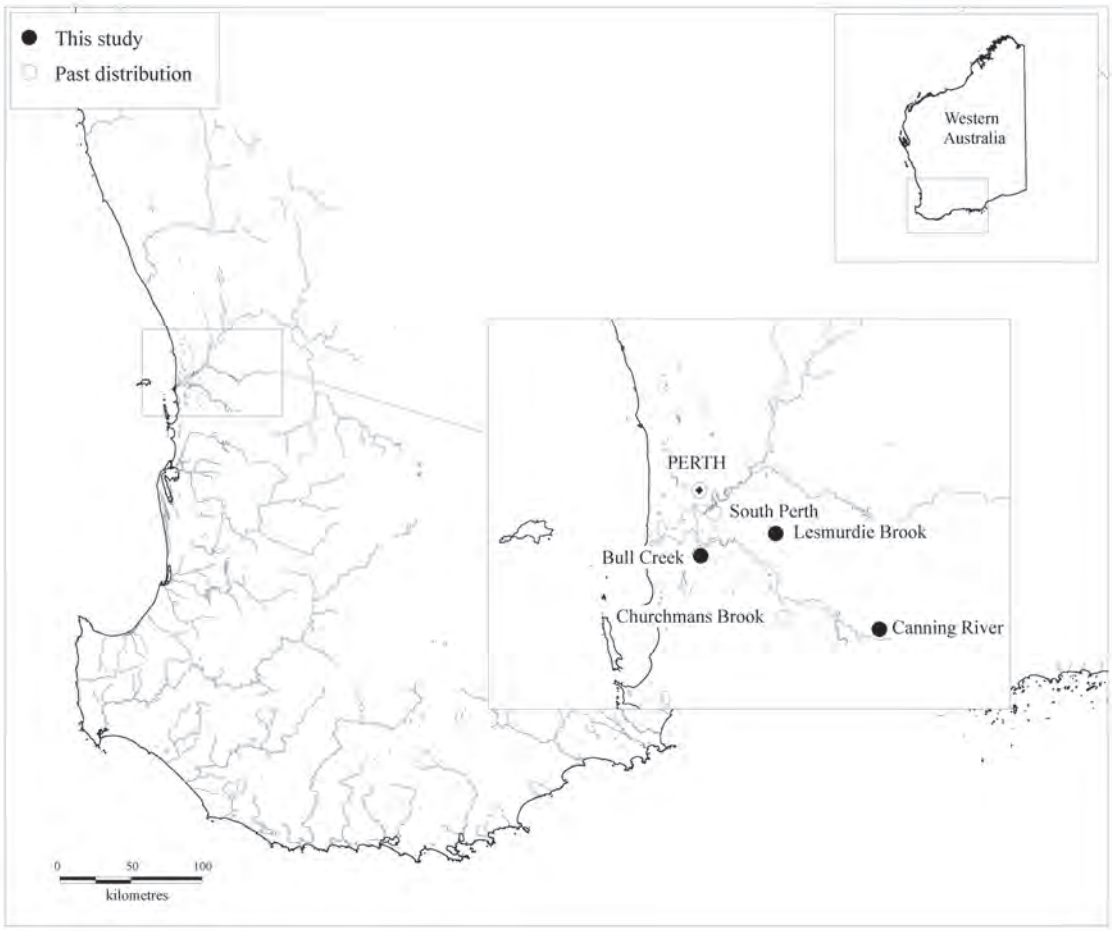

Fig. 6 Sites in Western Australia where the one-spot livebearer (*Phalloceros caudimaculatus*) was captured.

the small endemic black-stripe minnow (*Galaxiella nigrostriata*) that were exposed to *G. holbrooki*.

Within the Collie River, the prevailing temperatures restrict the breeding period to a 6-month period between October and March with high mortality occurring during the cooler winter months (Pen & Potter 1991). It is likely that in the more northerly rivers, including those of the Pilbara and Kimberley, breeding may be maintained throughout the year.

P. caudimaculatus (Fig. 6)

Phalloceros caudimaculatus has been recorded from five locations in the Perth metropolitan area (Fig. 6), with three of these locations currently containing specimens. These include the two sites in metropolitan Perth, and a small population located in a tributary of the Canning River, c. 60 km south-east of Perth along the Albany Highway. *P. caudimaculatus* was noted in a small well at the latter location, although not in natural water bodies nearby. Griffiths (1972) recorded populations of *G. affinis holbrooki* (subsequently identified as *P. caudimaculatus* by Trendall & Johnson (1981)) from Mill Point Road in South Perth (a small lake on the edge of the Swan River), outer metropolitan Perth (Churchmans Brook and possibly the nearby Canning River) (Fig. 6). The current survey suggests that it no longer exists at these locations.

The few reports on the temperament of *P. caudimaculatus* infer it to be a non-aggressive species in contrast to *Gambusia* spp. (Griffiths 1972; Merrick & Schmida 1984; McDowall 1999; Maddern 2003). For example, experimental work by Maddern (2003), utilising the experimental design of Gill et al. (1999) for *G. holbrooki* and the endemic *E. vittata*, demonstrated no significant differences in

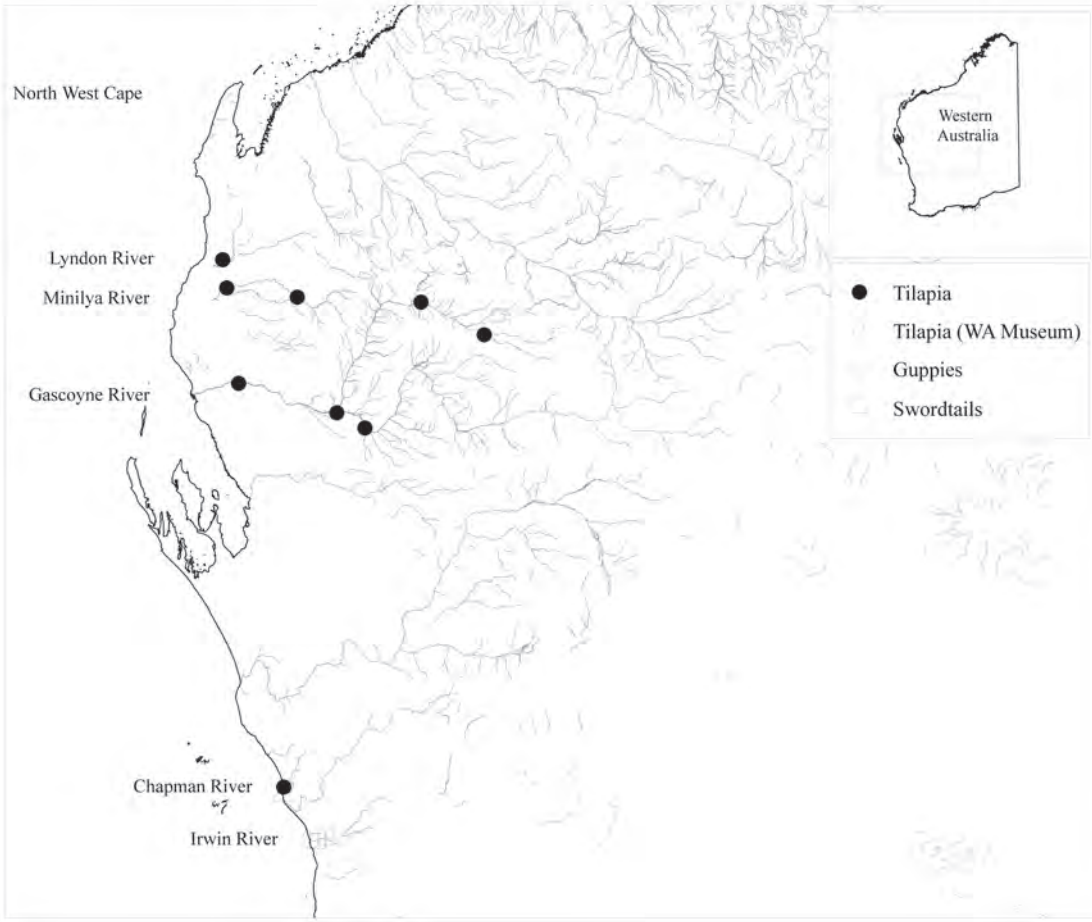

Fig. 7 Sites in Western Australia where guppies (*Poecilia reticulata*), swordtails (*Xiphophorus hellerii*), and the Mozambique mouthbrooder or tilapia (*Oreochromis mossambicus*) were captured.

the survival or fin condition of *E. vittata* in tanks in which *P. caudimaculatus* were present and in tanks in which they were absent. However, of major concern is that *P. caudimaculatus* is cold tolerant, and in south-western Australia, breeds throughout the year, with both sexes attaining maturity at c. 18 mm standard length (SL) and has a broad diet (vegetal matter, detritus, aquatic invertebrates), a combination of characteristics which has seen it apparently displace *G. holbrooki* from those sites at which the latter species was previously present (Maddern 2003). If this species was to be released in other systems within south-western Australia, such characteristics would also permit its survival and rapid colonisation of water bodies and possibly lead to the displacement of endemic fishes.

P. reticulata (Fig. 7)

Poecilia reticulata was captured at only one site in the Pilbara Drainage Division, i.e., a pool on Charles Knife Road on the North West Cape. This is the only site locality of this species known from Western Australia. Every effort was taken to eradicate this species from that water body.

X. hellerii (Fig. 7)

Xiphophorus hellerii was collected from five localities in the Irwin River (Fig. 7). Previous qualitative sampling recorded this poeciliid from almost all areas of the river except for upper reaches that did not contain permanent water, and also the very lower estuary (see also Morgan & Gill 2001). Currently in Western Australia, *X. hellerii* is only known from the Irwin River, where maturity is

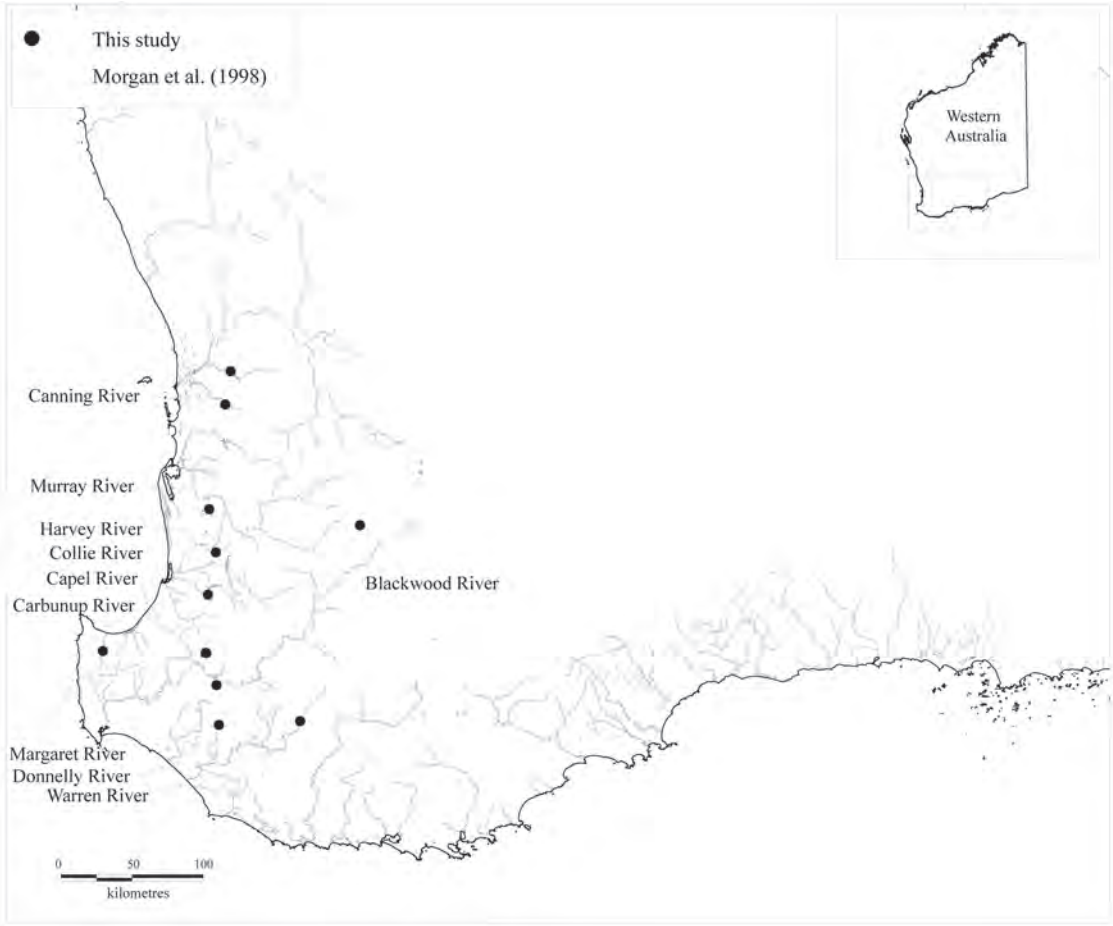

Fig. 8 Sites in Western Australia where redfin perch (*Perca fluviatilis*) were captured.

attained at c. 31 mm SL for both sexes (Maddern 2003). There is the potential to reproduce year round in the Irwin River with Maddern (2003) finding the percentage of females that were pregnant to be 45%, 33%, and 72% in spring, summer, and autumn, respectively. No winter samples were presented. The diets of *X. hellerii* in the Irwin River in spring, summer, and autumn consisted of between 26% and 53% silt/biofilm, however vegetal matter was consumed in all seasons (maximum contribution c. 21%) (Maddern 2003). They were also found to ingest aquatic invertebrates such as dipteran larvae, ephemeropteran larvae, and ostracods.

Unfortunately, although no data are available on the historical distribution of native or introduced fish in the Irwin River it is interesting to note that no native freshwater species, nor indeed *G. holbrooki*, were captured in this river during the current study. In contrast, the Greenough River to the immediate north contains the Pilbara endemic Murchison River hardyhead (*Craterocephalus cuneiceps*) and *G. holbrooki* whereas to the south the Arrowsmith River contains a two south-western Australian endemic fishes, i.e., *E. vittata* and *G. occidentalis*. Whether the lack of native species and *G. holbrooki* is a result of agonistic behaviour, competition for food, or the fact that other species were never present in the Irwin River cannot be determined, although Griffiths (1972) did not collect *G. holbrooki* during his survey work. However, Franck & Ribowski (1993) noted that male *X. hellerii* form long-term hierarchies and engage in costly fights with competitors (but do not state whether this aggressive behaviour is also directed at sympatric species), whereas Arthington

et al. (1986) consider that *X. hellerii* may have outcompeted *G. holbrooki* in southern Queensland. Furthermore, as the principal dietary items ingested by *X. hellerii* in all seasons were silt/biofilm and vegetal material, if this species should spread to rivers to the north and south it may well have a deleterious effect on *C. cuneiceps* that ingests the same food items in approximately the same proportions (Allen 2002; Maddern 2003).

Percidae

P. fluviatilis (Fig. 8)

Perca fluviatilis was present in most of the major river systems between the Swan and Warren Rivers inclusive (Fig. 8), including the Murray, Harvey, Collie, Capel, Carbunup, Margaret, Blackwood, and Donnelly Rivers. This species was not captured in rivers or lakes and is not known from east of the Warren River or north of the Swan River. Their distribution in Western Australia is probably limited by their inability to tolerate warm temperatures (>31°C) or salinities >10 ppt (Weatherley 1963; Privolnev 1970). The reproductive biology and growth in south-western Australia is described in Morgan et al. (2002), with males and females first attaining maturity in their first and second years, respectively; peak spawning occurring between August and September; and growth rates higher than reported elsewhere.

The severe, deleterious impacts that *P. fluviatilis* has had on the endemic fishes and decapods of south-western Australia is well documented (Hutchison 1991; Beatty 2000; Morgan et al. 2002). For example, Beatty (2000) and Morgan et al. (2002) considered that the recruitment of the large and recreationally important decapod, the marron *Cherax cainii* (formerly *Cherax tenuimanus*) was being seriously compromised through predation of its juveniles by *P. fluviatilis*, whereas Morgan et al. (1998, 2002) also considered *P. fluviatilis* to be largely responsible for the local extinction of the rare mud minnow (*Galaxiella munda*) from Big Brook Dam and its tributaries. The continued illegal translocation of *P. fluviatilis* is, after habitat degradation, perhaps the greatest threat to endemic fishes and decapods in many south-western Australian aquatic ecosystems. The continued spread of this noxious species by anglers must be discouraged, and may best be implemented by education programmes that explain to freshwater anglers that their introduction is likely to seriously impact on another major recreational freshwater fishery, i.e., that of the highly prized marron (*C. cainii*). The Department of Fisheries Western Australia has recognised the threat posed by *P. fluviatilis*, and it is now illegal to release them if captured.

Cichlidae

O. mossambicus (Fig. 7)

Oreochromis mossambicus was captured at nine sites in the Chapman, Gascoyne, Minilya, and Lyndon Rivers and in Western Australia is thus restricted to the Pilbara Drainage Division (Fig. 7). Whereas this species was first recorded at a single site in the Gascoyne River in the early 1980s, it has since spread throughout this river and into the other three rivers. In the Gascoyne River, *O. mossambicus* was often the numerically dominant species. The Western Australian Museum record for the Chapman region is from a farm dam suggesting that this may have been their avenue of introduction into the river (e.g., flooding or deliberate translocation). Although extremely large numbers of small juveniles and larvae were captured in the upper estuary of the Chapman River they were not found further upstream. This species is extremely tolerant of salt and during the study was found alive in a small salt lake associated with the Lyndon River that had salinities up to c. 95 ppt (seawater = 35 ppt).

The diet of juvenile *O. mossambicus* in the Chapman, and mature fish in the Gascoyne River was predominantly detritus/sand/biofilm based. Juveniles in the Gascoyne River also consumed a high proportion of aquatic insects whereas, with the exception of *C. cuneiceps*, the native fishes in these systems ingest little if any detritus/sand/biofilm (Allen 2002; Maddern 2003). It would therefore appear that, with the possible exception of *C. cuneiceps*, *O. mossambicus* poses little threat, in terms of competition for food, to the native species of the Pilbara region. However, during the breeding season, males become particularly aggressive when guarding their nests. These nests, which consisted of cleared shallow depressions of c. 60 cm in diameter, often covered over c. 80% of the shallows in the Gascoyne River and were vigorously guarded by their incumbent males. *O. mossambicus* is easily the largest species found in the river and as it excludes native species from large areas of the river through aggression, in conjunction with the reduction of available habitat to native fishes through nest building, this species must have serious deleterious effects on the native fishes. This is of particular concern during periods of drought, characteristic of

the Pilbara Drainage Division, when most of the region's rivers become dramatically reduced to disconnected, small pools. Considering the rapidity with which *O. mossambicus* has spread through the Gascoyne River, i.e., to become the dominant teleost in much of that system, it is of great concern that there is the potential, if not high probability, for the species to (be) spread to northern rivers in this state as a result of flooding or human intervention.

Terapontidae

B. bidyanus

Bidyanus bidyanus (Fig. 2) has been captured in the lower Swan River by the Department of Fisheries Western Australia and Murdoch University colleagues (B. Molony pers. comm.; G. Sarre pers. comm.). It is likely that these fish were escapees from aquaculture facilities (B. Molony pers. comm.). Aquaculture of *B. bidyanus* in Western Australia is currently permitted, with approval from the Department of Fisheries Western Australia, in all catchments of the Pilbara and in the majority of those in the south-west (Thorne & Brayford 2000). The areas excluded from the aquaculture of the species include all catchments of the Kimberley and most of those between the Donnelly and Hammersley Rivers on the south coast (Thorne & Brayford 2000). An expansion of the industry in Western Australia may lead to further occurrences of the species in the wild, and of concern is that all of the catchments of the Pilbara, which contain a number of endemic fishes, are potential aquaculture areas.

CONCLUSIONS

Introduced fishes dominate large expanses of aquatic ecosystems in southern Western Australia, with the south-western Western Australian (South West Coastal Drainage Division) region containing eight species and the southern Pilbara four species. In contrast, there are no introduced fishes in the northern Pilbara and the Kimberley (the exception being one isolated population of *G. holbrooki* in the western Kimberley, i.e., Beagle Bay). Introduced fishes in south-western Australia include *O. mykiss*, *S. trutta*, *C. auratus*, *C. carpio*, *G. holbrooki*, *P. caudimaculatus*, *P. fluviatilis* and most recently, the eastern Australian *B. bidyanus*. The introduced fishes in the Pilbara Drainage Division include *G. holbrooki*, *P. reticulata*, *X. hellerii*, and *O. mossambicus*. All rivers east of the Pallinup River in the South West Coastal Drainage Division and the Arrowsmith River, are free from introduced fishes, as are all the major rivers of the Kimberley, and those north of the Gascoyne River in the Pilbara, as well as the Murchison River in the Pilbara (Fig. 3–7). It is imperative that those systems that are currently free from introduced fishes, particularly in northern and south-eastern Western Australia, remain so. Of major concern is the current push by recreational anglers and aquaculturists to introduce species endemic to eastern Australia to catchments throughout Western Australia. In light of the results presented in this paper, the words of Gilbert Whitley (1947) on the fishes of the Pilbara are particularly pertinent. "We require more specimens for study, more exploration, and forebearance from introducing foreign types to the detriment of our native fauna."

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